Conceptualization of team situation awareness : attributes, measurement approach and underlying factors

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CONCEPTUALIZATION OF
TEAM SITUATION AWARENESS

KETUT SULISTYAWATI

2008

**NANYANG
TECHNOLOGICAL
UNIVERSITY**

**CONCEPTUALIZATION OF TEAM SITUATION
AWARENESS: ATTRIBUTES, MEASUREMENT
APPROACH, AND UNDERLYING FACTORS**

KETUT SULISTYAWATI

SCHOOL OF MECHANICAL AND AEROSPACE ENGINEERING

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School of Mechanical and Aerospace Engineering

A thesis submitted to the Nanyang Technological University
in fulfillment of the requirement for the degree of
Doctor of Philosophy

2008

**Conceptualization of Team Situation Awareness:
Attributes, Measurement Approach, and Underlying Factors**

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Abstract

Situation awareness (SA) is about knowing and understanding what is going on, and projecting what is going to happen in the near future. Having good SA is vital for performance in a complex and dynamic environment. This has driven a great research interest on SA in the past two decades. The development is however limited to individual level. With the prevalence of teams in today's organizational setting, an extension of SA concept to team level is needed. Despite its recognized importance, there has not been much research done in the area of team SA. Essentially, many questions are still unanswered. What do team members need to be aware of to be considered having a good team SA? What methods should be used to measure team SA? What are the underlying factors of team SA? What are the processes involved in the development and maintenance of team SA? This thesis aims to explore the fundamentals of SA in teams, specifically to define team SA and propose an integrated framework of team SA, which covers the underlying factors of team SA and approaches to measure the construct.

This thesis includes an extensive review of SA and team literature to derive a comprehensive list of factors that would be relevant to team SA. Four laboratory-based studies were also conducted to provide empirical investigations of the construct. The first study involved military helicopter pilots performing navigational and combat tasks, the second and third studies involved gamers performing urban warfare simulation, and the fourth study involved military fighter pilots in simulated air combat scenarios.

A definition of team SA proposed in this thesis is *team members' perception, comprehension, and future prediction of the system/task status relevant to their responsibilities, and of the team status, which is required for effective interaction in an interdependent team*. It consists of two main aspects, namely awareness related to taskwork and awareness related to teamwork, which can be further broken down into the awareness of the situation necessary to perform own responsibilities, awareness of the elements needed to backup teammate's responsibilities, awareness of own state of knowledge (meta-SA), and awareness of teammate's workload and SA levels. An approach to assess team SA using a combination of methods is determined. The empirical investigations revealed that these aspects are non-overlapping; implying that team SA is a

multifaceted concept and is best assessed by multiple methods. The application of multiple methods in conjunction would offer complementary roles, providing deeper insights of team SA, thus offering more confidence in drawing inferences regarding good and poor team SA through triangulation.

The results of quantitative and qualitative analyses across the studies suggest several features that would characterize a good team. Good teams are characterized by individuals with high SA related to own situation (particularly level 3), well-calibrated confidence level (and not simply less over-confidence), and good team interaction as shown by good (but not necessarily frequent) communication, feedback, support, and backup behavior. On the other hand, well performing teams do not necessarily possess higher similarity in perception of each other's workload and SA levels. Since good performance is generally associated with good SA, it is essential to question what input and process factors that support good SA, on both individual and team levels. Individual SA is supported not by high experience per se, but also by high cognitive abilities in spatial, memory, and reasoning. Insofar as team SA is concerned, the importance of team interaction (communication, feedback, and backup) is noted. Also possibly the influence of familiarity with teammate (with better teams associated with more familiar members) and homogenous team composition (with better team associated with less disparity of team members' experience levels).

The data collected across the studies also revealed additional measurement issues on top of those reported in the literature. In addition, it generates some insights regarding the prediction aspect of SA. Finally, an integrated framework of team SA is conceptualized, including a comprehensive list of factors derived from the literature review and those verified through the empirical studies.

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List of Abbreviations

AA	: Anti-air (guns)
ACMI	: Air Combat Maneuvering Instrumentation
AFOQT	: Air Force Officer Qualifying Test
BAT	: Basic Attributes Test
BVR	: Beyond Visual Range
C-SAS	: Cranfield Situation Awareness Scale
CARS	: Crew Awareness Rating Scale
CAST	: Coordinated Awareness of Situation by Teams
CLSA	: China Lake Situational Awareness
CP	: Check Point
CRM	: Crew Resource Management
CS	: Counter-Strike
CSAR	: Combat Search and Rescue
DLZ	: Dynamic Launch Zone
FLO	: First Launch Opportunity
GDTA	: Goal Directed Task Analysis
LOH	: Light Observation Helicopter
LSV	: Light Strike Vehicle
MARS	: Mission Awareness Rating Scale
NOE	: Nap-Of-the-Earth
QDATMA	: Questionnaire for Distributed Assessment of Team Mutual Awareness
QUASA	: Quantitative Assessment of Situation Awareness
RAF	: Royal Air Force
RWR	: Radar Warning Receiver
SA	: Situation Awareness
SA-SWORD	: Situation Awareness Subjective Workload Dominance Technique
SABARS	: Situation Awareness Behavioral Rating Scale
SACRI	: Situation Awareness control Room Inventory
SAGAT	: Situation Awareness Global Assessment Technique
SALIENT	: Situation Awareness Linked Indicators Adapted to Novel Tasks
SALSA	: In German, translated as: measuring Situation Awareness of Area Controllers within the Context of Automation
SAM	: Surface to Air Missile
SARS	: Situation Awareness Rating Scales
SART	: Situation Awareness Rating Technique
SASHA	: Situation Awareness for SHAPE (Solutions for Human-Automation Partnerships in European ATM
SME	: Subject Matter Expert
SOP	: Standard Operating Procedures
SPAM	: Situation-Present Assessment Method
TARGETs	: Targeted Acceptable Responses to Generated Events or Tasks
USAF	: United States Air Force
WEZ	: Weapon Employment Zone

Chapter 1 Introduction

1.1 Importance of Situation Awareness

The term situation awareness (SA) was originally used in commercial and military aviation. It is now increasingly discussed in other areas, such as air traffic control (Endsley & Rodgers, 1996), command and control (Artman, 1999; Blandord & Wong, 2004), driving (Horswill & McKenna, 2004), and medical procedures (Gaba et al., 1995). Research has demonstrated the importance of SA for decision making, action execution, and performance, particularly in complex and dynamic environment (e.g., Endsley, 1988; Jones & Endsley, 1996; Orasanu, 1995a). This type of environment can be characterized as follows (Dietrich & Childress, 2004; Orasanu & Connolly, 1993; Rouse et al., 1992):

1. The environment is highly dynamic; the information is typically incomplete, imperfect, uncertain, and can change in a fast tempo. As a result, situations and rules can change quickly. Further, these changes can happen both autonomously without any intervention by the operator (e.g., due to changes in external environment) and as results of operator's actions (Waern, 1998).
2. Goals can vary in time and can frequently be in conflict.
3. Decisions and actions are made under significant time pressure, and often in a matter of seconds. This imposes high levels of stress to the operators.
4. It has high risk; there is a high chance of damage to one's own life, life of others or to material properties.
5. The final output is usually not only defined by an individual, but it depends on the interaction of a multi-person team.

In such an environment, up to date assessment of the situation or SA – knowing what is going on – would be necessary, although not sufficient – for good decision making (Wickens, 2008). Loss of SA has often been identified as one of the main sources of performance failure. For example, Hartel, Smith, & Prince (1991) reported that a lack of SA was the leading causal factor in more than 200 aviation mishaps reviewed. Similarly, a study in commercial aviation accidents identified that 88% of problems related to human error are contributed by problems with SA (Endsley, 1995b). With the recognized importance of SA, enhancement of operator SA is always desired. This, however, cannot

be done without a good understanding of the construct, factors influencing it, and valid tools to assess it.

Several definitions of SA have been offered in the literature. The US Air Force referred to SA as ‘a pilot’s continuous perception of self and aircraft in relation to the dynamic environment of flight, threats, and mission and the ability to forecast and then execute tasks based on that perception’ (Carretta et al., 1996). Endsley (1995c) defined SA as ‘the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future.’ According to this definition, SA covers three levels, namely perception (level 1), comprehension (level 2), and future projection (level 3). It is in line with the one adopted by the US Air Force, but expressed in more generic terms to cater to different areas. It is the most commonly used and accepted definition of SA, and will be adopted in this thesis.

SA is also viewed as a person’s awareness to what s/he knows or does not know. Smith & Hancock (1995) suggested that SA as meta-knowledge is not merely the snapshots of the operator’s current mental model, but rather it is something that guides the process of modifying knowledge. Further, SA also guides the assessment of this picture, which enables that operator to know when what he knows is insufficient for the increasing demands (Smith & Hancock, 1995). It can also be treated as a confidence level of a person towards the quality of his situational knowledge. McGuinness (2004) suggested that this meta-cognition is essential for decision making and performance. It would determine the selection of next actions, e.g., whether to gather more information or to act immediately. The perceived SA is independent of the actual quality of the acquired SA (Endsley et al., 1998b). Alfredson (2007) suggested that difference between what an operator is aware of and what he think he is aware of can serve as another SA indicator.

Research on people’ perception of own knowledge can be traced back to the 1980s. Fischhoff (1977) revealed the tendency of people to over-estimate how much they knew about general knowledge. Lichtenstein et al. (1982) summarized several studies that investigate overconfidence. It was reported to be higher for difficult items compared to easy items in questions related to general knowledge. Overconfidence was also shown for the calibration of future events. However, the calibration for future events was somewhat better than for the general-knowledge items. In the context of SA, Lichacz et al. (2003)

reported that the participants had less overconfidence bias in level 3 (future) compared to level 1 and 2 (present) SAGAT answers. Unfortunately, no other study in SA context is found.

1.2 Limited Understanding of Team SA

Teams are usually engaged to perform tasks in a complex environment. In tactical flight, for example, the basic element of fighter/attack aircraft is a two-ship formation (Andrews et al., 1992). Two-ship aircrafts fly and fight as a team, although each aircraft may be operated by a single pilot (single-seat). As systems get more advanced and complicated, it is difficult for the responsibilities and demands to be met by a single person. Using teams to carry out such responsibilities can help reduce the individual's burden. Teams are also essential in tasks that require a combination of various knowledge and skills for success. For example, a surgical team requires the skills of surgeons, anesthesiologists, nurses, and other specialists relevant to the type of surgery. In addition, the use of a team can provide fail-safe redundancy in high-risk environment (e.g., a nuclear power plant). In a team, tasks can be performed concurrently and faster. When brainstorming or problem solving, multiple individuals can contribute more ideas and resources to the problems. Furthermore, a team might be more creative and innovative, and can improve the implementation of decisions, increase human commitment and motivation, and make an organization more livable for people (Leavitt, 1975). Teamwork brings with it many advantages, and the synergy can result in a performance "greater than the sum of its parts". The prevalent use of teams in organizations, especially those performing crucial, dangerous, and stressful tasks, requires the development of what Cannon-Bowers and Salas (1997) referred to as "team-centered human resource systems." This implies that research in SA should not be limited to individuals, but should also include teams.

The use of teams in complex, dynamic, and high risk environment is hoped to result in a safer performance. Nevertheless, although there is no doubt on the benefits of teamwork, it does not guarantee a success. For example is a crash of Eastern Air Lines Flight 401 near Miami, Florida on 29 December 1972. The captain, first officer, and flight engineer had become fixated on a faulty landing gear light and had failed to realize that the autopilot had been switched off. This case illustrates poor team situation awareness due to poor resource allocation of team members. None of the crews recognized that the plane

was slowly descending down, thus no corrective action was taken, which eventually resulted in a crash killing 101 out of 176 passengers and crews. An example of poor team SA in air battle management can be seen on a case of fratricide incident on 14 April 1994, where two US Air Force F-15 fighters accidentally shot down two US Army Black Hawk helicopters in northern Iraq, killing all 26 people on board. The fighter pilots may have had excellent SA with respect to their tactical environment. However, the higher level organization had failed to identify and manage the interconnectivity across their assets, and failed to deliver the information necessary to identify the Black Hawk helicopters as friendly aircrafts. Another example is an explosion of the space shuttle Columbia over Texas on 1 February 2003. This incident demonstrates the impact of poor team decision making as influenced by groupthink (Janis, 1982), where the team was so eager to launch the mission on time to the extent that they failed to realize the seriousness of its consequences on safety. These accidents, as well as many others such as Three Mile Island, USS Vincennes, and the SQ006, are partly caused by poor SA of the crews as well as poor team decision making. In a complex environment, even a minor breakdown in teamwork results in a severe effect. Guzzo & Dickson (1996) reported that over 70% of severe aircraft accidents between 1959 and 1989 are at least partially attributable to teamwork problems. This underscored the significance in gaining a deeper understanding of team SA.

Not only limited to the aviation, the importance of team SA is applicable across many other domains. Firefighters, for example, always work in a team. In the fireground, a firefighting team should always consist of at least two fire fighters, often referred as “buddy system”. They should enter together, work together; and if one member has to leave the fireground for any reason, the entire team must leave. Thus, the team members should know what each other is doing, be in constant communication with each other, and be accountable for self and buddy. In medical domain, all the team members (e.g., surgeon, anesthesiologist, nurses, etc.) need to have a shared understanding of what is happening to the patient, what causes the sickness, and what are the treatment and contingency plans, so that they can work cooperatively to treat the patient. Parush (2007) described an example of team SA in an operating room:

“A critical event in cardiac surgery with a by-pass is the event of switching from the heart-lung machine back to the patient's heart (getting off the pump). In this event, each person does their job: the perfusionist (heart-lung machine operator) slowly switches

operation to the patient's heart while monitoring vital signs, both anesthetist and respiration technician monitor vital signs and the patient, and the surgeon monitors the heart situation and other visual signs. The scrub nurse needs to monitor the situation in case something goes wrong and the patient needs to be put back on the heart-lung machine. Not only does each one do their individual job, but each needs to know what the others know in this situation, and each needs to communicate and coordinate with their team members.”

In team sports, such as football, basketball, baseball, etc., team SA is also important. The players have to be aware of the ongoing status of the game – where is the ball, where are the other teammates, anticipate whether teammate will pass the ball, and so on.

So what is team SA? How does it differ from individual SA? How to measure it? What influences it? What can be done to enhance it? Despite the recognized significance of team SA, only a few researchers have focused their attention on this area of research (e.g. Artman, 2000; Salas et al., 1995; Wellens, 1993). To date, none of the above questions has been well addressed in the literature. Unlike theories and models of individual SA that have been widely accepted and very much developed, theories of team SA are still being debated (Flach, 1995b). Although the theories and models of individual SA have been well developed, Artman & Garbis (1998) noted that they are inadequate for systems operated by teams, because they focus ‘almost exclusively on individuals’ and ‘have little to say about the coordinated effort required by teams while operating the systems’. When working in a team, the scope of operator awareness is no longer limited to one’s own situation, but extended to include the overall team situation. It is far more complex than combining the awareness of individual team members (Salas et al., 1995). The lack of effort devoted to understanding how team members interact dynamically over time has been acknowledged by several other researchers (e.g., Salas et al., 1992; Salas et al., 1995).

Many models of team performance have been proposed (e.g., Hackman, 1987; McGrath, 1964; Nieva et al., 1978). Each has its own contributions and limitations. However, they are found to be too generic to be directly applied in complex and dynamic environment. The dynamics of the teams may not be the same across different environments (high vs. low risk, fast vs. slow tempo, high vs. low stress). For instance, social communication needed for the development of interpersonal relationship would be important for the

development of the team in general, but the non-task related communication could be considered as a distraction for task performance in a complex environment under time pressure. Thus, team performance models that are developed in the generic team setting requires further analysis and modification before it can be applied in complex and dynamic environment settings.

Several definitions and models of team SA are offered in the literature (e.g., Endsley & Jones, 2001; Salas et al., 1995; Wellens, 1993). However, they are found to be impractical in guiding empirical research in team SA. Firstly, most of the team SA models identify the need of a certain degree of shared SA across team members, but to what extent the overlap in team members' SA is optimal, and the factors underlie the differences in SA across teams, are not clearly defined. In addition, they are limited to conceptualizing the processes that are directly linked to team SA, such as team characteristics, shared mental models, and team process/behavior. None however include a comprehensive list of factors that are potentially related to team SA. This limitation can be linked to the few numbers of empirical studies that specifically investigate the underlying factors of team SA. A comprehensive model that includes the determinants of team SA would be useful, especially to encourage empirical studies to better understand team SA, and for design and evaluation of various interventions for enhancing team SA. Input factors identified in teamwork literature, such as team experience, composition, familiarity, etc, would potentially influence team SA, and are worth investigating.

There are numerous methods to measure individual SA. Due to the lack of an established measure of team SA, these individual SA methods are often applied in a team setting, where the team score is derived by simply aggregating the scores of individual SA without good understanding on the nature of interdependence between the team members. It is however noted that the concept of team SA extends beyond the collective average or sum of SA of the individuals who make up the team (Cooke et al., 2002; Gorman et al., 2004). The lack of well-developed tools to measure team SA is a central problem in understanding the construct (Salas et al., 1995). Without valid measurement tools, it is not possible to investigate the factors that influence team SA.

Salas et al. (1995) discussed several issues that need to be considered in measuring team SA, i.e., *what* should be measured (individual SA or team processes), *when*, and *how* to

measure it. They suggested that no single method is currently adequate for measuring team SA, and thus several measures should be used. Similarly, Salmon et al. (2006) reviewed existing SA measurement techniques and reported that they are inadequate by themselves to be used for SA assessment in C4i (Command, Control, Communication, Computers and Intelligence). They also recommended the use of a combination of multiple measures. However, none of those studies provided a clear direction on how to select the combination of measures that will eventually be adequate to measure team SA. Without psychometrically sound measurement tools, theories will not move beyond the conceptual stage (Salas et al., 1995). A definition and model of team SA that support the search for suitable measurement techniques is needed. The measurement tools are also needed to evaluate the effectiveness of various design and training approaches intended to enhance team SA. Therefore, any research effort in team SA has to address this issue first, by identifying the important aspects of team SA and defining an approach to measure them.

1.3 Objective, Scope, and Research Approach

This research aims to define team SA and to conceptualize an integrated framework that can support the selection of measurement tools, and that includes the important aspects that attribute team SA and factors influencing team SA. To achieve these objectives, the research entails the following steps:

- Review and explore the concept of SA and team dynamics
- Identify the aspects that attribute team SA
- Determine (existing and modified) methods to assess team SA
- Examine and describe team SA in theory and through empirical evaluations
- Explore the input/design and process factors that influence team SA through analytical review and empirical investigations

This research adopts a mixed methods research approach. A mixed methods approach applies, combines, and integrates quantitative and qualitative research techniques, into a single study. It is particularly suitable for the current problem in team SA research, where a grounded theory is still lacking, and thus further in-depth exploration of the construct

through qualitative analysis is required. This approach is applied through interviews, observation of behavior, and protocol analysis of teams performing complex and dynamic tasks in a simulated environment. At the same time, quantitative data was collected through knowledge elicitation and performance assessment. A triangulation of findings obtained from the qualitative and quantitative assessment will provide complementary strengths and non-overlapping weaknesses of the two approaches (Johnson & Onwuegbuzie, 2004).

1.4 Overview of the Thesis

The research is carried out through three main phases: review of literature, conceptualization of team SA framework and identification of appropriate measurement tools, and empirical investigation through laboratory studies. Figure 1-1 outlines the structure of this thesis. A detailed description of the chapters follows.

Chapter 1 introduces the importance of SA in individual and team missions, and argues the need to resolve the problems with lack of framework and measures to assess team SA. It presents the objectives of the research and the research approach.

Chapter 2 and 3 reviews the literature of individual SA and team dynamics. Chapter 2 covers the fundamental theories of SA and the cognitive processes involved in the development of SA. It also reviews existing SA measurement tools and presents a taxonomy of SA measures based on their basic properties. Advantages and drawbacks of each property are discussed. The chapter ends with a mapping of the existing methods that would fit the SA measurement considerations.

In Chapter 3, the fundamentals of team dynamics and the current state of knowledge in team SA are reviewed. A comprehensive list of factors that has been theoretically and empirically reported to influence individual SA and team performance is derived, and each of them is discussed briefly. The end of Chapter 3 summarizes what is known about team SA, and then presents an overview of how the studies conducted in this research filled the gaps in the literature.

Figure 1-1 Structure of thesis

Chapter 4 reports a study aimed to understand the development, maintenance, and recovery process of team SA. The study involved twelve experienced helicopter pilots performing six combat missions, in which their behavior and communication were analyzed using Critical Incident Technique. The chapter is concluded with an identification of important aspects that compose team SA. The findings of this study, together with review from the literature, provide a basis to define team SA and conceptualize a framework to aid the assessment of team SA presented in Chapter 5.

Chapter 5 also presents an approach to measure team SA using multiple methods and the combination of methods to use.

Chapter 6, 7, and 8 report three empirical studies conducted to explore the factors affecting team SA, investigate the inter-relationships among various aspects of team SA, and examine their implications on team performance. Chapter 6 focuses on the utility of task experience to predict each aspect of team SA, including awareness of the situation related to own and teammate's responsibilities and awareness of teammate's workload and SA status. The study involved twenty participants performing a simulated urban warfare in teams of two. Chapter 7 reports an extension of this study to include familiarity and cognitive ability as predictors. In addition, the prediction aspect and perception of self SA were included in the team SA measures. The study involved thirty-two participants performing a similar urban warfare simulation in teams of two. Chapter 9 presents another study conducted to replicate the investigation in a more complex setting. Sixteen experienced military fighter pilots performed air combat simulation in formations of two. In this study, SA is investigated in relation to cognitive ability and diversity of pilot experience within the team. In all of the three studies, team processes were also evaluated in their relation with team SA.

Chapter 9 presents an integrated framework of team SA, a summary of findings, the limitation of this research, and directions for further research.

Chapter 2 Literature Review on Situation Awareness

The first section of this chapter reviews the fundamental theories of Situation Awareness (SA). Through the literature review, the issues that need to be considered for measuring SA are noted. The second part reviews the literature in cognitive processes and abilities important to SA. The last section presents a taxonomy of SA measurement tools and reviews the advantages and disadvantages of each characteristic. The existing measurement tools are then evaluated on the extent to which they satisfy the measurement considerations noted in the first part of the chapter.

2.1 Theoretical Underpinnings of Situation Awareness

Many definitions of SA have been proposed. Some are closely tied to the aviation domain. For example, Endsley (1988) defined SA as ‘a pilot’s internal model of the world around him at any point in time’. In more detail, Siem (1992) referred SA as ‘a pilot’s continuous perception of self and aircraft in relation to the dynamic environment of flight and mission, and the ability to forecast and then execute tasks based upon that perception’. The same definition is adopted by the US Air Force. Others have defined SA in a more generic way. For instance, Sarter & Woods (1991) described SA as ‘the accessibility of a comprehensive and coherent situation representation which is continuously being updated in accordance with the results of recurrent situation assessments’. Taylor & Selcon (1990) stated that SA is a multidimensional construct. It involves processes of memory and attention, and is a state of knowledge about the world that enables adaptive decisions to be made in uncertainty. A most commonly cited theory of SA is the one proposed by Endsley (1995c). She conceptualized a model of SA (shown in Figure 2-1) and defined SA as ‘the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future’. According to this definition, SA can be broken down into three levels:

- *Level 1 SA: Perception of elements in the environment.* Perception of relevant elements in the environment, which may include system parameters, characteristics and actions of other individuals, and features of the external environment. This is the

most fundamental requirement for SA as it is considered to provide the foundation for the development of level 2 and 3 SA.

- *Level 2 SA: Comprehension of the current situation.* For it to be useful, perceived information needs to be interpreted, integrated and related to the person's goal.
- *Level 3 SA: Projection of future status* based on the current situation. This is the highest level of SA, which requires understanding of the situation at levels 1 and 2. At this level, a person would be able to predict what will happen next and thus allow him to anticipate and act on upcoming situations proactively rather than reactively.

Figure 2-1 Model of SA in dynamic decision making (Endsley, 1995c)

Bryant et al. (2004) used the Critique, Explore, Compare, and Adapt (CECA) model (Bryant, 2003) to explain SA concept in the context of command and control. As shown in Figure 2-2, the CECA loop starts from planning the activities to establish the initial conceptual model of the operation. To be able to adapt, one has to compare this conceptual model with the current state of the situation. Critique phase involves questioning, identifying information needs, and determining ways to transform the current

situation towards the achievement of goals. The explore phase comprises the collection of data from the battlespace, similar to Endsley's level 1 SA. The directed telescope allows optimal search of relevant information (top-down), in addition to continual reception and filtering of data (bottom-up). The data are used to update the situation model which will then be compared whether there is any aspect of the conceptual model that is invalid. This is comparable to Endsley's level 2 SA. If inconsistencies exist, one can then adapt and decide to either ignore them, alter the means to achieve goals, or even alter the goals. Although the adapt stage is not directly comparable to Endsley's level 3 SA, it covers the further stage of decision making.

Figure 2-2 Critique, Explore, Compare, and Adapt (CECA) model (Bryant, 2003)

2.1.1 Three Levels of SA

The ascending levels of SA presented in the model has been criticized to represent a linear or successive stages of processing, where SA is seen to be developed through additive process that starts from perceiving stimuli from the environment, matching it with the mental stores, and followed by understanding and prediction of future status (Dekker & Lutzhoft, 2004). Banbury et al. (2004) argued that the acquisition of SA of familiar entities is automatically primed, i.e., once the object is perceived, understanding

and anticipation will follow intuitively, suggesting the non-hierarchical nature of SA. Endsley (2004) re-emphasized that the three levels are never meant to be linear; instead, a person who is able to project what will happen in the situation is considered as having a higher level of SA than a person who is able to comprehend the significance of information, and both have higher levels of SA than a person who only perceives the basic data. She noted that SA level 2 and 3 can also be developed directly from goal-driven process, and can also drive the search for level 1 data, such as represented by the feedback arrow in the model. Along with this theoretical debate, it is somewhat surprising to find limited study that empirically examines the relationship across the three levels of SA.

Banbury et al. (2004) used a *cognitive streaming* framework to explain how operators are able to acquire and maintain an awareness of present and future states of elements in their environment. The concept of *transitional probabilities*, the likelihood that certain types of event will occur following the occurrence of other events, was determined as a key mechanism in anticipating future events. If there is small information about the object, the transitional probability information is low, and it is difficult to determine the next trajectory of this object. As the information about the object builds up, there will be an increase in the transitional probabilities that allow future trajectory to be anticipated correctly. However, the further ahead in time, the strength of transitional probability is weaker, and thus the predictions will be less accurate. This is inline with Wickens (1986) who noted that the accuracy of prediction is decreasing as a function of time into the future, i.e., predicting for a longer span would be less accurate than a shorter span. In addition, Wickens (1986) indicated that the rate of decrease in accuracy is influenced by the inertia of the system and input disturbances. For instance, a light aircraft flying through turbulence would have a shorter valid prediction span than if it is operated in noise-free environment. Furthermore, the rate of prediction decrement is sharpened with the use of a human operator compared to an automated control, as human is more inclined to input an unanticipated control at any time (Wickens et al., 2000).

Projection of future status, the highest level of SA, is a critical skill an operator of a dynamic system must possess (McGowan & Banbury, 2004; Wickens, 1999). Decisions and actions based on accurate anticipation will lead to good performance. This anticipation ability could prominently distinguish good and poor performers apart.

Orasanu & Fischer (1997) analyzed decision making behavior of commercial aircraft crews and identified that higher performing crews anticipated and prepared for future uncertainties, which allowed them to carry out actions faster when the event occurred. Durso et al. (1995) indicated that perception and comprehension of current situation could distinguish good (master and intermediate) from bad (novice) chess players, but only the ability to predict the future status of the game was found to be able to distinguish master-from intermediate-level players. Rowe & McKenna (2001) showed that expert tennis players were more effective and faster in responding to anticipation test done using pre-recorded tennis videos. Hogg et al. (1995) also suggested that understanding the future is the most important aspect of operator SA in a nuclear power plant operation. Similarly in air traffic control tasks, Durso et al. (1998) noted that better performance, as indicated by the fewer number of control actions remaining at the end of a scenario, was associated with better score in answering future questions, but worse score in questions about the present situation. This finding suggested the negative effect of overly focus on the present situation and neglecting future prediction. O'Brien & O'Hare (2007) also found that performance in an air traffic control simulation was significantly associated with level 2/3 SA, but not with level 1. In addition, they reported that training the low SA ability participants using a cognitive management training strategy, which encouraged participants to extend their perception to consider the aircraft interrelations and potential future states, was more effective than the traditional procedural training method.

2.1.2 Product versus Process

A distinction of SA as 'product' or 'process' is often discussed in the literature. SA as 'product' refers to the state of awareness with respect to knowledge held in the operators' head; while 'process' refers to various perceptual and cognitive activities involved to construct, update, and revise the state of awareness, and this process is often referred as *situation assessment* (Adams et al., 1995). Each affects the other in an ongoing cycle (Endsley, 2000c). The process of assessing the situation determines the state of awareness achieved, and in turn, this state of knowledge influences the process of acquiring and interpreting new information in the environment (Figure 2-3). Sarter & Woods (1991) noted that situation awareness is based on the integration of knowledge resulting from recurrent situation assessments.

Endsley (2004) emphasized that differentiation between the two terminologies was meant to facilitate the discussion of SA, and it has ‘more to do with historical problems in miscommunication among different researchers and with different approaches for measuring SA’. There should not be an artificial line drawn to strictly distinguish the two terms (Endsley, 2004). Instead, both of them are important and intricately affect each other. Understanding of SA should cover one’s knowledge of a situation and also the processes responsible for producing such knowledge (Patrick & James, 2004). The interdependence between the processes and products of awareness is also stressed by Adams et al. (1995). Evaluating the product enables quantitative assessment of SA, how good is the operator’s SA in a particular context, at a particular point in time. Investigating the process provides an understanding of how the information is obtained and the effect of resource constraints on information processing. Evaluating only either one of the product or process would not provide a complete understanding of SA.

Figure 2-3 Situation awareness (product) and situation assessment (process)

2.1.3 Ecological Perspective of SA

Instead of seeing SA and performance as a linear relationship and completely separate stages, ecological psychologists emphasized on the holistic view, i.e., the intimate and dynamic coupling between perception and action (Flach, 1995a, 1995b). In his framework of perceptual cycle, Neisser (1976) explained how knowledge, perception, action, and environment interact to achieve goals. This framework was used as a basis to explain the development and maintenance process of SA (e.g., Adams et al., 1995; Smith & Hancock, 1995). Smith & Hancock (1995) described SA as ‘externally directed consciousness’ whereby the actor’s mental model facilitate the anticipation of events, directing his attention to cues in the environment and defining his actions. The actor then assesses whether the evolving situation confirm his expectations, and further search and

exploration will be carried out when there is any unexpected event. The result of this assessment is then used to modify the actor's mental model. Along this line, Suchman (1987) proposed that awareness is 'situation within', and that people's action is contextualized and tightly linked to their perception of the situation at a point in time.

Both perception-action cycle and situated action concepts stress the correspondence between the task constraints (i.e., the situation) and the mental representation (i.e., awareness) (Flach, 1995b). This suggests that SA should be defined relative to what is expected from the task requirements and what is afforded by the system design (see Figure 2-4). Every task imposes *SA requirements*, i.e., the elements that need to be known in order to respond adaptively to the functional task environment. It serves as a 'ground truth', a reference that defines whether the operator's SA is accurate or inaccurate, complete or incomplete. These SA requirements can be derived through a cognitive task analysis of the system, and through interviews with Subject Matter Experts (SMEs).

Figure 2-4 Venn diagram of SA in terms of what is required by the task, achievable by the system, and acquired by the operator

The operator acquires SA through an assessment of the ongoing situation – referred as *acquired SA*. The completeness and accuracy of acquired SA can be assessed by comparing it with the SA requirements for effective task performance. The intersection between the acquired SA and SA requirements defines the quality of SA acquired by the operators. Similarly, Alfredson (2007) suggested that the difference between what an operator is required to be aware of and what he is actually aware of can be used as SA-indicator. This difference can affect the quality of decision made and eventually the final performance outcome. The acquired SA is however filtered by what is *achievable*, as

afforded by the system. It is not fair to judge that the operator's ability to acquire and maintain SA as low only by comparing his acquired SA with the SA requirements. This is because it is possible that there is no way for him to form such awareness due to poor system design. Durso & Gronlund (1999) suggested that the environment sets an upper limit to SA, i.e., SA cannot be greater than the predictability of the system the operator controls. In other words, the acquired SA is constrained within what is achievable with the system design and environment.

2.1.4 Meta-SA

Inside the operator's head, there is a standard of awareness that he believes would be sufficient to achieve a mission success. This is referred as *desired SA*. It is influenced by a person's mental models about the task and system. It may and may not be the same as the real SA requirements imposed by the system. If the operator's desired SA is equivalent to the ideal SA, he would be able to direct his attention and behavior to achieve a good level of SA sufficient for effective and efficient performance. A person who has inaccurate desired level of SA may perceive that his level of SA as high without realizing that it is in fact not, and thus would not consider any corrective action. Knowledge about the system obtained through past experience and training helps to calibrate the desired SA to match the ideal SA imposed by the task. Measuring this knowledge (and thus desired SA) is possible using knowledge elicitation methods, such as Pathfinder, multidimensional scaling, and cognitive mapping (see Mohammed et al., 2000).

When one's attention is directed inward toward himself, he can evaluate the level of SA he has acquired. The estimation of the relative awareness by the operator is referred as *meta-SA* (Lundberg, 1999) or *perceived SA*. Smith & Hancock (1995) argued that SA as meta-knowledge is not merely the snapshots of the operator's current mental model, but rather it is something that guides the process of modifying knowledge. Further, SA also guides the assessment of this picture, which enables that operator to know when what he knows is insufficient for the increasing demands (Smith & Hancock, 1995). Figure 2-5 illustrates the conceptual links among the different types of SA.

McGuinness (2004) suggested that this meta-cognition is essential for decision making and performance. It can be treated as a confidence level of a person towards his acquired

SA. It can determine the selection of actions, e.g., whether to gather more information or to act immediately. The perceived SA is independent of the actual quality of the acquired SA (Endsley et al., 1998b). Alfredson (2007) suggested that difference between what an operator is aware of and what he thinks he is aware of can serve as another SA indicator. For example, a person who thinks that he is fully aware of the situation but in fact he is not, may decide to act directly and confidently without further assessment of the situation. On the other hand, a person who is aware that he has not gain enough understanding of the situation may decide to further assess the situation before taking actions, or select more conservative actions. In her experiment involving air-to-air combat, Endsley (1990) found that low SA elicited using SAGAT (objective measure) did not necessarily accompany low performance. She suggested that this was because the pilots could modify their behavior and act conservatively when they knew that their own knowledge was incomplete. Thus, obtaining the perceived SA can provide useful information to understand the basis of the operator's decisions and actions.

Figure 2-5 Types of SA and their conceptual links

2.1.5 Temporal Aspect of SA

SA is built over time through continuous situation assessment. A person's knowledge about the situation should include the temporal aspects of the environment, relating to the past, current, and future status (Endsley, 1995c). Edgar & Edgar (2007) noted that certain information that *was* true can become false due to the changes in situation. Similarly, the

same information in the environment may vary in its relevance and importance to task performance depending on the situation at the moment. Hauss & Eyferth (2003) revealed that more than half of the set of queries that were assumed to be relevant to overall air traffic management were found to be irrelevant at the time they were asked. Furthermore, they found that expert operators managed their cognitive resources by attending to the more relevant information, and were less accurate in answering irrelevant questions. As a result, they may obtain the same score as the worse performers who answered the same number of irrelevant questions. In the aviation domain, Endsley and colleagues (Endsley, 1993; Endsley et al., 1998a) identified that although a given SA requirement never really becomes unimportant; it can become secondary to others at a given point in time due to the shifting importance of the pilot goals. Similarly, Adams & Pew (1990) acknowledged that SA is not static but changing dynamically over time. He stated “at any moment in time, a person’s effective or active knowledge base consists of but a fraction of her or his total knowledge”.

In a dynamic environment, SA has to be maintained through continuous updates of the ongoing situation. A person may have perfect SA at one moment and lost it at the next moment. Assessing the temporal changes in SA can provide useful information during an evaluation of personnel or design and training interventions, such as to find out in which part(s) of the mission the operators have tendencies of losing SA, to know which display the operators do or do not attend to when SA is lost, to assess whether training is effective for maintenance of good SA, and to select personnel who have the ability to maintain SA steadily throughout the mission.

2.2 Cognitive Processes Involved in SA

In their model, Wickens & Hollands (2000) illustrated the information processing components whose limitation can influence the formation of SA, including attention, working memory (WM), long-term memory (LTM), and long-term working memory (LTWM) (Durso & Gronlund, 1999; Ericsson & Kintsch, 1995) (see Figure 2-6). The cognitive mechanisms involved in the development of SA based on this information processing theory will now be discussed.

Figure 2-6 SA in Human Information Processing model (Wickens & Hollands, 2000)

2.2.1 Attention

Processing of situation model requires resources for attention and this happens within the working memory (Lundberg, 1999). Due to limited resources, it is not possible to attend to all information cues available in the environment. Ability to direct attention to acquire the required information is important. Environmental cue is attended due to its *perceptual salience* (data driven or bottom-up) or by guidance of *active goals* in mind (goal driven or top-down). Jones & Endsley (1996) reported that the most frequent cause of SA errors involved situation where all the required information was present, but was not attended by the operator (35% of total SA errors).

Attention to information is prioritized based on how important that information is perceived to be (Endsley, 2000c). Correctly prioritizing information in a dynamic environment is challenging. According to Endsley (2000c), good SA requires enough awareness of what is going on in the big picture (global SA) to be able to determine where to focus for more detailed information (local SA). To achieve this, an operator must maintain a balance between ‘the big picture’ and ‘the small detail’ (Craig, 2001). Failure to do so can result in attentional narrowing, i.e., a situation when an operator is too fixated to attend certain information and disregard other information that may also be important at a point in time. Decisions made with insufficient information tend to be poor.

Wickens et al. (2008) proposed a computational model of attention and SA. The model suggests three variables that can influence the probability of attending to an event, namely

the salience of the events, the value of the events, and the likelihood that it will change since last inspected. It also assumes that workload has a negative effect on attention resources, which is needed to maintain SA.

2.2.2 Working Memory (WM)

According to Endsley (1995c), the formation of SA takes place in WM. Cognitive processes involved in anticipating future events often impose high demand on mental resources. This is because projection normally requires some form of mental computation necessary to extrapolate the future from the present and past, and the future estimates sometimes need to be stored in WM until they are actually used (Wickens, 1986). Engagement of other tasks imposing additional demand on WM can thus interfere and deteriorate prediction. As the development and maintenance of situational model is mostly done in WM (Lundberg, 1999), SA is somehow limited by the capacity of WM. As individuals have different limit in their WM capacity, differences in the capacity of WM may therefore differentiate individuals in their SA and performance, especially in a highly demanding environment. Sohn & Doane (2004) investigated the role of WM in flight situation awareness, and reported that novice pilots with higher WM capacity (spatial span) had higher SA performance.

Instead of merely functioning as the place of SA development and maintenance, Johannsdottir (2004) suggested that WM has a more active and complex role for SA, and that people rely on different components of WM to perform different tasks. She found that tracking moving object against a dynamic background significantly involves visuospatial subsystem of WM, but not the verbal subsystem. The importance of spatial system of WM for SA has also been shown in other navigating task (Garden et al., 2002). Interestingly, Johannsdottir (2004) found that verbal subsystem plays an active role to support prediction of future location of the tracked object (SA level 3). She reasoned that verbal system allows the operators to remind and cue themselves to monitor the area, and what to perform and when based on their knowledge stored in LTM. In navigation task, reliance on verbal resources was evidenced when the participants were required to follow verbal instructions (Barshi & Healy, 2002). Logie et al. (1989) suggested that although tasks such as keeping track of spatial location depends much on spatial system, people rely on both spatial and verbal in a more complex tracking task.

2.2.3 Long-term Memory (LTM)

Mental pictures of how things work is stored in LTM in a form of mental models. Rouse & Morris (1986) defined mental model as a ‘mechanism whereby humans are able to generate descriptions of the system purpose and form, explanations of system functioning and observed system states, and prediction of future system states’. From this definition, a mental model can be considered as serving three main functions: describing, explaining and predicting. Mental models help to direct limited attention, provide a means of integrating information without loading WM, and provide a mechanism for generating projection of future system states (Endsley, 2000c).

The term of ‘mental model’ is usually used to describe pre-task knowledge and largely represent generic knowledge about the system, such as how it looks like, its significant features, how it functions, etc. (Endsley, 2000b). SA, which is also referred as situation model, is a dynamic mental model of the present state of the system (Endsley, 2000b; Langan-Fox et al., 1997). A pilot may have a mental model of how to fly an airplane and how the controls in the airplane work. During flying, he will also develop a situation model of the current weather, altitude, or whether the engine functions normally. Thus, mental model and situation model interact with each other to form an understanding of what happens in the real world. The use of mental models in achieving SA is dependent on individual’s ability to pattern match between critical cues in the environment and elements in the mental models (Endsley, 2000c). The role of mental models in SA is shown in Figure 2-7.

Predicting the future requires a good understanding of the goals, a mental representation of the current state, and a mental model of the process dynamics (Wickens & Hollands, 2000). The goals in mind can direct attention to the relevant elements in the environment to be perceived. A comprehension of the current state is formed through pattern matching between this perception with mental model or prior knowledge stored in long term memory. Mental model provides rules as the basis for predicting future states from present information (Wickens, 1999). Adequate and accurate mental models are pre-requisites for achieving good SA (Sarter & Woods, 1991). Inadequate, inaccurate and over-reliance on mental model can lead to biases in selection and interpretation of

information. SA errors can occur when information is mismatched to incorrect mental model, leading to false expectations.

Figure 2-7 Role of goals and mental models in SA (Endsley, 2000c)

2.2.4 Long-term Working Memory (LTWM)

The ability to make LTM structures immediately available to short-term memory retrieval cues can reduce the burden imposed on WM, and make prediction process more efficient in skilled performance by experts (Ericsson & Kintsch, 1995). With this LTWM, the amount of information that can be maintained and directly accessible is not limited by a fixed capacity of WM. This ability requires the person to be able to rapidly store information in LTM, be familiar with the task to be able to anticipate the future information needs, and have appropriate retrieval cues to access the stored information effectively. All of these can be only achieved with extensive practice. Durso & Gronlund (1999) identified four strategies that can help this mechanism: remembering only the important information, reorganizing information into richer chunks, gistification or making meaningful relationship of relevant data, and restructuring the environment. Sohn & Doane (2004) found that the effect of WM was not significant for expert pilots, because they rely more on LTWM and did not depend much on WM. On the other hand,

novices seemed to perform explicit reasoning to understand the perceived situation and to project future states, which together, put a greater load on WM (Sohn & Doane, 2004).

2.2.5 SA and Naturalistic Decision Making

Endsley's conceptualization of SA is adapted from the information processing model (cf. Wickens & Hollands, 2000). In this model, SA is viewed as a separate stage that drives decision making and performance of actions. Based on this model, Endsley (1995c) postulated that good SA does not always lead to effective performance. Rather, SA and performance are related in a probabilistic link, i.e., with a good SA, there is a higher chance to produce good decision and performance. There are other factors that are related in turning good SA into successful performance, such as individual strategies, physical capabilities, system problems, luck, and status of the opponent (if present).

Although illustrated as separate stages in Endsley's model, SA and decision making is tightly linked. An operator could not solve a problem unless he recognizes that there is a problem and understand the nature of the problem. Orasanu & Fischer (1997) developed a model of decision making in naturalistic environment, which involves two components: situation assessment and choosing a course of action (see Figure 2-8). From an examination of National Transportation Safety Board (NTSB) accident reports, Orasanu et al. (1993) identified that poor situation assessment is a more common cause than faulty selection of course of action. The situation assessment process include defining the nature of the problem, determining how much time is available for coping with the problem, and assessing the level of risk associated with the situation. In many cases when problem is not understood and time is not limited, the decision is to gather more information before making a decision (Orasanu, 1995b).

Recognition-primed decision making (RPD) model (Klein et al., 1989) has been widely used to explain decision making in naturalistic environment. Unlike traditional models of decision making where the decision makers are faced with alternatives and that each alternative is analyzed in terms of expected consequences, the RPD model proposes that the operators select a course of actions rapidly once a mental picture of the situation is developed. Thus, situation assessment is central for RPD. Kobus et al. (2001) reported that experts took a significantly longer time to assess the situation than the less experience

operators, but once the assessment is completed, the experts select a course of action significantly faster than the novices. In military domain, most of the rules are made explicit through Standard Operating Procedures (SOP) and tactical engagement doctrine, in order to facilitate the rapid selection of actions.

Figure 2-8 Decision Process Model (Orasanu & Fischer, 1997)

2.3 Cognitive Abilities and Situation Awareness

Youngling et al. (1977, cited by Hartman & Secrist, 1991) identified that about 40% of the total kills made in the aerial combat was accounted by only approximately 4-5% of the pilots. What do these pilots possess that make them superior to the rest? According to Spick (1988), these *ace* pilots were not better trained, did not necessarily have more experience or better-equipped aircraft, and were not distinguishable from average pilots in terms of any personal or physical traits. They just seemed to have better awareness of what is going on. Hartman & Secrist (1991) suggested that superior fighter pilots have identifiable individual characteristics that contribute significantly to their superior performance. Therefore, individual differences underlying SA has been of high interest, particularly as a basis for pilot selection. In addition, the development of training program requires an identification of the specific skills related to SA that need to be trained (Endsley & Bolstad, 1994).

Many studies in individual differences of human abilities were aimed to develop and evaluate personnel selection battery, with the main interest being to identify candidates most likely to succeed as military pilots. Air Force Officer Qualifying Test (AFOQT) and Basic Attributes Test (BAT) are two aptitude tests currently used by U.S. Air Force for their pilot selection. AFOQT consists of 16 tests that assess five ability domains: verbal, quantitative, spatial, perceptual speed, and aircrew interests-aptitude. BAT consists of a short background questionnaire and eight computerized tests that assesses psychomotor coordination, information processing ability (reasoning, spatial transformation, short-term memory, perceptual speed), personality, and attitudes toward risk taking. Correlation between performance on AFOQT and BAT with training performance (i.e., graduation or elimination, fighter or non-fighter recommendation) were found to range from 0.20 to 0.40 (Carretta, 1989 cited by Carretta, 1992). Another study by Carretta & Ree (1994) reported AFOQT as the best predictor of pass-fail flying criteria and class rank at the end of flying training. Flying experience, psychomotor skills, and attitude towards risk were found to increment the prediction by 23%. As the ability to acquire and maintain SA was normally included as a part of pilot training assessments, the factors included in AFOQT and BAT may somehow correlate with pilots' anticipation ability. Nevertheless, further studies specifically targeted on anticipation ability are required.

Several studies have been conducted to investigate the cognitive issues underlying pilot's SA. Endsley & Bolstad (1994) examined the correlation between individual differences (spatial ability, attention, memory, perception, and cognitive functioning) across 25 experienced military fighter pilots and their SA in air-to-air engagement missions. Their results supported the importance of spatial and perceptual skills for SA, partially support the need for attention-sharing and pattern-matching skills for SA, but did not support the need for memory or analytical skills for SA. The study was however limited to level 1 SA, as the SA measure used only gauged the subject's knowledge of other aircraft's location, and not on the higher levels of comprehension and projection. They noted that higher levels of SA may draw on other skills, and this was unfortunately not addressed in the study.

Carretta et al. (1996) conducted a study to investigate the abilities predictive to SA in F-15 pilots. They tested 171 F-15 pilots using a computerized battery, which measured

cognitive ability, psychomotor ability, and personality, and used the result to predict supervisor and peer ratings of SA collected from operational tactical fighter squadrons. They found that hours of flying experience was the best predictor of SA. General cognitive ability based on WM, spatial reasoning and divided attention were also found to be predictive to SA. As the SA scores were obtained from supervisor and peer ratings, it is not clear if the measures have covered the three levels of SA. Furthermore, such subjective ratings of SA done by people who have prior knowledge about the pilot may be bias due to his credentials, such as experience, qualification status, and participation in special courses (Bell & Lyon, 2000).

O'Hare (1997) evaluated the utility of WOMBATTM to distinguish elite pilots from highly experienced pilots and non-pilots (control group). WOMBATTM test involves coordinated performance that requires motor skills, visual monitoring and scanning, working memory, and resource management. As a result, the distribution of WOMBATTM scores showed a clear difference across the three groups. This suggests that the test measures the underlying abilities associated with exceptional aviation skill. In an air traffic control simulation study by O'Brien & O'Hare (2007), participants with high SA ability measured using WOMBATTM were shown to perform better compared to participants with low SA ability. Similarly in air traffic control task, Durso et al. (2006) found that including SA measured by Situation Present Assessment Method (SPAM) in the battery of cognitive tests increased its validity in predicting performance.

Studies by Sohn & Doane (see Doane et al., 2004; Sohn & Doane, 2003, 2004) are among the very few studies that targeted directly at the third level of SA. They investigated the influence of WM and LTWM on the ability of pilots to anticipate a future status of various flight scenarios. The pilots were provided with screens that showed a goal description and two snapshots of changes in cockpit situation, and then asked to judge whether the aircraft would reach the specified goal state in the next five seconds. However, the use of static snapshots to simulate the dynamic changes of the aircraft status raises the concern whether the results would be the same for real-time dynamic tasks. In addition, the study needs to be expanded to include the role of other cognitive abilities, such as spatial ability and reasoning, which may also be relevant to pilots' anticipation.

Table 2-1 summarizes several aspects of cognitive abilities and the relevant findings from the existing studies and if the test is being deployed in any selection battery. The abilities can be categorized as follows:

1. Spatial ability

Spatial ability relates to ‘individuals’ abilities in searching the visual field, apprehending the forms, shapes, and positions of objects as visually perceived, forming mental representations of those forms, shapes, and positions, and manipulating such representations mentally’ (Carroll, 1993, p.304). Understanding of spatial relationships between dynamic objects in three-dimensional space contributes to spatial awareness. Its importance in the flight environment has been recognized, as shown by its employment in many pilot selection batteries, such as AFOQT and BAT by the U.S. Air Force (cf. Carretta & Ree, 1994) and Norwegian Air Force (cf. Martinussen & Torjussen, 1998). Existing studies also have shown good correlation between spatial ability and SA (Carretta et al., 1996; Endsley & Bolstad, 1994).

2. Memory

Both working and long term memory may be related to SA. In the absence of other mechanisms, higher order of SA (comprehension and future projection) must occur in the WM. Decision making and other flight task also impose demand on WM. As reported by Sohn & Doane (2004), WM capacity is important for novice pilots in anticipating the consequences of flight actions. When LTWM skills are obtained, usually through experience, these skills are found to play a more important role (Sohn & Doane, 2004). LTM stores can substantially reduce the load on WM, through recognition of familiar patterns, chunking, etc. Flying hours, a measure of experience level, was found to be a good predictor of SA (Carretta et al., 1996).

In air combat tasks, high demands are imposed on spatial WM, as the pilots need to perform calculations and estimations of where the aircraft will be in the future, given a mental model of the system’s dynamics. Sohn & Doane (2004) found that pilots’ anticipation correlated significantly with spatial memory, but no significant correlation with verbal memory. Similarly, Carretta et al. (1996) found a significant correlation between SA and spatial WM, when the flight hours was controlled. However, they found different result for correlation with the two verbal WM tests used, i.e., significant

correlation with continuous opposites test, but no significant correlation with verification span test. The importance of verbal resources for a more complex navigating task has been demonstrated in other studies as well (Barshi & Healy, 2002; Johannsdottir, 2004; Logie et al., 1989).

3. Reasoning

The relationship between SA and reasoning ability has been demonstrated (e.g., Carretta et al., 1996; Endsley & Bolstad, 1994). Reasoning ability, including the ability to recognize pattern, discern pattern in complex figures, and pattern matching were found to be important to SA, especially in the formation of the higher levels of SA. This is because the formation of situational model requires a pattern matching between the obtained (raw) information from the environment with the existing knowledge or mental model stored in one's LTM. WOMBATTM test, which correlates significantly with pattern recognition ability, was shown to be able to distinguish elite pilots (who are supposed to have superior SA ability) from very high experienced pilots and non-pilots (O'Hare, 1997).

4. Verbal ability

Previous studies reported a stronger effect of spatial than verbal ability on pilot SA and performance (e.g., Carretta et al., 1996; Sohn & Doane, 2004). Nevertheless, verbal ability would also be important because flight operations usually involve communication with air traffic controllers as well as intra/inter cockpit. Much of the vital information is obtained through audio means, relieving the workload of visual acquisition. These processes can support the development and maintenance of SA.

Table 2-1 Cognitive abilities and their correlation with SA

Cognitive Factor	Explanation	Findings from Previous Studies and Utilization in Personnel Selection Test Battery
Abilities in the Domain of Visual Perception (Spatial)		
Visualization	The ability to perceive spatial patterns accurately and to compare them with each other.	<ul style="list-style-type: none"> • Form Board Test – moderate correlation ($r = .317$) with SA level 1 (Endsley & Bolstad, 1994) • Pitch-roll-yaw – no support for correlation with supervisor and peer ratings of SA (Carretta et al., 1996) • Block counting – deployed in AFOQT
Spatial Orientation	The ability to perceive spatial patterns or to maintain orientation with respect to objects in space or manipulate relatively simple visual patterns, by whatever means (mental rotation, transformation, and otherwise). Similar to visualization, but visualization requires additional manipulation.	<ul style="list-style-type: none"> • Cube Comparison Test (3D mental rotation) – moderate correlation ($r = .353$) with SA level 1 (Endsley & Bolstad, 1994) • Aerial Orientation Test (2D mental rotation) – low correlation ($r = .150$) with SA level 1 (Endsley & Bolstad, 1994) • Maze Task – moderate correlation ($r = -.354$) with SA level 1 (Endsley & Bolstad, 1994) • Manikin test, Mental Rotation, Cube Spatial Orientation, and 3D mental rotation – no support for correlation with supervisor and peer ratings of SA (Carretta et al., 1996) • Rotated blocks – deployed in AFOQT • Mental rotation – deployed in BAT
Closure Flexibility	The manipulation of two configurations simultaneously or in succession.	<ul style="list-style-type: none"> • Hidden figures – deployed in AFOQT
Perceptual Speed	Speed in finding figures, making comparisons, and carrying out other very simple tasks involving visual perception	<ul style="list-style-type: none"> • Perceptual speed test adapted from BAT – moderate correlation ($r = -.448$) with SA level 1 (Endsley & Bolstad, 1994) • Hartman's test of perceptual speed – no support for

		<p>correlation with supervisor and peer ratings of SA (Carretta et al., 1996)</p> <ul style="list-style-type: none"> • Table reading – deployed in AFOQT
Abilities in the Domain of Memory		
Memory Span	The ability to recall a number of distinct elements (verbal, numerical, or figural) for immediate reproduction in its correct order	<ul style="list-style-type: none"> • Spatial span – high correlation ($r = .52$) with prediction of future aircraft status by novices, but low correlation ($r = .10$) for experts (Sohn & Doane, 2003) • Verbal span – no significant correlation with prediction of future aircraft status (Sohn & Doane, 2003) • Continuous Opposite (verbal working memory) – significant partial correlation with supervisor and peer ratings of SA (Carretta et al., 1996)
Visual Memory	The ability to remember the configuration, location, and orientation of figural material.	<ul style="list-style-type: none"> • Four-term ordering – no support for correlation with supervisor and peer ratings of SA (Carretta et al., 1996) • XYZ assignment – significant partial correlation with supervisor and peer ratings of SA (Carretta et al., 1996)
Immediate/Delayed Memory	The ability to recall a displayed stimuli immediately and after a delayed period of time	<ul style="list-style-type: none"> • Immediate/Delayed Memory – no support for correlation with SA level 1 (Endsley & Bolstad, 1994) • Item recognition – deployed in BAT
Long-term Memory		Age, years of flight experience, number of flight hours, and combat experience – weak correlation with SA level 1 (Endsley & Bolstad, 1994)
Abilities in the Domain of Reasoning		
Induction	This factor identifies the kinds of reasoning abilities involved in forming and trying out hypotheses that will fit a set of data	<ul style="list-style-type: none"> • Analytic subtest – no support for correlation with SA level 1 (Endsley & Bolstad, 1994)

Integrative Processes	The ability to keep in mind simultaneously or to combine several conditions, premises, or rules in order to produce a correct response. The tests frequently require the subject to follow a fairly complex set of directions or to handle a set of complex rules.	<ul style="list-style-type: none"> • Raven's Advanced Progressive Matrices – moderate correlation ($r = .243$) with SA level 1 (Endsley & Bolstad, 1994) • Spatial reasoning similar to Raven's Matrices – no support for correlation with supervisor and peer ratings of SA (Carretta et al., 1996)
General Reasoning	The ability to select and organize relevant information for the solution of a problem	<ul style="list-style-type: none"> • Rapid serial classification (spatial reasoning) – significant partial correlation with supervisor and peer ratings of SA (Carretta et al., 1996)
Logical Reasoning	The ability to reason from premise to conclusion, or to evaluate the correctness of a conclusion	<ul style="list-style-type: none"> • Simultaneous figure matching (spatial reasoning) – no support for correlation with supervisor and peer ratings of SA (Carretta et al., 1996) • Verbal analogies – deployed in AFOQT • Arithmetic reasoning – deployed in AFOQT
Abilities in the Domain of Language		
Verbal Comprehension	The ability to understand the English language	<ul style="list-style-type: none"> • Word knowledge – deployed in AFOQT

2.4 Measurement of SA

2.4.1 Measurement Considerations

Previous discussion on the theoretical construct of SA imposes several implications for developing and selecting measurement tools to assess SA. They are listed as follows:

1. Encompass the three levels of SA, i.e., perception, comprehension, and future projection. The perception, comprehension, and future projection processes help to form a mental picture of the situation; where the higher level of SA achieved shows a better quality of the formulated picture. A measurement tool that can capture all of the three levels of SA is often desired.
2. Evaluate the SA that is acquired by the operator with respect to SA requirements, bearing in mind the scope of SA achievable within the system. This is necessary because it would be invalid to judge a person's SA as poor when he does not have any SA on the things that are not relevant to his roles, or when it is impossible to attain such awareness because no information is available by the environment.
3. Assess the operator's perception of his SA. Eliciting this meta-cognition state, whether a person is aware that he is unaware, unaware that he is unaware, and so on, can provide a useful information in addition to knowing whether the content of his situational knowledge is accurate or not. This is because the way a person sees himself as having good or poor awareness can affect his decision and actions.
4. Account for the dynamic changes of the situation. As situation changes over time, a person needs to continuously update his mental model of the situation otherwise it may not be accurate anymore. Measurement of SA should also be able to capture these changes.

In addition to these primary considerations, several additional considerations may be imposed by the application or organization where SA assessment is done, e.g., non-intrusive, low cost, and easy to implement and administer. In a high risk environment setting, such as air traffic control, surgery, and flight operation, intrusion during task

performance is dangerous and thus not desirable. In other applications where the impacts of intrusion are not severe, such as in laboratory experiment and simulator, certain level of intrusion may be acceptable. Organizations with much funding may not care about the implementation cost of the method, but others may require it to be low cost. These additional considerations vary depending on the interest of the examiners, and they also play an important role in the selection of SA methods.

Furthermore, in the context of measurement, it is necessary to take note on the construct and predictive validity of the measures. Construct validity means that the measurement tool should really measure what it intend to measure and address the underlying construct or theory, or in other words, the extent to which the measures is underpinned by a sound theory or model of SA. Predictive validity means that the measure must be able to predict something it should theoretically be able to predict. In this context, it is well accepted that high SA is necessary for effective performance. Thus, good measures of SA should be able to predict the performance outcome.

In the following section, different types of SA measurement approaches are reviewed in terms of their capabilities and limitations in satisfying the measurement considerations.

2.4.2 Taxonomy of SA Measurement Tools

There are a number of SA methods currently available. It is however not practical to evaluate them one by one, as some of them have similar properties. In this thesis, the existing methods are categorized and evaluated according on their basic characteristics. Table 2-2 shows the taxonomy of SA measures according to their objectivity (objective or subjective), source of SA information (self, peer, or observer), targeting on SA product or process of situation assessment, time of measurement (concurrent, freeze, or retrospective), and level of measurement (individual or team). Examples of specific methods that correspond to each characteristic are also provided in the table. Table 2-3 provides a brief overview of each method. The advantages and disadvantages of each characteristic are discussed in the following sections.

Table 2-2 Taxonomy of SA measures

Objectivity	Source of information	Product / process	Time of measurement	Level of measurement	Example
Objective	Participant (self-report)	Product	Concurrent	Individual	- SPAM (Durso et al., 1998) - SASHA_L (Jeannot et al., 2003)
			Freeze	Individual	- SAGAT (Endsley, 1988) - SALSA (Hauss & Eyferth, 2003) - SACRI (Hogg et al., 1995)
			Retrospective	Individual	- Using video playback (Sulistyawati et al., 2006)
	Observer (performance)	Process	Concurrent, retrospective	Individual	- Think aloud
		Process	Concurrent, retrospective	Individual Team	- Testable response (Pritchett & Hansman, 2000) - Process tracing (Sulistyawati et al., 2007)
		Process	Concurrent	Individual	- EPOG – Eye Point of Gaze (Wickens et al., 2008) - P300 EEG
Subjective	Participant (self-report)	Product	Retrospective (but may be applied concurrently and using freeze)	Individual	- SART (Taylor, 1990) - SARS (Waag & Houck, 1994) - CARS (McGuinness & Foy, 2000) - MARS (Matthews & Beal, 2002) - SA-SWORD (Vidulich & Hughes,

	Participant (self, peer) Observer	Product	Retrospective (but may be applied concurrently and using freeze)	Individual, team	1991) - SASHA_Q (Jeannott et al., 2003)
					- C-SAS (Dennehy, 1997) - CLSA (Adams, 1998)
	Observer (behavior)	Process	Concurrent, retrospective	Individual, team	- SABARS (Matthews & Beal, 2002) - CAST (Gorman et al., 2005) - TARGETs (Fowlkes et al., 1994) - SALIANT (Muñiz et al., 1998) - Critical Incident Technique (Patrick et al., 2006)
Objective and subjective	Participant (self, peer)	Product	Freeze	Individual	- QUASA (Edgar et al., 2003; McGuinness, 2004)
	Participant (self, peer)	Product	Retrospective (but may be applied concurrently and using freeze)	Individual	- Questionnaires for Distributed Assessment of Team Mutual Awareness (MacMillan et al., 2004b)

Table 2-3 Brief overview of SA measurement methods

Method	Overview
SPAM (Situation-Present Assessment Method)	<ul style="list-style-type: none"> • Basic consideration: the operators need to know where to find the right information efficiently when needed rather than memorizing the information and then recall it • Applied to assess SA of air traffic controller, where the SA queries were administered online via telephone • The response time for those responses that are correct is taken as an indicator's of the operator's SA, the time taken to pick up the telephone is used to indicate the operator's workload • Acceptable validity and sensitivity (Jones & Endsley, 2000)
SASHA (Situation Awareness for SHAPE (Solutions for Human-Automation Partnerships in European ATM))	<ul style="list-style-type: none"> • Developed by Eurocontrol to assess air traffic controller's SA in automated systems • Consists of two parts: SASHA_L and SASHA_Q • SASHA_L is an online probing technique similar to SPAM. The response time to the queries is graded as 'too quick', 'OK', and 'too long', and the response content is graded as 'incorrect', 'OK', and 'correct'. • Requires the analyst/experimenter to generate the queries on-line during task performance to ensure the relevance of questions asked with the situation faced by the operator • SASHA_Q is a subjective measure, consists of 10 questions, completed by participants at the end of the task. • No data on validity and reliability is found in the literature.
SAGAT (Situation Awareness Global Assessment Technique)	<ul style="list-style-type: none"> • The most commonly used and tested method to measure SA • Assesses the operator's internal knowledge of the situation, by asking questions related to their perception, comprehension, and projection of future status, and then checking the responses with the actual situation • Requires the mission to be frozen and displays blanked out at randomly selected times • SAGAT queries are developed based on SA requirements analysis • High degree of validity, sensitivity, and reliability (1990; Endsley, 2000a; Endsley & Bolstad, 1994)
SALSA (measuring Situation Awareness of Area Controllers within the Context of Automation)	<ul style="list-style-type: none"> • Similar to SAGAT, applied in air traffic control systems • Considers the changing relevance of the elements in the environment by incorporating an expert rating system, where the SA scores are then weighted using this expert rating • All SA queries are administered during each freeze. This can be a disadvantage as the participants may be overloaded by the long list of queries, and also requires a relatively longer freeze time.

SACRI (Situation Awareness control Room Inventory)	<ul style="list-style-type: none"> • Developed based on SAGAT, applied in process control systems • SA queries include questions comparing the current situation with that of the recent past, comparing with normal operations, and predicting future situation developments. • SA scores are obtained by simply calculating the percentage of correct query responses, or by using signal detection theory to calculate the sensitivity of the operators according to their hit, miss, correct acceptance, or false alarm. • Acceptable sensitivity (Hogg et al., 1995), but requires further test of reliability (Stanton et al., 2005b)
Think aloud or verbal protocol	<ul style="list-style-type: none"> • The operator is asked to verbalize his thought processes throughout task performance or retrospectively while viewing a playback of the recorded mission • May impose additional workload to the operators, and they may stop verbalizing during high workload situation, which is often the part of a main interest of the SA assessment • People are not very accurate in reporting their own mental processes • Sullivan & Blackman (1991) found no difference in the verbal protocols for expert and novice pilots
Testable response	<ul style="list-style-type: none"> • Embeds specific situations to be tested into the simulation using programming or confederate • Uses specific measurable performance outcomes (responses) that are predetermined for a particular level of SA • The responses (or non-responses) to the specific events and the response time can be analyzed. Faster response time corresponds to higher SA
SART (Situation Awareness Rating Technique)	<ul style="list-style-type: none"> • Widely used and tested • Developed from interview with operational Royal Air Force (RAF) aircrew • Includes ten dimensions related to attentional demand, attentional supply, and understanding of the situation • Good sensitivity (Jones, 2000) • Construct validity of SART is questionable due to the inclusion of workload dimensions • It is subjective, people may not know what they don't know, and thus can lead to confidence bias
SARS (Situation Awareness Rating Scales)	<ul style="list-style-type: none"> • Derived 31 behavior elements from interviews with experienced F-15 pilots. These SA elements are then rated using a six-point scale, ranging from acceptable to outstanding. • Waag & Houck (1994) conducted a validation study by collecting self, peer, and squadron leader ratings, and found a high level of consistency and inter-rater reliability for peer and supervisory SARS. The squadron ratings of SA showed a significant correlation with performance in simulated air combat missions.

<p>CARS (Crew Awareness Rating Scale)</p> <p>MARS (Mission Awareness Rating Scale)</p>	<ul style="list-style-type: none"> • CARS and MARS are very similar methods • Comprises of two separate sets of questions: the content subscale and the workload subscale. The questions are to be rated by the participants using 4-point scale. • The first set includes ease of identification, understanding, prediction, and knowledge on how to achieve goals • The second set is related to workload, asking the participants how difficult, in terms of mental effort, it is to identify, understand, predict, and make decision in a mission • Construct validity has been questioned: that it actually measures the difficulty in acquiring and maintaining SA, rather than measuring SA itself (Stanton et al., 2005b). • McGuinness & Ebbage (2002) used CARS to evaluate the use of different technologies to support commander's SA and indicated sensitivity in content ratings, but not the workload ratings. • Matthews & Beal (2002) used MARS to compare the SA of platoon leaders and the less experienced squadron leaders, and showed that the method was able to differentiate between different levels of SA achieved by the two groups.
<p>SA-SWORD (Situation Awareness Subjective Workload Dominance Technique)</p>	<ul style="list-style-type: none"> • Adaptation of SWORD that was originally developed to measure mental workload • The operators are then asked to do a paired comparison of the tested systems; which system allows them to have a better SA. The SA dominance of one system over the other can be further differentiated by rating 'weak' or 'absolute'. • Vidulich & Hughes (1991) applied the technique to compare two F-16 cockpit displays, and reported that it was able to differentiate between the two displays, but no significant difference was found across flight segments and threat conditions
<p>C-SAS (Cranfield Situation Awareness Scale)</p>	<ul style="list-style-type: none"> • Originally developed to assess student pilot SA during training exercises • Includes five subscales, namely pilot knowledge, understanding and anticipation of future events, management of stress, effort and commitment, capacity to perceive, assimilate and assess information, and overall SA • Ratings to these subscales range from very poor (1) to very good (5), and can be obtained from the participants and observers. • No information on the validity and reliability
<p>CLSA (China Lake Situational Awareness)</p>	<ul style="list-style-type: none"> • Constructed by the Naval Air Warfare Centre at China Lake to measure SA in flight • Assesses the participants' awareness with respect to their knowledge of aircraft energy state/tactical environment/mission objectives and their ability to anticipate/accommodate event/situation development • Ratings using 5-point anchored scale

SABARS (Situation Awareness Behavioral Rating Scale)	<ul style="list-style-type: none"> • Involves Subject Matter Experts (SMEs) to observe participants during task performance and rate them on 28 observable SA related behaviors. The questions are developed to assess infantry personnel in field training exercise. SABARS ratings range from very poor (1) to very good (5), or not applicable. • Matthews & Beal (2002) reported a study that uses SABARS to compare the SA of platoon and squad leaders during a field training, and found that although the observers provided positive feedback towards the method, SABARS results were not able to differentiate between platoon and squad groups
CAST (Coordinated Awareness of Situation by Teams)	<ul style="list-style-type: none"> • Introduces roadblocks during the mission and assesses the team coordination when overcoming them. • CAST score sheet consists of four parts of boxes: who perceived the roadblock, who they coordinate the perception with, who was involved in coordinating actions, and whether the team overcome the roadblock successfully • CAST score is computed by counting the number of checked boxes divided by the number of total boxes • Gorman et al. (2005) tested the method and reported that it can differentiate between good and poor teams
TARGETs (Targeted Acceptable Responses to Generated Events or Tasks)	<ul style="list-style-type: none"> • The mechanism of TARGETs and SALIANT is similar • Allows a structured observation of the participants' behavior • A task analysis needs to be done to come out with a list of events, where an assessment will be done on whether the appropriate responses (targets) to the events are present or not. • TARGETs was applied to assess the team coordination effectiveness in a military cargo helicopter training (Fowlkes et al., 1994). The result showed a good inter-rater reliability, internal reliability, and test-retest reliability.
SALIANT (Situation Awareness Linked Indicators Adapted to Novel Tasks)	<ul style="list-style-type: none"> • In a study comparing SALIANT, SA probes, and SART, Fink & Major (2000, cited by Jeannott et al., 2003) suggested that SALIANT has the best psychometric properties
Critical Incident Technique	<ul style="list-style-type: none"> • Identify critical incidents through observation and determine its relation with SA • Critical incidents include extreme behavior that is outstandingly effective or ineffective with respect to attaining the general aims of the activity • Mostly qualitative, but observer rating can be incorporated to generate quantitative data • Patrick et al.(2006) reported satisfactory reliability of observer ratings tied to the technique

QUASA (Quantitative Assessment of Situation Awareness)	<ul style="list-style-type: none"> • Consists of two parts: 1) objective and 2) subjective assessments • The first part requires the operator to provide a true or false response to statements related to SA. Based on signal detection theory. SA score is obtained by the sensitivity of the operator to separate true and false information apart (Edgar et al., 2003). • The second part requires the operator to provide a confidence rating for every answer provided for the SA statement (McGuinness, 2004). Confidence bias is calculated by comparing the confidence level and the objective SA score • Sensitive to identify SA differences across participants (Edgar & Edgar, 2007). No predictive validity or reliability was reported.
QDATMA (Questionnaire for Distributed Assessment of Team Mutual Awareness)	<ul style="list-style-type: none"> • Includes three aspects: taskwork awareness, workload awareness, and teamwork awareness. • Taskwork awareness refers to awareness of what tasks other team members are completing and how important these tasks are. • Workload awareness refers to awareness of the loading that the taskwork imposes on team members. • Teamwork awareness refers to awareness of how well team members perform team-specific behaviors, e.g., coordination and back-up. • Mutual awareness is calculated by the similarity across team members' answers

1. Objective or subjective assessment

Objective assessment produces a numeral or judgment score that can be accurately given without a significant variation across judges, and that right/ wrong or success/no success can be easily differentiated. Subjective assessment is usually obtained through perception or observation of participants in performing the task. Compared to objective measures, subjective measures are generally less accurate and suffer from biases as different raters could have different interpretations of the values/ ratings.

Objective measures are usually applied specifically to the system of interest, involving task and system analysis in its development. For example, Endsley (1993) derived the SA requirements for air-to-air combat through unstructured interviews, goal-directed task analysis, and structured questionnaires administered to experienced fighter pilots. This information can then be used to derive SAGAT probes to assess pilot's SA in such environment. Hogg et al. (1995) also tailored the SA questions in SACRI with respect to the SA requirements in nuclear power plant control operation. This type of measures

therefore addresses the second measurement consideration, i.e., evaluate the SA acquired by the operator with respect to SA requirements.

On the other hand, subjective measures are usually generic and can be used across various applications. They are relatively cheap, and easy to administer, implement, and interpret. Thus, this type of measure is usually chosen when money and time to develop the measures are limited. However, as the methods are generic in nature, most of them do not consider the SA requirements specified by the task in hand. Some exceptions do apply, for example, SARS, SASHA_Q, SABARS, TARGETs, and SALIANT. SARS includes elements of SA important to fighter pilots, which was derived from interviews with experienced F-15 pilots; SASHA_Q includes elements related to air traffic control operations; SABARS includes a behavior list specific to a platoon leader in infantry military exercises; while TARGETs and SALIANT allows a specification of behavior list related to the SA requirements.

There is evidence that the two types of measures actually assess different parts of the SA construct. In a comparison between two mostly used measures, SAGAT (objective) and SART (subjective), no significant correlation (Endsley et al., 1998b) or only moderate correlation (Endsley et al., 2000) was found between the two. Subjective ratings were found to be more related to operator's confidence level of his SA (Endsley et al., 1998b). It seems that objective measures are better when used to measure the situational knowledge acquired by the operator (the second consideration), and subjective measures are better to measure the operator's perception of his SA (the third consideration). Nofi (2000) suggested that SA score is a function of the two measures, with high objective and high subjective scores being the best SA, and low objective and high subjective scores being the worst SA. Methods that integrate the two types of measures are needed. QUASA (McGuinness, 2004) is an example of methods that are moving towards this direction. The method consists of two parts. The first part asks the operators to assess the correctness of probe statements. The second part requires them to rate the confidence on their response to each statement. These two measures provide an indication on how well calibrated the operator is regarding his SA. A bias score can be calculated by the average confidence rating across all test items minus the proportion of the same items that were judged correctly (McGuinness, 2004). A positive bias indicates overconfidence and a

negative bias indicates under-confidence. Unfortunately, there is still no evidence on the validity of this method in predicting the performance outcome.

2. Source of information

Information regarding the operator's SA can be obtained from various sources, namely from the operator's self-report, operator's physiological functions, peer-report, or from the observers. Objective assessments obtained from self-report can generate information regarding operator's state of situational knowledge. SA questions can be developed to elicit what the operators know or do not know, whether they have perceived and comprehended the information correctly, and can predict future status accurately. In this way, the first measurement consideration, i.e., encompass the three levels of SA, can be addressed. Examples include SAGAT, SACRI, SPAM, SASHA_L, and QUASA.

Operator's physiological functions can also provide some indication of his SA. Eye point of gaze (EPOG) can sometimes be used to assess if the operator attended to relevant information. However, it cannot determine the degree of comprehension or projection. Similarly, EEG event-related potential (ERP) measures may be used to investigate if information is perceived and understood, but there is no indication if the comprehension is accurate. Thus, they could not be used to assess the three levels of SA.

When self assessment is used with subjective measures, some concerns are raised. In an evaluation study of SARS, Bell and Lyon (2000) found substantial agreement between supervisor and peer ratings, but noticeably less agreement with self-report. Similarly, Berggren (2000) found a weak correlation between self and instructor ratings of pilots' SA. This raises the question on which source would be the best to provide the SA ratings. Since the operators may not know what is really going on in the environment, their ability to estimate their own SA may not be very good (Endsley, 1988). In addition, although the operators may realize that they have some clues what is going on, they may not know if their knowledge is complete or accurate. However, self rating is the best source to reveal ones' perception and confidence about their SA quality, which can be used to reason the decisions they made. Further, the participants can also be asked to rate how they perceive themselves in achieving the three levels of SA. For example, CARS and MARS require the operator to rate their ability to identify mission-critical cues in the mission, understand

what is going on during the mission, and predict what is about to occur next in the mission.

On the other hand, observers have the likelihood to obtain more information about what is really happening and may have the ability to replay recorded missions and observe the task performance carefully. Thus, they are in a better position to provide a direct judgment on the awareness of the observed operators. However, they are generally not able to differentiate across the three levels of SA. This is because they tap on the later stage of the information processing, such as behavior, action taken, or final performance, after the cognitive processes have taken place. Valid rules are required to be able to validly infer which behavior or performance indicate achievement of level 1, 2, or 3 SA, but such rules are often difficult to generate. Another concern of using performance-based measure is due to its probabilistic relationship with SA, i.e., good SA should increase the probability of good performance, but does not guarantee it (Endsley, 2000c). Performance measures are only appropriate if the performance in question is driven solely or largely by SA (Pew, 2000). In using behavior to infer SA, a set of valid and reliable list of operator's behavior that directly relate to SA has to be derived. However, as operators may employ different strategies to deal with the same situation, it is rather hard to determine which behavior implies a better SA or whether the difference in behavior is solely due to their SA.

Similar to the problems with observers' rating, assessment by peers (who perform missions together with the operator) is incomplete as they can only assess the observable evidences and is limited in their ability to understand the operator's internal comprehension of the situation. In addition, peer and observer raters who have prior knowledge about the operator can provide a bias rating of SA due to his credentials, such as experience, qualification status, and participation in special courses (Bell & Lyon, 2000). Compared to observers' rating, information from peers is more vulnerable, because peers who themselves do not have good awareness during task performance may not provide accurate and reliable assessment of the other person's SA. Peer ratings should be used to inform the extent to which the raters are aware of their teammate awareness, rather than used as a rating of the teammate's awareness. Thus, peer assessment may be useful in team SA measurement. Questionnaires for Distributed Assessment of Team Mutual Awareness (MacMillan et al., 2004b), for example, requires the participants to

provide information on the tasks their teammates are completing, how important these tasks are, and the teammates' workload level. Similarly, Edgar and Edgar (2007) suggested that QUASA can be extended to include peer assessments. This is done by asking who else in the team would get the correct answer for each probe statement.

3. Product versus Process

The issues on different views of SA as a product versus process have been discussed in Section 2.1.1. Targeting SA measurement at the state or product allows a direct and quantitative comparison across different treatments. However, it cannot provide much explanation on the causes of variations in SA. It is easy to specify if a performance error is due to a lack of SA, but this will not explain the underlying cognitive mix-ups that lead to the lack of SA (Adams et al., 1995). In addition, it can only provide partial views, discrete pieces of awareness possessed at a point in time rather than a global view (Orasanu, 1995b). Assessing the process of situation assessment allows one to better understand the way SA is formed, maintained, and reformed when it is lost (Garbis & Artman, 2004). It allows a detailed investigation on the strategy that leads to effective development of SA and behavior that can result in loss of SA, which is important information for training purposes. Finally, process measures are advantageous as they can capture the dynamic changes of SA.

4. Time of Measurement

SA can be assessed concurrently during task performance, freezing the task, or after the task is completed. The operators can be asked to respond to SA-related probes or to think aloud concurrently during task performance. However, probing the operators during task performance can direct them to search for the requested information, which alters the assessment of their true SA (Endsley, 1988). In addition, this technique is intrusive to task performance and impose additional workload on the operator. As a result, the time taken to answer, which is traditionally used as an indicator of SA, may provide an indication of workload rather than SA.

Freeze technique pauses the task at randomly selected times and administers SA assessment during these freezes. This minimizes problems with bias of attention in

concurrent technique and overgeneralization of answers in retrospective technique. However, the freezes change the nature of dynamic environment and may have significant effect on SA, decisions, and actions in the subsequent sections of the mission (Dekker, 2000). In order to minimize this problem, Endsley (1988) suggested that tests to be conducted to determine the number and duration of stops permissible during a single trial. Alexander and Wickens (2005) applied SPAM (concurrent technique) and SAGAT (freeze technique) to examine the effectiveness of different display formats in supporting flight path tracking and SA. They reported an apparent speed-accuracy tradeoff between the two, where the subjects took longer but provided more accurate responses when probed using SPAM.

Retrospective technique collects SA information upon completion of the mission, and is thus non-intrusive. However, the operator may not remember what has happened due to rapid decay of memory. As a result, the information given may only reveal the tail end of the task (recency effect), suffers from over-generalization and over-rationalization. In addition, it does not reflect the accurate view of the actual SA possessed in the dynamic environment, thus disregarding the fourth measurement consideration. The effect can be reduced by recording and playing back the mission during the collection of SA information. However, this will not work for assessing the prediction aspect of SA (level 3). This is because the operators had been exposed to the outcome of the task and thus result in an invalid assessment of level 3 SA (Sulistyawati et al., 2006).

5. Individual or team level

SA measurement can be targeted at individual or team level. Measurement at team level can be done either by assessing the behavior or performance of the team as a unit, or by asking the team members to generate SA ratings for the team. Targeting the measurement at the team level requires the raters to have a good understanding of the overall nature of the team and task, in order to be able to make a valid and reliable judgment on whether the team has a good or poor SA. For example, TARGETs and SALIANT checklist can be developed to include assessment of teamwork behavior (communication, coordination, feedback, and backup behavior) would reflect the acquisition of good or poor team SA. CAST focuses on how team members coordinate their actions to overcome roadblocks introduced during task performance, by assessing who in the team perceived the situation

firsthand, who they coordinated their perception with, and who was involved in the performing the actions.

Compared to methods for individual SA, methods to directly assess SA at team level are still limited. As a result, it may be more convenient to target the measurement at individual level. In doing so, an appropriate method to aggregate the SA scores across team members is needed. Several possible methods are by using similarity, taking the sum, the minimum, the maximum, or the range of individual SA responses (Cooke et al., 2000). Unfortunately, there is still a lack of understanding on the underlying assumption of these aggregation methods and their appropriateness for different types of task and team characteristics. Even for similarity metric, which is useful to provide information on the degree the members share their understanding towards the same situation, there is no accepted and agreed way on how to calculate the similarity score. For example, Webber, Chen, Payne, Marsh and Zaccaro (2000) used inter-rater agreement index (referred as $r^*_{wg(j)}$ index) provided by Lindell, Brandt and Whitney (1999); Vernon et al. (2003) used inter-rater reliability calculated using Pearson's product moment; and MacMillan et al. (2004b) calculated the difference between self-reported and teammate's estimate for that individual, squared, summed, and averaged the scores of all items in the questionnaire for the team, and took its square root. Cooke et al. (2002) applied SPAM and SAGAT in team level by presenting the queries to the team as a whole. However, asking the team to provide a team response would encourage team members to discuss their responses and form a shared understanding, which may not actually take place in natural setting.

2.4.3 Mapping of SA Measurement Considerations and Available Methods

Several considerations that need to be taken care of when selecting an appropriate measurement tool were listed in Section 2.2.1. The existing tools that can address these considerations summarized as follows.

1. *Encompass the three levels of SA, i.e., perception, comprehension, and future projection.*

The tools that explicitly encompass the three level of SA are mostly in the category of objective measures that directly elicit the operator's state of knowledge (self-report). Subjective self-rating can address this issue only if its dimensions include the three levels,

e.g., CARS, MARS, and C-SAS. One important thing to note when eliciting the three levels of SA is on the timing of assessment. Retrospective assessment does not provide a valid measure of SA level 3.

2. *Evaluate the SA acquired by the operator with respect to SA requirements, bearing in mind the scope of SA achievable within the system.*

In order to address this, the tool should be specific and tailored to the application, involving extensive task and system analysis in its development, such as SAGAT, SALSA, SACRI, SPAM, SASHA_L, and QUASA. Subjective SA measures that address the SA requirements rather specifically include SARS, SASHA_Q, SABARS, and TARGETs.

3. *Assess the operator's perception of his SA.*

This issue is best addressed by self-rating of subjective measures. Another method to assess perceived SA is by incorporating a confidence rating to every question probed in a direct assessment such as that used in QUASA.

4. *Account for the dynamic changes of the situation.*

This can be done by assessing the operator's SA continuously during task performance (process measures), such as in process tracing and physiological measures. The other way is to administer any SA measure at several key points during task performance. SAGAT, SACRI, SPAM, SASHA_L, and QUASA are methods that operate in this manner. Although not common, subjective measures can also be applied several times during task performance to capture the changes in SA.

5. *Additional considerations* including non-intrusiveness, cheap, easy to implement and administer.

Most reviews would suggest that subjective measures would best satisfy these considerations. However this is not always true. Subjective measures, when applied several times during task performance, can be intrusive too. Thus, the intrusiveness of a measurement tool is attributed to the time of its application. Measures that require freezing the mission impose high level of disturbance to the operators' task. The same is true when the operators are asked to respond to the measurement concurrently during task performance. However, concurrent measures with data obtained from observers are non-

intrusive. As for cheap, easy to implement and administer considerations, they are usually satisfied by generic measures that do not require modification to tailor to the task in hand, such as subjective measures.

Table 2-5 provides a mapping of the measurement considerations and the available methods. As shown in the mapping, it is obvious that one type of measure would not be able to address all the considerations defined. They should thus be used in conjunction to complement each other's limitation. For example, a combination between objective (self-report) and subjective (self ratings) would be potential to address the primary considerations.

2.5 Summary

Much research effort has been devoted to understanding individual SA. The concepts that define SA are summarized in Table 2-4.

Table 2-4 What is SA

Concept:	Authors
- perception, comprehension, and future projection and ability to execute task based on that perception	Endsley (1988); Endsley (1995c); Siem (1992)
- a multidimensional construct, involving memory, attention, and decision making	Taylor & Selcon (1990)
- only temporarily true; thus needs to be continuously updated through recurrent situation assessment	Edgar & Edgar (2007); Sarter & Woods (1991); Adams et al. (1995)
- externally directed consciousness, meta-knowledge that guides the process of modifying knowledge	Smith & Hancock (1995); Lundberg (1999); McGuinness (2004)

Research that investigates individual differences, such as cognitive abilities and task experience, has been initiated. However, existing effort is limited to level 1 SA, often using non-dynamic simulation, and with peer or supervisor rating as a measure of SA. Nevertheless, these studies have provided valuable findings and have demonstrated the potential development of such studies. The review of various SA measurement methods shows that each one of them possesses advantages and drawbacks. The selection of measurement method should therefore be based on the targeted task and considering the

constraints imposed by the application. Furthermore, the extension of the concept and the implementation of the measurement methods of individual SA in team settings require an understanding of the fundamentals of team that differentiate it from individual unit of analysis.

With the existence of multiple individuals in the system and the possible interaction that happen between the individuals, the information processing that takes place in team is likely to be different from individual level. It may also vary across different types of team. Thus, an understanding of team and its characteristics is vital for the concept of team SA. Furthermore, factors influencing teamwork will be potentially relevant to team SA as well. The next chapter will present reviews of literature in team dynamics, current stage of knowledge in team SA, and identification of factors that potentially influence team SA.

Table 2-5 Mapping of SA measurement considerations and available methods

SA Measure \ Consideration	1 Encompass the three levels of SA	2 Evaluate SA acquired with respect to SA requirements and achievable SA	3 Assess operator's perception of his SA	4 Account for dynamic changes of the situation	5 Non-intrusive	6 Easy to implement & administer
SPAM	✓	✓	-	+	-	-
SASHA_L	✓	✓	-	+	-	-
Think aloud	✓	✓	-	+	-	-
SAGAT	✓	✓	-	+	-	-
SALSA	✓	✓	-	+	-	-
SACRI	✓	✓	-	+	-	-
Video playback	-	✓	-	✓	✓	-
EPOG	-	-	-	✓	-	-
P300 EEG	-	-	-	✓	-	-
SART	-	-	✓	+	+	✓
CARS	✓	-	✓	+	+	✓
MARS	✓	-	✓	+	+	✓
SA-SWORD	-	-	✓	+	+	✓
SASHA_Q	-	✓	✓	+	+	✓
SARS	-	✓	✓	+	+	✓
C-SAS	✓	-	✓	+	+	✓
SABARS	-	✓	-	+	✓	✓
CAST	-	✓	-	✓	✓	-
TARGETs	-	✓	-	✓	✓	-
SALIENT	-	✓	-	✓	✓	-
Testable response	-	✓	-	✓	✓	-
Process tracing	-	✓	-	✓	✓	-
QUASA	✓	✓	✓	✓	-	-
QDATMA	+	+	-	+	+	-

Note: (✓) yes; (-) no; (+) need modification

Chapter 3 Literature Review on Team Dynamics and Team SA

3.1 Team Dynamics

Researchers in both the management and human factors disciplines had proposed various definitions of teams. Brannick & Prince (1997) defined a team as comprising “two or more people with different tasks, working together adaptively to achieve specified and shared goals”. Cohen & Bailey (1997) considered a team as a collection of individuals who are: interdependent in their tasks; share responsibility for performance outcomes; see themselves and are seen by others as an intact social entity embedded in one or more larger social systems; and manage their relationships across organizational boundaries. In Human Factors, the most commonly used definition of a team is proposed by Salas et al. (1992). They defined a team as comprising of ‘a distinguishable set of two or more people who interact dynamically, interdependently, and adaptively toward a common and valued goal/objective/ mission, who have each been assigned specific roles or functions to perform, and who have a limited life span of membership.’

3.1.1 Team Taxonomy

According to Devine (2002), ‘What is true for one team is may not be true for another.’ This implies that the effects of team factors may not be the same or generic across different teams. Therefore, a taxonomy that differentiates teams according to the nature of tasks they perform, becomes important. Several researchers have proposed ways for classifying teams. For instance, Cohen & Bailey (1997) classified teams into four types: work, parallel, project and management teams; Sundstrom et al. (2000) classified teams into six types: production, service, management, project, action and performing, and advisory teams. However, these two classifications do not clearly define the underlying attributes that differentiate one type of team to the others. These attributes are necessary to explain the varying effects of team factors on team performance across different types of team. In this regards, Devine (2002) provided a more complete classification. His classification was based on seven contextual dimensions: fundamental work cycle,

physical ability requirements, temporal duration, task structure, active resistance, hardware dependence and health risk.

Another way to differentiate teams is by analyzing the interdependencies required for the members to complete their tasks. The way a task is divided into sub-tasks and assigned to team members, and the intensity of member interdependencies required by the task, affect how the team operates (Antoni, 2001). Team interdependencies imply a certain structure of team interaction, and the extent of this interaction affects the performance outcome. Thompson's (1967) and Tesluk et al. (1997) classified four basic work flow arrangements that characterize different types of team interdependencies, namely pooled interdependence, sequential interdependence, reciprocal interdependence, and intensive interdependence. Salas et al. (1992) suggested that team interdependence can fall on a continuum from highly structured, interdependent teams, to teams that interact minimally and perform tasks individually. This is illustrated in Figure 3-1.

Figure 3-1 Team interdependence (modified from Tesluk et al., 1997)

Adapting from Devine's (2002) and Tesluk et al.' (1997) taxonomy, six contextual dimensions to classify teams are derived, namely fundamental work cycle, physical and cognitive ability requirements, temporal duration, task structure, health risk, and interdependence. These six contextual dimensions are discussed in terms of how they may affect the inter-relationship among the team factors, as follows.

1. Fundamental work cycle

Fundamental work cycle refers to the smallest meaningful unit of the team activity (Devine, 2002). Some teams have short work cycles where seconds and minutes are critical for goal accomplishment, while other teams can range from days to years. SA, which has been found to be critical in tasks with short work cycle, may not be that critical in tasks with long work cycle. Teams with short work cycle work under high time pressure and stress, and they have little time available for team interaction. The time available would influence the way the teams should communicate in order to achieve effective performance. For instance, when time is limited, communication must be executed efficiently to convey the required information within the amount of time available. Unrelated communication can distract team members' attention towards task accomplishment. The effect of unrelated communication may be less severe if the team has a longer work cycle, as there is more time to filter the information being passed. The length of work cycle also determines the amount of time pressure experienced by the individuals, and thus their mental workload. Short work cycle also limits time for decision making, which may affect the strategies taken to make decision and perform actions.

2. Physical and cognitive ability requirements

Physical and cognitive ability requirements refer to the types and degree of individual characteristics needed to accomplish the tasks. According to Devine (2002), some tasks require high physical skills (e.g., sport teams), while others require low physical abilities but rely primarily on cognitive abilities associated with processing and yielding information. However, both skills may be required by certain type of task, such as a team of fighter pilots. They need to be skillful to fly the aircraft (physical) and also to strategize in tactical enemy engagement (cognitive). Personnel selection based on physical and cognitive ability depends highly on the requirements of the tasks. Thus, the relationship between cognitive ability and team SA may be high in problem solving task but low in assembly tasks (Devine & Philips, 2001).

3. Temporal duration

Temporal duration refers to the length of time for which the team exists (Devine, 2002). This can range from indefinite period of time to simply per mission base. This characteristic is important as ongoing teams may have to handle various maintenance

issues that short-term teams may only be able to deal with superficially. Harrison et al. (2003) studied the effect of temporal duration on team performance and found that after several sessions, teams with initially unfamiliar members reached the same performance level of teams with initially familiar members and outperformed one-shot teams (where team membership changes after every session). This is because time allows team members to develop a sense of belongingness as a social unit (i.e., cohesion), establish communication and coordination system, and also trust in their teammates. In addition, teams who stay together for a longer period are found to experience more conflicts than those with changing membership (Arrow & McGrath, 1993). This may be because the members are more comfortable with each other and more open to critique. This can be good if the conflicts lead to more open discussions toward task performance.

4. Task structure

Task structure refers to the degree to which members' actions relate to outcomes in an understandable and predictable fashion (Devine, 2002). It relates to the difficulty of task and the multiplicity of the solutions possible for the task at hand. Ill structured tasks are less predictable, and continuous assessment and adjustment are required to accomplish the task goal. On the other hand, highly structured tasks are simpler and can be tackled by prior planning and standard operating procedures. The performance indicators for ill structured tasks would be different compared to the simple ones. Cognitive abilities such as reasoning and pattern matching would be significant for solving ill structured problems. Devine & Philips (2001) suggested that the relationship between cognitive abilities and team performance would be stronger for complex tasks compared to simple tasks. The existence of active resistance, i.e., the opposition directly trying to prevent the team from accomplishing its goals, can make the task to become more ill-structured. This is because there is an increase in uncertainty, where the final outcome of a team does not only depend on its capability and team process, but also depends on the capability and process of the opponent team. In this case, assessing the state of the opponents becomes important too.

5. Health risk

Health risk refers to the likelihood and severity of human injury due to errors in team performance (Devine, 2002). When health risk involved in a task is high, such as involving death, team members may put aside their personal problems and put in their

effort to solve the problems and act accordingly to save their/other people's life. In addition, team members may also feel more motivated and at the same time pressured to perform their task well to avoid higher risk. The difference in health risk may therefore have impact on team member behavior.

6. Interdependence

Interdependence refers to the degree of team interaction required to achieve the team goals and perform the tasks successfully. If the task requires low interdependencies among members, team interaction may not be so critical for team performance. On the other hand, when the tasks of team members are highly interdependent on each other, the quality of team coordination plays a major role in determining the team outcome. Performance breakdown of one member can significantly create problems for the other members and the overall team tasks. As a result of the high demand of coordination and communication, team workload may be higher too (MacMillan et al., 2004a).

3.1.2 Models of Teamwork and Team Performance

A model of team performance is needed to better explain how teams work. There are many models of teamwork and team performance that provide a general view about team effectiveness found in the literature. Due to space limitation, not all of them will be presented here; only those commonly cited, had high impact on the literature when being introduced, and represent different domains of research (from cognitive engineering to social psychology) are explicitly discussed. Nevertheless, several similarities can be drawn across the models reviewed from the literature. First, the variables related to team are categorized into input, process, and output (e.g., Cohen & Bailey, 1997; Gladstein, 1984; McGrath, 1964; Salas et al., 1992). Although seemed to be over-simplistic, this categorization is useful to determine whether an intervention to enhance team performance should be directed before or during the team work period. Input includes all variables relevant to the team and task that can be defined and assessed *prior to work commencement*, such as individual, team, and task characteristics. A combination of input variables, mediated by team processes, defines the team output. Process in this regard is defined as a set of inter-related activities of team members, which is characterized by a set of specific inputs, to bring about a result. Communication, coordination, monitoring, feedback and backup are clustered under team process. A teamwork model by Dickinson

& McIntyre (1997) focuses on explaining the inter-relationship among these process variables. Output includes all team outcomes that can be seen, counted and felt at the end of team performance, such as quality and quantity of the performance and members' satisfaction.

The input-process-output flow may not always be linear or serial as proposed in some models (e.g., McGrath, 1964; Salas et al., 1992). An exception can be seen in pooled/additive interdependent type of team, where there is minimal interdependence, communication and coordination among team members, and that each individual contributes to overall task completion in additive manner (Thompson, 1967). In this type of teams, input variables may affect the performance outcome directly without mediation by the team interaction. For example, a team of salespersons can work with limited interaction among the members, and the team performance outcome is evaluated based on an additive function of individual sales. Hackman (1987) proposed two other alternatives input-process-output flows: (1) team process and performance are both influenced directly by the input conditions. Team interaction is then correlated with but may not determine performance on its own; (2) input conditions affect both team process and performance. In addition, the last two variables also affect each other reciprocally.

Another similarity is that most of the models only consider *teamwork* processes, but neglecting the *taskwork* processes. It should be noted that the effort involved in a team include both *taskwork* and *teamwork*. Taskwork covers everything that needs to be done to accomplish the task, while teamwork covers the interaction among the members. Therefore, although the team is performing a task that does not require team interaction (or very low interdependence among the members), the members still need to work on task-related processes to produce the team outcome. Team output is unlikely to materialise without the existence of either or both taskwork and teamwork.

In addition, most of the models do not illustrate the dynamic changes or interactions that take place during the work span of the team. Suchman (1987) noted that "the environment of our actions is made up of a succession of situations that we walk in to and to which we respond". Things that occur in the current time frame are the effects of previous actions that are based on previous perceived causes. These effects will further become the causes that determine what actions should be taken in the next time frame. This is a recurring

event, with a varied pace depending on the task nature/ fundamental work cycle. Team members may perceive the immediate impact of their actions through a dynamic and continuous process of situation assessment, such as a slower production rate or a low satisfaction level while they are working on the task. From the situation assessment, team members can adjust their behaviors and attitudes in accordance to the situations that they are faced with. Models proposed by Cohen & Bailey (1997) and Dickinson & McIntyre (1997) seem to address this issue, while a model by Salas et al. (1992) only includes a feedback loop from the output to input variables.

Another problem identified with most models is the generalization in the relations among teamwork variables without considering the task nature performed by the teams. As discussed in the previous section, the correlation among team factors and performance is contextual and highly dependent on the nature of tasks performed. A model by Dieterly (1988) illustrates task function design as a central and critical component. It emphasizes the importance of job (task) analysis to ensure effective team performance. Similarly, Gladstein (1984) proposed that task characteristics moderates the relationship between team process and effectiveness.

Finally, none of the models reviewed here explicitly considers technical or equipment design as an influencing variable. In most cases, the work of a team is supported by technical systems, such as physical tools, computer system, collaborative software, workplace, etc. A team member does not only interact with other members but also with the supporting tools. Thus, the design of the technical support system will also influence the outcome of the teamwork. A summary of contribution and limitation of the team models reviewed is shown in Table 3-1 and the models are shown in Figures 3-2 to 3-9.

Table 3-1 Review of team models

Model	Contribution	Limitation
Dickinson & McIntyre (1997)	<ul style="list-style-type: none"> • Incorporates teamwork activities needed to ensure team effectiveness. 	<ul style="list-style-type: none"> • Does not include the antecedents and final outcomes of teamwork.
McGrath (1964)	<ul style="list-style-type: none"> • Categorize team factors into input, process, and output, which is useful to determine whether an intervention to enhance team performance should be directed before or during the team work period. 	<ul style="list-style-type: none"> • The input-process-output flow may not always be linear or serial. • Only teamwork is considered in the process factors; but indeed, taskwork process influences performance too. • Does not consider the influence of technical system that supports the work of a team.
Nieva, Fleishman & Reick (1978)	<ul style="list-style-type: none"> • Includes external conditions such as organizational structure, policy, supervisory control, reward system and socio-cultural context, as factors influencing team performance. 	<ul style="list-style-type: none"> • Does not describe the team performance functions required in the process of achieving the team goals. • Does not consider the influence of technical system that supports the work of a team.
Cohen & Bailey (1997)	<ul style="list-style-type: none"> • Suggests that different categories of predictor variables and effectiveness outcomes exist for different types of teams. • Suggests that input variables (task design, team composition, and organizational context) can directly influence team performance. 	<ul style="list-style-type: none"> • Does not consider the influence of technical system that supports the work of a team. • Does not consider the influence of tasks nature.

Dieterly (1988)	<ul style="list-style-type: none"> • Emphasizes the importance of job (task) analysis to ensure effective team performance. 	<ul style="list-style-type: none"> • Only include individual capabilities and personality as input factors.
Gladstein (1984)	<ul style="list-style-type: none"> • The inputs are suggested to affect team effectiveness both directly and indirectly. • Team task moderates the relationship between team process and effectiveness. • Tested the model with 100 sales teams in the communication industry 	<ul style="list-style-type: none"> • Does not consider the task as an influencing factor of team process. • Does not include a feedback loop from performance to team processes. • Does not consider the influence of technical system that supports the work of a team.
Hackman (1987)	<ul style="list-style-type: none"> • Can be used to provide a diagnostic assessment of a work team, its standing, strength and improvements needed. 	<ul style="list-style-type: none"> • Does not specifically describe the interaction processes among the members (communication, coordination, etc.) • Does not consider the influence of technical system that supports the work of a team.
Salas et al. (1992)	<ul style="list-style-type: none"> • Include a feedback loop, which implies that team outputs can affect input conditions 	<ul style="list-style-type: none"> • Does not consider the influence of technical system support as a factor that can influence team performance.

Figure 3-2 Teamwork Model (Dickinson & McIntyre, 1997)

Figure 3-3 Traditional Input-Process-Output Model (McGrath, 1964)

Figure 3-4 Model of Team Performance (Nieva et al., 1978)

Figure 3-5 Heuristic Model of Team Effectiveness (Cohen & Bailey, 1997)

Figure 3-6 Team Performance Model (Dieterly, 1988)

Figure 3-7 Task Team Effectiveness Model (Gladstein, 1984)

Figure 3-8 Normative Model of Team Effectiveness (Hackman, 1987)

Figure 3-9 Model of Team Performance and Training (Salas et al., 1992)

3.2 Situation Awareness in Team

3.2.1 Shared SA

For a team to operate effectively, a certain degree of shared or common knowledge among the members should exist (Hinz et al., 1997). Wellens (1993) identified team SA as “the sharing of a common perspective between two or more individuals regarding current environmental events, their meaning and projected future status”. Shared knowledge provides a common reference for team interaction. This shared knowledge is often referred as team mental models, shared mental models, shared transactive memory or shared cognition. Despite of the differences in terminology used, they refer to similar concepts.

Cannon-Bowers, Salas & Converse (1993) defined shared mental model as a “knowledge structure held by members of a team that enable them to form accurate explanations and expectations for the task, and to coordinate their actions and behaviors to the demands of the task and other team members”. Artman (2000) stated that shared mental model is

crucial for the team to collectively assess the situation and share information. Shared mental model provides team members with a common understanding of who is responsible for what task and what information is required, so as to anticipate one another's needs and work synchronously (Stout, Cannon-Bowers, Salas & Milanovich, 1999). Dekker (2000) stated that crew SA is "the extent of convergence between multiple crew members' continuously evolving assessments of the state and future direction of a process".

With the importance of sharing, some approaches to measure team SA is based on the similarity across team members' SA. One example is Questionnaires for Distributed Assessment of Team Mutual Awareness (MacMillan et al., 2004b). However, it should be noted that part of the reasons for using teams is due the increase in system complexity. If every team member has to attend and process the same piece of information, the workload and demand imposed would still be high, especially if the information is not relevant to his assigned task. Sperling (2005) demonstrated that access to additional and irrelevant information can increase workload, add confusion and degrade performance.

3.2.2 SA as Distributed Cognition

Another concept to understanding team SA is using "distributed cognition" or "distributed SA" perspective. A team-oriented cognitive system is comprised of a team of people and the artifacts that they use (Artman & Garbis, 1998). The aspects of the overall SA of a system (perception, comprehension and projection) are distributed between different members and also the artifacts (Lundberg, 1999). In an environment where the process as well as the information is truly distributed, no single team member or artifact can be said to constitute an information hub in its own. Rather, all team members and artifacts should be considered as integral parts of the cognitive system (Artman & Garbis, 1998). Therefore, Artman & Garbis (1998) referred to team SA as "the active construction of a model of a situation partly shared and partly distributed between two or more agents, from which one can anticipate important future states in the near future". As different members can have different purposes, roles and responsibilities, each member may hold very different SA from (although compatible to) the other members (Stanton et al., 2005a). According to Endsley (1995c), team SA refers to a "degree to which every crew member possess the SA required for his position". Wellens (1993) suggested that

team SA can be optimized by having each member monitors a different segments of the environment with enough overlap among members to facilitate coordination.

When decision and action require integration of cognition of different members, coordinated activity between these members becomes necessary. Therefore, the way cognition is distributed and coordinated becomes particularly important for effective performance. According to Lundberg (1999), for SA to be correctly distributed, it has to be present for the member executing the relevant process. Optimal distribution of information (i.e., design of information system) and its assignment to team members is required to develop a good team SA. Current approach to allocate task and resources to team members includes task analysis (e.g., hierarchical task analysis, cognitive task analysis, etc.), work domain analysis, and communication and social network analysis (see Gibson et al., 2005; Sperling, 2005; Walker et al., 2005).

Sperling (2005) proposed an approach to distribute information in a system by presenting only relevant information to members according to their roles. Good team SA can be achieved when each member has the knowledge and information to conduct his tasks, knows which information is available to other members should he needs to seek for it, and knows which and when information is needed from him (Sperling, 2005). With this regard, each member must understand his roles and responsibilities well. Ambiguity in roles (i.e., lack of clear information associated with a particular role, including the breadth of one's responsibilities, the behavior associated with one's role, the way to evaluate one's responsibilities and the consequences of a failure to fulfill one's role) can bring negative impact to the development of team SA and ultimately team performance (cf. Beauchamp et al., 2002; Jackson & Schuler, 1985; Tubre & Collins, 2000).

3.2.3 Models of Team SA

To date, there are only a few frameworks or models of team SA offered in the literature. The existing models are found to be inadequate to provide a good understanding of team SA, and do not offer much information on its measurement implications. Salas et al. (1995) proposed a framework for conceptualizing team SA as shown in Figure 3-10. They noted that team SA involves “two critical but poorly understood abstractions: individual SA and team processes”. Therefore, the model includes the two (individual SA and team

processes) as the contributing elements of team SA, such as information processing functions, pre-existing knowledge, team characteristics and processes, which interact and affect one another as well. The resulting team SA can also modify these contributing elements, both directly and indirectly.

Cooke et al. (2001) also proposed a model of team SA as shown in Figure 3-11. This model is similar to Salas et al.' (1995) in several ways. Both models highlight the role of mental model and team process on the development of team SA. However, Cooke et al. (2001) placed further emphasis on shared understanding and shared mental model among team members, which can also be seen in a model by Stout et al. (1996) (see Figure 3-12). However, the extent to which team members' SA should be shared is not clear. As discussed previously, a complete sharing may not be necessary. In addition, what influences the need of this sharing is not apparent. Perhaps understanding the interdependence and team characteristics, another determinants of team SA in Salas et al.' (1995) model, would be able help in defining the need (and extent) of SA sharing.

Figure 3-10 Conceptualization of team SA by Salas et al. (1995)

Figure 3-11 Team SA model by Cooke et al. (2001)

Figure 3-12 Dynamic team SA model by Stout et al. (1996)

Another similarity between the two models is the dynamic and inter-relationships between the team SA components, which is also in line with Bolman's (1979) concept of team SA. Bolman (1979) referred to team SA as the crew's *theory of the situation*, which is used as a common frame of reference for the team task, and which is modified whenever inconsistencies arise. Along this line, a dynamic model of team SA proposed by Stout et al. (1996) argued that team SA is a dynamic, rapidly evolving state that is developed through situation assessment process by team members. The model implies that team SA can change instantaneously, as influenced by the situational, environmental, and temporal factors. Unfortunately, little is known about how one can deduce that a certain state of team SA can be considered better than the other states (e.g., team SA in Time 3 is greater than Time 1 and 2).

MacMillan et al. (2004b) proposed a concept of team mutual awareness. They suggested that the extent to which team members are informed of the other members' behavior can be used to assess the presence of shared awareness in a team. The proposed model shown in Figure 3-13 includes three inter-related aspects that provide a structure to assess team mutual awareness, namely taskwork awareness, workload awareness, and teamwork awareness. Taskwork awareness involves knowing the task that each of the other members is performing at a certain point in time. Workload awareness refers to knowing the loading of taskwork imposed on each of the other members. Team members should be aware of the workload of their teammates so that he can provide backup or assistance when the teammate is overloaded. Teamwork awareness refers to the perception teamwork behaviors, such as coordination, communication, and backup. Measurement of team mutual awareness based on this model has been applied in command and control teams and the result shows to be able to differentiate different types of team structure and was found to correlate with anticipation ratio in communication (MacMillan et al., 2004a). Among the team SA models available in the literature, this model is found to be the most practical as it provides a mean towards the measurement of team SA. However, as the basis of measurement is based on the mutual awareness or similarity in team members' responses, it may not be applicable to all types of teams. The need to have mutual awareness may not be as crucial for teams with less inter-dependent roles and with no/little overlap in their responsibilities. The factors that influence the mutual awareness requirements are however not addressed in this model.

Figure 3-13 Team mutual awareness model by MacMillan et al. (2004b)

In summary, unlike the team performance models reviewed previously, the various team SA models focus more on conceptualizing the processes of development of team SA, and do not include the input factors that can potentially influence the team SA. The development of a framework that specifically formulate an integration of factors and cognitive processes and products within teams can provide a foundation to derive empirically testable principles and is an important step to advance the knowledge in team SA (Fiore & Salas, 2004). Having a comprehensive list of factors that influence team SA (and therefore team effectiveness) would be useful as a guide for empirical studies in team SA research, to ensure that the variables other than those of interests, which may confound the result of the experiment, are properly controlled and addressed. In addition, it can be used as a guide for evaluation of a team-oriented system, by providing a holistic overview of the team phenomenon.

3.3 Factors Influencing Individual SA and Team Performance

From the review of literature presented in this and previous chapter, factors that are related to individual SA and team performance can be derived. These variables are organized into input (design factors), process, and output, as shown in Figure 3-14. Input/design factors refer to those that can be identified and manipulated during early system specification. Process factors are those involved in the development process of team SA, after the team commences their work. Performance output is the final outcome at the end of the work span.

Figure 3-14 Factors Related to Team Situation Awareness

3.3.1 Input/design Factors

3.3.1.1 Individual Characteristics

Some characteristics of individuals, such as cognitive ability, physical/psychomotor ability, personality, age, and experience, have been identified to influence individual SA, team processes, and ultimately team SA and performance outcomes. Understanding these specific attributes would be useful a basis in personnel selection and training.

Cognitive ability is the capacity to understand complex ideas, learn from experience, reason and problem solve (Devine & Philips, 2001). It has a strong correlation with individual and team performance in various tasks (Barrick et al., 1998; Devine & Philips, 2001). It has been identified as a predictor of individual SA (Carretta et al., 1996; Endsley & Bolstad, 1994). Specifically in dynamic task performance, Endsley (2000c) asserted that differences in ability to achieve SA can be due to individual differences in term of their mechanisms of perception, attention, working memory, long-term memory, and other cognitive functions. More extensive reviews on the role of cognitive abilities and processes for SA are in Sections 2.2 and 2.3.

Physical/psychomotor ability. According to Endsley & Bolstad (1994), individuals who possess very good psychomotor ability are able to devote much more of their attention for situation assessment instead of for manual control. Carretta & Ree (1994) found that psychomotor ability provided an incremental validity to cognitive measures in predicting pilot training performance (pass-fail flying training and class rank at the end of flying training). Similarly, a meta-analysis by Martinussen (1996) indicated that psychomotor ability had moderate correlation with pilot performance measured by pass-fail in pilot training, ratings of pilot performance during training, and grades from pilot training. Increase in experience and exposure to the task, however, may reduce individual differences in general and specific psychomotor ability (Carretta et al., 1996).

Personality covers character, behavioral, temperamental, emotional and mental traits of an individual, which is relatively stable over time and across situation (Chidester et al., 1991). The Big Five personality factors (Goldberg, 1990) have been widely used as personality measures. It includes five factors, namely extraversion, emotional stability,

agreeableness, conscientiousness, and openness to experience (Neuman & Wright, 1999). The Big Five personality was reported to have low power in predicting individual job performance in time critical, high risk, and with ill structured problems, such as in aviation, command and control tasks (e.g. Carretta et al., 1996; Martinussen, 1996). This may be because the personality tests are generally designed to diagnose clinical populations rather than for high risk jobs (Martinussen, 1996). Hormann & Maschke (1996) used Temperament Structure Scales (TSS), a special questionnaire related to job demands of aviators, to examine the use of personality test on job success of pilots. They found that TSS can predict the pilot job performance, and that TSS is a valid instrument for pilot selection.

The impact of personality may be more pronounced in team level. Cooperation in a team can be enforced by personality traits that are associated with positive social interaction (Forsyth, 1999). Extraverts, for example, are enthusiastic, sociable, energetic, and enjoys responsibilities of leading others. They enjoy working with others and therefore, would try to get the team to work well together. Emotional stability can bring a more relaxed atmosphere and positive affect into team interaction (Barrick et al., 1998). A team member who is emotionally unstable (e.g., quick to anger, pessimistic, neurotic) can bring negative feelings into the team that makes it difficult for the team to work together. Agreeable team members are tolerant, trusting, friendly, and always try to seek harmony. They can maintain good interpersonal relationship with others and are usually good team players. Conscientious members are responsible, motivated and goal oriented, and they would act in a way to achieve good team performance. Team members with high openness to experience are more ready to accept changes, which can facilitate better sharing of ideas and opinions among them.

Age. Human ability may degrade as people aged. Kerr et al. (1996) reported that age-related decrement in discrete pursuit tracking tasks was prevalent in the 70-79 and 80-89 years age group, while the performance of younger groups (20-60 years) was quite stable. Age effect can also manifest itself in terms of decline in cognitive functions, such as perceptual processing, memory, problem solving and decision making (Tsang, 1992). The age effect is however less pronounced for those who have experience in the related tasks. For instance, Tsang & Voss (1996) examined the effect of age and experience on time-sharing performance of pilots and non-pilots. The results showed that older participants

were in general less efficient in time-sharing than younger ones, and had poorer attention allocation control. The results also demonstrated that time-sharing performance of pilots was less sensitive to age than that of non-pilots. Morrow et al. (2003b) investigated the effect of age, cognitive ability and experience on pilot communication, particularly in comprehending air traffic controller (ATC) messages. The result also shows that younger participants were more accurate in their read-back and answers to probed task. Although Morrow et al. (2003b) found that experience did not moderate age-related declines on the aviation tasks, they suggested that more flying experience among older pilots helped to buffer age-related declines in cognitive resources.

Task-related experience can increase domain-related knowledge by providing opportunities for knowledge acquisition (Palumbo et al., 2005). Experts differ from novices in their factual knowledge, efficient retrieval of stored knowledge, ability to monitor motor and perceptual processes, ability to efficiently allocate cognitive resources, ability to perceive meaningful patterns and associate actions to those pattern (Randel & Pugh, 1996). Several studies have identified that job experience is a stronger predictor of performance compared to cognitive ability, psychomotor ability and personality (Carretta et al., 1996; Palumbo et al., 2005). Morrow et al. (2003a) reported that expert and novice pilots (measured by flying hours) differed significantly in scenario-specific knowledge, but not in general aviation knowledge. This domain-related knowledge provides foundation for the experts to have better comprehension of flight situations and make decisions based on this comprehension (Morrow et al., 2003a).

Randel & Pugh (1996) examined the differences between experts and novices of electronic warfare technicians from U.S. Navy ships. This study revealed that the experts put greater emphasis on situation assessment while the novices emphasized on the course of action. As they have larger collection of mental models to draw on, experts can quickly decide on their action once they understood the situation (Randel & Pugh, 1996). Experts also developed better underlying model of the situation. This is facilitated by the ability of experts to chunk meaningfully related information in a given situation. The superior ability of experts in chunking and retrieval from long-term memory store allows them to functionally increase their working memory capacity (Doane et al., 2004). Sohn & Doane (2004) reported that experts and novices did not differ in their working memory span, but experts were significantly better in long-term memory skills. They found that spatial

measures of working memory span was predictive to SA for novices, while long-term working memory skill measures was predictive to SA of experts.

3.3.1.2 Team & Work Design

The design of teams and their task can influence the way they work and interact, which ultimately affect their effectiveness. For instance, Milliken & Martins (1996) and Pelled (1996) suggested that **diversity** in demographic background (e.g., age, gender, race, team tenure, organization tenure, education and functional background) of the team, can affect task and social interaction within the team. Team members with different backgrounds have dissimilar schemas, belief structures and assumptions due to previous training and experiences. As a result, they may have different expectations and interpretations of the same situation, spend more energy to resolve conflict of perspective among the members, and have weaker social cohesion (Pelled et al., 1999; Webber & Donahue, 2001). However, Milliken and Martins (1996) reported that a greater variety of perspectives can have positive cognitive outcomes, such as reducing groupthink and enhancing decision making.

Team-related experience. In a team, good performance does not only rely on knowledge that is related to task performance, but also on knowledge pertaining to the team. Mathieu et al. (2000) noted that having good mental models about the team members are essential for effective team process and performance. Similar to the task-related knowledge that develops through experience with the task, team-related knowledge can develop through experience with the team. A longitudinal study by Harrison et al. (2003) suggested that team performance gets better as teams are more matured. Teams with members who are familiar with each other develop greater cohesion, have an established communication system and are able to trust their teammates (Peterson & Thompson, 1997). Furthermore, as team interaction matures over time, shared knowledge among the members is developed, leading to a more predictable team interaction. This allows them to understand each other's style of work. Thus, they are able to be more aware of the information each member is likely to focus on, which is important for SA formation. This can also have an impact in their management of workload (Bowers et al., 1997). Knowing the manner in which team members operate in a team allows them to focus on a specific aspect of the task, which in turn would reduce their information load (Kim, 1997). However, although

familiarity in a team can lead to the mentioned advantages, several studies have found that it can also have negative effects, such as groupthink (e.g., Janis, 1982) which can lead to poorer decision making (e.g., Kim, 1997) and poorer performance (e.g., Peterson & Thompson, 1997).

Shared mental model within the team is another crucial factor of team effectiveness (Klimoski & Mohammed, 1994; Rouse & Morris, 1986). It provides team members with a common understanding of the team goals, and who is responsible for what task and what information is required, so as to anticipate one another's needs and to work in sync (Stout et al., 1999). Inappropriate behaviors such as excessive communication and erroneous behaviors may arise if team members do not have appropriate expectations and explanations of the others (Rouse et al., 1992). Thus it would be useful for performing time critical tasks, where limited time is available for explicit communication (Espinosa et al., 2004). Various ways to reinforce such shared understanding can be done, e.g., selection of individuals composing the team, making goals and assignment of roles and responsibilities clear to all members, and designing a technical system that supports effective and efficient sharing of information among team members.

Team structure is a stable pattern of relationship among the members of a team (Forsyth, 1999). It defines the way a team divides its tasks and responsibilities and controls its resources (e.g., information, properties) to achieve its goals (MacMillan et al., 2004a). The workflow in a team would have impacts on the need for interaction among team members, the way coordination and communication is structured in a team, and therefore the integration process of individual SA to team SA. Several studies that attempted to manipulate team structure to enhance the development of team SA have emerged. For example, MacMillan and associates (e.g., MacMillan et al., 2004a; MacMillan et al., 2000; MacMillan et al., 1999) suggested the design of teams that minimizes the need for coordination and communication, which can increase the workload of team members. Sperling (2005) proposed a team design that provides team members with the only information relevant to their roles. This type of structure can provide better clarity in division of roles and responsibilities among members and limit access to irrelevant information that may add confusion and increase workload. This, in turn, will improve accuracy and efficiency of team SA development (Sperling, 2005). Artman (2000) compared serial and parallel structure of team information processing in

command and control teams, and suggested that the choice of optimum structure depends on the amount of workload imposed by the task and the reliability of the result desired. Serial (sequential) structure was found to be better in high workload situation and when high reliability is demanded by a task, while parallel structure was better if the workload is low and faster decisions are required.

Roles and Responsibilities refer to specifications of individual positions and tasks in a team. For a team to work effectively, the members should have clear perceptions of their responsibilities, the behavior associated with their roles, ways to evaluate their responsibilities and the consequences of a failure to fulfill their roles (Eys & Carron, 2001). Individuals who are unsure on their roles cannot work and use resources in a timely and effective manner. Ambiguity in roles has been identified to negatively correlate to performance (e.g., Beauchamp et al., 2002; Jackson & Schuler, 1985; Tubre & Collins, 2000).

Goal states what a team wishes to achieve. Team performance can significantly improve when goals are accepted by all members and are similar to the individual members' goals (Mulvey & Klein, 1998). Goals can direct attention to search for information in the environment. In addition, the information is treated and interpreted with respect to these goals. A degree to which team members share the team goals influence the degree to which they treat the information in the same or different way, and in turn will influence other phases of team information processing (Hinz et al., 1997). The same information may be interpreted differently by different members if they possess different goals. This affects the integration of team SA.

Norm are implicit agreements or standards that can describe how people do things, and what behaviors should and should not be assumed by team members (Bradford, 1984; Forsyth, 1999). An individual who joins a team must first learn to adjust himself to the norms adopted by the team. According to social identity and self-categorization theory, people's attitudes and behaviors change as they psychologically categorize themselves as team members (Wellen et al., 1998). This transforms their attitudes, feelings, and behaviors to conform to the norms of the team. Salience of team membership affects the attitudinal congruence of the norms. The more an individual perceives himself as a team member, the higher is his tendency to comply with team norms (Wellen et al., 1998).

Most norms emerge gradually as members align their behaviors until they match certain standards. Teams adjust their norms according to changes in their membership, task, situation and surrounding environment. Norms provide direction, motivation, and organize social interactions (Forsyth, 1999). They make other members' responses meaningful and predictable, which facilitate anticipation of teammate's information needs and actions.

Leadership refers to “a reciprocal, transactional and sometimes transformational process, in which cooperating individuals are permitted to influence and motivate others to promote the attainment of team and individual goals” (Forsyth, 1999). Leadership behavior can be clustered into two: relationship and task leadership. Relationship leadership involves actions that develop and maintain members' inter-personal relationship, such as trust, openness, socio-emotional, etc., while task leadership involves actions that promote task completion such as monitoring, coordination, task assignment, etc. Their existence and proportion in a team can vary according to a team's needs. For example, Watson et al. (2002) found that early in the team's development, relationship leadership is required in ethnically diverse teams to solve inter-personal differences, while task leadership kicks in immediately in ethnically homogeneous teams. A good leader can coordinate team members' resources to attend to the important aspects of the team situation, and integrate their SA to build the big picture, and eventually coordinate what actions to be taken by each member. Leadership behaviors such as letting people do their job but making sure they do it, developing the team, setting the right tone, setting an example, were identified to be important aspects that support team SA (Prince & Stout, 1995).

3.3.1.3 Technical System Design

The technical systems can be designed to afford effective performance. Automation, for instance, can assist the operators to cope with their cognitive load if it is designed well. But poorly designed automation can degrade situation awareness due to changes of the work nature from active worker to passive observer. For example, Wickens et al. (1997) indicated that automation in air traffic control system may introduce potential dangers if it degrades air traffic controller and cockpit communication (Wickens, Mavor & McGee, 1997). Technical system can also be designed to support the development of team SA

through good interface and display. Bolstad & Endsley (1999) found that a shared display has an indirect effect on the development of shared SA. The results showed that a shared display slowed performance due to a higher demand in processing the information, but significant improvements in team performance were found after their removal due to the development of shared understanding.

3.3.1.4 Organizational Factors

Organizational variables such as organizational structure, policy, supervisory control, and reward system also play an important role on the effectiveness of team performance (Guthrie & Hollensbe, 2004; Hackman, 1987). For example, sterile cockpit rule which discourage pilots to engage in non-essential communications and activities during critical phases of the flight, was originally imposed to ensure that the pilots stay focus and away from distraction that can threaten flight safety. However, misunderstanding of this rule, confusion and disagreement on what is permissible to be brought up to the cockpit when it is sterile was found to be one factor that discourage cabin crews to pass safety-critical information to the pilots (Chute & Wiener, 1996). Cultural issues such as the superiority of pilots over first officers can restrain the first officer from questioning the pilot's decision, even when the pilot is making a wrong decision.

3.3.2 Process Factors

A team can be viewed as an information processing unit. This view combines individual cognitive processes with social interaction processes such as communication and coordination (Brauner & Scholl, 2000). Team information processing involves activities that occur within and among the minds of team members (Ickes & Gonzales, 1994). At the team level, information is *shared* (i.e., similar existing information in the head) and is *being shared* (i.e., the teamwork involves sharing of information during work) among the members (Hinz et al., 1997). According to Tindale & Kameda (2000), these concepts of “shared” and “being shared” are the ones that make team information processing possible, and distinguish it from individual level processing. In addition, team information processing involves interaction among individuals for sharing and processing their information. Team behaviors or process factors that are relevant to team SA are as follows.

Communication enables team members to share their situational models in order to build shared understanding of the situation (Cooke et al., 2001). Through this exchange of information, team members update their individual SA, which in return affects the content and the way they communicate. Although communication is good for building team SA, more communication does not always mean better communication. Communication has cognitive cost; it consumes cognitive resources and energy (Dietrich, 2004). Particularly in time critical tasks, it should be executed effectively and efficiently, sharing all the required information accurately with the least amount of resources consumed. MacMillan et al. (2004a) reported that efficiency of communication measured in term of anticipation ratio (i.e., ratio of the number of communications transferring information to the number of communications requesting information) correlates to team outcome measures.

Communication can be verbal (spoken and written) and non-verbal (gesture, picture, sign, etc.). They are rarely mutually exclusive, and their combination is commonly used during operation (Sperling, 2005). The environment in which a team operates plays an important role for communication channels that are available to the team. For instance, a team with co-located members can afford communication through gestures, while distributed teams cannot. In addition, task and work characteristics also determine the most effective channel for communication. Teams that have to share spatial information may find pictorial display to be more effective in the development of team SA than sharing it verbally. Teams with members that are visually overloaded may find verbal communication better as they use different information processing channel.

Coordination is carried out by a team to manage the interdependencies among its members (Espinosa et al., 2004). Dickinson & MyIntyre (1997) noted that “a critical feature of teams is that individuals must coordinate their decisions and activities by sharing information and resources to attain shared goals”. Coordination can be done explicitly through communication and implicitly through team cognition and development of shared knowledge (Espinosa et al., 2004). Implicit coordination enables team members to explain and anticipate the actions of their teammates, and thus to coordinate without spending extra resources for communication. This would be useful when time is critical as it can save time and reduce the workload resulted by communication.

Planning involves process of formulating or strategizing actions to achieve a team's goal. Planning prior to a mission leads to more effective communication through the development of a shared mental model among the members (Stout, 1995). Through planning, team members can understand, predict and anticipate each other's information requirements, and so communicate efficiently (Stout, 1995). Prince & Stout (1995) reported that professional aviators identified planning during pre-flight brief is useful to encourage team SA. This is done by providing clear tasking to all individuals and also to use brief for contingency planning. Orasanu (1995a; Orasanu, 1995b) analyzed the differences between high and low performing teams in terms of their observable behaviors, communications and action. She found that Captains of better performing teams engaged in more planning to prepare for future events or high workload episodes. Orasanu (1995a) also reported that there is an increase in planning utterances during abnormal phase of flight. The difference between high and low performing teams in facing this situation is that high performing teams anticipated the possibility of abnormality and began planning earlier than lower performing teams. As planning at abnormal phase can induce higher workload to team members, starting to plan during lower workload condition would be beneficial.

Perceived Workload. Mental workload accounts for 'aspects of interaction between a person and a task that cause task demands to exceed the person's capacity to deliver' (Gopher & Donchin, 1986). SA maintenance is not without a cost. It takes up cognitive resources. When it was done unwisely, performance can suffer. For example, if a model of future situation which is not immediately relevant (but which will be relevant in a later stage) is maintained in a high workload situation, and the execution of a relevant task therefore has to be abandoned, SA is achieved at the expense of performance instead of providing the basis for good performance (Wellens, 1993). In return, when operators are overloaded by task demands, limited resources are left for the development of SA. Workload can narrow a person's field of attention, cause cognitive tunneling, which also affects the operator's SA. Jentsch, Barnett, Bowers & Salas (1999) found that the Captains of cockpit crews lose SA more often and made more tactical errors when they were also performing the aviating task compared to when the aviating task was assigned to the co-pilot.

However, higher workload does not necessarily result in impairment of SA. According to Endsley (1995), workload may have different effects on SA. In a prolonged time of low workload condition, an operator can be less aroused and gets bored easily, leading to vigilance decrement and low SA level. This situation can be found in tasks that require the operator to detect signals over a long period of time and the signals are intermittent, unpredictable and infrequent. In contrast, a high workload condition may impose higher arousal level to the operator and thus result in high SA, as long as there still enough capacity left in the working memory for SA formation.

When an individual works alone, he is required to deal merely with *taskwork* (i.e., work related to task, tools, machines and systems). When individuals come together as a team, additional *teamwork* activities are required. Team workload can be conceptualized to include teamwork, taskwork and requirements to time-share task performance with team interactions (Bowers et al., 1997). Because of the additional requirements to time-share taskwork and teamwork processes, the overall demands on a team extend beyond the sum of individual workload of team members (Bowers et al., 1997).

3.4 Summary

The current state of knowledge on SA and team SA as reviewed from the literature (as presented in Chapters 2 and 3) can be summarized as follows. Endsley's three levels definition had been widely used across studies that investigate SA. She noted that being able to project to the near future (level 3) to having higher level of SA compared to those who can only perceive and comprehend the present situation. This proposition was supported by several studies that showed the relatively higher importance of future projection (level 3) for performance. However, it seems that the cognitive construct of level 3 SA has not been studied much. For instance, in her model, Endsley (1995c) proposed that future projection requires a good understanding of the present situation, but there is no reported empirical data on the inter-relationship between the three levels of SA to support this proposition. It was expected that better awareness of the present situation would be associated with better prediction of the future situation. In addition to knowing what was and going to happen, SA was also associated with knowing what one knew and did not know (meta-cognition), where the latter had been identified as influencing one's decision making. Little was known on how people were calibrated on what they know

across the three levels of SA, and the results from different studies were somewhat ambiguous. In several studies, people were found to be more overconfident on difficult than easy items, and in another study, people were less overconfident on their prediction (usually perceived as being more difficult) as compared to the present situation. Nevertheless, we can at least expect that there will be differences in confidence bias of present and future status.

From the review of literature, several factors that potentially influence team SA are identified, including individual characteristics (cognitive ability, physical/psychomotor ability, personality, age, experience), team and work design (diversity, familiarity, team structure, leadership), technical system design, organizational factors, and process factors. As it is not possible to cover all of these factors in this research, only a set of these factors shall be investigated in the studies reported in the following chapters. Among these factors, it is reckoned that individual differences in experience and cognitive ability have received substantial support in the literature as factors influencing individual SA. For instance, Endsley's (1995c) model includes several factors that are related to individual SA, such as experience and abilities. The relationship between experience and SA is substantiated by several other researchers. With respect to cognitive abilities, although there are several studies conducted to investigate its impact on SA, there are very few studies that included level 3 SA in their evaluations. Among these few, the focus is limited on working memory and long-term working memory, excluding other abilities such as spatial or reasoning. In the context of team SA, as teams are composed by individual members, these factors would certainly be applicable to team SA. However, the extent to which they are important may not be the same due to the interaction takes place among team members. As for the team factors, the literature suggests the importance of team composition (such as familiarity with teammate, diversity in task experience) as an input factors that can influence team process and eventually performance. Very few of these studies, however, focused on team SA. The same is true for the team process factors. There is little understanding on what kind of team interaction that would have high associations with team SA. It is hypothesized that these factors (cognitive ability, experience, familiarity, diversity, and team processes) would be associated with team SA.

This research aims to contribute to the knowledge gaps mentioned above. Prior to this, it is necessary to define what team SA is and how it should be measured. Chapters 4 and 5 address these fundamental issues. Study 1 in Chapter 4 reports on the qualitative evaluation of teams of experienced helicopter pilots performing navigating and air combat tasks. The analyses are focused on when the teams made critical performance errors, and on identifying the sources of errors, in order to better understand the attributes that team members need to be aware of to be considered as having good team SA. Findings from this study are then integrated with the literature and a conceptual framework of team SA is presented in Chapter 5. The framework covers the main attributes of team SA, as well as approaches to measure them.

Studies 2, 3, and 4 presented in Chapters 6, 7, and 8 report three empirical studies to investigate different factors associated with team SA. Study 2 focuses on task experience, while Study 3 covers experience, cognitive ability, and team familiarity. Finally, Study 4 covers cognitive ability and team composition based on the diversity of team member experience. All the three studies aim to investigate the teamwork behavior that is related to team SA, the inter-relationships between different measures of team SA, as well as to verify the relationship between team SA and performance. In addition, Studies 3 and 4 aim to evaluate meta-cognition across the three levels of SA and its relationship with the performance outcome.

Chapter 4 Study 1: Identifying the Attributes of Team SA

This study was conducted primarily to identify the important aspects of team SA, as a basis to develop a model of team SA and determine an approach towards its measurement. Particularly, the study aimed to answer the following questions: “What do team members have to be aware of to be considered as having good team SA?” Towards this objective, team SA phenomena were explored and analyzed, including how team SA is developed, maintained, lost, and recovered throughout a mission. An observational method called Critical Incident Technique was used to aid in the analysis. Inter-team differences were also investigated to determine the variables related to team SA that can differentiate good and poor performing teams. In order to minimize the interruption to the task and to preserve the natural flow of the dynamic situation, data from participants were collected offline through observation and using subjective measures at the end of the mission.

4.1 Experiment Design

4.1.1 Task

A game called COMANCHE 4 was used to simulate a helicopter combat environment. It offers realistic scenario customization through modification of enemy strength and characteristics, and area trigger and events. These features allow different levels of mission complexity to be designed. The screen capture of the cockpit simulated by COMANCHE 4 is shown in Figure 4-1. The participants were assigned to teams of two, consisting of a pilot and a co-pilot. The teams were tasked to fly according to the planned route and engage the enemies while inflicting the least damage to the helicopter. The pilot’s role was to fly the helicopter, while the co-pilot’s role was to navigate and engage the enemy. They played a total of six missions.

Figure 4-1 Screenshot of helicopter cockpit simulated by Comanche 4

4.1.2 Participants and Subject Matter Expert

Twelve male helicopter pilots with age ranging from 27 to 34 years ($M = 30$; $SD = 2$) participated in the laboratory simulation. Their flight experience ranged from 500 to 2200 500 flying hours ($M = 1200$, $SD = 458$), and none of them had been exposed to the simulator game used in the study. The missions were designed by a Subject Matter Expert (SME), who was a trained helicopter pilot with an experience of 1000 flying hours. In addition, he was a game enthusiast and was extensively exposed to the game. He had basic Human Factors knowledge and was consulted in the data analysis with respect to military practice.

4.1.3 Simulation Set Up

The simulation set up is shown in Figure 4-2. The participants were seated side by side facing the screen, and the simulation game was displayed on a projection screen. The pilot used a joystick to fly the helicopter and the co-pilot used a keyboard and mouse to control the weapon system. Two video cameras were used to record the team process: one camera recorded the projected display and the other recorded the behavior of the participants. Three experimenters stationed behind the participants. There was minimum interaction between the experimenters and the subjects during the test.

Figure 4-2 Simulation set up

4.1.4 Missions

Six missions of different difficulty levels were designed by varying the mission objective, navigation route and number and type of enemy. Missions “Easy” 1 and 2 were straight forward and had the lowest workload among the missions. The routes were easy to navigate and the enemies were sparse. In Missions “Duckhunt” 1 and 2, the terrain and mission route were more difficult, and the enemies were clustered. In missions “CSAR” (Combat Search and Rescue) 1 and 2, the enemies were concentrated in a denser clutter, and the teams were required to cover and keep a close distance to a Search and Rescue (SAR) helicopter. The detailed description of the missions is included in Appendix A.

4.1.5 Procedure

The participants were introduced to the objectives of the experiment and equipment set up. After giving their consent to join the experiment, they were asked to fill in a background information form. The subjects were given hands-on training that included familiarization of the software, hardware controls, terrain appreciation and enemy engagement. The subjects were cross-trained so that they understand the roles and responsibilities of the other member. The teams were free to decide who would be the pilot and co-pilot, and the assignment was then fixed throughout the simulation. The SME

observed and decided if the participants had gained sufficient skills to begin the test. A pre-mission briefing was given to provide the teams with the mission objective, planned route, and expected enemy locations. The co-pilot of each team was equipped with a terrain map that contains the suggested route, general heading and time to travel from one to the next check point, and enemy characteristics and locations. The teams completed six missions in one session, with short breaks in between. SA ratings were collected after each mission. At the end of the simulation, the subjects were debriefed on their overall performance. Semi-structured interviews were then conducted to clarify erroneous behaviors and the actions taken to recover. The duration of the test was approximately 2 hours and 15 minutes.

4.1.6 Assessment Tools

Team Performance

Two measures were used to assess the team performance in this simulation:

1. Navigation. The teams were assessed in terms of the deviation from the planned route, altitude and time as suggested in the mission brief. The SME traced the heading (track), altitude, and time taken from one check point to the next check point. This tracing aided a more systematic and objective identification of critical incidents and also helped to enhance the reliability of the method. The SME then rated the navigation performance using 5-point scale (0 for very good (no deviation) and 5 for very poor performance).

2. Enemy Engagement. The combat performance was assessed from the mission success and survivability. If a team chose to confront the enemy recklessly, they might be able to kill more enemies, but at the same time suffered a higher possibility of being shot. Although the helicopter was programmed to be invulnerable to make sure all teams completed the mission, the survivability can be assessed by the number of shots received. Thus, two numbers were recorded, namely the number of enemy successfully killed and number of shots received.

Critical Incident Technique

Team process was assessed through observation of behavior, communication, and actions of the participants. This was achieved through using a video playback of the recorded missions. Observations were focused on critical incidents, i.e., extreme behaviors that are outstandingly effective or ineffective with respect to attaining the general aims of the activity. This approach was based on Critical Incident Technique – a method to observe human behavior and make inferences from the observed incidents (Flanagan, 1954). Since extreme incidents can be more accurately identified than average behavior, a more efficient data collection is possible using this technique. Patrick et al. (2006) applied Critical Incident Technique to evaluate control room teams and reported that it was practicable and had satisfactory intraclass and inter-rater reliability. In general, the technique includes five following steps, namely: 1) determining the general aim of the activity; 2) developing specifications for collecting the critical incidents; 3) collecting the data; 4) analyzing the data; and 5) interpreting the data and reporting the requirements of the activity (Flanagan, 1954). By analyzing the critical incidents that took place throughout the simulations, the sources of team performance errors and the actions taken to recover the errors can be identified. This information would eventually provide insights regarding the concept of team SA. Since the objectives of the missions were to fly according to the planned path and to take down the enemy, the specifications of critical incidents were based on the team performance in these two activities. Any occasion when the team deviated from the planned path or failed in enemy engagement was identified as a critical incident that needs to be further analyzed.

Team Communication

Communication is central in teamwork processes (Dickinson & McIntyre, 1997). It facilitates information exchange, coordination, feedback, and other team processes. A thorough understanding of team processes, team responses to specific stimuli, and an identification of effective/ ineffective team behaviors is thus possible through analyzing the team communication (Jentsch & Bowers, 2004). In this study, the team communication was transcribed and separated into thought units. A thought unit is defined as a “sequence of few words conveying a single thought” (Weldon et al., 1991, p. 559). Guidelines for unitizing adopted from Jehn & Pradhan (1997) are as follows:

1. The unit of analysis is a “thought unit”; each separate thought should be considered as a different unit.
2. Acknowledgement of a previous statement is a separate unit (e.g., [Okay], [but how should we approach them?])
3. Conjunctions separate a thought. A sentence should be checked to see whether it would convey the same content if the preceding or ending phrase were omitted. If not, the two phrases are coded as two units. If so, it is coded as one unit. “Wait, I think they are coming out” is coded as two units, while “Hey, wait for me!” would be coded as one unit.

The communication intensity was then calculated by the amount of thought units transferred in a mission divided by the amount of time taken to complete the mission. Several studies that utilized frequency counts (e.g., Orasanu, 1990; Orasanu & Fisher, 1991; Sexton & Helmreich, 2000) indicated the positive relationship between communication frequency and team performance. Each thought unit was further coded according the following categories:

1. *Planning* includes commands, statements and questions about how acts should be performed, who should do what, in what order and when acts should be performed, and also commands to do certain actions (e.g., “let’s go to the next check point”; “where do you want to go?”).
2. *Information transfer* includes statements about the situation, the predicted future situation, feeling towards the situation (e.g., “enemy is behind you”, “I’ve killed one enemy”; “I am lost”).
3. *Information request* includes questions and requests on task- and team-related information (e.g., “do you see the enemy?”; “where are you?”; “how many enemies are left?”)
4. *Responses* includes answer to information request
5. *Acknowledgement* includes statements to ensure the receipt of certain information (e.g., “yes”; “ok”; “roger”)
6. *Feedback* includes statements made to feedback on teammate’s behavior, or commands made to correct erroneous behavior
7. *Others* include statements, questions and responses that are unrelated to the mission accomplishment, and that cannot be classified in the previous categories.

Situation Awareness

The participants were asked to rate their overall team SA using a subjective SA measurement tool, China Lake Situational Awareness (CLSA) shown in Figure 4-3. The rating was done at the end of each mission, using 5-point Likert scale (1 for very good and 5 for very poor). Each rating represents a different level of participants' knowledge of the aircraft, tactical, and mission status, and the ability to accommodate situation development.

China Lake SA Rating Scale	
SA SCALE VALUE	CONTENT
VERY GOOD 1	<ul style="list-style-type: none"> • Full knowledge of a/c energy state/tactical environment/mission; • Full ability to anticipate/accommodate trends
GOOD 2	<ul style="list-style-type: none"> • Full knowledge of a/c energy state/tactical environment/mission; • Partial ability to anticipate/accommodate trends; • No task shedding
ADEQUATE 3	<ul style="list-style-type: none"> • Full knowledge of a/c energy state/tactical environment/mission; • Saturated ability to anticipate/accommodate trends; • Some shedding of minor tasks
POOR 4	<ul style="list-style-type: none"> • Fair knowledge of a/c energy state/tactical environment/mission; • Saturated ability to anticipate/accommodate trends; • Shedding of all minor tasks as well as many not essential to flight safety/mission effectiveness
VERY POOR 5	<ul style="list-style-type: none"> • Minimal knowlege of a/c energy state/tactical environment/mission; • Oversaturated ability to anticipate/accommodate trends; • Shedding of all tasks not absolutely essential to flight safety/mission effectiveness

Figure 4-3 China Lake SA Rating Scale

4.2 Results and Discussion

4.2.1 Analyses of Critical Incidents

The SME traced the team performance and noted it down on an observation form such as shown in Figure 4-4. Check Point (CP) 1 to CP 7 written on top of the graph indicates the seven check points that need to be flown over by the teams in this mission. The three graphs in the middle represent the navigation, height, and time taken by the teams. The tracings were represented in terms of deviation from the assigned path or values, to indicate errors in navigation performance. The number of enemy successfully killed and the number of shots received by the helicopter were reported at the bottom part of the form. Enemy deposition in each checkpoint was also noted as a reference to evaluate the

combat performance. The descriptions of military symbols used are included in Appendix A.

An analysis using critical incident technique was conducted to reveal various behaviors that would lead to performance errors. The observation was focused on the occasions when the team deviated from the planned path or failed in enemy engagement. For example, in a critical incident analysis shown in Figure 4-4, two critical incidents can be derived from the performance tracing. First, the team managed to take down one observation helicopter (OH) but failed to take down the two light strike vehicles (LSV) in check point 3. This was due to poor visual scanning and situation assessment of both team members, who missed the presence of the LSV when flying over them. They only realized the presence of enemy after receiving shots by the LSV. They attempted to engage the enemies, but were not successful. They then decided to continue the mission to check point 4. Along the route from check point 3 to check point 4, the pilot flew the helicopter too high, deviating from the assigned altitude. He seemed to have poor awareness of the flight status and was not aware of his performance error. The co-pilot however had good monitoring behavior and reminded him to fly lower. This incident reflected the role of teammate in the recovery of SA. The complete result of the critical incident analyses can be found in Appendix A.

Fault Tree Analysis (FTA) was also conducted to determine the potential causes of the incidents (Figure 4-5 and Figure 4-6). FTA is a graphical model that displays the various logical combinations of failures (human errors, equipment and management system failures) to identify and represent the root causes of incidents systematically. From the critical incident and fault tree analyses, sources of team performance errors can be summarized in Table 4-1.

Figure 4-4 Example of Critical Incident Analysis

Figure 4-5 Fault tree analysis of team navigation

Figure 4-6 Fault tree analysis of enemy engagement

Table 4-1 Sources of team performance errors

Elements	Frequency
Awareness related to own task/responsibility	(40 %)
Poor mental model of the mission and enemy's locality	11
Poor visual scanning, did not detect existence of enemy / SAR	8
Poor monitoring of aircraft status (altitude, speed)	5
Poor monitoring of status of SAR helicopter	5
Misinterpretation of threat status (friendly as enemy)	1
Information sharing	(39%)
No / inaccurate navigation guidance	11
Accurate navigation guidance, but was not easily understood / followed	11
Information given at inappropriate time (too early or too late)	3
Did not attend to information given by teammate	2
Too much information given at the same time	1
Misunderstanding of the information shared	1
Monitoring and feedback	(9%)
Co-pilot did not provide feedback on pilot's aircraft handling (altitude, heading, speed)	5
Did not question improper action	1
Unaware that teammate was incapacitated	1
Strategy and decision making	(8%)
Improper navigation - climbed over high terrain	2
No contingency plan	2
Open contact, did not try to hide and engage	1
Climbed up to confirm existence of threat	1
Action execution	(4%)
Poor weapon handling, random fire	2
Unsteady aircraft control while engaging	1

A total of 75 critical incidents were identified during the analyses (refer to Table 4-1), and the possible source of performance errors can be classified into five main categories, namely lack of awareness of the environment or other source of information necessary to perform the task, problems with information sharing between team members, poor monitoring of teammate's status and failure to provide feedback, improper strategy and poor decision making, and problems in action execution. The last two categories of errors were related to decision making and performance of action, rather than team SA. They

contributed only 12% of the total performance errors. The major proportions of the errors identified were related to the development and maintenance of team SA.

The first category is related to failure to acquire and maintain SA that is related to own responsibility. This can be considered as SA errors that occurred at the individual level. They mostly happened due to inattention that leads to failure to monitor or observe data, misinterpretation of data, and wrong expectation due to incomplete or inaccurate mental model of the mission. Pilots had to scan multiple sources of information regarding the flight status, such as altitude and speed indicators. Direct consequences of failure to do so can be seen in the deviation from the assigned aircraft altitude and speed. Other poor monitoring behavior that leads to loss of SA can be clearly observed when the helicopter passed the assigned enemy sites but none of the team members attempted to contact the enemies or called out the presence of enemy. Another example is when the participants did not see the SAR helicopter that flew pass by and thus failed to maintain a visual proximity with it. Incomplete or inaccurate mental model of the specific mission objectives, such as which enemy sites should be destroyed, their type, strength, and location, was also found to be one common source of SA error. One example is when the pilot of team E thought that check point 6 is the last checkpoint in mission Easy 2 and he slowed down and started to search for enemy. In fact, there were seven checkpoints in that mission and the enemy site was located in the last check point.

The second category of errors involved information sharing between the pilot and co-pilot. Sharing of information is necessary to develop team SA, especially when the information that is required by one member to perform his role is not directly available to him, but needs to be obtained through another member. For example, in navigation task, the co-pilot had access to the navigational information (location of every checkpoint, detailed navigational route to follow, terrain information), while the pilot handled the flying controls. Therefore, the co-pilot had to convey the navigational information to the pilot in order for the pilot to navigate closely according to the planned path from one to the next checkpoint. Breakdown in this sharing of information was found to be the main source of navigational errors occurred during the simulation. It could happen due to any of the following reasons:

1. Co-pilot had low SA on the situation. For example when the co-pilot could not locate the helicopter's position on the map and was confused with the direction they were supposed to go next. This error in co-pilot's SA led to poor information sharing, and eventually poor team SA and performance. As the pilot had no access to the navigational information, there was not much that he could do to find out the information by himself or to cross check on the accuracy of information.
2. Co-pilot had poor understanding of the pilot's information needs. For example, a copilot may not know what information is needed by the pilot, when it was needed, and how it should be best presented for it to be understood clearly. Some of the navigation errors observed were not due to inaccurate navigation, but because it was provided at improper time or in a format that was difficult to understand. For instance, ambiguous statements, such as "Can you see the high ground on the 11 o'clock? Fly to the south of it", requires much mental resources to understand as compared to "hug to the right of this coming high ground". It was also observed that the co-pilots provided the navigational information in different formats. Generally, there were two types of phrases used: general directional headings (exocentric), such as *heading 070, Southerly, North Easterly*; and use of more specific guides with respect to landmark displayed on the screen (egocentric), such as *hug to the left of high ground, turn left at the end of the ridge line*. When the helicopter was flying low¹, there was a higher chance of crashing to the ground. Thus, it was important for the pilot to keep his attention to the outside terrain and minimize the time to look at the flight instruments. When the co-pilot provided the navigation in general heading (exocentric), the pilot would need to check the flight instruments and this took his attention away from the outside terrain. On the other hand, egocentric guidance facilitates the pilot to maintain his attention to the terrain. In addition, although the team could still reach the designated check points using the general heading, using egocentric navigation would allow them to follow the route given closely.

¹ One of the combat maneuvering unique to helicopter is NOE (Nap of the earth), i.e., for the helicopter to keep very close to the ground, following the contours of hills, streams, canyons, and all other land features (hugging the terrain), in order to minimize radar detection by the enemy.

3. Poor communication skills of team members. An example can be seen in Team F, Mission Easy 1. There were two high grounds in front of the helicopter, but the co-pilot was not clear in specifying which high ground he was referring to when providing the navigational guides. The Co-pilot was referring to the right high ground, but the pilot thought that he was referring to the left high ground, and this resulted in confusion. See the following transcription:

00:46 Co-pilot : Keep *this* high ground on the right... [co-pilot was referring to the right high ground; he made a slight pointing, but was not noticed by the pilot]

00:47 Pilot : Keep *this* high ground on the right? [pilot thought that co-pilot was referring to the left high ground, thus made a left turn to keep the left high ground on the right side of the helicopter]

00:48 Co-pilot : No, no... right, right [co-pilot showed a more distinct hand movement, directing the pilot to turn right]

00:49 Pilot : Keep on the right?

00:50 Co-pilot : Keep it on your right

00:51 Pilot : Keep it on the right? [pilot was still unsure, but followed the direction to turn slightly to the right]

Another example is the co-pilot of Team D, Mission Easy 1, who provided navigation information as follow: "070 to check point 1, after that just continue straight 060 to check point 2, and after check point 2 turn left 340". There were too much information given at the same time, which confused the pilot. As a result, the pilot made a left turn (wrong action) right after receiving this information. The erroneous action may be caused by the "recency effect", where the pilot only remembered the last part of the information (which in this case he should use the first part of the information to go to check point 1).

Recovery from performance errors were slower if no feedback was given by teammate on the observable erroneous behavior. Lack of or poor feedback can occur because the team member was unaware of teammate's erroneous behavior (poor monitoring of teammate's status), or he was aware but failed to communicate it due to poor communication skills. An example of this situation can be observed in Team C when performing Mission Easy 1. The pilot was not aware that he was flying the helicopter at a higher altitude than suggested, and the co-pilot (who perhaps was also not aware of the deviation in altitude or who was aware but did not communicate his perception to the pilot) did not provide any

feedback, and thus resulted in a prolonged duration of navigational errors. Another example can be seen in Team E when performing Mission Easy 2. The co-pilot was not aware of the helicopter position, and thus giving confusing navigation on where to go next, “Go slightly to the South... eh... North... Westerly.” The pilot, however, did not attempt to assist the co-pilot to regain awareness, as he also seemed to be unaware that the co-pilot was incapacitated.

On the other hand, recovery of errors was more effective if team members monitored each other’s actions to identify occurrence of errors, and communicated this perception (feedback). This would help to trigger the teammate to reassess the situation and his actions. For instance, when the pilot of team E made a wrong left turn in Mission Easy 2, the co-pilot noticed the error and corrected pilot’s behavior by saying “after check point 2!”, thus allowed the pilot to be aware of his mistake and recover from it. Another example is shown in team D, where the co-pilot forgot the mission objective to take down enemies at checkpoint 3 and directed the pilot straight to check point 4. See the following transcript:

01:41 Co-pilot : Let’s continue to CP4, left 11 o’clock
01:45 Co-pilot : Keep to the low ground
01:49 Pilot : I thought *at CP3 we [are] supposed to wait for enemy*
01:53 Co-pilot : **Correct!** Make a turn!
01:54 Pilot : Let’s go back

Providing feedback to teammate’s erroneous behaviors, thoughts, decisions, or actions, are advantageous in several ways. First, it is an indication that a member is aware of his teammate’s status, which reflects good monitoring behavior. Second, it can bring teammate’s attention towards evaluating own thoughts, decisions, and actions (meta-cognition), and thus trigger him to recover from the errors. This feedback is particularly important when actual backup in action is not possible due to different access in resources, such as in this simulation. The co-pilot did not have access to the helicopter control, thus can only provide feedback to trigger the pilot to evaluate his controls and change the direction of the helicopter heading.

4.2.2 Differences across Teams

Team Performance

Team performance in navigation and enemy engagement tasks are shown in Figure 4-7 and Figure 4-8 respectively. The means and standard deviations for navigation, kill, and being shot are 2.17 ($SD = .47$), 10.86 ($SD = .1.67$), and 5.92 ($SD = .2.58$) respectively. For navigation performance, a score (0 – 5) was given according to errors or deviation in navigational route, height, and time deviation. Lower score denotes better navigation performance with respect to the suggested route, height, and time from one check point to the next one. From the graphs, it can be seen that team B and E performed generally better in both navigation and enemy engagement compared to the other teams.

Figure 4-7 Navigation performance (errors) across teams

Figure 4-8 Enemy engagement performance across teams

Subjective Ratings of Team SA

Team members were asked to rate the overall team SA using CLSA at the end of each mission. Pearson product-moment correlation coefficients (one-tailed) between the average team members' ratings of the team SA and team performance scores in the six missions were calculated. The result in Table 4-2 showed that the correlations between team SA and performance were in the expected direction, where better team SA was associated with better performance. The correlation between team SA and number of kill was significant, $r = -.80$, $p < .05$, while the correlation between team SA and the number of shots received were marginally significant, $r = .69$, $p = .06$. The more significant correlation with the number of enemy killed was perhaps due to the type of measure used to elicit SA. CLSA is a subjective measurement; it captures the participants' perception of their team SA. As the data was collected at the end of the mission, the rating may be biased to their perceived performance. Team's success in killing the enemy seemed to be more obvious and easier to recall than the other two measures of performance. If possible, future studies should incorporate the collection of SA measurement several times during the mission to minimize the effect of perceived outcome on the SA ratings, and also to include objective (explicit) measures to allow an assessment of the content of team member's situational knowledge.

Table 4-2 Correlations between team SA rating and performance

	Mean (SD)	Navigational errors	Number of kill	Number of being shot
Ratings of team SA	2.51 (.46)	.64	-.80*	.69

$N = 6$; * $p < .05$ (one-tailed)

Team Communication

The thought units in team communication were differentiated according to their relevance to navigation and enemy engagement before further classified into the different categories, i.e., planning, information transfer, information request, response, acknowledgement, and monitoring/feedback. All teams were found to engage in very little non-task relevant communication (an average of 1 non-task unit per mission), and thus this type of communication was omitted in the analysis. Pearson product-moment correlation coefficients between team performance (navigation and enemy engagement) and communication categories (navigation and enemy engagement respectively) are

reported in Table 4-3. Most of the correlations between communication frequency and SA were not significant, while the correlations between communication frequency and performance measures showed contradicting trends. Teams who had better navigational performance were shown to engage in less navigation-related communication, while teams with better performance in enemy engagement engaged in more enemy-related communication.

Table 4-3 Correlations between team communication and SA and performance

	Navigation		Enemy Engagement		
	Rating of team SA	Navigation errors	Rating of team SA	Kills	Being shot
Communication intensity	.50	.95**	-.50	.90*	-.34
Planning	.47	.92**	-.64	.88*	-.44
Information transfer	.27	.72	-.24	.77	-.15
Information request	.54	.98**	-.71	.96**	-.47
Response	.59	.99**	-.85*	.97**	-.74
Acknowledgement	.08	.81	.25	.29	.27
Feedback	.69	.66	-.13	-.05	.04

$N = 6$; * $p < .05$; ** $p < .01$ (two-tailed)

The difference in the trends may be due to the difference in the way communication was used to support the achievement of the two tasks. In enemy engagement, both team members can detect the presence of the enemies through the windscreen. Thus, communication was mainly used to bring teammate's attention towards the detected enemy, to share information and update each other's SA regarding the enemy's location, and planning of actions to take. On the other hand, in navigating and aviating task, the resources necessary to perform the task were distributed to the two members. The co-pilot had access to the map, which contained most of the navigation information, while the pilot had access to the flight control. Therefore, information sharing becomes crucial especially to update pilot's SA regarding the navigation route. As identified in the critical incident analysis, most navigational errors were resulted by breakdown in information sharing.

In navigation and aviating task, better performing teams were observed to provide more accurate, precise, concise, and unambiguous communication compared to the poorer

teams. As a result, the poorer teams were observed to engage in more communication to further clarify the ambiguous information or correct the erroneous performance. When the numbers of thought units in each category were transformed into a percentage of the total units communicated (see Table 4-4), the percentage of information request and response were found to significantly correlate to navigation errors, $r = .93, p < .01$ and $r = .95, p < .01$, respectively. Previous study by Hollenbeck et al. (1995) also found that low performing teams made more information request as they could not anticipate the information needs of teammates. In this study, poorer performing teams were observed to provide information less voluntarily, such that it had to be explicitly requested by teammate. They were also not so clear in their expression, which often led to confusion, as illustrated in the following communication by team D:

01:47 Co-pilot : I think all the features are all behind this high ground
 There is no saddle to go
 01:52 Pilot : Hug around?
 01:53 Co-pilot : Yes, hug around
 02:02 Pilot : After this, what is the heading?
 02:03 Co-pilot : Heading 158
 02:07 Co-pilot : Go up behind this high ground, heading Easterly
 02:19 Pilot : Turn right?
 02:20 Co-pilot : Turn left, turn left
 02:27 Co-pilot : Go right
 02:28 Pilot : Go left?
 02:28 Co-pilot : No, no... Go to the right side, *Where are we now?* Oh, ok...

Table 4-4 Percentage of navigation thought units and their correlations with performance

	Percentage for each team						Correlation with Navigation errors
	A	B	C	D	E	F	
Planning	35	33	40	35	37	32	-.41
Information transfer	43	52	39	26	41	38	-.78
Information request	6	6	5	16	7	15	.93**
Response	5	4	5	9	6	9	.95**
Acknowledgement	2	5	3	3	5	4	-.22
Monitoring/feedback	10	0	8	11	4	3	.36

$N = 6$; ** $p < .01$ (two-tailed)

Contrary to the findings by Hollenbeck et al. (1995), Schreiber and colleagues (Schreiber et al., 1998; Schreiber et al., 1996) reported that high SA pilots requested more information. The latter finding is similar to the trend found in the enemy engagement task, where the teams who managed to kill more enemies also requested significantly more information, $r = .96, p < .01$. Zooming in further to the type of information requested, it was revealed that most of the time, the information request was done to bring the other's attention towards assessing the team situation or evaluating performance status rather than requesting an information held by teammate, e.g., "is that all [the enemies]?"; "what is that?" [pointing at the enemy on screen]; "from where is that shot?". Such information requests do not associate with erroneous behavior, but instead they were useful for team SA development and maintenance.

4.3 Summary

The analysis of the study provides several insights towards the concept of team SA. First, in a team setting, there is another factor that contributes to SA in addition to the awareness that is related to the task in hand, namely awareness related to teamwork. Therefore, to be considered as having good team SA, team members should possess the following aspects:

1. *Awareness related to taskwork* – awareness of team members on the elements of the environment, which are relevant to the achievement of their task and responsibilities. For example, pilot's awareness of the altitude and speed of the helicopter, co-pilot's awareness of the weapon capacity, pilot's and co-pilot's awareness of the location of the helicopter and existence of enemies.
2. *Awareness related to teamwork* – awareness of team members on the elements of the team, which are required to support each other toward the achievement of the team goals. For example, awareness of teammate's task status to allow anticipation of information needs and actions, awareness of teammate's actions to allow feedback of erroneous behavior, awareness of teammate's status and capacity to allow backup if he is incapacitated.

The analyses of critical incidents also elicit several teamwork behaviors that are important for the development and maintenance of team SA. They include monitoring each other's behavior and actions, communicating perception and actions to update each other's SA, and providing feedback on observed behavior of teammate. These behaviors serve two main purposes:

1. to share information necessary for teammates to build their SA. This is particularly important when the sources of information are distributed in such a way that the information necessary for one's task is only accessible by his teammate.
2. to let team members to be aware of each other's status, so that they can adjust their SA and behavior accordingly.

Team communication can be considered as both a cause and an effect of team SA. Breakdown in communication can be used as an indicator of team SA. However, the analysis of team communication is not straight forward. Communication is contextual (Suchman, 1987); different types of teams and tasks require different way of communicating according to their needs and situation faced. For instance, when the sources of information are distributed across members and need to be integrated through communication, breakdown in communication such as shown in more information request, clarification, etc., can generally determine poor performance. On the other hand, when all members have the access to the information resources, communication is mainly used to bring teammate's attention towards the shared information, and thus better performance was found to associate with more intense communication. In other words, the way the system is designed, e.g., shared physical environment, display, and information distribution, would influence the way communication is utilized to develop and maintain team SA. Therefore, an analysis of team communication requires an understanding of the nature of the teamwork, in order to assess the quality and content of the communication; whether the necessary information exchange is done effectively according to what is needed for the team to perform effectively.

Finally, the method used to assess SA in this study was limited to retrospective method, which as discussed previously in Section 2.4.2, maybe subjected to over-generalization and over-rationalization. Subsequent studies will consider the measurement of SA during task performance to in order to minimize this effect.

Chapter 5 Defining the Concept and Measurement of Team SA

5.1 Framework to Assess Team SA

Based on the literature review and analysis of the first study, a framework to assess team SA is conceptualized, as illustrated in Figure 5-1. The framework includes the important aspects of team SA, factors that define team SA requirements, and processes that are related to the acquisition and maintenance of team SA.

Figure 5-1 Conceptual framework to assess team SA

5.1.1 Attributes of Team SA

The centre of the model shows two main aspects of team SA, namely SA related to taskwork and SA related to teamwork. SA related to taskwork is dependent on the responsibilities required from each member. It can be treated similar to the SA necessary to perform individual missions. SA related to teamwork is the one that differentiates team SA from individual SA. It includes the awareness of teammate's task status such as teammate's workload level and the ability of teammate to cope with and perform his tasks, which would be required to support cooperative activities. Being aware of the status of teammate's SA does not necessarily mean that a member has to be aware of whatever SA elements the teammate should be aware of; instead he should know if the teammate has the required awareness to perform his responsibilities well. Knowledge about teammate's status could influence a member's behavior towards his teammate, whether and when he should step in to help his teammate recover from the loss of SA, and the extent to which a member would trust his teammate in performing the task. For instance, if one is aware that his teammate is overloaded, he would not impose additional workload and instead, should help to reduce it. These aspects of awareness can be obtained through ongoing monitoring of teammate's behavior, and identification of cues that reflect loss of SA and changes in workload.

Without good team SA, it is difficult for team members to provide timely assistance, and this will hinder smooth and effective collaboration (Gutwin & Greenberg, 2004). Consider a situation where a First Officer is required to take over the aircraft when the Captain becomes incapacitated. The First Officer would not be able to initiate the take over if he is not aware that the Captain is incapacitated. If a member is not aware that his team member is overloaded or losing SA, he would not be able to provide timely assistance for the recovery of SA, and poor team performance becomes inevitable. A study of 37 accidents in the 1994 NTSB report revealed that in 31 of the events, one or more crew members failed to monitor and/or challenge the errors or lack of awareness of their team members (Bovier, 1997).

5.1.2 Influence of Task Requirements

The top part of the framework introduces two characteristics of a team that can be used to define team SA requirements, namely role interdependence and degree of overlap in responsibilities. Interdependence among roles indicates the extent to which team goals can be achieved with an absence of team interaction. This interdependence among team members' roles imposes the requirement for the awareness related to teamwork, that is, the extent to which an individual member has to be aware of his teammate's status. On the other hand, the degree of overlap across team members' responsibilities would define the extent to which they have to possess similar or overlapping awareness of the elements of the system.

Although the term "shared" is commonly used in describing team SA, it should not be interpreted that every member has to be aware of the same information. One reason for engaging teams is because an individual is unable to cope with the high demand and complexity of the system. If every team member has to attend to and process the same information, the main purpose of using teams will be defeated. In addition, access to additional irrelevant information may increase workload, add confusion and degrade performance (Sperling, 2005). It should again be noted that team members are often assigned to specific roles and functions. They should possess SA that is required to fulfill their responsibilities (Endsley, 1995c). The extent to which team members' SA overlap, i.e., shared SA requirements, should depend on how these responsibilities are assigned to the members. Team members can be assigned with completely different to completely overlapping responsibilities. The assignment of these responsibilities would define each member's SA requirements and the ideal degree of shared SA.

In highly interdependent teams, team interaction is vital for the achievement of the team goals. Thus, team members need to be aware of each other so that feedback and backup can be provided in a timely manner. An example would be a team consisting of a pilot and a weapon system officer in a fighter cockpit. The pilot takes care of the aviating task while the weapon system officer controls the weapons for enemy engagement. The two roles are highly interdependent in such a way that the weapon system officer would not be able to take accurate aim of the target if the pilot does not provide a position of advantage for enemy engagement. On the other hand, low interdependent teams allow an

achievement of team goals with minimal interaction among the members. This type of team is not common in complex and dynamic environment, but can be found in other areas. For example, in a team of salesmen, the sales target can still be achieved although the team members work independently to perform the sales tasks.

Thus, team SA can be defined as *team members' perception, comprehension, and future prediction of the system/task status relevant to their responsibilities, and of the team status, which is required for effective interaction in an interdependent team*. This definition extends Endsley's characterization of SA (1995c) to include other aspects of awareness that may not be directly relevant to own responsibilities, but would be necessary to support teamwork activities, especially for feedback and backup.

5.1.3 Role of System's Affordances and Team Processes

The bottom part of the framework illustrates the factors that can limit the achievement of team SA. It should be noted that the actual SA acquired by the team members may or may not be the same as the team SA requirements defined by the task. As discussed in Chapter 2, the acquired SA is constrained within what is achievable with the system design and environment. The environment sets an upper limit to SA, i.e., SA cannot be greater than the predictability of the system the operator controls (Durso & Gronlund, 1999). In other words, the acquisition of team SA is limited by what is afforded by the system. A system has an affordance or potential interpretative actions, in which users interpret these actions based on his/her experience, context and expectations (Suchman, 1987). Affordance provides clues to people on how to operate or make use of things. In addition to physical affordance, Gibson (1966) included affordance that is provided by the presence of other people. In fact, affordance provided by other people is considered as the richest and most intricate of an environment. According to Clark & Uzzell (2002), people are "mediators" in perceptual processes, i.e., the affordance available to an individual changes with the presence or absence of other people. A good team-based system should afford the actors to establish teamwork processes required towards achieving the team goals. For instance, a physically colocated team provides affordance for team members to interact closely. On the other hand, a system with geographically distributed team members with no communication aid does not afford the members effective communication and coordination.

The use of communication in team setting can extend the limit of a team member's SA imposed by the system design. As an illustration, task Z requires the team members to have shared awareness of situation X. A system that informs the status of situation X to all members, i.e., shared display, can support the development of shared SA. However, if the display is only accessible to one member, the other member would not have the awareness of situation X. In this case, communication plays a crucial role in transferring the necessary information to develop the shared awareness.

Thus, sharing of awareness among members is influenced by the system's affordances and team interactions. This sharing can be facilitated by:

- Overlap in team member resources, such that they can assess the same parts of the environment due to the existence of shared display (Bolstad & Endsley, 1999; Perla et al., 2000), and good monitoring behavior of team members who share the same physical environment or workspace (Rognin, 1998), etc.
- Sharing of each other's perception through verbal communication (Garbis & Artman, 2004; Schraagen & Rasker, 2001). This allows teams with members who have access to completely different resources/ information to form shared SA.

Team SA is also illustrated to influence team processes in return. Similar to the relationship between the product and process of SA illustrated in Section 2.1.1., the relationship between team SA and interaction processes is cyclical. For instance, if a member is aware that his teammate is overloaded, he can avoid communicating unnecessary information that can impose additional workload. If a team member is aware that teammate is incapacitated or loss SA, then he can provide feedback and backup to support him.

5.2 Approach to Assess Team SA

The framework imposes several implications for measurement of team SA:

- The assessment of team SA should include SA related to taskwork and SA related to teamwork.

- Analysis of roles and responsibilities of each member and identification of the shared SA requirements are necessary as references to assess the quality of the overall team SA, particularly for SA related to taskwork.
- Analysis of the degree of inter-dependence among team members is necessary to determine the extent to which team members need to be aware of the teammate's status, which will be necessary to support good coordination and backup.
- Assessment of team communication and behavior would be useful to provide an understanding of the development process of team SA, especially when the development of shared SA is not directly supported by the system design.

Figure 5-2 shows different types of measures that are targeted to assess different aspects of team SA. Flowchart shown in Figure 5-3 provides a guide to identify the type of measurements to assess team SA.

Awareness of the situation related to own task, i.e., the extent to which team member possesses the SA required for his role, can indeed be assessed using any existing individual SA measurement methods. However, when shared awareness needs to be assessed, objective tools that can elicit the content of team members' knowledge regarding the situation would offer an advantage as they allow direct comparison in evaluating the similarity across team members' responses on the aspects where their responsibilities overlap. It should be noted that both similarity and accuracy are important in the assessment of shared SA. It is possible that team members share the same information, but both of them are wrong, and this shall not be considered as having good team SA. If both members perceive similar but wrong information, they may have a lower tendency to ask the other member to re-assess the situation. Examples of potential tools to assess awareness related to own task include SAGAT (Endsley, 1988), SPAM (Durso et al., 1998), SACRI (Hogg et al., 1995), SALSA (Hauss & Eyferth, 2003), and SASHA (Jeannot et al., 2003).

Figure 5-2 Approach to assess team SA

SA related to teamwork can be measured in several ways. One way is to find out how much the team member is aware of the situation related to his teammate's task, by using the same tools used to assess the awareness of own task as described above. Although this aspect may not be necessary for the completion of the task, this is important when one has to take over teammate's task when he is incapacitated. Table 5-1 lists examples of objective probes related to own and teammate's task.

Figure 5-3 Flowchart to select team SA measurement tools

Table 5-1 Objective probes related to own and teammate's task

	SA related to own task	SA related to teammate's task
Level 1	Perception of current data (system and environment) relevant to own responsibilities	Perception of actions taken by teammate, relevant data needed to backup teammate's task
Level 2	Comprehension of status with respect to own responsibilities, capability to cope with the task	Comprehension whether teammate is coping with his responsibilities, the effects of teammate's actions on the team goals
Level 3	Prediction of system's responses, success of action	Prediction of teammate's actions, system's responses on teammate's action

Knowing the correct time to provide feedback and backup requires a team member to be aware of teammate's status, such as when he is overloaded or losing awareness. Such awareness can be assessed by eliciting the perception of teammate's SA and workload using subjective measures. Subjective methods can also be used to determine whether the

team members perceive each other's SA and workload similarly and are sensitive to the changes in each other's SA and workload. Existing methods that can be used to measure perceived SA include SARS (Taylor, 1990), CARS (McGuinness & Foy, 2000), CSAS (Dennehy, 1997), and CLSA (Adams et al., 1995). Examples of methods to measure perceived workload are NASA Task Load Index (Hart & Staveland, 1988), Subjective Workload Assessment Technique (Reid & Nygren, 1988), and Rating Scale Mental Effort (Zijlstra, 1993). Awareness of teammate's workload and awareness level can also be assessed indirectly through observing the feedback and backup behavior of team members. This method is advantageous as it does not rely on team members' ratings that can sometimes be highly subjective and bias. However, this method may only work well when team member's inability to cope occur during the mission performance.

Finally, assessment of team processes would provide a picture regarding the processes involved in developing and maintaining team SA. For example, task Z requires the team members to have a shared awareness of situation X. However, information regarding situation X is only accessible by member A. Member B is only able to acquire an awareness of situation X if such information is communicated by member A to B. Capturing the communicative behavior would provide an understanding of how team members share their SA. The utility of analyzing communication to better understand how team SA is developed, maintained, and recovered when it is lost has been suggested by other researchers (e.g., Artman, 2000; Garbis & Artman, 2004). Methods such as CAST (Gorman et al., 2005) evaluate the perception and coordination of information among team members through observation. Similarly, checklist such as TARGETs (Fowlkes et al., 1994) and SALIANT (Muñiz et al., 1998) can be used to assist a more structured evaluation of team behavior, using a list of targeted behaviors expected to be exhibited by the operators during occurrence of certain events. Detailed protocol analyses can also be conducted to find out the communication pattern that would better support team SA. For instance, Hollenbeck et al. (1995) found that low performing teams made more information request as they could not anticipate the information needs of teammates. Artman (2000) found that the more successful teams engaged in more intense communication, and thus suggested the importance of think aloud in order to update and maintain team SA and to work co-operatively in a coherent manner. Several other studies have also shown the significant relationship between communication frequency and team performance (e.g., Orasanu, 1990; Orasanu & Fisher, 1991; Sexton & Helmreich, 2000).

Finally, it would also be advantageous to complement the process measure by obtaining team members' perspective on their teamwork behavior. This is advantageous to capture the implicit process or product perceived by the team, which is inaccessible by the outsiders (observers).

5.3 Summary

Team SA is defined as *team members' perception, comprehension, and future prediction of the system/task status relevant to their responsibilities, and of the team status, which is required for effective interaction in an interdependent team*. A model of team SA is also proposed, and it offers advancement to the existing models of team SA, which do not include ways to operationally measure the construct. The measurement of team SA can be targeted on three major areas, namely awareness related to taskwork, awareness related to teamwork, and team interaction.

The following three chapters will report laboratory-based studies that utilized the team SA measurement approach described in this chapter. Due to constraints in time and resources, the type of teams evaluated in these studies is limited to two-person teams with high inter-dependence in roles and high overlap in responsibilities. Three main questions aimed to be answered through these studies are:

1. What are the input factors that affect each aspect of team SA? Factors related to individual characteristics (task experience and cognitive abilities) and team composition will be the focus of the studies.
2. What processes associated with good / poor team SA?
3. How do the aspects of team SA inter-relate with each other? Does having good awareness on one aspect necessarily mean having good awareness on the other aspects?
4. What are the consequences of having good or poor awareness in each aspect of team SA?

Chapter 6 Study 2: Investigating the Relationships between Experience, Team Processes, and SA

The study aimed to investigate: 1) the role of individual task experience as an input factor to predict team SA; 2) the relationship between team process and team SA; 3) the inter-relationship between the aspects of team SA identified in Chapter 5; and 4) the relationship between team SA and performance outcome.

6.1 Theoretical Basis and Hypotheses

Role of task experience on SA

Domain-related knowledge increased with experience. Several studies have identified that job experience is a stronger predictor of performance compared to cognitive ability, psychomotor ability and personality (Carretta et al., 1996; Palumbo et al., 2005). Morrow et al. (2003a) reported that expert and novice pilots (measured by flying hours) differed significantly in scenario-specific knowledge, but not in general aviation knowledge. This domain-related knowledge provides foundation for the experts to have better comprehension of flight situations and make better decisions (Morrow et al., 2003a). Specifically on SA research, previous research had reported the positive effect of task experience on individual SA (e.g., Carretta et al., 1996; Doane et al., 2004; Randel & Pugh, 1996; Sohn & Doane, 2004). Randel & Pugh (1996) noted that the experts put greater emphasis on situation assessment while the novices emphasized on the course of action. As they have larger collection of mental models to draw on, experts can quickly decide on their action once they understood the situation. With their ability to chunk meaningfully related information in a given situation, experts also developed better underlying model of the situation. However, not much is known about the impact of experience on the various aspects of team SA, namely SA related to own task, SA related to teammate's task, and awareness of teammate's workload and SA levels. It was expected that the relationships in team level would be the same as those found in the individual level.

H1: better task experience will be associated with better team SA

SA and process in team missions

Salas et al. (1995) noted that team SA involves “two critical but poorly understood abstractions: individual SA and team processes”. Existing models of team SA (e.g., Cooke et al., 2001; Salas et al., 1995) noted the important role of team process to integrate individual SA into team level awareness. Sharing information through verbal communication enables team members to share their situational models in order to build shared understanding of the situation (Cooke et al., 2001). Through this exchange of information, team members update their individual SA, which in return affects the content and the way they communicate. In their model of teamwork, Dickinson & McIntyre (1997) conceptualized monitoring of teammate (which is part of team SA) as an important behavior leading to effective feedback, backup, and coordination. Similarly, from an interview with 50 aviators, Prince & Stout (1995) identified several teamwork behavior that encourages team SA, including communication, providing backup of each other, adaptability, and listening to communication of other members.

H2: better team processes (measured by self ratings of teamwork behavior, observer’s evaluation, and communication frequency) will be associated with better team SA

Inter-correlations among aspects of team SA

No study that investigates the different aspects of team SA was found in the literature, thus it was hard to develop a strong hypothesis regarding this issue. However, it was suspected that each aspect of team SA may be achieved from different sources and through different processes, and thus they may not be highly correlated to each other.

H3: better awareness in one aspect of team SA (e.g., awareness of own situation) will not be associated with better awareness in the other aspects of team SA (e.g., awareness of teammate’s task)

Correlations of SA and performance

On the other hand, the literature has been fairly consistent in suggesting the positive association between SA and performance (e.g., Endsley, 1995c; Orasanu, 1995a). Several studies have also documented the close association between lack of SA and aviation mishaps. For example, Hartel, Smith, & Prince (1991) reported that a lack of SA was the leading causal factor in more than 200 aviation mishaps reviewed. A study in commercial aviation accidents identified that 88% of problems related to human error are contributed by problems with SA (Endsley, 1995b). Similarly, controlled flight into terrain (CFIT)

accidents were documented to be the number one cause of fatalities in commercial accidents during the 1990s, and the direct cause of these is a loss of SA.

H4: better team SA will be associated with better team performance outcome

Finally, the study also aimed to identify the variable that matters most, i.e., the variable that accounts for the most variance in team performance.

6.2 Experiment Design

6.2.1 Task

The context of this study was combat teams in urban warfare. Urban warfare is complex, dynamic, challenging, and involves high risk. The close proximity of fighting units due to the density of built-up areas in urban space compresses the battlefield in terms of space and time (Fong, 2006). In this research, an urban warfare was simulated using a multiplayer first-person shooting game, Counter-StrikeTM (CS). The screen capture of CS is shown in Figure 6-1. CS has sufficient task fidelity, replicating the characteristics of complex and dynamic environment to a certain extent. It is *dynamic*, the simulated environment spontaneously changes its states over time even without any intervention by the participant; *reactive*, the states changes appropriately with respect to participant actions; *rapidly changing*, the pace of status changes is fast, where decisions and actions have to be made under *time pressure*; and the information presented is sometimes *incomplete and uncertain*, resulting in a certain degree of unpredictability. In addition, the game is motivating and engaging, and can stimulate participants' willingness to put their fullest effort into the given tasks. This is important because even though other types of compensation such as money or academic credits may help to motivate the participants, they can be as good as nothing if the participants are totally uninterested in the game.

There were two opposing teams in CS, namely counter-terrorists and terrorists. The mission's objective was to eliminate the opponent while inflicting the least injury on one's own team. The team members were assigned with the same responsibilities, i.e., to search and kill the opponent players. In order to perform the assigned responsibilities, each team member had to be aware of their own task status and the enemy information. Therefore, ideally team members should share the awareness related to the enemy's

information. In terms of inter-dependence, although the mission objective can still be achieved when team members work independently, there would be a higher chance to win if they work closely together in searching and engaging the enemy. In addition, the need to back up of each other for survivability imposes an additional degree of inter-dependence to the team. Since the inter-dependence among members was relatively high, team members were also expected to be aware of their teammate's task status, workload, and SA level. Various team interaction may also be required to maintain good team SA throughout the mission as the resources to build team SA may not always be available to all members.

Figure 6-1 Screen shot of CS game

Task analysis (Table 6-1) was conducted prior to the simulation to:

1. Determine the motor skills required to perform the task effectively. This information was used to assess the qualification of the participants.
2. Determine behavioral cues that can differentiate between experts and novices. This information was used to develop an observer's checklist to identify participants' experience level during pre-test.

3. Determine the knowledge or mental models necessary for the players to perform their tasks well. This information was used to develop a pre-test questionnaire to assess the expertise level of the participants.
4. Determine the visual and auditory cues of each sub-tasks, and the decisions and actions that should be made based on the cues, as a basis to develop SAGAT queries.

6.2.2 Participants

The participants were twenty males with age ranging from 18 to 26 years ($M = 23.5$, $SD = 2.01$) and CS playing experience ranging from 0.5 to 8 years ($M = 3.53$, $SD = 2.80$). All participants had the basic skills required for playing the game, i.e., maneuvering and weapon handling. The participants were assigned into teams of two. All teams were composed of participants who did not know each other prior to the experiment. A Subject Matter Expert (SME) was involved in designing the mission, developing SAGAT queries, and interpreting the result. He had been playing CS actively for six years and had the basic knowledge of Human Factors Engineering.

6.2.3 Simulation Set Up

Four sets of computers (two for participants and two for experimenters) with a network connection were used in this simulation (see Figure 6-2). The participants' computers were placed back to back so that the participants could not see each other's display. Three web-cameras were used, two to capture the facial expression of the participants and one to capture the overall view. The game playing and team communication were recorded using FrapsTM.

Table 6-1 Task analysis of CS game

Task	Description	Decision cues	Relevant mental model	Basic playing skills	Indicator of expert players	Performance indicator	Behaviors that support TSA
1. Buying weapon, ammunitions, and equipment	Purchasing a primary weapon, ammunitions, and other equipment for the mission. Transaction can only be done in the shopping area and within the first 90 seconds of the mission.	Time displayed on the screen Amount of money available Choice of strategy Familiarity with the weapon Type of map Estimated usage level of ammo	Price of each weapon, ammo, and equipment Characteristics of the weapon Characteristics of the equipment	Know how to buy weapon Know the area where shopping is allowed	Use shortcut keys to do transactions Configure command keys to change weapon faster	Time taken to buy weapon, ammo, and equipment	Communicating what weapons to buy Buying weapon according to the agreed team strategy
2. Reloading weapon	To replace the empty ammunition clip of the weapon with a new clip	Indicator on the display Estimation of ammo fired Time and location to reload during firefight	Number of ammo in a clip of the weapon used Time required to reload the ammo for the weapon used	Know how to reload a weapon	Ability to reload on the move Know when he should reload the weapon	Does not run out of ammo in the middle of confrontation	Inform if run out of ammo or backup is needed
3. Searching for enemy	Seeking out the location of the enemy.	Foot steps, doors open/shut, gun shots, people climbing, throwing grenade Strategy agreed by the team, whether to rush in or wait	Characteristics of the map Strategy of opposing players	Same as maneuvering	Know the shortest route to enemy's home base Know the advantageous locations to camp	Time taken to detect enemy Detecting enemy without being noticed	Inform detected enemy location Constantly inform current location
4. Maneuvering	Moving around the map	Terrain, obstacles Characteristics of material stepped on	Best posture to use for the terrain	Know how to : move forward, move backward, jump, crawl, crouch, strafe, turn, climb	Maneuver the terrain faster Use the best posture with respect to terrain Better psychomotor coordination	Injury caused by maneuvering actions, e.g., falling down from high place	Planning - role assignment for maneuvering formation, e.g., who would be in front

5. Camping	Hiding and waiting for the enemy to appear	Terrain Characteristics of map Type of weapon used	Characteristics of the map: where the enemy most likely to come from	-	Know the best time to camp Know the best place to camp	Can spot the enemy before being spotted	Planning – role assignment (who camps where)
6. Confrontation with enemy							
6.1. Detecting other player	Identifying if there is a player around him and determining whether this player is friend or enemy	Visual: outfit of the detected player Auditory: foot steps, doors open/shut, gun shots, people climbing, throwing grenade	The outfit of the terrorist and counter-terrorist Knowing the location of teammate	-	Faster and more accurate detection of other players	Time to detect Accuracy in detection	Keep updating on each other's location
6.2. Contacting the enemy	Actions when encountering the enemy	Strategy: whether to fire or to hide Location of contact Own and enemy's skill level Teammate's location Type of own and enemy's weapon Amount of own and enemy's life Amount of own and enemy's ammo left Type of own and enemy's equipment	Characteristics of weapon, ammo, and equipment	-	Make use of distractions, e.g., mislead enemy to other location while he comes from behind Dodging bullets	Time taken from detection to contact	Strategizing how to contact the enemy Coordinating actions Backup during contacting
6.3. Firing the enemy	Aiming and effectively kill off the enemy	The enemy Weapon and equipment to use Type of enemy's weapon Number of enemy around	Characteristics of weapon and equipment Vulnerable parts of the body	Aiming skill Coordination in maneuvering and firing	Know how to aim using the different weapon Know the best posture for aiming Jumping around so that the enemy cannot aim at him easily	Time taken to kill the enemy Type of kills: normal or head shots Number of enemies killed	Inform enemy fire Inform if enemy is killed

Figure 6-2 Experiment set up

6.2.4 Procedure

The study was conducted in two separate sessions: pre-test and main test. In the pre-test, the participants were first introduced to the study. After obtaining their consent for participation, they were asked to play a trial mission, where the SME assessed whether they had the gaming skills required to qualify them for the experiment. The qualified participants were asked to answer a set of CS-related questions, and then given five minutes to familiarize themselves with the game controls. All participants played six individual missions against a pre-programmed terrorist with three different levels of difficulty. In the main test, the participants were introduced to their assigned teammate and given approximately five minutes to play the game together. They were asked to assess the relative importance of six NASA TLX workload dimensions of the team missions they had just performed. All teams then played four team missions against two pre-programmed terrorists. They were given one minute to strategize prior to each mission. In order to reinforce teamwork, the participants were informed that the team mission would be considered a failure if any of the team members got “killed”. However, they were asked to continue with the mission to the end. No communication was allowed after the elimination of any member. At the end of the mission, the participants were asked to provide an assessment of their own and teammate’s SA, workload, and teamwork behavior. The recorded missions were then played back, and the participants were asked to think aloud while watching the video, explaining their thought processes and the situations they encountered. As the experimenters had the view of the terrorists,

they further added on the information related to the terrorists. This allowed a formation of a big picture of the overall situation. Finally, a short interview was conducted to obtain participants' feedback on the study.

6.2.5 Pre-test

Unlike in aviation where flying hours can be used to represent the experience level of a pilot, there is no general way to identify the experience level of CS gamers. Using the number of playing hours may not be accurate since it is not formally recorded. Using the number of years they have played CS may not be a good indicator, because one may have played it only for several months but intensively, and others may have played it for several years but for less than one hour per week. In this regard, Randel and Pugh (1996) noted that although experience level such as hours of subject's exposure to the task is much used as indicator of expertise, other performance measures related to area of expertise may be necessary. They suggested that such performance measurements seem to be the best way for identifying experts, although as a result of this, experts may be found only in small proportions of pooled subjects. Therefore, a pre-test was conducted prior to the experiment to elicit the level of participants' expertise in CS gaming. In the test, all participants played six single-player missions against a pre-programmed robot. Three levels of mission difficulty were assigned by varying the skill of the robot. The test took about half an hour to complete. Three assessment tools were developed to elicit the skill level of the participants. They include:

1. *Gaming score of six missions:* The number of times the participants won the game was taken as one indicator of gaming skills.
2. *Domain-related knowledge score:* Thirteen questions related to CS, such as characteristics of weapons, maps, and tactical knowledge were developed to gauge the participants' knowledge related to the game (see Appendix B).
3. *Observer score of participant behavior:* Several behaviors that can differentiate between experts and novices were identified from task analysis, e.g., whether the player used various command keys as shortcuts, maneuvered without injury, used weapons and equipment effectively, aimed accurately, and had a good scanning behavior. The score was obtained through a consensus of two observers.

Pre-test result

Pearson product-moment correlation coefficients presented in Table 6-2 shows that the pre-test measures were highly correlated to each other. Their correlations with the reported CS playing years were also significant. This suggested that any of the pre-test measures can be used as a gauge of expertise level in CS.

Table 6-2 Correlations among pre-test scores

	Gaming score	Knowledge score	Behavior score
Knowledge score	.60**		
Behavior score	.71**	.86**	
CS playing years	.43**	.85**	.68**

$N = 20$; ** $p < .01$ (one-tailed)

6.2.6 Assessment Tools

The assessment tools used in the study is listed in Table 6-3. The team SA measurement tools are further elaborated in the following. The complete set of SA assessment is available in Appendix B.

Table 6-3 Assessment tools

Variable	Measure	Code
Experience	CS knowledge score	
Aspects of team SA:		
Awareness of own situation	SAGAT of own situation	SAGAT _{Own}
Awareness of teammate's situation	SAGAT of teammate's situation	SAGAT _{Tmate}
Subjective SA	Self-rating of SA	SA self-rating
SA related to teammate's status	Awareness of teammate's workload level	WL Aware
	Awareness of teammate's SA level	SA Aware
Team process	Adapted CAST	CAST
	Rating of teamwork behavior	TW rating
	Team communication frequency	
Performance	Total blood/health score of the team members plus 100 points per terrorist successfully killed	

SAGAT

SAGAT probes were derived from task analysis and interviews with the SME. SAGAT queries related to own situation included identification of location and direction of movement, weapon, activity, and live/dead status of self and enemies. SAGAT to evaluate awareness of teammate's situation included location and direction of movement, weapon, activity, and live/dead status of teammate. To avoid participants guessing the answers, they were told to leave the question blank if they really did not know the answer. SAGAT data were collected twice throughout the missions. The selection of points to probe the participants was based on the occurrence of critical events, i.e., when the counter-terrorists were within terrorists' viewing range or vice versa, and when there was an opportunity to engage. The accuracy of answers was evaluated with respect to what actually happened in the game. The scores of team members were averaged to represent the team score. The overlap in team members' SA requirements and the SAGAT questions on the awareness related to own and teammate's situation are shown in Figure 6-3.

Figure 6-3 Team SA requirements of CS team

Awareness of teammate's workload level (WL Aware)

Before answering the SAGAT queries, the participants were asked to rate their own and teammate's level of workload using NASA TLX. The assessment covers six workload dimensions, namely mental demand, physical demand, temporal demand, performance, effort, and frustration level. Description of each dimension was provided to the participants. The weightage of importance of each dimension to the overall workload was obtained using pairwise comparison. A score for awareness of teammate's workload level was computed by the average difference of a workload level reported by a team member

and the level estimated by teammate. The score can range from 0 to 6, where a smaller score would indicate better estimation of each other's workload.

Awareness of teammate's SA level (SA Aware)

Before answering the SAGAT queries, the participants were also asked to rate their own SA and estimate their teammates' SA using a seven-point Likert rating scale. Descriptions were attached to the end points of the scale: 1 for 'I have no idea of what is going on'; and 7 for 'I understand what is going on very well'. These simple descriptors were deemed necessary as the participants may not be familiar with the concept of SA. A score for awareness of teammate's SA level was computed by the average difference of SA level reported by a team member and the level estimated by teammate. The score can range from 0 to 6, where a smaller score would indicate a more congruence in self-rating and rating estimated by teammate.

Adapted CAST

An observation form was developed based on CAST method. The original CAST requires an introduction of roadblocks in the mission and assesses the team coordination in overcoming these unanticipated events (Gorman et al., 2005; Gorman et al., 2006). In this study, no roadblock was introduced. Instead, the team coordination processes were analyzed at every critical event, whenever there was a chance of contact with the terrorists, i.e., when any of the terrorist's location was within the counter-terrorist's viewing range or vice versa. The coordinated perception and action of the teams were noted in the observation form shown in Figure 6-4. The adapted CAST score was calculated by the number of ticked box divided by the total of applicable items.

	Event # 1	Event #2
Team No:	Perceive firsthand ☒ 1 ☒ 2	Perceive firsthand ☒ 1 ☒ 2
Mission No:	Coordinated perception ☒ 1 ☐ 2	Coordinated perception ☐ 1 ☒ 2
	Action ☒ 1 ☒ 2	Action ☒ 1 ☒ 2

Note: ☒ yes; ☒ no; ☐ not applicable

Example of calculation: ☒ = 6; ☒ = 4; Adapted CAST score = $6 / (6+4) = 0.6$

Figure 6-4 Observation form adapted from CAST method

Self-Ratings of Teamwork Behavior

The participants were asked to rate, using a seven-point Likert scale, the extent to which they agree that his and his teammate's behavior conform to the following statements:

1. fully understood the team goal(s)
2. fully understood the team strategy
3. fully understood his role(s) in the team
4. always executed his duties as prior agreed upon
5. always regarded the opinions of teammate with respect
6. always passed important information to teammate
7. always provided feedback readily and voluntarily
8. always seek feedback when the need arose
9. always assisted teammate whenever needed
10. always able to step in when teammate was not able to perform

Communication Frequency

Team communication was transcribed and separated into thought units. A thought unit is defined as a "sequence of few words conveying a single thought" (Weldon et al., 1991, p. 559). Guidelines for unitizing were adopted from Jehn and Pradhan (1997) (refer to Section 4.1.6). Each unit was coded according the following categories:

1. *Planning* includes commands, statements and questions about how acts should be performed, who should do what, in what order and when acts should be performed, and also commands to do certain actions (e.g., "let's go to the bridge and wait there"; "where do you want to go?"; "shoot the enemy!").
2. *Information transfer* includes statements about the situation, the predicted future situation, feeling towards the situation; which is transferred *voluntary* without being asked (e.g., "enemy is on the rooftop", "I've killed one enemy"; "I am in the front door").
3. *Information request* includes questions and requests on task- and team-related information (e.g., "do you see the enemy?"; "where are you?"; "what weapon are you using?")

4. *Response* includes answer to information request; information transfer that is not given voluntarily
5. *Acknowledgement* includes statements to ensure the receipt of certain information (e.g., “ok”; “roger”)
6. *Feedback* includes statements or commands or questions regarding critical evaluation of teammate’s actions (e.g., “Nice shot!”; “Thank you very much”; “Are you ready?”).
7. *Others* include statements, questions and responses that are unrelated to the mission accomplishment, and that cannot be classified in the previous categories (e.g., “Oh my Gosh!”; “oh, man...”).

A transcript from one team containing 115 thought units were coded by four independent raters. Inter-coder reliability was calculated using Cohen’s Kappa and the results were .89, .83, .90, .79, .80, and .86, which were outstanding (Landis & Koch, 1977). The author coded the rest of the transcript. The frequency of each category was derived by dividing the amount of thought units transferred divided by the amount of time taken to complete the mission.

6.3 Results

6.3.1 Effect of Task Experience on Team SA

A linear regression analysis was conducted to evaluate the prediction of each aspect of team SA from the experience level of team members. Experience did not lead to significant predictions of SAGAT of own situation, $R^2 = .31$, $F(1,9) = 3.56$, $p = .09$, as well as SAGAT of teammate’s situation, $R^2 = .35$, $F(1,9) = 4.26$, $p = .07$. The prediction of self-rating of SA from task-experience was significant, $F(1, 9) = 6.36$, $p < .05$, explaining about 44% of the variance. Regressions on the other two criteria, i.e., awareness of teammate’s workload and SA level, were not significant.

6.3.2 SA and Team Processes

The relationship between SA and team processes can be bi-directional; team SA can be achieved through the process of situation assessment and team interaction, and team SA

can also determine the subsequent behavior of team members. To investigate the associations between team SA and processes, Pearson's product-moment correlations were calculated between each of their measures. The correlation coefficients are reported in Table 6-4.

Table 6-4 Correlations between SA and team processes

	SAGAT Own	SAGAT Tmate	SA Self- rating	WL Aware	SA Aware
Self-rating of teamwork behavior					
– Understand team goal(s)	.15	.40	.68*	.11	-.20
– Understand team strategy	.10	.47	.73**	.05	-.09
– Understand own role(s)	-.15	.36	.75**	.13	-.06
– Execute duties	-.36	.27	.42	.13	.38
– Respect teammate	.10	.21	.52	.42	-.31
– Transfer important information	.66*	.55*	.33	.06	-.31
– Provide feedback	.71*	.72**	.54	-.23	-.41
– Seek feedback when needed	.79**	.64*	.45	-.17	-.50
– Assist when needed	.54	.72*	.80**	-.14	-.58*
– Back-up when needed	.38	.69*	.60*	-.27	-.04
CAST (observed)	.28	.65*	.29	-.31	-.02
Frequency of thought units					
– Planning	.32	.44	.53	-.47	-.62
– Information transfer	.36	.48	.09	-.42	-.25
– Information request	-.06	-.03	-.37	-.08	-.17
– Response	.19	.29	-.16	-.26	-.27
– Feedback	.40	.34	.15	.19	-.50
– Acknowledgement	.20	.20	-.18	-.45	-.22
– Others	.29	.31	.11	.18	-.46

$N = 10$; TW behavior & CAST: * $p < .05$; ** $p < .01$ (one-tailed); Comm. freq (two-tailed)

The result showed mixed result of significant and non-significant associations between team SA and team processes. Information transfer had high associations with SAGAT scores of own and teammate's situation. High correlation coefficients also resulted from the correlations between helping behaviors of team members (providing and seeking feedback, providing assistance and backup) and SAGAT of own situation, SAGAT of

teammate's situation, self-rating of SA, and awareness of teammate's SA level. Note that the lower score of awareness of teammate's SA represented better awareness. Observation of team processes using adapted CAST method also showed high correlation with SAGAT of teammate's situation. All of the correlations between communication frequency and team SA measures were not significant. However, some trends were observed in the correlations between team SA and the frequencies of planning and feedback, where teams with better SA scores also engaged higher communication in these two categories.

6.3.3 Inter-correlations among Aspects of Team SA

The inter-correlations among the measures of team SA are presented in Table 6-5. The analyses were conducted in team level. Each measure of team SA was calculated by averaging the scores obtained from the individual team members. As hypothesized, some of the correlations were high and the others were not. The correlation between SAGAT of own and teammate's situation was significant, $r = .64, p < .05$, indicating that participants who were better in answering the questions related to own situation were also better in answering teammate-related questions. Participants who had better scores in SAGAT of teammate's situation also rated their SA as higher ($r = .62, p < .05$). There was a tendency for team members who were more aware about their teammate's situation to be able to estimate teammate's workload better ($r = -.61, p < .05$). In addition, team members with higher awareness of own situation were also better in estimating teammate's SA level ($r = -.63, p < .05$). The rest of the correlations were not high.

Table 6-5 Inter-correlation among measures of team SA

	SAGAT _{Own}	SAGAT _{Tmate}	SA Self-rating	WL Aware	SA Aware
SAGAT _{Own}					
SAGAT _{Tmate}	.64*				
SA Self-rating	.39	.62*			
WL Aware	-.33	-.61*	-.09		
SA Aware	-.63*	-.37	-.49	.12	

$N = 10$; * $p < .05$; ** $p < .01$ (one-tailed)

6.3.4 Team SA and Performance

Table 6-6 presents the correlations between team SA and processes with performance outcome. Among the team SA measures, only self-rating of SA had a high correlation with team performance, $r = .60, p < .05$. Team performance also showed high correlations with team process measures: self-rating of teamwork behavior ($r = .63, p < .05$) and observed CAST ($r = .64, p < .05$). Note that the overall teamwork behavior was represented by an average of the ten teamwork behavior rated by team members. This result suggests that good teamwork process (measured by self-rating and CAST) is the variable that matters most for team performance.

Table 6-6 Correlations between team SA and performance

	Performance
SAGAT _{Own}	.10
SAGAT _{Teammate}	.36
SA Self-rating	.60*
WL Aware	.11
SA Aware	-.03
Overall teamwork (self-rating)	.63*
CAST (observation)	.64*

$N = 10$; * $p < .05$ (one-tailed)

6.4 Discussion

Research in individual SA has reported the importance of task experience on the achievement and acquisition of SA. The result of this study showed that it also plays an important role in team SA as measured by self-ratings. Individuals with more experience are likely to have established a larger pool of the domain-knowledge such as strategies on what, how, and where to search for the necessary information, which eventually resulted in better SA.

The other aspects of team SA, namely awareness of teammate's workload and SA levels, however were not influenced by task experience. It is possible for the low experienced teams to be able to accurately estimate each other's workload and awareness level. One example was Team 9, which was composed by low experienced members. Both team

members rated that the workload imposed by the task to self and teammate was high, thus resulting in high score in awareness of teammate's workload. Both also rated that neither of them had the awareness of what was going on, which resulted in high awareness of teammate's SA level. In contrast, Team 1, one of the most experienced teams participated in the study, had a tendency to cover different parts of the environment in order to increase the possibility of detecting the enemy. With continuous information sharing, team members were able to estimate their teammate's awareness well. However, they were not able to gauge each other's workload level accurately, which was probably due to a lack of visual cues on the severity of situation that teammate was facing.

By exploring recorded videos of the teams, it was observed that high awareness of teammate's workload usually resulted when team members maintained spatial proximity to each other in the virtual environment, i.e., they can see their teammate on the screen. Graham et al. (2007) investigated the impact of physical and social network distance on the ability of team members to estimate teammates' workload, and reported that they provided better estimation in colocated and closer social network than in a distributed environment. In this study, as team members shared the same location in the game, they were more likely to be exposed to the similar situation. For instance, one could see when teammate was engaging the enemy and thus inferred that teammate's workload at the point in time was high. This can also explain the high correlation between awareness of teammate's workload and SAGAT of teammate's situation. The similar case applied to the awareness of teammate's SA level. However, in addition to visual cues, the awareness level of teammate can be derived from the quantity and quality of information communicated.

Additional analyses were conducted to investigate participants' responses towards self- and peer- ratings. The results revealed that the participants tend to provide a similar rating for own and teammate's workload ($r = .83, p < .001$) and SA ($r = .90, p < .001$) levels. The estimation of teammate's workload and SA, however, was not always similar to what was perceived by teammate himself: $r = .02$ ($p = .46$) for workload level and $r = -.20$ ($p = .41$) for SA level. The tendency of participants to derive teammate's values from own may also be the reason why team members who were exposed to the similar situation seem to be better in estimating each other's workload and awareness status. It is less

cognitively demanding to use information regarding self, which is more readily available, to estimate the value of others (egocentric bias).

This study also demonstrates the associations between team SA and processes. As shown in Table 6-4, effective sharing of information is crucial for the development and maintenance of team SA. This is particularly true when team members decided to split up to cover different areas of the map and they were exposed to different information. With effective information sharing, team members would have higher awareness of the team situation compared to when team members just rely on the information that is directly accessible to them. The result also reveals the association between team SA and teamwork behavior in providing feedback whenever necessary, supporting each other, and providing backup whenever required. Feedback, assistance, and backup would be more effective when team members are aware of enemy's and teammate's information. If a team member is not even aware that teammate needs help, no assistance and backup can be effectively done.

With respect to team performance outcome, only self-rating of SA showed a high correlation with performance (refer to Table 6-6). As self-rating of SA was collected at the end of the mission, it is possible that the rating is influenced by one's perception of how good he performed in the mission. The lack of evidence on the relationship between the other measures of team SA and performance can be due to any of the following reasons. First, SA data were collected only at selected points, thus only the snapshots of the participants' awareness were captured. Second, it was possible that team members were aware about each other's status but yet did not take any action to assist each other towards the achievement of the team goals. Finally, team members may have high awareness, but still could not take down the enemy due to poor skill in weapon handling. As suggested by Endsley (1995c), the link between SA and performance is probabilistic. Good SA would allow a higher chance of obtaining good performance, but does not guarantee it, as performance is also affected by decision making and action execution. Team process measures tap on the observable behavior and actions of team members, thus considering SA, decision making, and action execution altogether. This is perhaps the reason of the high correlations between team performance outcome and team processes (measured by CAST and overall teamwork behavior).

6.5 Participants' Feedback

Participant feedbacks regarding the experiment are summarized in Table 6-7. Overall, the participants were positive toward the experiment. They reported that the game was motivating and engaging; provided realistic feedback to the players' actions, such as different types of footstep sound when the player stepped on the rooftop, solid ground, staircase, etc., the sound of closing door, gunshots, and grenade. These were some of the important cues required to assess the situation. Continuous situation assessment was crucial for winning the game, because if the participants did not know the existence of threats and their location, they would not be able to take effective actions to engage them.

Table 6-7 Participant's response to the reaction form ($N = 20$)

	<i>M</i>	<i>SD</i>
1. I would like to play more Counter-Strike™ missions	5.85	1.04
2. I felt engaged when I was playing the game	5.80	.95
3. The game replicates real-life warfare scenario	3.90	1.97
4. The missions used in this study demonstrated the importance of assessing the surrounding situation to be able to accomplish the mission objective	5.55	.94
5. The missions used in this study demonstrated the importance of teamwork	6.40	.68
6. Overall, the game can be used to study how human assess the situation around them	5.70	.92
7. Overall, the game can be used to study interactions among team members	6.15	.88
8. The questions asked are sufficient to capture my assessment of the situation	5.50	1.24

In terms of teamwork, assigning team members to assess different parts of the map would allow them to cover a wider area of scan, which would increase the probability of detecting the enemies. In addition, since the robot players were highly skilled, there would be a higher chance of winning if both members work together in the enemy engagement. However, the participants commented that the robot players were 'too smart'. Using human players as the opponents would be more realistic and motivating. They also reported that they faced some difficulties in answering the NASA TLX, particularly the paired comparison section. It should also be noted that all of the team

members in this study did not know each other prior to the experiment. In addition, all participants were required to communicate in English, which may not be the language that they are fluent with.

6.6 Summary

Task experience of team members was shown to be able to predict the level of team SA as measured by self-rating. This finding is in line with previous research, where experience was shown to facilitate the development and maintenance of SA. The other aspects, such as awareness of teammate's workload and SA level, however, are not determined by the level of experience. The mixed of high and low inter-correlations among the measures of team SA suggests that team SA is not a uni-dimensional construct. Each type of methods used in this study targets on different aspects of team SA, which are non-overlapping. Team processes including information sharing, feedback, support, and backup behavior, were shown to have strong associations with team SA. Measures that utilize communication frequency however do not provide much information regarding team SA. Analysis of communication content, such as used to derive CAST, was found to be more informative. Finally, self-rating of SA, adapted CAST, and overall rating of teamwork behavior were shown to relate significantly with team performance.

In this study, all the participants did not know their teammate prior to the experiment. It would be interesting to see if the result will be the same for familiar team members. As reviewed in Section 3.3.1.2, teams with familiar members would likely have an established way of interaction. Team members would have developed a mental model and understanding of how their teammates work, which facilitated acquisition of shared awareness through unspoken communication, as well as implicit coordination. This factor will be addressed in Study 3. SA assessment in Study 3 is extended to include an assessment of participants' prediction of the future situation and their confidence on the quality of their situational knowledge. Inclusion of these assessment methods is hoped to provide additional insights regarding SA. The inclusion of the additional methods allows an exploration regarding participants' responses to the present and future situation, their confidence bias, and how these relate to performance outcome.

Chapter 7 Study 3: Investigating the Relationships between Experience, Cognitive Ability, Familiarity, Team Processes, and SA

This chapter presents a second simulation study of combat teams in urban warfare. This study aimed to investigate the influence of task experience, cognitive abilities, and team familiarity on each aspect of team SA.

7.1 Theoretical Basis and Hypotheses

Participants' responses in awareness of present vs. future prediction and confidence level

Endsley's (1995c) three levels definition has been widely used across studies that investigate SA. She noted that being able to project to the near future (level 3) as having higher level of SA compared to those who can only perceive and comprehend the present situation. This proposition was supported by several studies that showed the relatively higher importance of future projection (level 3) for performance (Durso et al., 1998; Durso et al., 1995; O'Brien & O'Hare, 2007; Orasanu & Fischer, 1997). No empirical data was found on the inter-relationship between the three levels of SA. Based on Endsley's (1995c) model, it is expected that a person who is better in one level of SA would likely be better in other level of SA. In addition to knowing what is and going to happen, SA has also been associated with knowing what one knows and does not know (meta-cognition), where the latter has been identified to influence one's decision making. Little is known on how people are calibrated on what they know across the three levels of SA, and the results from different studies are somewhat ambiguous. Lichtenstein et al. (1982) noted that overconfidence tend to be higher for difficult items compared to easy items in questions related to general knowledge. Overconfidence was also shown for the calibration of future events, but the calibration for future events was somewhat better than for the general-knowledge items. In the context of SA, Lichacz et al. (2003) reported that the participants had less overconfidence bias in level 3 (future) compared to level 1 and 2 (present) SAGAT answers.

H1a: better awareness of the present situation will be associated with better prediction of the future situation

H 1b: there will be differences in the confidence bias of present and future status

Role of task experience, cognitive ability, and team familiarity on SA

The relationship between task experience and SA has been investigated in previous research as well as in Study 2, and the finding was expected to replicate here as well. In addition to task experience, individual differences in cognitive ability were expected to influence SA. Cognitive abilities had been reported to have positive relationships with SA, but the cognitive tests that show significant associations varied across studies. From the review of literature, several domains of cognitive abilities that may contribute to SA includes spatial (Carretta et al., 1996; Carretta & Ree, 1994; Endsley & Bolstad, 1994; Martinussen & Torjussen, 1998), memory (Carretta et al., 1996; Sohn & Doane, 2004), and reasoning (Carretta et al., 1996; O'Hare, 1997). In terms of team familiarity, there was no previous study reported on the relationship between team familiarity and SA. Nevertheless, some studies have suggested the influence of team familiarity on how the members interact to each other (e.g., Harrison et al., 2003; Kim, 1997; Peterson & Thompson, 1997), and thus may influence team SA as well. Mathieu et al. (2000) noted that having good mental models about the team members are essential for effective team process and performance. Team-related knowledge can develop through experience with the team. Harrison et al. (2003) found that team performance gets better as teams are more matured. Teams with members who are familiar with each other develop greater cohesion, have an established communication system and are able to trust their teammates (Peterson & Thompson, 1997). Furthermore, as team interaction matures over time, shared knowledge among the members is developed, leading to a more predictable team interaction. This allows them to understand each other's style of work. Thus, they able to be more aware of the information each member are likely to focus on, which is important for SA formation.

H 2: task experience, cognitive ability, and team familiarity, independently or altogether, will be associated with SA

SA and process in team missions

(please refer to Study 2 Section 6.1 for the theoretical basis of this hypothesis)

H 3: better team processes (measured by self ratings of teamwork behavior, observer's evaluation, and communication frequency) will be associated with better team SA

Inter-correlations among aspects of team SA

(please refer to Study 2 Section 6.1 for the theoretical basis of this hypothesis)

- H 4: better awareness in one aspect of team SA (e.g., awareness of own situation) will not be associated with better awareness in the other aspects of team SA (e.g., awareness of teammate's task)

Correlations of SA and performance

(please refer to Study 2 Section 6.1 for the theoretical basis of this hypothesis)

- H 5: better and poorer performers will differ in their SAGAT scores, confidence bias, self-rating of SA, and processes

In addition, the study also aimed to identify the variable that matters most, i.e., the variable that accounts for the most variance in SA and performance.

7.2 Experiment Design

7.2.1 Participants

Thirty-two university and polytechnic students (31 males and 1 female) with age ranging from 18 to 24 years ($M = 20.38$, $SD = 1.70$) participated in the study. Their CS experience ranged from 1 to 9 years ($M = 3.86$, $SD = 2.12$). Participants in a team were familiar to each other prior to the experiment. The participants were recruited through advertisement on campus, and they were requested to register for the experiment in teams of two with similar level of CS experience. Two teams with matched experience levels were involved in one experimental session. Every participant was paid S\$30 for 3 hours participation in the study.

7.2.2 Simulation Set Up

Five sets of computers (four for participants and one for experimenter) with a network connection were used (see Figure 7-1). The workstations were partitioned so that the participants could not see each other's display. The participants within the same team communicated using headsets through SkypeTM. The game and communication were

recorded using FrapsTM. Four small tables were placed behind the participants for them to answer the SA assessment sheets.

Figure 7-1 Experiment set up

7.2.3 Assessment Tools

The similar assessment tools used in Study 2 were employed with several modifications (see Table 7-1). The SAGAT probes were extended to include blood level of each player, identification of opponent that is of a higher threat, weapon reach, and prediction of what will happen within the next 10 seconds, e.g., projected location, direction of movement, activity, weapon reach, and blood level of all players. The participants were also asked to provide a confidence level (high/low) on each of their responses to the SAGAT probes. A seven-point Likert uni-dimensional scale was used to assess perceived workload, as a replacement to NASA TLX. Descriptions were attached to the end points of the scale: 1 for ‘underloaded and could cope with much more additional demand’; and 7 for ‘overloaded and could not even cope with the current demand’. No change was done on performance, subjective SA, adapted CAST, teamwork behavior, and team communication measures.

SAGAT

Additional SAGAT questions were included to the set used in Study 2, particularly on the prediction of situation in the next 10 seconds. Examples of queries are in Table 7-2. The complete set of SAGAT questions are in Appendix C.

Table 7-1 Assessment tools

Variable	Measure	Code
Experience with CS	CS knowledge score	
Familiarity with teammate	Frequency of playing CS with teammate	
Familiarity with opponent	Frequency of playing CS with opponent	
Cognitive ability	See Table 7-3	
Aspects of team SA:		
Awareness of own situation	SAGAT of own situation	SAGAT _{Own}
Awareness of teammate's situation	SAGAT of teammate's situation	SAGAT _{Tmate}
Awareness of own situational knowledge	Over-confidence bias	Over-conf. bias
	Absolute confidence bias	Abs. conf. bias
Subjective SA	Self-rating of SA	SA self-rating
SA related to teammate's status	Awareness of teammate's workload level	WL Aware
	Awareness of teammate's SA level	SA Aware
Team process	Adapted CAST	CAST
	Rating of teamwork behavior	TW rating
	Team communication frequency	
Performance	Total blood/health score of the team members plus 100 points per terrorist successfully killed	

Table 7-2 Example of SAGAT queries

	SAGAT of own situation / individual SA	SAGAT of teammate's situation
Present	<ul style="list-style-type: none"> - location and direction of movement of own and enemy - activity of own and enemy - blood/health of own and enemy - weapon of own and enemy 	<ul style="list-style-type: none"> - location and direction of movement of teammate - activity of teammate - blood/health of teammate - weapon of teammate
Future	<ul style="list-style-type: none"> - next location and direction of movement of enemy - next blood/health of own and enemy 	<ul style="list-style-type: none"> - next location and direction of movement of teammate - next blood/health of teammate

Confidence Rating

The participants were also asked to rate their confidence level (high/low) on each answer given to the SAGAT queries. A score for over-confidence bias was calculated by the average confidence rating across all test items minus the proportion of the same items that were judged correctly. A positive bias indicates over-confidence and a negative bias

indicates under-confidence. The absolute score of confidence bias indicates the distance of self awareness from a well-calibrated zero-value.

Cognitive Ability

The 1976 ETS kits of Factor-Referenced Cognitive Tests (Ekstrom et al., 1976) were used to measure the cognitive abilities of the participants. The selection of tests to include was based on the similarity of the tests to those used in several previous research conducted to investigate individual differences in SA (refer to Table 2-1 in Chapter 2). No test in the domain of verbal ability was included due to the unavailability of test that was appropriate to assess this domain. Nine tests in the domains of spatial, memory, and reasoning were used as shown in Table 7-3. The description and example of each test is available in the Appendix E. Score in CS-related knowledge questionnaire (same as the one used in Study 2) was used as a measure of experience level.

Table 7-3 Cognitive test battery

Factor	Name of Test	Time to complete
Spatial ability		
Flexibility of closure	Hidden Figure Test	12 minutes
Perceptual speed	Number Comparison Test	1.5 minutes
Spatial orientation	Cube Comparison Test	3 minutes
Visualization	Form Board Test	8 minutes
Memory		
Memory span	Auditory Number Span Test	10 minutes
Visual memory	Building Memory	9 minutes
Reasoning		
Induction	Figure Classification	8 minutes
Integrative processes	Following Direction	7 minutes
General reasoning	Mathematic Aptitude Test	10 minutes

7.2.4 Procedure

Four participants were involved in one experimental session. The participants were first introduced to the study and briefed on the procedure of the experiment. After obtaining their consent, they were assigned into teams with a balanced skill level and asked to fill in a background information form and answer thirteen CS-related questions (see Appendix C). Two cognitive tests were administered afterwards, followed by a break. Two participants then played individual missions, while the other two continued on the

cognitive test. After the individual missions were completed, they had another break, and the assignments were rotated. The four participants were gathered again to complete the cognitive test. After another break, they performed the team missions, followed by a short debrief and interview.

In the individual missions, two participants played four one-versus-one missions. Before starting the test, the participants were given about five minutes to familiarize with the map. Throughout the missions, the game was paused twice to administer the paper-and-pen based SA assessment. When the game was paused, the participants were asked to turn around and answer the questions, which were placed on small tables behind them. They took about 1-2 minutes to complete the questions, and then the game resumed. In the team missions, four participants played five two-versus-two missions. They were allowed to use their preferred language to communicate during the missions. At the end of the team missions, the participants were asked to provide an assessment of self and teammate's teamwork behavior.

7.3 Results

The presentation of result is divided into several sections. The first section presents the evaluation of participants' responses towards SAGAT of present situation and prediction of future status, followed by evaluation of their confidence ratings. Section 6.7.2 will investigate the impact of task experience, cognitive ability, and familiarity on SA. The associations between team SA and process are reported in Section 6.7.3. Section 6.7.4 investigates the inter-correlations between different measures of team SA, followed by an evaluation of the difference in SA between good and poor performing teams.

In this study, the participants were assigned randomly as either terrorists or counter-terrorists. A one-way analysis of variance (ANOVA) was performed to determine whether the SA scores were independent of the side to which each subject was assigned. The analyses showed that none of the scores in individual (SAGAT, over-confidence bias, and self-rating of SA) and team missions (SAGAT of own and teammate's task, over-confidence bias, awareness of teammate's workload and SA levels, CAST score, and ratings of teamwork behavior) was affected by the role assignment. The subsequent analyses will not differentiate between the two roles.

7.3.1 Participants' Responses on Awareness of Present vs. Future Prediction and Confidence level

The means and standard deviations of participants' SAGAT scores in individual and team missions are presented in Table 7-4. Correlation coefficients (one-tailed) were computed to evaluate whether participants who had better awareness of the present situation were also better in predicting the future status. None of the correlation coefficients were high, $r = .26$, $p = .07$ for SAGAT in individual mission, $r = .21$, $p = .12$ for SAGAT of own situation in team mission, and $r = .20$, $p = .14$ or SAGAT of teammate's situation. The result did not support the hypothesized relationship, indicating that better knowledge of the present status did not guarantee better prediction of future status.

Table 7-4 Means and Standard Deviations for SAGAT and confidence ($N = 32$)

		Individual mission SAGAT	Team mission SAGAT _{Own}	Team mission SAGAT _{Teammate}
		<i>M</i> (<i>SD</i>)	<i>M</i> <i>SD</i>	<i>M</i> <i>SD</i>
SAGAT	Present	.77 (.11)	.73 (.11)	.66 (.16)
	Future	.52 (.18)	.42 (.21)	.38 (.24)
Confidence Level	Present	.80 (.17)	.73 (.18)	.75 (.26)
	Future	.61 (.24)	.46 (.31)	.45 (.39)
Over-confidence bias	Present	.03 (.19)	.00 (.17)	.10 (.29)
	Future	.06 (.27)	.04 (.34)	.07 (.46)
Absolute confidence bias	Present	.15 (.11)	.14 (.09)	.25 (.17)
	Future	.22 (.17)	.28 (.19)	.35 (.29)

In order to compare participants' responses across the awareness of present and future prediction, two 2 x 2 within subjects ANOVAs were conducted: one using SAGAT of own situation (in individual vs. team missions) and the other using different targets of SAGAT questions in team missions (own vs. teammate's situation). The result of the first ANOVA revealed a significant difference in the scores of SAGAT of own situation across individual and team missions, $F(1,31) = 7.93$, $p < .01$, and across the present and future prediction, $F(1,31) = 102.20$, $p < .001$. The interaction effect between the two was not significant, $F(1,31) = 3.32$, $p = .08$. Plots in Figure 7-2 shows that participants were generally better in answering SAGAT queries of own situation related to the present than

the future situation, and were more accurate in individual than team missions. The decrement in their accuracy to future status was higher in team compared to individual mission, but was not significant. The second ANOVA resulted in a significant difference across present and future status, $F(1,31) = 81.13$, $p < .001$, where the participants were more accurate in answering questions regarding the present than future status. There was no significant difference between SAGAT scores of own and teammate's situation in team missions.

Figure 7-2 Plots of 2 x 2 ANOVA for SAGAT of own situation

The means and standard deviations of participants' confidence levels on the accuracy of their SAGAT answers, over-confidence bias, and absolute confidence bias are also reported in Table 7-4. A score for over-confidence bias was calculated by the average confidence rating across all items minus the proportion of the same items (SAGAT queries) that were answered correctly (McGuinness, 2004). A positive bias indicates over-confidence and a negative bias indicates under-confidence. An absolute score of confidence bias indicates the distance from a well-calibrated zero-value of self awareness.

Similarly, two 2 x 2 ANOVAs on participants' **over-confidence bias** were performed to compare participants' responses across the awareness of present and future prediction, one using SAGAT of own situation (in individual vs. team missions) and the other using different targets of SAGAT questions in team missions (own vs. teammate's situation). Both ANOVAs showed no significant result.

Two 2 x 2 within subjects ANOVAS were also performed on participants' **absolute confidence bias**. The 2 x 2 (mission x SA level) within subjects ANOVA showed a significant difference between the absolute confidence bias for the present and future prediction, $F(1,31) = 23.00$, $p < .001$, where the participants were significantly more calibrated in how much they know about the present than future prediction. The 2 x 2 (target x SA level) within subjects ANOVA revealed a significant difference in the scores of SAGAT of own and teammate situation, $F(1,31) = 6.99$, $p < .05$, and across the present and future prediction, $F(1,31) = 12.64$, $p < .001$. The participants were less calibrated in SAGAT of teammate's than own situation, and for future than present status (see Figure 7-3).

Figure 7-3 Plots of 2 x 2 ANOVA of absolute confidence bias in team missions

7.3.2 Effect of Task Experience, Cognitive Ability, Role Assignment, and Familiarity on SA

The descriptive statistics of participants' cognitive test result are reported in Table 7-5. The result was compared with the statistics collected from previous studies reported in the ETS Kit manual. Except for Auditory Number Span test, all of the tests consist of two parts. In the current study, only Part 1 of the test was used due to limited time available, bearing that doing so would sacrifice the possibility to test the reliability of the result. Nevertheless, previous studies have reported high reliability values between part 1 and 2 of the test. A percentile rank was calculated to estimate a point where the sample collected in this study falls in the normal curve of the result reported in the manual.

Table 7-5 Cognitive test result of the participants ($N = 32$)

Test	Data from ETS Kit Manual				Current Study		
	Sample	M	SD	Rel	M	SD	%ile
Hidden figure	167 college males	14.0	6.4	.83	9.7	4.3	80
Number comparison	145 college males	26.6	4.8	.82	15.4	3.3	81
Cube comparison	46 college students	22.7	9.4	.84	11.4	5.3	50
Form board	46 college students	124.8	38.3	.81	66.3	23.0	58
Auditory number span	181 college students	8.3	3.2	.63	8.9	3.0	57
Building memory	542-574 Naval recruits	10.9	4.7	.80	9.9	1.9	97
Figure classification	288-300 males Suburban 11 th & 12 th graders	120.0	30.0	.77	69.3	23.6	73
Following direction	542-574 Naval recruits	10.4	3.8	.75	7.2	2.2	85
Math aptitude	83 army enlistees	14.0	-	.81	7.7	3.0	-

As there were numerous tests used to capture the cognitive ability of the participants, and considering the sample size of this study, it was necessary to reduce the number of variables before entering them into the multiple linear regressions. Dimensionality of the nine tests used to measure cognitive abilities of the participants was analyzed using principle components analysis. The scree test was used as the criteria for identifying significant factors in the analyses. The scree plot (Figure 7-4) suggested that the tests were uni-dimensional, thus the reported item loadings represent unrotated factor solution. Despite of the considerably small sample size used in the study, all item loadings were higher than .30, which is acceptable. The factor explained 41.3% of the total variance. A new set of scores for cognitive ability factor was then calculated by regression weighting of the respective tests.

Figure 7-4 Scree plot of the eigenvalues

Individual mission

A multiple linear regression analysis was conducted to evaluate the role of task experience, cognitive ability, and familiarity with opponent on individual SA. Regression analysis with SAGAT score as a criterion indicated no significant effect from any combination of task experience, cognitive ability, and familiarity with opponent. Task experience significantly predicted over-confidence bias, $F(1,30) = 5.51$, $p < .05$. The sample multiple correlation coefficient was .39, accounting for approximately 16% of the variance. This showed the tendency of the more experienced players to be more over-confident, thinking that they knew more than they actually did. Variance in absolute confidence bias was also significantly accounted by task experience, $R^2 = .14$, $F(1, 30) = 4.78$, $p < .05$. Finally, the results indicated that task experience accounted for a significant amount of the variability in SA self-rating, $R^2 = .14$, $F(1,30) = 4.69$, $p < .05$, indicating that participants with higher experience tended to rate themselves higher in SA. In summary, task experience accounts for the most variance in individual SA.

Further exploration was conducted to determine the specific cognitive ability test that associates with SA. The bivariate and partial correlations (controlling for CS experience and familiarity with opponent) between each cognitive test and individual SA scores are reported in Table 7-6. Building Memory, Following Direction, and Math Aptitude tests consistently had moderate bivariate and partial correlations with SAGAT scores.

Table 7-6 Bivariate and partial correlations between cognitive tests and individual SA

	Bivariate correlation		Partial correlation (control: experience)		Partial correlation (control: experience, familiarity with opponent)	
	SAGAT	SA self- rating	SAGAT	SA self- rating	SAGAT	SA self- rating
Hidden figure	.07	.16	.09	.11	.10	.13
Number comparison	.05	-.09	.07	-.13	.07	-.13
Cube comparison	.19	-.11	.20	-.16	.24	-.11
Form board	.05	.03	.09	-.05	.09	-.05
Auditory number span	-.09	.16	-.07	.11	-.07	.11
Building memory	.32*	-.25	.30*	-.21	.35*	-.17
Figure classification	.09	-.09	.09	-.11	.09	-.12
Following direction	.37*	-.14	.37*	-.12	.37*	-.14
Math aptitude	.34*	.01	.33*	.06	.36*	.11

$N = 32$; * $p < .05$ (one-tailed)

Team mission

One of the objectives of this study was to evaluate the prediction of each aspect of team SA from task experience, cognitive ability, and familiarity with teammate and opponent. To examine these issues, a step-wise regression was performed on each measure of team SA. For each resultant model, variables included in the model were submitted to independent regressions to verify their unique contribution to the model. Only models with significant partial correlations (controlling the other predictors) between the individual predictor and criterion are reported here. The analyses were conducted in team level, taking the average of the scores collected at the individual level to represent the team score.

The linear combination of task experience and familiarity with opponent was significantly related to SAGAT of own task score, $F(2,13) = 6.25$, $p < .05$. The multiple correlation coefficient was .70, indicating that approximately 49% of the variance in SAGAT of own task can be accounted for by the linear combination of these predictors. The bivariate correlations between SAGAT of own task with task experience and familiarity with opponent were .59 ($p < .01$) and .26 ($p = .16$), respectively. The partial correlations were .67 ($p < .05$), .47 ($p < .05$), respectively.

The regression on SAGAT of teammate's situation scores was not significant with task experience and familiarity with teammate included as predictors, $F(2,13) = 3.34, p = .07$. The bivariate correlations between SAGAT of teammate's task and task experience was .51 ($p < .05$), and between SAGAT of teammate's task and team familiarity was .46 ($p < .05$). The partial correlations were .41 ($p = .07$) and .33 ($p = .12$) respectively. The regression model produced by including only task experience as predictor was statistically significant, $F(1,14) = 4.92, p < .05$. However, it was not possible to conclude that task experience was the only useful predictor because it is difficult to dismiss the potential existence of correlation between task experience and team familiarity, $r = .39, p = .07$. Since the participants signed up for the experiment as teams, it was suspected that the members within the same team had similar CS gaming history, and that most likely they gained the task experience through playing together with teammate.

The result of linear regression analysis on self-rating of SA indicated that task experience and familiarity with teammate did not account for a significant amount of the variability in SA self-rating, $R = .59, R^2 = .34, F(2,13) = 3.78, p = .07$. The bivariate correlations between self-rating of SA and task experience was .51 ($p < .05$), and between self-rating of SA and familiarity with teammate was .47 ($p < .05$). The partial correlations were .40 ($p = .07$) and .34 ($p = .11$) respectively. The regression model produced by including familiarity with teammate as the only predictor was statistically significant, $F(1,14) = 3.93, p < .05$. However, due to the potential moderate correlation between task experience and familiarity with teammate, it was not possible to conclude that the variance self-rating of SA was only contributed by familiarity with teammate.

Significant variance in over-confidence bias was accounted by familiarity with teammate, $F(1,14) = 9.66, p < .01$. The correlation coefficient was .64, explaining approximately 41% of the variance in over-confidence bias. This suggested that there was a tendency for teams who had played very frequently with teammate to be over-confident towards the quality of their situational knowledge. The regression on absolute confidence bias did not show significant prediction from any of task experience, cognitive ability, and familiarity with teammate and opponent.

None of the regression models resulted in a significant prediction to awareness of teammate's workload and SA levels. Similar to the result found in Study 3, the

participants in this study were relatively consistent in their ratings. They had a tendency to provide a similar rating for self and teammate's workload ($r = .83, p < .01$) and awareness level ($r = .78, p < .01$). However, one's self-rating did not always similar to what was estimated by his teammate, i.e., $r = .01$ ($p = .48$) for workload level and $r = .36$ ($p < .05$) for awareness level. Comparing the effect size across the input variables, it seems that task experience is the one that accounts for the most variance in team SA.

7.3.3 SA and Team Processes

Pearson's product-moment correlations between various team process measures and each aspect of team SA are presented in Table 7-7. CAST and communication frequency were team level measures. The other scores were collected at individual level and were averaged to represent the team scores. The results showed mixed of significant and non-significant correlations. All of the correlations between self-rating of teamwork behavior and self-rating of SA were high, which can be attributed by the consistency in participants' subjective ratings. Similar to the previous CS study, better information transfer was associated with better SAGAT of own situation. The associations between helping behaviors (seeking feedback and providing feedback and backup whenever needed) and SAGAT scores found in the previous study were not replicated here. Instead, helping behaviors had significant correlations with over-confidence bias. Providing assistance and backup were also associated with better awareness of teammate's workload and SA levels, suggesting that helping and backup behavior were more effective if team members knew when their teammate needed such assistance, such as when overloaded or losing awareness. The associations between communication frequency and team SA measures were also not consistent with the previous study. Teams who engaged in more planning were shown to have higher over-confidence bias. Teams who shared information and provided feedback more frequently were also better scores in SAGAT of own situation. Finally, it was rather puzzling to find that teams who had poorer awareness of teammate's SA communicated more responses and acknowledgment.

Table 7-7 Correlations between SA and team processes

	SAGAT Own	SAGAT Tmate	SA self- rating	Over- conf. Bias	Abs. conf. bias	WL Aware	SA Aware
Teamwork (self-rating)							
Understand team goal(s)	.26	.39	.60**	.41	-.28	.23	.18
Understand team strategy	.32	.46*	.80**	.38	-.35	.11	-.03
Understand own role(s)	.14	.43*	.86**	.36	-.26	.15	-.01
Execute duties	.38	.30	.78**	.33	-.19	-.11	-.15
Respect teammate	.44*	.30	.54*	.47*	-.16	-.08	-.04
Transfer information	.44*	.30	.63**	.43	-.09	.17	.17
Provide feedback	.38	.30	.63**	.49*	-.01	-.10	-.05
Seek feedback	.36	.31	.71**	.51*	-.10	-.06	-.23
Assist when needed	.12	.00	.47*	.38	.34	-.45*	-.28
Back-up when needed	.31	.14	.54*	.58**	.26	-.44*	-.44*
CAST	.52*	.19	.49*	.40	-.10	.05	-.04
Frequency of thought units							
Planning	.20	-.01	.13	.48	.19	.13	.36
Information transfer	.49	-.01	.07	.16	-.28	.26	.12
Information request	.40	.02	-.18	.23	.20	.13	.27
Response	.31	.03	-.28	.04	.20	.18	.48
Feedback	.44	.23	.18	.12	.07	-.32	.21
Acknowledgement	.10	.09	-.15	.14	.11	.30	.58
Others	.30	-.26	-.10	.23	.12	.15	-.12

$N = 16$; TW behavior & CAST: * $p < .05$; ** $p < .01$ (one-tailed); Comm. freq (two-tailed)

7.3.4 Inter-correlations among Aspects of Team SA

The inter-correlations among the team SA measures are reported in Table 7-8. The analyses were performed in team level, taking the average of team members' score to represent the team score. The correlation between the two SAGAT scores were moderate, $r = .46$, $p < .05$. Self-rating of SA had moderate correlation with SAGAT of teammate's situation and over-confidence bias, i.e., $r = .44$, $p < .05$ and $r = .46$, $p < .05$, respectively. None of the awareness of teammate's workload and SA levels correlated highly with the rest of team SA measures. However, participants with better awareness of teammate's

workload were shown to have better awareness of teammate's SA level too, $r = .46$, $p < .05$.

Table 7-8 Inter-correlation among measures of team SA

	SAGAT Own	SAGAT Tmate	SA Self- rating	Over- conf.bias	Abs. conf.bias	WL aware	SA aware
SA _{Own}							
SA _{Tmate}	.46*						
SA self-rating	.24	.44*					
Over-conf. bias	.38	.07	.46*				
Abs. conf. bias	-.42	-.34	-.23	.09			
WL aware	-.15	-.00	.00	.21	-.01		
SA aware	-.05	.25	-.26	-.12	.22	.46*	

$N = 16$; * $p < .05$ (one-tailed)

7.3.5 Team SA and Performance

In this study, the participants played against each other, and thus the performance score was tied to the opponent participant who played in the same game. The existence of active resistance, i.e., the opponents directly trying to prevent the team from accomplishing its goals, can increase the uncertainty, where the outcome of a team does not only depend on its capability and team processes, but also depends on the capability and processes of the opponent team. As the players' experience levels within one game were balanced, the losing team in that game was not necessarily worse than the winner of the other game. Two observers identified four teams who performed well and four teams who performed poorly from the entire pool of subjects. Independent-samples t tests were conducted to evaluate whether the better performers also obtained higher scores in the team SA measures. The comparison between the better and worse team performers is shown in Table 7-9. The better teams attained higher scores in answering the SAGAT queries, rated themselves higher in SA, were more over-confident, and had less absolute confidence bias. The better performing teams on the average also showed better team SA processes than the poorer teams. Note that the overall teamwork behavior was represented by an average of the ten teamwork behavior rated by team members. The members of better and poorer performing teams, however, did not differ significantly in their

awareness of teammate's workload and SA. In summary, differences in team performance seem to be best indicated by differences in team processes measured by CAST.

Table 7-9 Comparison between better performers and worse performers

	Better performers <i>M (SD)</i>	Worse performers <i>M (SD)</i>	<i>t</i> -test (two-tailed)
SAGAT _{Own}	.80 (.02)	.65 (.09)	3.13, $p < .05$
SAGAT _{Tmate}	.78 (.09)	.60 (.10)	2.54, $p < .05$
SA self-rating	6.13 (.66)	4.44 (.83)	3.19, $p < .05$
Over-confidence bias	.04 (.07)	-.06 (.06)	2.48, $p < .05$
Abs. confidence bias	.11 (.02)	.20 (.08)	-.2.26, $p = .06$
WL aware	.31 (.13)	.56 (.66)	-.75, $p = .48$
SA aware	.44 (.55)	.75 (.41)	-.91, $p = .40$
CAST	.65 (.07)	.44 (.08)	4.01, $p < .01$
Teamwork behavior	6.13 (.62)	4.89 (.43)	3.32, $p < .05$

$N = 4$ in each group

7.4 Discussion

7.4.1 Prediction of Future Status

Endsley (1995c) implied that projection of future status requires an accurate understanding of current status. The result of this study however showed a low association between participants' awareness of the present situation and the accuracy of their prediction. The result also showed that the scores on the future status were significantly lower than the present status. This is possibly resulted by the task nature that was highly dynamic, with much uncertainty involved. Wickens (1986) noted that the accuracy of prediction decreases with time, and the rate of this decrement is sharper when system time constant is shorter and the input disturbance is greater. In CS game, the system has low inertia and short time constant. The close proximity of fighting involved in urban warfare imposes additional compression in time and space. As a result, changes in one's situation take place rapidly (practically in a matter of a second). In addition, one's current anticipation of what is going to happen influenced his behavior, and this behavior further changed what actually happens in the future. As a result, one's accurate prediction collected during the freeze points may not be accurate when compared to what

really happened 10 seconds later. Wickens et al. (2000) also noted that the accuracy of prediction is further reduced by the existence of force acting on the system, such as human opponents, who may be inclined to input unanticipated control movement at any time. In this study, the existence of other human players as teammate and opponents further complicated the matter. As shown in the result (see Figure 7-2), the accuracy of future prediction decreased dramatically in team mission. Sudden changes in any player's intention can change the overall situation, and thus can make the previously accurate prediction (given everything continued in the same pattern) become inaccurate. There are numerous choices of actions to take, such as to camp and wait, hide, run quickly, duck slowly, etc, and there is little restriction that frames the choice of actions at any point in time, and this increases the uncertainty tremendously.

If a player kept updated with the changes and was able to adjust his actions quickly, his SA should be considered as good, although his prediction, compared to what actually happens, had become inaccurate due to the changes in situation. Consider a case scenario extracted from the simulation described as follows. The detail of changes evolved in the situation is available in Table 7-10.

The four players involved in this scenario were among the most experienced players in the pool of subjects, with CS playing years of 5, 6, 9, and 9 years, and CS knowledge score of 12, 12, 13, and 11 out of a maximum 13 points. A while after the game started, one of the terrorists (T1) decided to go out from the warehouse and camp on the rooftop². The other terrorist (T2) decided to camp inside the warehouse, near the back door. The counter-terrorists (CT2 followed by CT1) initially intended to sneak in through the front door, observed the situation, and then decided to go in through the back door. When they were about to reach the back door, they were detected by T1 who was camping on the rooftop. T1 started to shoot CT2. At the same time, CT1 also identified T1, and started firing. CT2 did not perceive the existence of T1 on the rooftop, but understood that T1 was somewhere near and firing him. CT1 transferred the information that the T1 was on

² In the game, there were four hostages kept inside the warehouse and guarded by the terrorists. The objective of the counter-terrorists was to rescue the hostages or kill all the terrorists. The terrorists should prevent this from happening by killing the counter-terrorists. When the game started, the terrorists were stationed inside the warehouse, while the counter-terrorists were outside.

the rooftop, by saying “Upstairs! Upstairs!” while he was firing. T2, who was inside the warehouse, also did not perceive the existence and location of the enemies, but T1 passed the information by saying “They come!” when he saw the two counter-terrorists approached the warehouse. Understanding that his teammate was on the rooftop, T2 could assume the location of the two counter-terrorists. The game was paused a second after detection of the opponent player.

According to the responses to the SA probes, T1 predicted that he will be killed within the next 10 seconds if he stays in the same location, and the two counter-terrorists would go in through the back door and kill T2 who will still be hiding behind the back door. T2 anticipated that one of the counter-terrorists would go up to the rooftop, chase and kill T1, while he is going out to kill the other counter-terrorist. CT1 predicted that the two terrorists (whom he thought were on the rooftop) would run away from shots, while CT2 predicted that both teams would engage a direct contact. Eventually, after the game resumed, T1 continued to fire for about two seconds and decided to move away from the edge of the rooftop as he thought he might not be able to handle the two counter-terrorists, who started to throw grenades at him. T2 went out to provide back up and started shooting the counter-terrorists. Making a few random shoots, he realized that his position was not of an advantage and thus decided to retreat into the warehouse. Hearing shots, CT2 realized the existence of T2 and informed CT1. They then decided to go back to the original position, away from the warehouse.

In the above case, the players’ intention changed just within a few seconds and it influenced the whole scenario. For instance, T1’s prediction captured by SAGAT would have been accurate if he did not change his intention. However, as he was aware of the risk and anticipated that he would die if he continued to contact the two counter-terrorists, he decided to retreat, which was an appropriate action to survive. Similarly, T2, who initially expected that one of the counter-terrorists would be going up to the rooftop and thus leaving the other one outside the backdoor, went out thinking that he could take down the second counter-terrorist. However, when he realized that his prediction was inaccurate, he quickly went back into the warehouse before being killed by the two counter-terrorists who were just outside the back door. On the other hand, the two counter-terrorists realized that their enemies were attacking from two different directions, and thus decided to retreat and re-strategize. Scoring the accuracy of prediction by

comparing the responses to SAGAT queries and what actually happened would result in low SA scores for the four players. However, through observation, it can clearly be seen that they actually kept updated with the changes involved and made quick and indeed good decisions and actions based on the assessment of the situation and their capabilities.

As a result, the level 3 SA scores obtained by comparing the participants' answers with the actual scenario resulted in invalid inference regarding the participants' SA. This does not mean that prediction is not important for performance in CS. The anticipation of what is going to happen influences the decision of what action to perform, which in turn changes the situation that occurs next. The assessment tool used in this study failed to capture this prediction reliably. Perhaps the SAGAT queries were not phrased properly to allow an objective comparison between the answers and the actual situation. On top of all, main reasons for the failure to capture SA level 3 were due to tremendous uncertainty as there was no rule of actions (everybody can do anything he likes at anytime he wants), and the extremely dynamic environment due to space and time compression of the task. In other words, the high bandwidth of the simulation itself presents an upper bound of prediction that is possible.

The result also showed the tendency of participants to be less confident in their answers to future prediction. This trend of appropriate calibration is the same as a study by Lichacz et al. (2003), who reported that the participants in their study rated lower confidence towards level 3 compared to level 1 and 2 SAGAT answers. The distribution of over-confidence bias range from under-confident to over-confident, reflecting that some participants felt less confident on what they knew while others thought that they knew more than they actually did. Some participants, who were not sure on the answers to SAGAT queries, were allowed to write down their guess and asked to rate "low" in the respective confidence level. As a result, under-confidence bias partly represents the number of guessed answers given by the participants. Absolute confidence bias denotes the calibration of participants' self awareness. The absolute confidence bias of participants' responses to future situation is shown to be higher than the present situation, indicating that they were more calibrated and more aware of what they know and do not know at the present as compared to future prediction.

Table 7-10 Example of rapid changes in situation as extracted from the recorded mission

Time	Communication	Terrorist 1	Terrorist 2	Communication	Counter-terrorist 1	Counter-terrorist 2
4:50 4:46		Camped inside the warehouse	Camped inside the warehouse	CT1 “Be careful!” CT2 “Go in through back door?”	Went towards the front door of the warehouse	Went towards the front door of the warehouse
4:44	T1 “Don’t get caught by them”	↓	↓		↓	↓
4:38				CT1 “Go through back door “		
4:37				CT1 “Be careful [they may shoot from] upstairs”		
4:32		Went out from the back door Climbed up to the rooftop	Camped inside the warehouse, near the back door		Decided to go in through the back door instead	Followed CT1
4:25	T1 “They may come from this direction, look carefully”	↓	↓		↓	↓
4:23	T2 “I know”					
4:20		Detected two CTs walking towards the back door			Detected T1 on the rooftop	Received shots from T1
4:19	T1 “They come!”	Started firing CT1	↓	CT1 “Upstairs! Upstairs!”	Started firing T1	
4:18	[Freeze]

4:16		Firing CT1	Went out through the back door, started to shoot the CTs		Threw grenade towards the rooftop	Threw grenade towards the rooftop
4:15		Retreat, went towards the vent	Retreat back into the warehouse through the back door	CT2 “There is an enemy at the back door”	Retreat towards the front part outside the warehouse	Retreat towards the front part outside the warehouse
4:12	T1 “Did they see you?”					
4:10	T2 “They saw me”					
4:08		Ducked in the vent, going back into the warehouse

7.4.2 Factors Influencing Team SA

This study investigates the effectiveness of task experience, cognitive ability, and familiarity with teammate and opponent in determining SA of the participants. In individual mission, task experience contributed significantly to over-confidence bias and self-rating of SA. Participants with more experience tended to see themselves having high SA, and sometimes higher than what they actually achieved. In team mission, awareness of the situation related to own responsibilities can be significantly predicted by a linear combination of task experience and familiarity with opponents. Task experience and familiarity with teammate were predictive to the awareness of teammate's situation and self-rating of SA. Familiarity with teammate also contributed significantly to the tendency of participants to be over-confident on the quality of their situational knowledge. The role of task experience for SA has been much discussed in the literature and also in the previous study. What is interesting and important to discuss more is the role of familiarity with teammate and opponents for team SA, as it has not been much reported in the literature.

Familiarity can develop through social and task interaction. All participants in this study were familiar in the social context; they were childhood friends, classmates, or members of the same clubs and societies. The variable tested was on the familiarity in performing the task together, that is, how much the participants within the same experimental session knew each other in the context of CS, as measured by the frequency of playing CS together. Performing a task together for a certain period of time can facilitate the development of mental model regarding teammate's knowledge, ability, behavior, strategy, and preferences. This mental model of teammate can help a top-down processing, which facilitates the development of team SA, especially when there is a lack of cue from the environment. The impact of familiarity with team members on the team SA seems to be beneficial. As shown in this study, it helps the development of awareness related to teammate and enemy. However, it can also increase team members' over-confidence, which can have bad impacts on decision making and performance.

The overall cognitive ability did not have significant effect on SA in either individual and team missions. Analysis on each cognitive ability test reported in Table 7-6 revealed that Building Memory, Figure Classification, and Math Aptitude had moderate correlations

with individual SAGAT scores. None of the tests of spatial ability correlated highly with SA in this study. This is perhaps because all of the participants were familiar with the map used in the simulation. Instead, spatial memory, as measured by Building Memory test, was found to have moderate correlation with SAGAT score. Spatial memory is needed to remember the location of each player and report them on the map provided in the SAGAT assessment. The role of visual memory for developing and maintaining SA in a spatially demanding task has also been reported in previous research (Johannsdottir, 2004; Logie et al., 1989; Sohn & Doane, 2004). Following Direction and Math Aptitude assess the reasoning domain of cognitive ability. In environment with high uncertainty and scattered information, reasoning ability is important to integrate data from various resources to build a mental picture of the situation. Similarly, Endsley & Bolstad (1994) reported moderate correlation between pilot's knowledge of the location of the enemy aircraft and Raven's Advanced Progressive Matrices (measure of pattern recognition); Carretta et al. (1996) showed high correlation between pilot SA and Rapid Serial Classification (reasoning test).

The low to moderate correlations between cognitive ability tests and SA found in this study are possibly due to the relatively low complexity involved in performing the tasks. Devine & Philips (2001) suggested that the relationship between cognitive abilities and performance would be stronger for complex tasks compared to simple tasks. In CS, the players simply need to detect the existence of the opponent (level 1 SA) and take action to eliminate the opponent. Once the players perceive the existence of the opponent, they had to react quickly otherwise he will be possibly be eliminated first by the opponent. This imposes high risk (being eliminated) and time pressure to the individual player, which would force him to apply rule (shoot the enemy once seen) straight away, rather than taking a long time to cognitively process and make decision on what action to take. This flow is noted in red on the decision process model by Orasanu & Fischer (1997) shown in Figure 7-5. This behavior can also be associated with what Rasmussen (1986) referred as *skill-based* behavior, where assignment of stimuli to response is done in a rapidly and automatically, using minimum cognitive resources. Such automatic selection of action is also facilitated by the experience of participants in CS (in this study, all participants had played CS for at least one year).

Figure 7-5 Decision Process Model (Orasanu & Fischer, 1997)

As shown in Table 7-7, there are associations between team processes (measured by information transfer and CAST) and team SA (measured by SAGAT and self rating). Team interaction is needed to share team members' perception and status update, which is crucial for the development of team SA. This is particularly applicable when team members are distributed in the physical or virtual space. Consider the situation described in Section 7.3.1, the CT2 had no access to the information of the terrorists, but his situational model was updated by information communicated by CT1. Another example of sharing information to build a big picture of the team situation can be seen from the following communication transcript.

<u>Time</u>	<u>Player</u>	<u>Thought Units</u>
4:40	T2	you are at the opposite, right?
4:39	T2	there's somebody at the garage door
4:37	T2	it's him at the door..
4:37	T2	I can see him from here
4:36	T2	one is near your location
4:34	T1	ok, we just shoot from upstairs
4:08	T1	there's somebody, somebody
4:06	T1	he is just running around there
4:05	T2	do you see him?
4:04	T1	just come down if you can
4:01	T1	Somebody on top

4:00	T1	Somebody on top
3:53	T2	vent... vent
3:48	T1	go there, go there, ambush!

The lower correlation coefficients between information sharing and SAGAT scores in this study as compared to Study 2 may be attributed by the fact that all of the teams were familiar to each other prior to the experiment. Previous research has indicated that teams with familiar members would have better shared mental model, which can facilitate team interaction through implicit coordination (Espinosa et al., 2004). The frequency of playing CS together can develop a mental model of teammate's preferences and habit, such as what kind of weapon he prefers to use, his favorite places to camp, his playing strategy, and so on. This mental model of the team can help in the development of team SA, relying less on the explicit sharing of information.

7.4.3 Aspects of Team SA and Implication on Performance

The result in Table 7-8 showed high correlations between SAGAT of own and teammate's situation, indicating that participants who were more aware of own situation, were also more aware to what was happening to their teammate. The inter-dependency nature of the task requires the participants to be aware of his teammate's status. However, development of SA requires cognitive resources (Lundberg, 1999), and acquiring awareness of teammate imposes additional resources on top of the resources spent to develop an understanding of own situation. A team member who has the ability to gain awareness of own situation would be more likely to have the extra resources to attend to his teammate, as compared to the one who is not even able to form the awareness of own situation. The ability to attend to teammate's situation seems to contribute to the perception of the level of SA achieved, such as shown by the high correlation between self-rating of SA and SAGAT of teammate's situation. It is also interesting to note the high correlation between self-rating of SA and over-confidence bias, as this suggests that the self-rating of SA is more related to a person's perception of his awareness rather than what he really knows. The similar finding was also reported in a study by Endsley et al. (1998b), who found high correlation between subjective rating of SA and confidence level, but not with SAGAT. The other inter-correlations between the team SA measures were not high, implying that these measures are non-overlapping and targeting different aspects of team SA.

Evaluation of team SA with respect to performance reported in Table 7-9 showed that better performers were better in their SAGAT scores related to own and teammate's situation, rated higher in their SA, and had better team processes measured by CAST and self-rating of teamwork behavior. This confirms the importance of team SA in achieving better performance. Better performers were found to be more over-confident on their situational knowledge, and poorer teams were indeed under-confident. As the participants were allowed to write down their responses although they were unsure, and were asked to tick "low confidence" for such responses, under-confidence can be resulted by correct or lucky guesses. Poorer performing teams were shown to have significantly poorer calibration on what they knew (more over-confident or under-confident) compared to the better performing teams. A good calibration means good self-awareness or meta-SA, knowing what one knows and does not know. The better and poorer performing teams however did not differ in terms of awareness of teammate's workload and SA levels. Being aware to teammate's workload and SA levels will facilitate an initiation of providing assistance and backup whenever teammate is overloaded or incapacitated. This is supported by the high associations between the two awareness scores with participants' ratings of assistance and backup behavior. However, if the support or backup is not done effectively, good awareness in teammate's status may not be translated into good performance.

7.5 Summary

This study investigates the influence of task experience, cognitive ability, and familiarity with teammate and opponent for SA in individual and team missions. The influence of task experience and familiarity with teammate were apparent. The relatively low effect of cognitive ability on SA was suspected to be due to the limited cognitive complexity involved in the task. There were also significant associations between team SA and processes (measured by self-rating of teamwork behavior in information transfer and helping behavior and observer evaluation using adapted CAST). In addition, the study reveals the non-overlapping relationship between team SA measures. Each type of methods targets on different aspects of team SA. With respect to performance, better and poorer performing teams were shown to be different in their SA, where better teams had better scores in most of the team SA measures. This finding is in line with previous

research that proposed good SA would increase the probability of achieving better performance.

In order to compare the results of this study to those found in Study 2, a bivariate space was constructed (Figure 7-6) with effect size (variance accounted for, r-squared) of the results of Study 2 on the x-axis and Study 3 on the y-axis. The data points on the upper right corner and the lower left corner are strong replications. Task experience consistently showed high correlations with SAGAT of own and teammate's tasks, and self-rating of SA. The correlations between SAGAT of own task and information transfer, between SAGAT of own task and SAGAT of teammate's task, between SAGAT of teammate's task and self-rating of SA, and between self-rating of SA and helping behavior, also showed consistent high correlations. On the other hand, the correlations between awareness of teammate's workload with information transfer, helping behavior, SAGAT of own task, self-rating of SA, and between awareness of teammate's SA and information transfer, were consistently low. The rest of the results were not consistent and these could be reasoned due to the slight difference in the methodology used in the two studies. For instance, the correlations between helping behavior and SAGAT of own and teammate's tasks Study 2 were high, but not in Study 3. This may be attributed by the fact that in Study 3, the teams were familiar to each other prior to the experiment, and thus would likely have a mental model about teammate's behavior. When such mental models do not exist (in Study 2), team members would need to rely more on the understanding of own and teammate's task in order to provide effective help to teammate's needs.

Finally, it should be admitted that this study failed to capture the prediction aspect of SA, which was factored in by the limitation of the method used, and uncertainty due to unlimited choice of actions available to the participants, and rapid changes of the situation. This study will be replicated in Study 4, by involving fighter pilots performing air combat missions. It is reckoned that the nature of task in Study 4 will allow a better assessment of future prediction, unlike in Study 3. The existence of standard rules and military doctrine frames and limits the number of possible actions that can be taken by fighter pilots, which would form the baseline for possible prediction to be done. In addition, the participants are asked to provide a brief reasoning on their prediction, which will be useful to justify whether the prediction is done based on valid reasoning or purely based on guess. Similar to Study 3, Study 4 will also investigate the role of task

experience and cognitive abilities relevant on SA. However, Study 4 will not only investigate the relationship between task experience and team SA, but further examine the impact of diversity in experience in team composition.

Note: the numbers above represent the correlations between variables on the table below:

	SA _{Own}	SA _{Tmate}	SA self-rating	WL Aware	SA Aware
Task experience	1	2	3	4	5
Information transfer	6	7	8	9	10
Helping behavior	11	12	13	14	15
SA _{Own}	-	-	-	-	-
SA _{Tmate}	16	-	-	-	-
SA self-rating	17	20	-	-	-
WL Aware	18	21	23	25	-
SA Aware	19	22	24	26	27

Figure 7-6 Effect size of Study 2 versus Study 3

Chapter 8 Study 4: Investigating the Relationships between Cognitive Ability, Diversity in Experience, Team Processes, and SA

Teams of fighter pilots performing air combat were simulated and analyzed to investigate whether findings generated from the previous studies also show the same trends in a more complex task. Particularly, this study aimed to investigate the influence of task experience and cognitive ability on SA, the inter-relationships among the aspects of team SA, and the impact of SA on decision making and performance.

8.1 Theoretical Basis and Hypotheses

Participants' responses in awareness of present vs. future prediction and confidence level
(please refer to Study 3 Section 7.1 for the theoretical basis of this hypothesis)

- H1a: better awareness of the present situation (level 1 and 2 SA) will be associated with better prediction of the future situation (level 3 SA)
- H 1b: there will be differences in confidence bias of present (level 1 and 2 SA) and future status (level 3 SA)

Role of cognitive ability and diversity in experience on SA

Similar to previous studies, Study 2 and 3 showed some supports to the role of experience (Doane et al., 2004; Randel & Pugh, 1996) and cognitive abilities (Carretta et al., 1996; Endsley & Bolstad, 1994; O'Hare, 1997). It is suspected that these findings will be replicated here despite of the difference in task nature. In addition, this study extended to investigate the impact of team composition. In team level, differences in the way the team is composed can introduce additional variations in the level of SA achieved by its team members. Milliken & Martins (1996) and Pelled (1996) suggested that heterogeneity in demographics of team members (e.g., age, gender, race, team tenure, education, and functional background) can affect the task and social interaction within the team. Team members with different backgrounds have dissimilar schemas, belief structures, and assumptions due to previous training and experiences. As a result, they may have different expectations and interpretations of the same situation, face difficulties in

communication, spend more energy to resolve conflicting perspective, and have weaker social cohesion (Pelled et al., 1999; Webber & Donahue, 2001). However, Milliken & Martins (1996) reported that a greater variety of perspectives can also have positive cognitive outcomes, such as reducing groupthink and producing higher quality decisions. Argote & McGrath (1993) suggested that the different impact of diversity may be due to the characteristics of tasks performed by the team. In time-critical and high risk tasks, diversity may not result in favorable outcomes, because of the limited time available to resolve team members' differences. For instance, in aviation industry, improper crew pairing that result in "trans-cockpit authority gradient" (a term used to refer the pairing of very senior and very junior pilots, usually in dual-seat cockpits) has been identified as one source of commercial aviation accidents (Shappell & Wiegmann, 2000). Alkov, Borowsky, Williamson, & Yacavone (1992) examined the difference in military rank of pilot and co-pilot and the occurrence of Navy and Marine Corps helicopter mishaps. They reported that pilots differed by two or more ranks yielded the largest error rate, and pairing of equal ranks yielded the lowest rate. Findings from previous studies in a similar task domain suggested the negative impact of heterogeneity on team performance. It is plausible to expect that its impact on team SA would be in the negative direction as well.

H 2a: participants with better task experience and cognitive ability will have better SA

H 2b: teams composed by individuals with high difference in experience will have poorer team SA compared to those with similar experience level.

SA and process in team missions

(please refer to Study 2 Section 6.1 for the theoretical basis of this hypothesis)

H 3: better team processes (measured by self ratings of teamwork behavior, observer's evaluation, and communication frequency) will be associated with better team SA

Inter-correlations among aspects of team SA

(please refer to Study 2 Section 6.1 for the theoretical basis of this hypothesis)

H 4: better awareness in one aspect of team SA (e.g., awareness of own situation) will not be associated with better awareness in the other aspects of team SA (e.g., awareness of teammate's task)

Correlations of SA and performance

(please refer to Study 2 Section 6.1 for the theoretical basis of this hypothesis)

H 5: better SA will be associated with better performance outcome

In addition, the study also aimed to identify the variable that matters most, i.e., the variable that accounts for the most variance in SA and performance.

8.2 *Experiment Design*

8.2.1 Task

The nature of air combat is complex and dynamic, and it involves high risk. A good team SA is required for fighter pilots to work together in a coordinated manner, so as to maintain mutual support that is vital for combat performance. For instance, taking turns making attacks and covering for each other effectively during air combat would require the pilots to have high SA on the task and on teammate's status. Poor team SA can result in poor coordination and misuse of resources, such as launching missiles at the same target, not taking over the targeting when teammate is out or aborting, etc.

Air combat environment was simulated using a PC-based simulation game, Falcon 4.0. The F16 cockpit simulated by Falcon 4.0 is shown in Figure 8-1. The game provides a detailed and realistic simulation F16 fighter jet cockpit. It allows multiplayer mode and scenario customization through modification of enemy characteristics and firepower, flight path, and time on target³. Two fighter pilots were involved in each experimental session. The team goal was to sweep all adversaries along the assigned navigation route. An additional objective to reach a designated checkpoint at specific time was incorporated such that the participants would meet the pre-programmed enemy aircrafts at the targeted location and specified aspect angle⁴. This was to control for similar exposure across all the participants. As the two aircrafts flew together along the navigation route indicated, the pilots would ideally share the awareness related to the navigational route and the enemy's information. Although the pilots were likely be exposed to the same information regarding the navigational and the enemy, due to the criticality of the mission, sharing of perception and integration of information through various team

³ Time at which aircraft are scheduled to reach/attack the target

⁴ The relative angle between the path of the target(enemy aircraft) and the beam of the radar observing it

interaction processes were still necessary to keep both pilots updated and have an accurate picture of the overall team situation. This is particularly important for the flight lead, so that he can effectively coordinate the team towards a mission success. With regards to inter-dependence, as the adversaries that were designed to appear in a group of two-ship aircraft, the pilots needed to work together closely to execute tactics required to increase the probability of gaining the upper hand to take down all adversaries while maintaining survivability. With this high inter-dependence, team members were also expected to be aware of their teammate's task status, workload, and awareness level.

Figure 8-1 Screen shot of F16 cockpit simulated by Falcon 4.0

A goal-directed task analysis (Endsley, 1995a) was used to derive SA requirements and SAGAT probes. The analysis identified the major goals and sub-goals of the mission, major decisions that have to be made towards achievement of each sub-goal, and the SA needed for making the decisions. A goal-directed task analysis and a list of SA requirements derived from the task analysis are shown in Figure 8-2 and Table 8-1 respectively.

Figure 8-2 Goal-directed task analysis of a typical air combat mission
The breakdown of each of the three sub-goals is shown in the following figures

Figure 8-3 Goal-directed task analysis of aviating

Figure 8-4 Goal-directed task analysis of combating

Figure 8-5 Goal-directed task analysis of surviving

Table 8-1 Individual and team SA requirements

Level 1: Perception	Level 2: Comprehension	Level 3: Projection
<ul style="list-style-type: none"> - Current position, heading, attitude, altitude, airspeed - Location of next checkpoint - Current time - Specified time on target 	<ul style="list-style-type: none"> - Flight path - Deviation between current flight path and planned navigational route - Time left to reach next checkpoint - Distance to next checkpoint 	<ul style="list-style-type: none"> - Prediction of possibility to reach next checkpoint maintaining current heading - Projected time to reach next checkpoint maintaining current speed
<ul style="list-style-type: none"> - Existence of other aircraft - Aircraft status (friendly/ foe) - Type of enemy's aircraft - Enemy's position, heading, attitude, altitude, airspeed - Detection of spike/ being locked/ missile launch by enemy 	<ul style="list-style-type: none"> - Enemy's weapon employment zone - Threat determination & level of threat - Enemy's flight path - Relative position of enemy to own aircraft: bearing, range 	<ul style="list-style-type: none"> - Projected trajectory of enemy aircraft relative to own - Projected point and time of contact - Predicted possibility of detection by enemy - Predicted survivability
<ul style="list-style-type: none"> - Number of enemy aircrafts - Current damage - Available weapon & ammunition - Enemy's status (defensive or offensive) 	<ul style="list-style-type: none"> - Enemy's strength relative to own - Relative threat level of enemy aircrafts - Relative strength of enemy aircrafts 	<ul style="list-style-type: none"> - Projected impact of engaging/ not engaging - Projected probability to survive - Projected probability to kill each enemy
<ul style="list-style-type: none"> - Weapon selected - Weapon's envelope 	<ul style="list-style-type: none"> - Target's vulnerability - Target's position relative to weapon envelope - Weapon employment zone - Desired launch zone 	<ul style="list-style-type: none"> - Projected behavior of target following weapons launch – threat reaction - Projected damage to target with weapon - Projected time to impact
<ul style="list-style-type: none"> - Teammate's position, heading, altitude, airspeed - Teammate's weapon capacity - Teammate's status (defensive or offensive) 	<ul style="list-style-type: none"> - Possibility and need of support and backup - Teammate's flight path relative to own and enemy - Teammate's weapon employment zone 	<ul style="list-style-type: none"> - Probability of formation to obtain first launch opportunity - Prediction of teammate's survivability - Prediction of teammate's next action

8.2.2 Participants and Subject Matter Expert

Sixteen male military fighter pilots participated in the study. They age between 25 to 37 years ($M = 29.43$, $SD = 3.08$), with flight experience ranging from 390 to 2600 flying hours ($M = 1091$, $SD = 530$). They were assigned into eight teams of two, one as the flight lead and the other as the wingman. All participants were from the same military aviation organization, and were familiar with their teammate prior to the experiment. It should be noted that due to the difficulty in recruiting fighter pilots, team composition was dependent on the availability of two participants during any particular experimental session. As such, some limitations in team composition exists. One participant was not able to complete the full experiment (i.e., the team missions), hence another subject participated twice as wingman for two different flight leads. One of the participants was not able to complete the cognitive tests. The composition of team members' experience varied across the teams. The profile of the teams can be seen in Table 8-2. The teams can be further clustered into three categories. The first category featured teams composed by two Cat A pilots with relatively little difference in their flight experience (0–200), the second category grouped teams with relatively lower experience groups (Cat A and B pilots) and moderate difference in flight experience (60–320), and the last category included teams that had one highly experienced pilot pairing with a low-experienced pilot, with difference in flying experience of 600 and 2210 hours.

Table 8-2 Profile of the teams

Team #	Flying hours of more experienced members	Flying hours of less experienced members	Team Type
1	1200 (Cat A)	600 (Cat C)	3
2	1100 (Cat A)	780 (Cat B)	2
3	1700 (Cat A)	1500 (Cat A)	1
4	800 (Cat A)	500 (Cat B)	2
5	2600 (Cat A)	390 (Cat D)	3
6	1200 (Cat A)	1100 (Cat A)	1
7	1200 (Cat A)	1200 (Cat A)	1
8	1020 (Cat A)	960 (Cat B)	2

Two SMEs (F-16 pilots) were involved in the study. The first SME was a Cat A pilot, had 1200 flying hours, and spent more than 900 hours on fighter aircraft. The second SME was a Cat B pilot with 1000 flying hours and more than 600 fighter hours. Both of them

had considerable experience as flight supervisors and had been involved in training and assessing younger pilots in the squadron.

8.2.3 Simulation Set Up

The experiment was conducted in an isolated room. Two simulator consoles and one control station were networked and set as shown in Figure 8-6. A partition was placed in between the two simulator consoles to prevent the subjects from seeing each other's screen during the team missions. A Thrustmaster® HOTAS Cougar Flight Controller, which is an almost exact replica of the flight control used in F-16 aircrafts, was used to control the simulation. It was programmed to replicate the actual flight control system to conserve the transfer of learning from the real aircraft controls and minimize the time required to familiarize with the system.

Figure 8-6 Experiment set-up

8.2.4 Mission

Two individual and two team missions with varied levels of difficulty were designed by the SMEs. The participants were tasked to maintain in 25,000 feet and to over-fly each steerpoint along the navigation route planned by the SMEs. They were assigned to reach a designated steerpoint at a specific time, and to engage and destroy all enemy aircrafts along the route. The number and types of enemy aircrafts in each mission are listed in Table 8-3. A more detail description of each mission and the mission map is in Appendix D. Although the aircraft was loaded with unlimited munitions, the participants were told to use only up to 4 AIM-120B (for beyond visual range combat) and 2 AIM-9M (for

within visual range combat). The aircraft was set to be invulnerable to ensure that all participants completed the flight until the last designated steerpoint. Assessment of any aircraft damage can be retrieved using Air Combat Maneuvering Instrumentation (ACMI) recordings. To reduce the complexity of the task, maximum amount of fuel was assigned to the aircraft to ensure that there was enough fuel to complete the mission along with small deviations away from the planned route. The simulated weather condition was clear with good visibility.

Table 8-3 Types of adversaries in each mission

Mission	Number and type of adversaries
Mission 1 (individual)	2 x MiG-29A
Mission 2 (individual)	1 x MiG-29A, 2 x F-5E
Mission 3 (team)	2 x MiG-29A
Mission 4 (team)	2 x F/A-18C, 2 x F-5E

8.2.5 Procedure

The experiment was divided into two sessions. Two participants were involved in each experimental session. In the first session, the participants were introduced to the study and the hardware and software used. Their consent to participate and demographic background information were then obtained. The participants were given enough time to familiarize the game controls until they felt ready and the SME judged they had sufficient familiarity of the system. Each participant performed two individual missions, followed by two team missions. The participants took turn in playing the individual missions. While a participant was playing the individual mission, the other was asked to leave the experiment room. The missions were paused several times for data collection. During the freeze time, the participants turned around and answered paper-and-pen based SA assessments placed on small tables behind them. This was done to avoid them searching the answer on the computer screen. The first session took about 2 to 2½ hours to complete data-collection of both participants. In the second session, both participants completed a set of cognitive ability tests, with one-minute breaks between each test and a 15-minutes break in the middle of the session.

8.2.6 Assessment Tools

The assessment tools used in the study is listed in Table 7-1. The team SA measurement tools are further elaborated in the following. The complete set of SA assessment is available in Appendix D.

Table 8-4 Assessment tools

Variable	Measure	Code
Experience	Flying hours	
Cognitive ability	see Table 7-3	
Aspects of team SA:		
Awareness of own situation	SAGAT of own situation	SAGAT _{Own}
Awareness of teammate's situation	SAGAT of teammate's situation	SAGAT _{Tmate}
Awareness of own situational knowledge	Over-confidence bias	Over-conf. bias
	Absolute confidence bias	Abs. conf. bias
Subjective SA	Self-rating of SA	SA self-rating
SA related to teammate's status	Awareness of teammate's workload level	WL Aware
	Awareness of teammate's SA level	SA Aware
Team process	TARGETs: providing necessary information	Targets_info
	TARGETs: acknowledging receipt of information	Targets_ack
	TARGETs: anticipatory & clarification of information	Targets_anti
	TARGETs: feedback, backup, and support	Targets_fbac
	Rating of teamwork behavior	TW rating
	Team communication frequency	
Performance	Survivability: number of shot received	Shot
	Number of enemy successfully taken down	Kill

SAGAT

SAGAT queries assess participants' perception (level 1 SA), comprehension (level 2 SA), and future projection (level 3 SA) of the situation. In team missions, both questions related to own and teammate's situation were included. The complete set of SAGAT questions is available in Appendix D. Some examples of SAGAT questions are as follows:

SAGAT of own situation (individual and team missions):

Level 1: Indicate your location, altitude, heading, and airspeed; number of enemy aircraft detected; determine the bearing, range, and altitude of each enemy aircraft.

Level 2: Are you within the enemy's weapon envelope? Are you able to achieve FLO (First Launch Opportunity) based on current flight parameter?

Level 3 queries are: Will you be in a position to take shots in the next 10 seconds?
Will the bandit take shots within the next 30 seconds?

SAGAT of teammate's situation (team mission):

Level 1: Indicate position of teammate relative to your aircraft

Level 2: Is teammate's aircraft within the enemy's weapon envelope?

Level 3: Will teammate take shot in the next 10 seconds?

The accuracy of SAGAT answers was evaluated based on the actual situation and judgment by SMEs. A guide was developed to aid in scoring the open ended questions and giving different weightage to each question based on the relevancy to the situation and severity of impact of not knowing certain information. For example, during cruising and no enemy engagement, response to current altitude with a difference of 1000 feet to the actual altitude was considered as correct (scored 1), a difference of 1000 – 2000 feet was scored 0.5, and more than 2000 feet errors was considered wrong (scored 0). During enemy engagement, the pilots were expected to have less resource to attend to the flight indicators, and that maneuvers taken can influence changes in altitude more rapidly than during peace-time situation. Thus, the scoring was adjusted, such that deviation within 2000 feet to the actual altitude was scored 1, 2000-4000 feet was scored 0.5, and more than 4000 feet was scored 0 (see Appendix D for a complete set of scoring guides).

The questions were derived from the goal-directed task analysis. The simulation was frozen at specified times (trigger points) defined on each mission (see Table 8-5). The use of trigger events was useful as it can ensure a similar treatment across the participants and facilitate the determination of SAGAT queries that would be relevant to the situation faced by the participants during the point of freeze. When the simulation was frozen, the participants were asked to turn around and answer the paper-and-pen-based SA assessment. The participants took about 1 to 3 minutes to fill up the questions, depending

on the number and type of questions asked. Endsley (1995a) reported no decrement in pilot situation awareness for freezes of up to five minutes.

Table 8-5 Trigger events to freeze the mission

Purpose	Trigger events	Freeze point
Navigational	- 1 minute after mission started	M1 F1
	- 30 seconds after end of enemy engagement	M2 F3, M4 F3
Assessment of threat	- 10 seconds after enemy aircraft appeared on radar or 25 nm range with enemy aircraft	M1 F2, M2 F1&4, M3 F1, M4 F1&4
	- 2 seconds after weapon employment (missile launch)	M1 F3, M2 F2, M3 F2, M4, F2

Note: M – mission; F – freeze point

Confidence rating

The participants were also asked to rate their confidence level (high/low) on each answer given to the SAGAT queries. A score for over-confidence bias was calculated by the average confidence rating across all test items minus the proportion of the same items that were judged correctly. A positive bias indicates over-confidence and a negative bias indicates under-confidence. The absolute score of confidence bias indicates the distance of self awareness from a well-calibrated zero-value.

Awareness of teammate's workload level (WL Aware)

The participants were asked to rate their own and teammate's level of workload using a simple seven-point Likert scale. The participants were experienced pilots and were familiar with the term workload. A score for awareness of teammate's workload level was computed by the difference of workload level reported by a team member and estimated by teammate. The score can range from 0 to 6, where a smaller score would indicate better estimation of each other's workload.

Awareness of teammate's SA level (SA Aware)

The participants were asked to rate their own SA and their teammates' SA using a seven-point Likert scale. The rating was done to the overall awareness and did not distinguish between level 1, 2, and 3. A score for awareness of teammate's SA level was computed by the difference of awareness level reported by a team member and estimated by

teammate. The score can range from 0 to 6, where a smaller score would indicate better awareness of teammate's SA status.

Teamwork behavior rating

The participants were asked to rate, using a seven-point Likert scale, the extent to which they agree that his and his teammate's behavior conform to the following statements:

1. fully understood the team goal(s)
2. fully understood the team strategy
3. fully understood his role(s) in the team
4. always executed his duties as prior agreed upon
5. always regarded the opinions of teammate with respect
6. always passed important information to teammate
7. always provided feedback readily and voluntarily
8. always seek feedback when the need arose
9. always assisted teammate whenever needed
10. always able to step in when teammate was not able to perform

Communication Frequency

There have been numerous studies that utilize communication frequency to predict team performance in aviation, although the number was considerably lower in the military domain compared to civil and general aviation. Svensson & Andersson (2006) suggested that some categories of communication may relate to performance in a positive manner, while others may relate in opposing direction. Team communication was transcribed and separated into thought units, and the contents were then coded into several categories. The categorization was similar to the one used in Chapter 4, 6 and 7, but with slight modification and adaptation to a category scheme for beyond visual range (BVR) combat used by Svensson & Andersson (2006). Table 8-6 describes how the thought units were coded. The author transcribed and coded all the communication. A segment 127 thought units taken from two missions was also coded by the SME and another trained observer⁵ for an inter-coder and category reliability test. Cohen's Kappa of coding by two independent observers was .67, .68, and .73, which can be considered as substantial

⁵ The trained observer was a military helicopter pilot (Cat B, 850 flying hours) who was also involved in the study and thus was familiar with the missions, engagement tactics, maneuvers, and military jargons.

(Landis & Koch, 1977). The frequency of each category was derived by dividing the amount of thought units transferred by the amount of time taken to complete the mission.

Table 8-6 Communication category for content coding

	Category	Sub-category	Description
1	Planning/ Tactics	Order/decision	Order/decision of what to do
		Strategy	Share and discuss overall tactics
		Discussion, help/cooperation	Help/coordination within team
		Request, help/cooperation	Urge for help/coordination
2	Information transfer	Information, activity, enemy	Current enemy position or movements
		Information, activity, launch	Targeting, firing a missile
		Information, intents, enemy	Enemy possible/probable intents
		Information, activity, self	My position or current activity
		Information, intents, self	What I intend to do
		Information, continue follow	Spike, radar lock, missile launch on my aircraft
3	Information request/ question	Question, activity, teammate	Ask teammate's current activity
		Question, intents, teammate	Ask teammate's intention
		Question, status, teammate	Ask for teammate's status
		Question, activity, enemy	Ask for enemy's current activity
		Question, intents, enemy	Ask for possible/probable enemy intentions
		Request clarification	Request more/better information or repeat
4	Response	Response, information	Response to information request
		Repetition of message	Repeat same information
		Correction/clarification	Correct/clarify information
5	Feedback, evaluation	Feedback, action, teammate	Feedback on teammate's action/behavior
		Evaluation, status, enemy	Evaluation on kill or not
		Evaluation, status, own	Evaluation on damage, weapons, incapacitated
6	Acknowledgement		Confirm information or acknowledge
7	Other		Comment on other issues, unintelligible

TARGETs

An observation form to facilitate evaluation of team SA processes was developed based on TARGETs method (Fowlkes et al., 1994). TARGETs was used instead of CAST method used in the CS studies (see Chapter 6 and 7) because CAST was too simplistic to capture the complexity of team processes involved in the air combat scenarios. In

addition, as the participants were experienced fighter pilots, they were familiar to the standard operating procedure (SOP), tactical doctrine imposed in the military aviation, crew resource management (CRM), thus affording a structured evaluation of team behaviors. The list of events and targeted behavior was developed based on GDTA and interviews with the SMEs. The observation form included a list of events and appropriate observable responses (targets) to the events. Team members were evaluated on whether they performed the targeted response or behavior. The targeted behavior can be classified into four main categories: 1) providing and coordinating necessary information; 2) acknowledging receipt of information; 3) anticipatory and clarification of information; 4) feedback, backup, and support. The mission was further divided into several flight segments, such as navigation (peace time), first enemy engagement, second enemy engagement, retargeting, and so on.

Observation was done per flight segment instead of the overall mission in order to provide more sensitivity and to avoid over-generalization of observation. TARGETs score for each category was derived by dividing the ticked items with the total number of applicable items. The TARGETs form is shown in Figure 8-7. The assessments for all teams were conducted by the author. The SME was asked to perform the TARGETs assessment for one team to evaluate the inter-rater reliability of the method. Two separate judgments were made during the observation. The observers first had to decide whether the targeted behavior was applicable or non-applicable for the specified events taking place within the flight segment. The two observers agreed in 80 out of the 84 possible judgments (95%) that were made. They then judged whether the crew hit or missed the targeted behavior. From the 80 events that were agreed to be present, the two observers agreed on 65 TARGETs (81%).

Providing and coordinating necessary information Acknowledging receipt of information					
Event	Target	Flight Segment:			
		Hit	A	Hit	A
Navigating task	Flight lead to ensure ingress formation is correct, wingman to maintain formation				
	Attempt to update each other's location voluntarily - Only if wingman is "blind"				
	Flight lead provide reference heading to regain mutual support(post-engagement)				
Search for enemy	Flight lead to build picture, wingman to talk in accordance with doctrine				
Tactical engagement	Inform when spiked / naked				
	Inform when there is missile launch by enemy				
	Flight lead executes mission to fulfill objectives, directs wingman in accordance with briefed tactics				
	Confirm targeted contacts are hostile				
	Inform when one is targeted (including bullseye)				
	Inform when fox (including bullseye)				
	Inform maneuver taken, e.g., cranking 080				
	Inform when pitbull / enemy killed / not				
	Inform if picture changes				
	Inform when deviating from briefed gameplan				
	Inform when aircraft is damaged or if equipment malfunctions				
	Inform weapon capacity (left)				
Anticipatory and clarification of information					
Event	Target	Flight Segment:			
		Hit		Hit	
Anticipation of information need	Most information is provided clearly and voluntarily				
	Question when information is not provided / unclear				
	Clarify whenever needed				
Feedback, backup, and support					
Event	Target	Flight Segment:			
		Hit		Hit	
Incapacitated	Request for help / support				
	Feedback on each other's SA / action execution				
	Provide help & backup effectively				

Note: ✓ - target behavior observed; ✕ - target behavior unobserved; NA - not applicable

Figure 8-7 Modified TARGETs

Cognitive Abilities

Ten tests representing the domain of spatial, memory, reasoning, and verbal abilities were selected from the 1976 ETS kits of Factor-Referenced Cognitive Tests. The selection was

based on several considerations, including the use of similar test in the previous research and in military selection batteries, and the time taken to complete the test. The list of tests used is presented in Table 7-3. The description of each test is available in the Appendix E. The estimated time to complete all tests (including reading of instruction and breaks) is about 2 hours. Flying hours of the participants was noted down as a measure of experience level.

Table 8-7 Cognitive test battery

Factor	Name of Test	Time to complete
Spatial ability		
Flexibility of closure	Hidden Figure Test	12 minutes
Perceptual speed	Number Comparison Test	1.5 minutes
Spatial orientation	Cube Comparison Test	3 minutes
Visualization	Form Board Test	8 minutes
Memory		
Memory span	Visual Number Span Test(modified)	10 minutes
	Auditory Letter Span Test	10 minutes
Visual memory	Building Memory	9 minutes
Reasoning		
Induction	Figure Classification	8 minutes
Integrative processes	Following Direction	7 minutes
General reasoning	Mathematic Aptitude Test	10 minutes

8.3 Results

The result sections are organized according to the hypotheses presented in the beginning of this chapter. The first and second section will evaluate participants' responses to the three levels of SAGAT queries and their confidence level. Section 8.3.3 will evaluate the effect of task experience and cognitive ability on individual and team missions. In addition, as the teams were composed by varied combination of experience levels, an additional variable on team composition will also be factored in the analyses. Section 8.3.4 will present the evaluation of the team processes associated with team SA. Section 8.3.5 will evaluate the inter-correlations among the aspects of team SA, and Section 8.3.6 will analyze the consequence of achieving or not achieving any aspect of team SA in decision making, actions, and performance outcome. Throughout the analyses, confidence level of .10 was considered as significant to compensate for the low sample size, a constraint necessary because of the limited availability of experts as participants of this study.

8.3.1 Three Levels of SA

SAGAT queries covered three levels of SA, namely perception (level 1), comprehension (level 2), and future projection (level 3). The means and standard deviations of each level of SAGAT scores are presented in Table 8-8.

Table 8-8 Means and Standard Deviations for SAGAT scores ($N = 16$)

	Individual mission SAGAT	Team mission SAGAT of own situation		Team mission SAGAT of teammate' situation	
	<i>M</i> (<i>SD</i>)	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Level 1	.72 (.08)	.71	(.14)	.70	(.18)
Level 2	.83 (.15)	.83	(.17)	.80	(.22)
Level 3	.67 (.23)	.62	(.21)	.54	(.33)

Correlation coefficients (one-tailed) were computed among level 1, 2, and 3 SAGAT scores (see Table 8-9). The results obtained from **individual mission** showed that the correlation coefficients ranged from moderate to high, i.e., $r = .41$, $p = .06$ between level 1 and 2, $r = .54$, $p < .05$ between level 1 and 3, and $r = .68$, $p < .01$ between level 2 and 3.

In **team mission**, the correlation coefficients obtained from the individual responses to SAGAT of own situation also range from moderate to high, i.e., $r = .61$, $p < .01$ between level 1 and 2, $r = .36$, $p = .09$ between level 1 and 3, and $r = .78$, $p < .001$ between level 2 and 3. These findings implied that an individual who has better perception and comprehension of what is going on is more likely to have better prediction of future event. This result together with the relationship found in individual mission confirmed the first hypothesis that better awareness of the present situation (level 1 and 2 SA) will be associated with better prediction of the future situation (level 3 SA).

The correlations among the scores of the three levels of SAGAT (teammate's situation) were however not high, indicating that an individual who had more accurate information regarding his teammate (teammate's position, location), may not necessarily be better in comprehending the meaning of this information (whether teammate is in position to shoot / in danger) or predicting teammate's next action (whether teammate is going to shoot within the next 10 seconds). The inter-correlation among teammates may also be lower

because of the raw accuracy (reliability) of this measure is lower at least for level 3 (which had a mean of .54).

Table 8-9 Correlations among three levels of SAGAT scores

	Individual mission SAGAT		Team mission SAGAT of own situation		Team mission SAGAT of teammate' situation	
	Level 1	Level 2	Level 1	Level 2	Level 1	Level 2
Level 2	.41	-	.61**	-	.04	-
Level 3	.54*	.68**	.36	.78**	.05	.11

$N = 16$; * $p < .05$; ** $p < .01$ (one-tailed)

In order to compare participants' responses across the three levels of SA, two 2 x 3 within subjects ANOVAs were conducted, one using SAGAT of own situation (in individual vs. team missions) and the other using different targets of SAGAT questions within team missions (own vs. teammate's situation). The result of the first ANOVA showed a significant main effect of SA level, $F(2,28) = 18.24$, $p < .001$ ⁶. The result of the second ANOVA also showed a significant main effect of SA level, $F(2,30) = 10.93$, $p < .001$. There was no significant difference across the different types of missions and targets of questions.

Paired-samples t tests in **individual missions** indicated that scores for SAGAT level 2 was significantly more accurate than either level 1, $t(15) = 3.26$, $p < .01$, and level 3, $t(15) = 3.07$, $p < .01$. The scores for SAGAT level 1 and 3 did not differ from each other. Similarly for SAGAT of own situation in **team missions**, the participants were significantly more accurate in answering SA level 2 queries than either level 1, $t(15) = 2.93$, $p < .05$, and level 3, $t(15) = 3.78$, $p < .05$, but scores on level 1 and 3 did not differ from each other. As for SAGAT of teammate's situation, the only significant difference was found between level 2 and 3, where the accuracy for level 2 was significantly higher than in level 3, $t(15) = 2.70$, $p < .05$.

It is also worth noting that the Cat D pilot participant was able to answer the level 1 SA queries equally well as compared to the more experienced pilots, but left most of the level

⁶ Note that one of the participants played twice in team missions. His scores in the two team missions were averaged as an input to this analysis.

2 and 3 queries blank, which were translated into low SA scores in level 2 and 3. This was partly due to the lack of experience and his scanning habit, where in real life he only flew as a junior wingman, whose responsibilities were mainly to maintain the assigned formation (thus he was not bad in instrument reading) and execute the tactical commands planned by his flight lead.

8.3.2 Confidence in Answers to SAGAT level 1, 2, and 3

The confidence level of participants towards the accuracy of their answers to SAGAT level 1, 2, and 3 queries are provided in Table 8-10. The result showed that the participants were less confident in their responses to the perception than the prediction questions. However, the participants' responses towards SAGAT level 3 queries were generally less accurate than level 1 and 2 (refer to Table 8-8 for the distribution of SAGAT scores in three levels).

Table 8-10 Means and Standard Deviations for confidence levels and biases ($N = 16$)

Measures		Individual		Team mission			
		mission		Own situation		Teammate's	
		<i>M</i>	<i>(SD)</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Confidence level	SAGAT level 1	.78	(.13)	.76	(.16)	.82	(.23)
	SAGAT level 2	.85	(.08)	.95	(.14)	.91	(.18)
	SAGAT level 3	.89	(.24)	.90	(.25)	.96	(.17)
Over-confidence bias	SAGAT level 1	.07	.12	.04	.23	.12	.20
	SAGAT level 2	.02	.13	.11	.20	.12	.30
	SAGAT level 3	.22	.19	.28	.31	.41	.36
Absolute-confidence bias	SAGAT level 1	.10	.08	.17	.15	.15	.17
	SAGAT level 2	.11	.07	.15	.17	.20	.23
	SAGAT level 3	.24	.17	.36	.21	.43	.34

Two 2 x 3 within subjects ANOVAs on participants' **over-confidence bias** were performed. The 2 x 3 (mission x SA level) on SAGAT of **own situation** revealed significant main effect of SA level, $F(2,28) = 12.91, p < .001$, where over-confidence bias for level 3 was significantly higher than for level 1 and 2. The 2 x 3 (target x SA level) within subjects ANOVA on participants' over-confidence bias in **team missions** revealed

significant main effect of the target of SAGAT questions, $F(1,14) = 4.60, p < .05$, as well as SA level, $F(2,30) = 12.46, p < .001$. The over-confidence bias was significantly higher for SAGAT of teammate's than of own situation, and was significantly higher for level 3 than for level 1 and 2 (see Figure 8-8). The interaction effect was not significant.

Figure 8-8 2 x 3 ANOVA result of over-confidence bias in team missions

Similarly, two 2 x 3 within subjects ANOVAs were performed on participants' **absolute confidence bias**. The 2 x 3 (mission x SA level) within subjects ANOVA of absolute confidence bias on SAGAT of own situation showed significant main effect of the mission, $F(1,14) = 5.06, p < .05$, as well as SA level, $F(2,28) = 20.19, p < .001$. The absolute confidence bias was significantly higher in team than individual mission, and was significantly higher for level 3 than for level 1 and 2 (see Figure 8-9). The 2 x 3 (target x SA level) on SAGAT of own situation revealed significant main effect of SA level, $F(2,30) = 9.58, p < .001$, where over-confidence bias for level 3 was significantly higher than for level 1 and 2.

Figure 8-9 2 x 3 ANOVA of absolute confidence bias of SAGAT of own situation

8.3.3 Effect of Task Experience, Cognitive Ability, and Team Composition on SA

The descriptive statistics of the cognitive test result of the participants are reported in Table 8-11. The result was compared with the statistics collected from previous studies reported in the ETS Kit manual. Except for Auditory and Visual Number Span test, all of the tests consist of two parts. The reported reliability between part 1 and 2 of the test reported was considerably high. Due to time constraint, only Part 1 of the test was used in the current study. A percentile rank was calculated to estimate a point where the sample collected in this study falls in the normal curve of the result reported in the manual. The result showed that the participants had mostly better cognitive abilities compared to the sample used in the previous studies reported in the manual. The participants had undergone pre-selection and screening qualification as military pilots, and thus represent the better proportions of the population.

Dimensionality of the ten tests used to measure cognitive abilities of the participants was analyzed using principle components analysis. The scree plot indicated that the tests were not uni-dimensional. As a result, it was not possible to use a single value to represent the factor of cognitive ability. The association between each test and SA was analyzed using Pearson's product-moment correlation. Similar to the study by Carretta et al. (1996), no correction for range restriction was applied, because the interest was on the determination of cognitive domain related to SA rather than the absolute magnitude of correlations.

Table 8-11 Cognitive test result of the participants ($N = 16$)

Test	Data from ETS Kit Manual				Current Study		
	Sample	M	SD	Rel	M	SD	%ile
Hidden figure	167 college males	14.0	6.4	.83	9.23	3.67	76
Number comparison	145 college males	26.6	4.8	.82	16.07	2.43	87
Cube comparison	46 college students	22.7	9.4	.84	11.21	6.05	50
Form board	46 college students	124.8	38.3	.81	69.29	13.89	64
Auditory number span	181 college students	8.3	3.2	.63	12.08	3.23	88
Visual number span	-	-	-	-	12.77	2.62	-
Building memory	542-574 Naval recruits	10.9	4.7	.80	8.46	2.99	90
Figure classification	288-300 males Suburban 11 th & 12 th graders	120.0	30.0	.77	67.93	17.33	70
Following direction	542-574 Naval recruits	10.4	3.8	.75	7.25	2.16	86
Math aptitude	83 army enlistees	14.0	-	.81	6.14	2.39	-

Individual mission

Correlations between experience level and each of the SA measures did not show any significant result. The bivariate and partial correlations (controlling for flight hours) between each of the cognitive test results and the SA scores obtained in individual mission are reported in Table 8-12 and Table 8-13. Only participants from Cat A and B were included in this analysis, as pilots from Cat C and D were considered to be of different expertise levels. The bivariate and partial correlations showed similar result, where Hidden Figure test (spatial – flexibility of closure), Cube Comparison (spatial orientation), Following Direction (reasoning – integrative processes), and Mathematic Aptitude (general reasoning) were associated significantly with SAGAT scores and self rating of SA.

Table 8-12 Bivariate correlations between cognitive tests and individual SA

	Level 1	SAGAT Level 2	Level 3	SA self-rating
Hidden figure	.67*	-.03	.30	-.08
Number comparison	-.27	-.08	-.03	-.09
Cube comparison	-.04	.66*	.47	.51*
Form board	-.43	.24	-.15	-.09
Auditory number span	-.20	-.41	.02	-.48
Visual number span	.01	-.10	.09	-.40
Building memory	.36	-.24	.06	.10
Figure classification	.05	.10	-.05	-.44
Following direction	.50	.66*	.73**	.31
Math aptitude	.48	.57*	.50	.54*

$N = 12$; * $p < .05$; ** $p < .01$ (one-tailed)

Table 8-13 Partial correlations between cognitive tests and individual SA

	Level 1	SAGAT Level 2	Level 3	SA self-rating
Hidden figure	.75**	-.13	.19	-.04
Number comparison	-.27	-.08	-.02	-.09
Cube comparison	.12	.75**	.55*	.71**
Form board	-.40	.26	-.14	-.06
Auditory number span	-.18	-.42	.02	-.47
Visual number span	-.03	-.10	.09	-.03
Building memory	.26	-.25	.11	-.03
Figure classification	-.10	.06	-.13	-.50
Following direction	.54	.63*	.69*	.38
Math aptitude	.42	.59*	.49	.56**

$N = 12$; * $p < .05$; ** $p < .01$ (one-tailed)

Team Mission

Correlations between cognitive ability tests and SAGAT scores are shown in Table 8-14. The only significant correlation was between Hidden Figure test and level 1 of SAGAT related to own task, which was consistent to the result found in individual missions. The rest of the result was neither consistent to the Hypothesis nor significant. It is suspected that the inconsistent result is attributed by the way the team was composed, which will be discussed in the following.

Table 8-14 Bivariate correlations between cognitive tests and SA in team missions

	SAGAT _{Own}			SAGAT _{Tmate}		
	Level 1	Level 2	Level 3	Level 1	Level 2	Level 3
Hidden figure	.67**	.36	.28	-.36	.36	-.05
Number comparison	.15	-.20	-.16	-.24	-.24	-.10
Cube comparison	-.02	-.34	-.28	-.47*	-.42	-.26
Form board	-.00	-.22	-.29	-.38	-.21	-.29
Auditory number span	.25	-.26	-.01	-.29	-.26	.08
Visual number span	.23	-.28	-.16	-.23	-.22	-.02
Building memory	.37	-.07	-.04	-.35	-.14	.30
Figure classification	.29	.02	.10	-.39	.10	-.22
Following direction	.38	-.19	-.38	-.44	-.14	-.23
Math aptitude	.35	-.21	-.27	-.57*	-.22	-.16

$N = 15$; * $p < .05$; ** $p < .01$ (one-tailed)

The teams can be differentiated into three groups: Group 1: two Cat A pilots with little difference in flight experience; Group 2: combination of Cat A and B pilots with moderate difference in flight experience; Group 3: combination of Cat A and Cat C/D pilots with high difference in flying experience. ANOVA was performed to evaluate the differences in team SA across three groups. SAGAT of own situation across the three groups did not differ significantly, $F(2,5) = 3.04$, $p = .14$. However, note that teams in group 2 had significantly better score than teams in group 3, $t(3) = 3.82$, $p < .05$. The analyses for SAGAT of teammate's situation was significant, $F(2,5) = 9.35$, $p < .05$. Teams in group 1 was significantly better than group 3, $t(3) = 3.57$, $p < .05$, and teams in group 2 was marginally better than group 3, $t(3) = 2.60$, $p = .08$. The data showed that the poor score of group 3 was attributed by the poor SAGAT score of the lower experienced member in the team. There was also a significant difference in absolute confidence bias across the three groups, $F(2,5) = 8.13$, $p < .05$. Teams in group 3 had higher absolute confidence bias than teams in group 1, $t(3) = 2.93$, $p = .06$, and group 2, $t(3) = 4.09$, $p < .05$. No significant difference across teams was found on the over-confidence bias, self rating of SA, and awareness of teammate's workload and SA levels.

The poor SA scores of teams in the third group seemed to be determined by the lower experienced member in the team. Four ways of representing team task experience, i.e.,

average, the highest, the lowest, and difference in flying hours, were correlated with each of the team SA measures (average of individual members' SA scores). The results in Table 8-15 showed that SAGAT and over-confidence bias scores were highly correlated with flying hours of the lower experience member in the team and also with the difference in flying hours between two members.

Table 8-15 Correlations between members' experience level and team SA

	Flying hours (average)	Flying hours (higher)	Flying hours (lower)	Flying hours (difference)
SAGAT of own situation	.37	-.14	.81**	-.53
SAGAT of teammate's situation	-.29	-.77*	.66*	-.95**
Self-rating of SA	-.27	-.39	.13	-.38
Over-confidence bias	-.20	.18	-.60	.46
Absolute confidence bias	.52	.66*	-.12	.57
Awareness of teammate's WL level	-.56	-.41	-.32	-.15
Awareness of teammate's SA level	.29	.13	.29	-.06

$N = 8$; * $p < .05$; ** $p < .01$ (one-tailed); expected negative correlations are shaded in gray

8.3.4 SA and Team Processes

Table 8-16 presents the correlation coefficients between team SA measures collected during several freeze points (product measures) and the scores derived from the overall process of team processes derived from TARGETs. The analysis was conducted in team level, using the mean value of team members' scores to represent team SA, while the team process measures were originally obtained at team level. Evaluation of participants' rating on each statement of teamwork behavior indicated the tendency of participants to rate highly on themselves. This resulted in either binary data (only 5s and 6s in the ratings) or distribution that was skewed to the left (most ratings of 6s). The non-normal distribution of the data violated the assumption needed to perform linear correlations, and thus self-rating of teamwork behavior was omitted in the subsequent analyses.

Two important findings emerged from the TARGETs scores derived from observer's assessment. Providing and coordinating necessary information whenever required, as measured by TARGETs, was associated with higher scores in SAGAT of own situation, $r = .60$, $p = .06$, SAGAT of teammate's situation, $r = .69$, $p < .05$, and less over-confidence

bias, $r = -.71$, $p < .05$. Similarly, providing feedback, support, and backup, as measured by TARGETs, was also associated with better scores in SAGAT of own situation, $r = .80$, $p < .05$ and less over-confidence bias, $r = -.65$, $p < .05$. Inconsistent and non-significant patterns were found in the correlations between team SA measures and each category of team communication frequency. Scatter plot analyses of the correlations between acknowledgement frequency with SA self-rating and awareness of teammate's workload showed that the high correlations were due to an outlier and shall not be regarded as significant findings. One team had a tendency to acknowledge every thought units transferred, which was almost twice the frequency of the rest of the teams.

Table 8-16 Correlations between SA and team processes

	SAGAT Own	SAGAT Tmate	SA Self- rating	Over- Conf. Bias	Abs. Conf. Bias	WL Aware	SA Aware
TARGETs (observer)							
Provide information	.60	.69*	-.27	-.71*	-.08	-.36	.09
Acknowledgement	.51	.25	.49	-.24	-.31	.36	-.28
Anticipatory of information	.45	.18	-.13	-.30	-.08	-.13	.08
Feedback, support, backup	.80**	.53	.46	-.65*	-.60	.44	-.17
Communication frequency							
Planning	.10	-.01	.21	.00	.13	.07	-.29
Information transfer	.11	.03	-.30	.05	.50	-.46	-.10
Information request	.42	.04	-.22	-.30	.42	-.39	-.26
Response	.37	.06	.10	-.19	.25	-.15	-.28
Feedback	.61	.16	-.23	-.51	.40	-.51	-.07
Acknowledgement	.27	.20	.87**	-.06	-.68	.83**	-.15
Others	.58	.27	-.10	-.53	.20	-.30	-.16

$N = 8$; * $p < .05$; ** $p < .01$ (one-tailed); Comm. frequency: ** $p < .01$ (two-tailed)

8.3.5 Inter-correlations among Aspects of Team SA

Table 8-17 shows the inter-correlations among the various measures of team SA. The analysis was done in team level, aggregating the team members' scores across the three levels to represent the team score. As hypothesized, some of the measures were highly correlated, while some others were not. The correlation between SAGAT scores of own and teammate's situation was high, $r = .60$, $p = .06$, showing that team members who

were more aware of the situation directly related to their task were also more aware about their teammate's situation. The over-confidence bias showed high negative correlations with SAGAT of own situation, $r = -.85$, $p < .01$. Absolute confidence bias was highly correlated with SAGAT of teammate's situation, $r = -.61$, $p = .06$ and with self-rating of SA, $r = -.81$, $r < .01$. Self-rating of SA did not show any significant association with SAGAT and over-confidence bias scores. The correlations between awareness of teammate's workload and SA levels with the rest of team SA measures were low. From scatter-plot inspection, the high correlation between SA rating and awareness of teammate's workload was found to be due to an outlier and will not be considered a significant finding.

Table 8-17 Inter-correlation among measures of team SA

	SAGAT Own	SAGAT Tmate	SA self- rating	Over- conf. bias	Abs. conf. bias	WL Aware	SA Aware
SAGAT _{Own}							
SAGAT _{Tmate}	.60						
SA self-rating	.22	.37					
Over-conf. bias	-.85**	-.51	.04				
Abs. conf. bias	-.34	-.61	-.81**	.28			
WL Aware	-.02	.09	.80**	.03	-.82**		
SA Aware	.14	.29	.20	.20	-.10	-.24	

$N = 8$; * $p < .05$; ** $p < .01$ (one-tailed)

Analyses were performed to evaluate whether there was a tendency for an individual participant to estimate teammate's workload and SA similarly to his own, as found in previous two studies. Correlation coefficient between self-rating and rating by teammate for workload was low, $r = .11$ ($p = .35$), suggesting that not all participants were accurate in estimating their teammate's workload level. Instead, there was a tendency for them to rate their teammate's workload more similar to their own, $r = .93$ ($p < .001$). The same trends were also found for SA ratings. The participants were more similar in rating their own and teammate's SA, $r = .75$ ($p < .001$), but the team members did not necessarily provide a similar awareness rating on the same member, $r = .26$ ($p = .16$). ANOVA analyses showed that the role assignment, whether as flight lead or wingman, had no

significant effect on the accuracy in estimating teammate's workload, $F(1,15) = .15$, $p = .70$, and awareness level, $F(1,15) = .01$, $p = .94$.

8.3.6 SA and Performance

Individual mission

Correlation coefficients were also computed between the various SA measures (SAGAT, over-confidence bias, and self-rating of SA) and performance outcome in individual mission. SAGAT level 3 scores showed significant correlation with the number of times the aircraft is being shot by the enemy, $r = -.53$ ($p < .05$). The correlations between performance outcome and level 1 and 2 SAGAT scores, as well as self-rating of SA, did not show significant results. The overall over-confidence and absolute confidence biases, on the other hand, was found to contribute to poor performance, as shown by the high correlations with the number times the aircraft is being shot by the enemy, $r = .63$ ($p < .01$).

Table 8-18 Correlations between SA and performance (individual)

	Kill enemy	Shot by enemy
SAGAT Level 1	.34	-.39
SAGAT Level 2	.02	-.20
SAGAT Level 3	.38	-.53*
Self rating of SA	.02	-.30
Over-confidence bias	-.30	.63**
Absolute confidence bias	-.30	.63**
<i>M</i>	3.77	1.53
<i>SD</i>	.90	1.12

$N = 16$; * $p < .05$; ** $p < .01$ (one-tailed); expected negative correlations are shaded in gray

Team mission

The correlation coefficients between SA measures and performance and experience in team missions are reported in Table 8-19. As there was little variation in the number of enemy successfully killed by the enemy (the result was binary), no further analysis was conducted on this performance measure. Instead, the survivability indicated by the number of shot received by the aircraft was used as the sole indicator of team performance outcome. Similar to the results found in individual missions, the number of

being shot by enemy was shown to have high correlations with SAGAT of own situation, $r = -.69, p < .05$, over-confidence bias, $r = .68, p < .05$, and absolute confidence bias, $r = .68, p < .05$. Note that the correlation between awareness of teammate's workload and performance was in the opposite direction from expected, where better performing teams were found to be poorer in estimating each other's workload. Awareness of teammate's SA level did not show significant association with performance outcome. In addition, team behavior scores in acknowledging receipt of information, anticipatory and clarification of information, and feedback, backup, and support of each other's actions also showed high correlations with team survivability, where the latter seems to account for the most variance in team performance outcome, $r = -.88, p < .01$.

Table 8-19 Correlations between SA and performance (team)

	Shot by enemy
SAGAT of own situation	-.69*
SAGAT of teammate's situation	-.42
Self-rating of SA	-.36
Over-confidence bias	.68*
Absolute-confidence bias	.68*
Awareness of teammate's workload level	-.51
Awareness of teammate's SA level	.16
Targets_info	-.27
Targets_ack	-.50
Targets_anti	-.59
Targets_fbac	-.88**
<i>M</i>	2.38
<i>SD</i>	1.69

$N = 8$; * $p < .05$; ** $p < .01$ (one-tailed); expected negative correlations are shaded in gray

8.4 Discussion

8.4.1 Three Levels of SA

The result reported in Table 8-9 showed that there are high correlations between SAGAT level 1, 2, and 3 obtained in individual mission and in SAGAT of own situation (team mission). These findings support Endsley's (1995c) proposition on the importance of

perception and understanding of current situation to accurately predict what is going to happen in the near future. Making a prediction, such as whether the participants would be able to shoot within the next 10 seconds, is not as simple as it may sound. It requires integration of information from various sources, such as information regarding the range, aspect, and altitude of the enemy relative to own aircraft, weapon superiority, comprehension of whether the enemy is within WEZ (Weapon Envelope Zone), whether the pilot will be able to achieve FLO (First Launch Opportunity), and whether it will still be safe for him to continue with the engagement in case the enemy had launched the missile. Every second in air combat is vital. Launching the missile too soon (too far from the enemy) before even reaching the desired DLZ (Dynamic Launch Zone) could risk a waste of missile. Waiting too long in order to reach the range whereby the missile launched will have high possibility of hit, would risk losing FLO and having missiles launched first by the enemy. Thus, prediction involves extensive cognitive processes, in which integration of both level 1 and 2 SA are important to form an accurate prediction.

In contrast, the correlations between the three levels of SA on SAGAT of teammate's situation (team mission) were low. The inclusion of an additional intelligent agent (teammate) increases the uncertainty and reduces the possibility of making an accurate prediction. Wickens et al. (2000) implied that the accuracy of prediction is reduced with the existence of additional human operators, who may perform unanticipated action at any time. Predicting situation in individual setting is complex enough, and even more so in team setting. One way to make it far less complex is through exchanging information regarding each other's situation and intention. It was observed that team members often share the level 2 and 3 SA information directly. Therefore, a member may not need to know the level 1 information about his teammate to comprehend and predict teammate's situation. For instance, in the context of the simulated scenario, when the teammate communicates, "Viper two targeted bullseye 178, 11, 27000, hostile, standby fox", he can infer that the enemy is within teammate's weapon employment zone (level 2 SA) and that teammate will be launching a missile soon (level 3 SA), without knowing the exact range and relative position of teammate's aircraft. In addition, since the two aircrafts are exposed to the same enemies, comprehension and prediction of teammate's situation can be more or less inferred from own situation (see discussion in Section 8.4.5 on the relationship between SA of own and teammate's situation). Good communication skills can help to bring the higher levels SA information into the perception level, which can

help to reduce the mental workload imposed in developing a mental picture of the team situation. The explicitness of the communicated information can make the distinction between the three levels of SA (Endsley, 1995c), which is relatively clear in the individual level, become vague when applied in team level. When the teammate explicitly communicated “I’m going to take a shot now”, or “I’m going to crank South East”: is predicting teammate’s next action still a level 3 or has now brought into the perception level? This dynamic interaction between individuals that takes place in team level differentiates team SA from the traditional view of individual SA.

In terms of relationship with performance (see Table 8-18), only level 3 SA was found to associate with performance. There was no significant correlation between the lower levels of SA and performance. This finding, along with previous studies reported in the literature, ascertains the importance of future prediction for performance. Durso et al. (1998) reported that the more efficient air traffic control operators who had fewer number of control actions remaining at the end of a scenario, were better in answering queries about the future. Orasanu & Fischer (1997) also found that higher performing crews in commercial aviation engaged in more anticipation and preparation for future uncertainties compared to the poorer performing crews. In the current study, predictions such as whether one would be able to take shot within the next 10 seconds, whether the enemy is going to take shot within the next 30 seconds, whether the enemy is going to employ any threat reactions, and so on, can influence the selection of next action. If the pilot anticipates that the enemy is going to launch a missile at him, and that this missile is likely to hit his aircraft based on the comprehension of the spatial relations and characteristics of the weapon system, he may decide to abort the engagement and plan for a retargeting plan, attempting to gain a position of advantage with less risk of getting killed. Inaccurate predictions can lead to poor decision, and eventually poor performance such as getting shot. Although the pilot may be able to shoot and kill the enemy, his performance will be considered as poor if he gets shot during the engagement. If this happens in real life, he would have died.

The result also revealed the tendency of participants to be particularly over-confident (and higher absolute confidence bias) on the accuracy of their level 3 SAGAT answers (Table 8-10). In both individual and team missions, the over-confidence and absolute confidence bias on responses to SAGAT level 3 was shown to be significantly higher than to SAGAT

level 1 and 2, implying that the participants were more calibrated on how much they think they know about the current situation than on what they think would happen in the near future. Level 1 SA probes required the participants to report specific information such as flight parameter, number of enemy aircrafts, and location of enemy. The participants usually knew when they did not report this information accurately and reported a low confidence when they were unsure on the accuracy of their answer. On the other hand, most of the participants were generally confident on their prediction, regardless the high or low confidence of their level 1 and 2 SAGAT answers. Lichtenstein et al. (1982) reported several studies with similar findings, where over-confidence was higher for the accuracy of answers to difficult items compared to easy items in questions related to general knowledge. Over-confidence was also shown for the calibration of future events. However, the calibration for future events was somewhat better than for the general-knowledge items. In SA context, Lichacz et al. (2003) involved 32 individuals in simulations, and SAGAT was used to collect the subjects' SA and confidence in their responses. They reported that the participants had less over-confidence bias in level 3 compared to level 1 and 2 SAGAT answers. This is the opposite of the result of the current study, where higher over-confidence was found in participants' responses to level 3 compared to level 1 and 2. It is suspected that the different result is due to the characteristics of pilots, who are taught to be confident on their ability to control the plane during their training. Unfortunately, no participants' background was reported in Lichacz et al. (2003) to justify this comparison.

In summary, several important findings have emerged from this study. Similar to previous research, the ability to accurately project future status (SA level 3) is an important contributor to better performance. In addition, there is a tendency of people (or rather, pilots) to be more over-confident on their level 3 than level 1 and 2 SA. As shown in Table 8-18 and Table 8-19, more over-confidence in general relate to worse performance. These findings collectively further emphasize the importance of level 3 SA and the calibration of self-perception of SA for performance.

8.4.2 Cognitive Ability and SA

In general, the results shown in Table 8-12 and Table 8-13 substantiated the hypothesis on the existence of relationship between cognitive ability and SA, particularly on the

spatial and reasoning domains. Similar to a study by Endsley & Bolstad (1994), none of the memory tests were found to correlate highly with SA. This may be because the participants included in the analysis considerably had high experienced in the task domain (Cat As and Bs), who were likely to possess the mental models necessary to assist the acquisition of SA. Expert pilots rely more on long-term working memory (LTWM) in SA development than working memory (WM). This finding is similar to the study by Sohn & Doane (2004). They reported that differences in the anticipation ability of expert pilots were significantly affected by the LTWM, but not WM. Instead, WM was found to have a significant effect on the anticipation ability of the novice pilots. High experienced pilots can chunk the information available in the environment into a meaningful pattern, quickly relate this information with the mental models stored in Long Term Memory (LTM), and store it in LTWM which is readily available for recall. This explains why pilots with lower WM span were able to answer the SAGAT questions equally well as those with higher WM span.

Two of the spatial ability tests, Hidden Figure and Cube Comparison, showed high bivariate and partial correlations with individual SA scores. Hidden Figure is a test for flexibility of closure, the ability to hold a given visual configuration in mind and disembed it from other well defined perceptual material. The similar test is included in AFOQT, an aptitude test currently used by U.S. Air Force for their pilot selection. Cube Comparison test measures spatial orientation, the ability to maintain orientation with respect to objects in three-dimensional space. Endsley & Bolstad (1994) used a similar test and found a moderate correlation between this test and the pilot's knowledge of the location of the enemy aircraft. Aviating task is performed in a 3-dimensional space. SA in flight environment, especially in air combat, relies on understanding of spatial relationships between own and enemy aircraft. The determination of threat level of the enemy requires information on range or distance separation, aspect or relative heading of the two aircrafts, and all of these are highly spatial.

Two of the reasoning tests, Following Direction and Math Aptitude, showed high correlations with level 1, 2, and 3 SAGAT and self-rating SA measures. The Following Direction test involves the ability to keep in mind simultaneously or to combine several conditions, premises, or rules in order to produce a correct response. The Math Aptitude test assesses the ability to select and organize relevant information to solve a problem.

Reasoning ability is important to build SA, especially when the information was not directly available and when integration of information from various resources was required to build a mental picture of the situation. A large amount of information regarding own and enemy aircraft can be obtained from the cockpit displays. However, these information need to be integrated to form an understanding of the ongoing situation and to project future status. For instance, determination of threat level posed by an enemy aircraft requires integration of range, bearing, altitude, aircraft type and weapons, radar capability, and weapon effective ranges. An enemy at 20 nautical miles (nm) coming straight would be more threatening than one beaming (going across) at 15 nm. Critical range between two aircrafts, which is crucial to know to successfully avoid detection and weapon employment by the enemy, needs to be derived from different information such as characteristics of aircraft, radar, and weapon. Thus, the ability to integrate information from various sources and from mental model stored in long-term memory would support the acquisition of SA.

8.4.3 Team Composition (Diversity in Experience) and SA

The results revealed the differences in team SA across different composition of team based on members' experience level. Based on the diversity in team members' experience, the teams were grouped into three: 1) Two Cat A pilots with little difference in flight experience; 2) combination of Cat A and B pilots with moderate difference in flight experience; 3) combination of Cat A and Cat C/D pilots with high difference in flying experience. The result showed that teams in group 3 generally had the worst SAGAT scores and the highest absolute confidence bias. As shown in Table 8-15, the poor scores seem to be attributed by the lower experienced member in the team.

As a case study, consider a classic case demonstrated by one of the team participants described as follows. Team #5 was composed by a Cat A pilot (2600 flying hours) as flight lead and a Cat D pilot (390 flying hours) as wingman. In Mission 4, first engagement, the wingman committed a fatal error by launching multiple missiles on his flight lead (fratricide). The scenario started by the two aircrafts flew in trail. The wingman detected the existence of the enemy, and called spike. The lead acknowledged, and commanded wingman to target the contact. Unfortunately, the wingman was unable to lock. The lead identified that there were two contacts, locked and launched missiles on

one of the adversaries. After pitbull⁷ on his missile, he went out⁸ to escape from enemy's missiles. After escaping from the enemy missiles, the lead pitched back and launched a missile on the second adversary. The wingman, all this while, did not update his status. He was receiving missile shots from the enemy, and attempted to escape but was not effective. He was unaware that the flight lead had taken down all adversaries. Despite his poor awareness, he did not make any attempt to request any information from the lead. After a while, he pitched back and detected a contact (who happened to be his flight lead) on his radar, he called out the targeted bullseye position, but communication was unclear. Flight lead did not acknowledge, perhaps because communication was unclear, and flight lead did not attempt to ask for clarification either. Wingman targeted the contact without waiting for acknowledgement or seeking for clarification. He communicated that he targeted the contact, which was again not acknowledged by the lead. Soon after, he launched multiple missiles at his flight lead (targeted contact) without attempting to positively identify the targeted contact to be hostile. The transcribed communication is as follows:

<u>Time</u>		<u>Thought units</u>	<u>Remarks</u>
9:02:10	L	we are going to steerpoint 3	
9:02:13	W	two spike ⁹ north east	W is spiked
9:02:15	L	ok	
9:02:18	L	two target ¹⁰ 000, 14, 26000	
9:02:22	W	two is targeted 008, 28, 26000	
9:02:28	L	ok	
9:02:35	L	contact drag ¹¹	
9:02:52	L	radar shows 2 contacts	
9:03:01	L	two, status of contact	
9:03:04	W	two shows contact <i>beaming</i> ¹² south	W called contact beaming instead of coming hot ¹³
9:03:05	L	ok	
	L	one targeted hot contact 28000, 005, 15	
9:03:13	W	two is targeted 020, 27, 28000	L: fox three ¹⁴ launched
9:03:20	W	two fox three	W: did not fox
9:03:21	L	one ... 31, 110	
9:03:28	L	two, status!	Multiple missiles launched by
	W	two is....	enemies

⁷ Pitbull – missile goes active and can self-guide to the target without support of the aircraft's radar

⁸ Out – a terms used to describe that the fighter is turning away from the combat arena

⁹ Spike – threat is displayed on RWR (Radar Warning Receiver)

¹⁰ Target – specification of sort responsibility

¹¹ Drag – bandit maneuvering to 60 degree or less aspect

¹² Beam – aircraft maneuvering stabilized, generally given with cardinal directions: east, west, north, south

¹³ Hot – attack geometry that results in rollout in front of the target

¹⁴ Fox three – launch of AMRAAM (Advanced Medium-Range Air-to-Air Missile)

9:03:35	L	one is out	L: pitbull
9:03:54	L	one is notching ¹⁵ west	
9:04:04	L	spike east	
	W	spike east	
9:04:56	L	one fox 300, 11, 29000	L: fox three launched
9:05:00	L	skate right	
9:05:25	L	heading 240	
9:05:28	L	spike east	
9:05:37	W	... (??) 18000 [unclear]	W targeted L
	W	two is ... (??) [unclear]	W fox on L (2 x AIM-120B)
9:06:05	W	two fox three	W fox on L (2 x AIM-120B)
9:06:12			W fox on L (1 x AIM-120B)
9:06:34	W	is that you?	
9:06:51	L	I think you just shot me, you know	
	L	a*****!!	
9:06:56	W	sorry...	

Note: L / one – flight lead; W / two – wingman

The occurrence of incident described above was attributed by several reasons: 1) poor awareness of wingman; 2) probably coupled by poor awareness or communication of flight lead as he did not respond when wingman communicated that he was targeting a contact, who had the same bullseye position as him; 3) poor integration of information – no attempt to check whether a contact was friendly/enemy; 4) poor teamwork behavior, poor CRM practice – no acknowledgement, no attempt to request for information, and taking action without clearance from flight lead.

The steep “trans-cockpit authority gradient” (a term used to refer the pairing of very senior and very junior pilots, usually in dual-seat cockpits) may also play a role the way the team members interact. The senior pilots usually play a directive role, while the juniors are hesitant to question and request for information from the flight lead. Steep gradient can hinder smooth integration of members’ SA, degrade communication and coordination, and worse, can lead to aviation mishaps. Alkov et al. (1992) examined the relative military rank of pilot and copilot and the occurrence of Navy and Marine Corps helicopter mishaps. They reported that pilots differed by two or more ranks yielded the largest error rate, and pairing of equal ranks yielded the lowest rate. Due to the small sample in this study, it is not possible to draw any conclusion regarding the optimum pairing of experience levels. In addition, as teams with both low experienced members were not sampled, the lower scores obtained in the third group maybe mainly due to the

¹⁵ Notch – missile defensive maneuver to place threat radar/missile near the beam

low experience of one of the members. Nevertheless, the observable effects of diversity in team members' experience on team processes and SA suggest that this factor needs to be taken care of. This can be done either through proper crew rostering or through CRM training to manage differences in cockpit for safety and effective performance. Further studies on the impact of diversity on team SA are needed.

8.4.4 SA and Team Processes

The correlation analyses of SA and team processes shown in Table 8-16 suggested the link between the two variables. Sharing of necessary information had high association with team SA. Sharing information regarding own and enemy is necessary to build a big picture of the overall team situation. Earlier detection of enemy aircraft on one member's radar, when communicated, allowed teammate to anticipate the presence of the enemy even though this information is not yet shown on his radar. Communicating own status, actions, and intentions is critical especially when visual proximity is lacking. It should be noted that due the limitation of experimental set up, the field of view was restricted by what is displayed on the screen, and it was hard to visually search teammate on the screen. Therefore, most of teammate's information had to be obtained through verbal communication. Feedback, support, and backup behaviors also closely related with SA. If a team member is aware that his teammate is not coping well, then he can step in to provide feedback and support. However, support, and backup would be effective only if one has an accurate understanding of his teammate's situation in relation to the enemy.

The communication frequency measures did not show any meaningful relationship with SA. One possible reason is because in time critical and stressful environment such as military aviation, clear, precise and concise communication is encouraged. Thus merely counting the communication frequency may not provide meaningful information, because the more may not mean the better. Although providing the necessary information to teammate is good for the development of team SA, engaging in excessive communication such as excessive use of words, repeating and clarifying communication problem, requesting information that should be given voluntarily, etc., can impose additional demand on mental resources and can have negative impact on team SA. Therefore, analyzing team communication within the context of team situation, whether the

necessary information is being communicated at appropriate times, such as done in TARGETs assessment, was more informative.

8.4.5 Various Aspects of Team SA

Examination of the inter-relationships between different measures of team SA revealed that they are non-overlapping. The correlation between SAGAT of own and teammate's situation was high ($r = .60$ in Table 8-17), indicating that team members who had better awareness of own situation also tend to have better awareness of teammate's situation. This result is expected for teams with high overlap in responsibilities across members. In this simulation, the two fighters had high overlapping responsibilities, i.e., to survive and take down all adversaries. In the process towards this goal, team members maintained within a specified range and altitude separation, and were exposed to the same group of adversaries. Awareness of own situation need to be derived from information of own aircraft status and the enemy's. Similarly, awareness of the higher levels of teammate's situation (understanding whether teammate is within the enemy's weapon envelope, whether teammate is within an advantage position to take a shot, etc.) has to be derived from the information about the teammate as well as the enemy. As the awareness of own and teammate's situation need to be derived from the same enemy information, it is reasonable and expected that the two aspects of awareness correlate to each other. The correlation of the two variables may not be high for other types of team characteristics where team members' responsibilities are completely different.

The result also revealed that teams who were more aware of the situation were also more calibrated on their awareness. In general, the participants had high confidence in their answers. This resulted in high confidence bias for participants with low SAGAT scores. Confidence bias thus can be considered to include two aspects of SA, namely a person's knowledge about the ongoing situation and his perception of the accuracy of this knowledge (meta-SA).

There was no evidence on the correlation between self-rating of SA and the rest of the SA measures. A close inspection of the data revealed that some of the participants rated very high for their SA, but their SAGAT responses were poor. The same finding was also reported by Endsley et al. (1998b), who revealed no correlation between SART

(subjective SA measure of SA, Taylor, 1990) and SAGAT, but instead SART was found to correlate highly with confidence level of their SA. In this study, the self-rating of SA showed high correlation with absolute confidence bias, but not with confidence level and over-confidence bias. Please note that the participants were asked to provide their SA rating first prior to answering the SAGAT queries and confidence level, so that their SA rating was not influenced by their feeling towards performance in answering the SAGAT queries. It is possible that the participants changed the perception towards their SA along the process of answering the SAGAT questions and thus had different confidence rating, or that the participants' baseline on what it is referred as good or poor SA is different to the SA requirements derived by experimenters' to formulate the SAGAT queries. However, as the sequence in which the measures were administered in Endsley et al.' (1998b) study was not reported, it is hard to even speculate if the difference in result is due to the experimental procedure.

The low correlations in Table 8-17 suggested that team members, who obtained high scores in SAGAT and were calibrated in their confidence, were not necessarily more accurate in estimating their teammate's workload and SA level. This result can be due to any of the following reasons. First, two types of measures may indeed represent independent aspects of team SA and were developed from assessing different sources of information in the environment. Therefore, it is possible for a team member to be aware that his teammate is having high workload/ awareness level, through assessing changes in teammate's communication pattern (talkative became quite), intonation, etc., although he may not necessarily know accurately what is going on, and vice versa. Second, subjective ratings may not be the best way to derive the awareness of teammate's status of workload and SA, due to the biases of self-estimation and heuristics used in estimating others.

Analyses confirmed that the participants tended to estimate teammate's workload and SA level similar to own. The tendency of participants to use an "egocentric heuristic" of self ratings, as a proxy for estimating those variables for others, can explain this result. According to Tversky & Kahneman (1982), people rely on heuristics in making prediction and judgment under uncertainty, which sometimes yield reasonable judgments but sometimes lead to severe systematic errors. In this study, the participants were first asked to rate their own workload and SA levels, and then to estimate their teammate's. The availability bias of self-rating provided a shortcut, quick-and-dirty rule for estimating

teammate's status, which is so compelling to use rather than performing an extra evaluation that would require additional cognitive resources. In addition, the differences in the amount of information available regarding self, which is much more than information regarding teammate, could promote egocentric recall (Ross & Sicoly, 1982).

8.4.6 SA and Performance

The relationship between SA and performance was evidenced in both individual (Table 8-18) and team missions (Table 8-19). Performance had high correlations with SAGAT level 3 scores in individual mission (refer to discussion in Section 8.4.1), and with SAGAT of own situation in team mission. This finding supported the theory that proposes higher SA will increase the likelihood of obtaining better performance (Endsley, 1995a). The correlation between SAGAT and performance has been reported in some other studies (Endsley, 1988; Endsley et al., 2000).

What is interesting to note in this study is the strong relationship between confidence bias and performance in both individual and team missions. When people are over-confident, they will prematurely close off the search of evidence, feeling that they “know the truth”, and confidently making decision and taking action that are prone to errors. On the other hand, people who are under-confident tend to be more cautious and possibly hesitant to engage decisions and actions. Over-confidence of own ability is dangerous as one would bear to take higher risk, thinking that they are doing better than they really are, and does not hesitate to take aggressive approach when the situation indeed should be handled with greater caution. For instance, as demonstrated in this study, some of the fighters over-confidently continued with enemy engagement as they thought they knew the situation well, which indeed they did not. This poor decision resulted in low survivability (being shot by the enemy). A less over-confident pilot would rather abort the engagement and planning for retarget. Wiegmann & Goh (2000) similarly noted that pilot's over-confidence of own ability may encourage continuation of a flight because of an unrealistic optimism about being able to avoid harm through personal control of the flight.

The correlation between awareness of teammate's workload level and team performance was high, but in the opposite direction. Better performing teams were found to be poorer

in estimating each other's workload. This can be due to several reasons. First is the reliability of the measures used, where the participants tend to provide a similar rating to self and teammate's workload / SA levels. It is possible that the team members who provided a different rating to self and teammate's workload (thus reflected as poorer awareness of teammate's workload), were indeed the ones who made the effort to properly evaluate teammate's workload rather than deriving teammate's workload through heuristics. Second, team members who felt that teammate's workload was higher than his may provide more backup and support to teammate (as shown by the moderate positive correlation between awareness of teammate's workload and feedback, backup, and support measured by TARGETs reported in Table 8-16), and this would eventually resulted in better performance (high positive correlation between feedback, backup, and support measured by TARGETs and performance in Table 8-19). There was no significant correlation between performance and awareness of teammate's SA levels. This does not mean that this aspect of SA is not important. Issues in self and peer ratings discussed in Section 8.4.5 may also play a role in the low correlation with performance. In addition, the reliability of self rating as a source of SA may also attribute to the insignificant result.

8.5 Summary

This study aimed to investigate the concept of team SA and examine the factors affecting team SA. The investigation on SA level 1, 2, and 3 of own situation showed that they are highly correlated to each other. The study also revealed that the participants were less accurate in answering SAGAT level 3 queries, and they were also less calibrated in their confidence towards level 3 compared to level 1 and 2. The tendency of over-confidence in own awareness, especially in the prediction aspect, and the significant role of over-confidence bias for performance, make important topics for further research. Result on the relationship between cognitive ability and SA showed the importance of spatial and reasoning abilities for SA in air combat tasks. This finding is in line with previous studies conducted in the similar domain. This study, although was not specifically targeted to address team composition, has revealed its importance on team process and SA, and eventually team performance outcome. Compared to teams composed by both high experienced members, teams composed by high and low experienced members had significantly poorer SAGAT scores of own and teammate's situation, were less calibrated

in their perception of own SA, and were observed to be less effective in their team processes. Not many of such studies were found in the literature. Further studies looking onto this issue are deemed to be necessary. The inter-relationship between various aspects of team SA revealed mixed of significant and non-significant results. Team SA seems to be a multi-faceted concept that requires various approaches to adequately measure it. Furthermore, heuristics and biases in participants' responses brought up questions regarding the validity of using subjective measures to measure awareness of teammate's workload and SA levels.

In order to compare the results of this study to those found in Study 2 and 3, a bivariate space was constructed (Figure 8-10) with effect size (variance accounted for, r-squared) of the results of Study 2/3 on the x-axis and Study 4 on the y-axis. The data points on the upper right corner and the lower left corner are strong replications. As shown on the figure, there were consistent positive associations between SAGAT of own task and information transfer, between self-rating of SA and helping behavior, and between SAGAT of own and SAGAT of teammate's task. On the other hand, the associations between information transfer and absolute confidence bias, awareness of teammate's workload and SA levels, were consistently low. Similarly, the inter-correlations between team SA measures involving awareness of teammate's workload and SA levels were consistently low. The rest of the result was not replicable and this can be due to the difference in task nature across the studies. For instance, the correlation between over-confidence bias and absolute confidence bias was low in Study 3, but high in Study 4. This maybe resulted by the differences in characteristics of the groups who participated in the studies. Pilots, who participated in Study 4, were observed to be confident on what their knowledge and ability, to an extent that it was very few instances where they were found to be under-confident.

Note: the numbers above represent the correlations between variables on the table below:

	SA _{Own}	SA _{Tmate}	SA self-rating	Over-conf. bias	Abs. conf. bias	WL Aware	SA Aware
Information transfer	1			2	3	4	5
Helping behavior			6	7	8	9	
SA _{Own}							
SA _{Tmate}	10						
SA self-rating		11					
Over-conf. bias	12	13	14				
Abs. conf. bias	15	16	17	18			
WL Aware	19		20	21	22		
SA Aware				23	24		

Figure 8-10 Effect size of Study 2/3 versus Study 4

Chapter 9 General Discussion and Future Research

9.1 General Discussion

9.1.1 Integrated Framework of Team SA

The importance of team SA in complex and dynamic environment has been identified by many researchers and practitioners. A number of models have been proposed to explain the phenomenon; however most of them are limited to conceptual stage as they do not provide the ways to measure the construct. In addition, they do not comprehensively address the factors that may influence team SA, which would be useful for design considerations and system evaluation. This research derives the potential factors that influence the development and maintenance of team SA from the review of literature (Chapter 3) as well as empirical investigation across the four studies reported in Chapter 4, 6, 7, and 8. A summary of findings across these four studies is shown in Table 9-1. An approach to assess team SA, taking into consideration task characteristics that define team SA requirements, and system's affordance that define the upper limit of achievable SA, are incorporated in a framework presented in Chapter 5. Figure 9-1 presents an integration of this framework to include the input (design) factors that influence the acquisition of team SA, process factors that can both affect and be affected by the quality of team SA, and final performance outcome. This integrated framework offers several advantages. First, it includes the underlying variables related to team SA, integrating the cognitive processes and products within teams. Fiore & Salas (2004) suggested that such frameworks can provide a foundation to derive empirically testable principles and is an important step to advance the knowledge in team SA. It can be used as a guide to ensure that the variables other than those of interests, which may confound the result of the experiment, are properly addressed. Second, as demonstrated in Chapter 5, it can assist the development and selection of measurement approaches to measure team SA. Finally, it provides a holistic overview of the team phenomenon, which is essential for an evaluation of a team-oriented system. As noted by Lewin (1951), to understand how a team works, team members and their environment should be considered as one constellation of mutually interdependent factors.

Figure 9-1 Integrated framework of team SA

Table 9-1 Summary of main findings

	SA _{Own}			SA _{Tmate}			SA self-rating				Over-conf. bias		Abs. conf. bias		WL Aware			SA Aware		
Study #	2	3	4	2	3	4	1	2	3	4	3	4	3	4	2	3	4	2	3	4
Task experience	-	✓	✓	-	✓	✓		✓	✓	-	-	-	-	-	-	-	-	-	-	-
Cognitive ability		-	-		-	-			-	-	-	-	-	-		-	-		-	-
Familiarity		-			✓				✓		?		-			-			-	
Diff. in experience			✓			✓				-		-		✓			-			-
Information transfer	✓	✓	✓	✓	-	✓		-	✓	-	-	✓	-	-	-	-	-	-	-	-
Helping behavior	✓	-	✓	✓	-	✓		✓	✓	-	✓	✓	-	-	-	✓	-	-	-	-
CAST	-	✓		✓	-			-	✓		-		-		-	-		-	-	
SA _{Own}																				
SA _{Tmate}	✓	✓	✓																	
SA self-rating	-	-	-	✓	✓	-														
Over-conf. bias		-	✓		-	-			✓	-										
Abs. conf. bias		-	-		-	-			-	✓	-	-								
WL Aware	-	-	-	✓	-	-		-	-	✓	-	-	-	?						
SA Aware	✓	-	-	-	-	-		-	-	-	-	-	-	-	-	✓	-			
Performance	-	✓	✓	-	✓	-	✓	✓	✓	-	?	✓	✓	✓	-	-	-	-	-	-

Note: relationship (✓) exists; (-) not exist; (?) opposite direction from expected; () not tested

Table 9-2 Summary of the relationships between variables

Factors associated with team SA	
- Task experience	Showed positive impacts on SA related to own task, SA related to teammate's task, and self-rating of SA
- Cognitive ability	Did not have a direct impact on team SA
- Familiarity	Was only investigated in Study 3. Team members who were more familiar with each other had higher SA related to teammate's task and self-rating of SA, but also higher over-confidence bias
- Difference in experience	Was only investigated in Study 4. Teams with higher gap in experience levels of team members had poorer SA related to own and teammate's tasks, and calibration of self awareness.
- Information transfer	Showed positive associations with SA of own and teammate's task in Study 2 and 4. The lower association in found Study 3, where the teams were more familiar with each other.
- Helping behavior	Showed positive associations with SA of own and teammate's task in Study 2 and 4. The lower association found in Study 3, where the teams were more familiar with each other.
Inter-correlations among aspects of team SA	
<ul style="list-style-type: none"> - Consistent positive association between SA of own and teammate's tasks - The rest of the associations were inconsistent and non-conclusive 	
Associations between team SA and performance	
<ul style="list-style-type: none"> - There was evidence on the positive association between performance and awareness of own and teammate's tasks, and self rating of SA - Over-confidence bias in Study 4 showed negative impact on performance, but the association was in opposite direction to Study 3. However, both studies were consistent in the association between absolute confidence bias and performance. - Awareness of teammate's workload and SA levels consistently showed low associations with performance across the three studies 	

9.1.2 Definition and Attributes of Team SA

Team SA is defined as *team members' perception, comprehension, and future prediction of the system/task status relevant to their responsibilities, and of the team status, which is required for effective interaction in an interdependent team*. It consists of two main aspects, namely awareness related to taskwork and awareness related to teamwork. The extent to which team members are required to share the awareness related to taskwork is dependent on the distribution of responsibilities in the team. The extent to which team members need to acquire awareness related to teamwork is dependent on the level of

inter-dependence among members. The two main aspects can be further broken down into awareness of the situation necessary to perform own responsibilities, awareness of the elements needed to backup teammate's responsibilities, awareness of own state of knowledge (meta-SA), and awareness of teammate's workload and SA levels (see illustration in Figure 9-2).

Figure 9-2 Different aspects of team SA

The results from the three studies reported in Chapter 6, 7, and 8 suggested that team SA is multi-dimensional construct, not a unitary one. The average inter-correlations between the measures of team SA were not high, indicating that they are non-overlapping. This suggests that each of the measure were targeting on different aspects of team SA. For instance, SAGAT of own situation measures the extent to which an individual member *accurately* perceives and comprehends the current status and is able to predict the future status of the elements of the system that are directly related to his responsibilities. On the other hand, SAGAT of teammate's situation assesses the extent to which an individual member knows what is happening to his teammate. The correlations between these two aspects of team SA were high across the three studies, $r(10) = .64, p < .05$ in Study 2, $r(16) = .46, p < .05$ in Study 3, $r(8) = .64, p = .06$ in Study 4. The high correlations are suspected due to the high overlap in the elements of SA requirements across the team members, e.g., enemy information would be required to derive understanding of both own and teammate's status. In addition, an individual member that could not even cope with own responsibilities may not have the extra resources to build the awareness regarding his teammate.

In contrast, the correlations between SAGAT related to own situation and self-rating of SA were consistently low across the three studies; while the correlations between SAGAT related to teammate situation and self-rating of SA showed mixed of high and low correlations. Self-rating of SA, such as SART, provides an assessment of individual's perception or feeling on his SA. It may not accurately represent the quality of his SA because different individuals may have different standard to what is referred as good SA, and it is highly possible that "you don't know what you don't know". A person may think that his SA is very high but have low score in SAGAT, because he feels that he knows extensive information regarding certain elements, which are actually of low relevance to his responsibilities. Thus, the two aspects are independent, where there can be four combinations of high SAGAT and high self-rating, high SAGAT and low self-rating, low SAGAT and low self-rating, and low SAGAT and high self-rating; where the latter would be the worst.

Over-confidence and absolute confidence bias combines the accuracy of situational knowledge and the subjective perception of own SA. As reported in Table 7-8 (Study 3) and Table 8-17 (study 4), their correlations with SAGAT scores of own and teammate's situation were not significant, except for the correlation between over-confidence bias and SA related to own situation in Study 4, $r(8) = -.85, p < .01$. This is possibly because the participants (fighter pilots) tended to have high confidence in their responses, which resulted on high over-confidence bias for those with low SAGAT score.

Awareness of teammate's workload and SA status measured by similarity in rating of self and rating estimated by teammate, assess another aspect of team SA, different from those described above. Across the three studies, they showed non-significant result for almost all correlations with SAGAT of own and teammate's situation, self rating, and over-confidence and absolute confidence bias. Knowing whether teammate is overloaded or losing awareness does not necessarily means that a person understands what exactly is happening to him or his teammate, as this information can be derived from different sources. Awareness of teammate's workload and SA status can be obtained from explicit statement by teammate, observation of changes in teammate's behavior, or implicitly as facilitated by shared mental models existing in teams with familiar members.

9.1.3 Team SA and Performance

All of the measures discussed here are important to provide a more complete overview of team SA. However, if the evaluator needs to eliminate any of these measures due to constraints in time or resources, a question may then be raised on which measure should be kept. This issue can be addressed by evaluating the utility of each measure to predict team performance outcome. Across the three studies, better and poorer performing teams were generally different and can be best predicted from SAGAT of own situation, absolute confidence bias, and team processes as measured by overall self-rating of teamwork behavior and observer evaluation using CAST and TARGETs method.

A team member who is unaware of the information required to perform own task (measured by SAGAT of own situation), such as not knowing the location of enemy, will not be able to select the appropriate action, when and how to act, which will eventually result in poor performance. As shown in Table 7-9, the poorer performing teams in Study 3 were shown to have significantly worst scores in SAGAT of own situation compared to the better teams. Similarly, in Study 4, poorer score in SAGAT of own situation was associated with worse survivability, $r(8) = -.69, p < .05$ in Table 8-19. When broken down into the three levels of SA in individual level analysis, only level 3 SA was shown to correlate significantly with performance, $r(16) = -.53, p < .05$ in Table 8-18.

Awareness of the quality of own SA is also crucial as it determines what kind of actions to take. Better performing teams were found to have significantly less absolute confidence bias (more calibrated in what they knew/did not know) than the poorer teams. Similarly, absolute confidence bias was shown to have significant associations with performance in both individual and team missions, $r(16) = .63, p < .01$ and $r(8) = .68, p < .05$, respectively. People who are over-confident, thinking that they know more than they do, will opt to prematurely close off the search of information and confidently making decision and actions that are prone to errors. On the other hand, people who are under-confident tend to be cautious and hesitant to engage decisions and actions, which can also be bad for performance in time-compressed scenarios. The result on over-confidence bias (signed value: negative for under-confidence, positive for over-confidence) were however not consistent between Study 3 and 4. In Study 3, better performing teams were found to have higher over-confident bias than the poorer team. On the other hand, in Study 4, over-

confidence bias was associated with poorer performance, $r(16) = .63, p < .01$ in individual mission and $r(8) = .68, p < .05$ in team mission. One possible explanation to this result is perhaps due to the nature of pilots to be highly confident towards what they know and can do. This is shown by the distribution of the over-confidence bias of the pilots which was skewed to the left (see Table 8-10).

Better team processes measured by overall self-rating of teamwork behavior and observer evaluation using CAST and TARGETs methods were also shown to significantly associate with better team performance outcome in all the three studies. Team processes include not only sharing of cognition through communication, but also cover the actions taken by team members, such as support and backup behavior. According to human information processing model (cf. Wickens & Hollands, 2000), the latter would have a direct influence on team performance outcome. As shown in Study 4, there was a high correlation between feedback, support, and backup behavior measured by TARGETs and the number of getting shot by the enemy, $r(8) = -.88, p < .01$ in Table 8-19.

Awareness related to teammate, including the situation relevant to his responsibilities, workload and SA level, is necessary in a team with high inter-dependencies among team members' roles. The correlations between these aspects of team SA and team performance across the three studies were however not consistent. SAGAT of teammate's situation was found to associate only modestly with team performance in Study 2 and 4. In study 3, better performing teams had significantly better score in SAGAT of teammate's situation as compared to the poorer performing teams. Higher self-rating of SA was associated with better performance in Study 2 and 3, but the association was not significant in Study 4. The awareness of teammate's workload and awareness levels, however, did not show any significant relationship with team performance across all three studies. This may be attributed by the measurement methods used (this is further elaborated in Section 9.1.5), or due to the mediation of teamwork behavior – whether or not the good awareness of teammate's status is accompanied with appropriate assistance and backup.

9.1.4 Factors Underlying Team SA

As illustrated in the integrated framework, there are many factors that can influence the development and maintenance of team SA. This research investigates individual differences in task experience (Study 2, 3, and 4) and cognitive ability (Study 3 and 4), team composition based on familiarity with teammate (Study 3) and diversity in team members' experience (Study 4), and team processes (Study 1, 2, 3, and 4) in their relation with team SA. The impact of task experience on individual SA has been established in the literature. Its influence on team SA is however less researched. Teams with higher experienced members consistently showed better scores in SAGAT of own situation, SAGAT of teammate's situation, and had a higher self-rating of SA across Study 2, 3, and 4. Domain-related knowledge is developed through experience, and this pool of the relevant knowledge or mental model aids the development of SA.

In addition to task experience, individual SA is also associated with higher levels of certain cognitive abilities. Similar to the other existing studies, cognitive ability was found to have certain associations with SA. Study 3 and 4 were consistent on the significant associations of SA and reasoning ability as measured by Figure Classification and Math Aptitude tests. These findings further justify the importance of reasoning ability for SA in complex and dynamic environment, where scattered and uncertain information need to be integrated to make sense of what is happening and especially for future projection. However, some of the results were different between the two studies. In Study 3, correlations between tests in spatial ability and SA did not show significant result. In Study 4, spatial ability as measured by Hidden Figure and Cube Comparison tests correlated significantly with SA (see Table 7-6). This is possibly because aviating task in 3D environment in Study 4 is more spatially demanding than the navigating task in urban environment simulated in Study 3. In addition, all of the participants in Study 3 were familiar with the map used in the game. Spatial working memory measured by Building Memory test showed a significant association with SA in Study 3, while none of the memory tests correlated with SA in Study 4 (see Table 8-12 and Table 8-13). Finally, the role of cognitive ability to predict team SA is however less critical, which perhaps due to the mediation of team process variables that takes place in the team level interactions.

Familiarity with team members and opponent was investigated in Study 3. The result showed that it can predict SAGAT scores of own and teammate's situation, and self-rating of SA. If task experience is important for the development of task-related knowledge, similarly, familiarity with the other human operator in the system is important for the development of mental model of the team. Knowledge regarding the others' habits, behaviors, knowledge level and preferences, can help to reason why they do certain things, predict what they will do for a given scenario, and notice changes in behavior when they are under stress and losing awareness. All of these facilitate smoother team interaction and effective integration of each other's perception. However, more familiarity with teammate can have negative influence as well. Teams with higher familiarity were found to be more over-confident, which is not really desired as over-confidence can have bad impact on performance. Study 4 explored the diversity of team members' experience and team SA. Although no strong conclusion can be derived due to the small sample size used, the study revealed the negative impacts of composing a team high diversity in team members' experience. The big gap between members' experience can introduce a resistance to team interaction, which would have a negative impact when integration of perception across members is necessary for team SA.

Team SA includes two different constructs: individual SA and team processes (Salas et al., 1995). The association between team SA and processes was evidenced across all the studies reported in this thesis. Team process measured by CAST, TARGETs, information sharing, feedback and backup, consistently showed high correlation with the measures of team SA across the four studies conducted. Sharing of information is important to integrate team members' perception, especially when they are exposed to different situation. Communicating one's perception and intention regularly affords the other team member an opportunity to keep updated with his status, and to be prepared to provide backup whenever needed. The associations between communication frequency and team SA across the studies however were not consistent. In Study 1, higher frequency in enemy-related communication was associated with better engagement performance, while higher frequency in navigation-related communication was associated with poorer navigation performance. No meaningful association was found in the rest of the studies. These results suggest that the engagement of effective and timely communication matters more than the frequency of communication per se.

9.1.5 Measurement Issues

Team SA is a multidimensional construct. Thus, multiple measures are required to adequately capture the phenomenon. A guide to select measurement tools to assess team SA is presented in Chapter 5 and were applied in studies reported in Chapter 6, 7, and 8. Each measure has its advantages and disadvantages. In addition to those reviewed from the literature (see Chapter 2), this research reveals several measurement issues that are worth addressing.

1. Snapshots versus continuous assessment

SA is dynamic, it changes over time. As noted in Chapter 2, a good measurement tool should capture this dynamic nature of SA. This can be done through a continuous assessment or collection of SA data at several key points during task performance. The latter only captures snapshots of SA and the quality of SA is dependent on the time the data is collected. Consider a scenario when information X required by member B is only visible to member A or has to be integrated from other information possessed by member A. If the mission is frozen at Time 1 to collect member's knowledge through SA probes, only member A would have a high score. Member B would not be able to answer the probes accurately as the information is not yet transmitted by A. However, if the SA probes are administered at Time 2, both members would have high score (see illustration in Figure 9-3). In contrast, continuous measures such as CAST and TARGETs are not dependent on the time of data collection. This is perhaps the reason why the continuous measures had more significant associations with team performance outcome than the product (snapshots) measures across the studies. However, the drawback of CAST and TARGETs is that they assume that the shared information would be perceived accurately by the other members. They rely on observable behavior and communication, and may overlook implicit coordination that can take place due to prior shared understanding or set rules. They are also limited to the observers' ability to infer and understand the operator's internal comprehension of the situation, and are time-consuming to perform. The advantages and disadvantages of different types of measures further emphasize the need to use multiple measures.

Figure 9-3 Illustration of different timings to collect SA data

2. *Heuristics and biases*

In this research and several other studies reported in the literature (e.g., Gorman et al., 2006; MacMillan et al., 2004a; MacMillan et al., 2004b), awareness of teammate's workload and SA levels were represented using the similarity or congruence between team members' self-rating and estimation by teammate. People's judgments are however prone to heuristics and biases. Analyses of responses of self- and peer-ratings across the studies revealed the tendency of participants to use perception of self as a proxy for estimating the values for others. This heuristics provides a shortcut that is so attractive to use rather than making a careful evaluation of teammate's status that would impose higher cognitive demand. Egocentric recall is promoted when the amount of information available for the judgment is greater for oneself than for teammates (Ross & Sicoly, 1982). As the ratings provided by a team member may not be representative of his *true* evaluation of teammate, the data collected may not be valid to represent awareness of teammate's status. Other assessment methods, such as observer's assessment, need to be developed to allow a triangulation of result and reduce the reliance on subjective ratings. Nevertheless, bias in participants' responses can also be a good indicator of their SA as well. Study 3 and 4 revealed that people tend to have higher confidence bias and are less calibrated on what they think they know about the future prediction than about the present situation (Fischhoff, 1977; Tversky & Kahneman, 1982). However, they were actually poorer in answering questions regarding the future compared to the present status. The confidence bias of own situational knowledge was shown to have high association with performance outcome. Thus, it seems to be a useful measure of meta-SA.

3. *Assessing Prediction Aspect of SA*

Prediction (level 3) has been indicated to be the most important aspect in the conception of SA. The result of Study 4 also supported this proposition. It is the one that distinguishes the concept of SA from traditional human information processing model. However, there

have been few studies devoted to examine it. In team level, studies that address the third level of SA are scarce. Results obtained from Study 3 and 4 revealed the challenges in assessing prediction. Study 3 in some way has failed to capture the prediction aspect of SA. This is a result of many factors, such as the rapid changes of situation or short time constant, high frequency of disturbance inputs due to existence of other human operators in the system who can exhibit unanticipated actions, and high uncertainty due to lack of rules that frame the selection of actions by the operators. Freeze probe methods such as SAGAT can only capture snapshots of a person's SA at the point the SA questions are being asked, and thus the elicited prediction is based on his understanding of the situation at that point in time. Judging from the likelihood of the situation, the prediction may be accurate at the point it was elicited. However, if the situation changes within the next second due to changes in other player's intention, this accurate prediction can become inaccurate. If a player takes note of these changes and is able to adjust his actions quickly based on his updated mental picture of the situation, his SA should be considered as good, although his answers to the prediction questions, as compared to what actually happens, has become inaccurate. Thus, when the development of scenarios is rapid and there are many possibilities of what could happen (high uncertainty), it becomes hard to objectively judge the accuracy of the prediction. The problem is less pronounced with the existence of rules of actions. In air combat, for example, military tactical doctrine limits the choice of action that can be selected by pilots. In contrast, the participants in CS study were not formally trained and can basically choose any action they like at anytime they want, and this reduces the predictability of each others' actions tremendously.

9.2 Contributions of Research

This research has contributed to an advancement of individual and team SA literature in the following areas:

1. Several models of team SA have been proposed in the literature. However, they are limited on conceptual stages as they do not provide ways to measure the construct. The conceptual framework of team SA proposed in this research contributes by further extracting the important attributes of team SA. In addition, this research provides extensive review of SA measures and determines ways to measure team SA

in accordance to the framework. This provides a foundation for future empirical studies conducted to investigate the construct.

2. None of the existing team SA models found in the literature includes a comprehensive list of factors influencing team SA. Understanding of these factors and how they influence team SA is important for determining ways to enhance team SA, e.g., through personnel selection, training, and system design. This research derives a comprehensive list of factors that potentially influence team SA through literature review and include them in the integrated framework shown in Figure 9-1. The series of studies (Study 2, 3, and 4) empirically investigate the role of individual differences (task experience and cognitive ability), team composition (familiarity and diversity in experience), and team processes on team SA. A meta-analysis of findings across the three studies showed several replicable results, which suggest the robustness of the findings. These studies, on their own, and altogether, are unique contributions to the literature.
3. The most accepted model of SA proposed by Endley (1995c) includes three levels, i.e., perception, comprehension, and future projection. The representation of these three levels in a linear or successive stages of processing invited various criticism (Dekker & Lutzhoft, 2004). Along with this theoretical debate, it is somewhat surprising to find limited study that empirically examines the relationship across the three levels of SA. The review of literature also revealed that the cognitive construct of level 3 SA has been under-represented in SA studies. This research explores the three levels concept of team SA and showed that they are closely associated to each other, although their development may not happen in an ascending order. The finding that shows the importance of level 3 SA on performance is also worth noting. In addition, this research also reveals the cognitive abilities that relate to the three levels of SA, which has not been well established in the present literature.
4. Little is known on how people are calibrated on what they know across the three levels of SA, and the results from previous studies are somewhat ambiguous. This research also explores the meta-cognitive aspect of SA across the three levels and indicates that people are less calibrated on their judgment to what they know about the

future than present situation. Furthermore, this research shows that confidence bias to own awareness level can lead to poor performance.

5. Finally, this research discusses the issues with heuristics and egocentric bias in peer ratings. It has important implications on team SA measurement, considering that subjective measures are perhaps the easiest way to measure awareness of teammate in team SA studies. The result of this research cautions future studies that use only subjective measures in team SA assessment, not only due to the existence of heuristics and biases in human judgment, but also because the low association between these measures with the objective measures such as SAGAT, as well as their low associations with performance outcome.

9.3 Limitations of Research

This research has several limitations and challenges. Interpretation and generalization of the results need to bear these limitations in mind. First, the sample size used in each study was small, and with the large number of correlation analyses performed, this may invite type 1 errors. As the research aims to investigate SA, it was felt crucial to engage participants who are familiar with the task, so that the variations across participants are mainly due to differences in their cognitive processes and interaction behavior involved in the development of SA, and not due to other factors such as unfamiliarity with the system, manual control, etc. Short exposure to the task through pre-test training of naïve participants was felt to be insufficient to build the mental model and proficiency required for the task. Unfortunately, expert participants are not very easy to recruit, specifically for military pilots who are very tight in their schedule and are very expensive to train. As a result, it was also hard to control the assignment of participants into teams. Nevertheless, the use of experienced operators as participants demonstrates the face validity of this research. The confidence level used (taking .05 as significant and considering .06 as marginally significant) is a constraint necessary to compensate for low sample size used due to the limited availability of experts as participants. In addition, the comparing the result across the three studies helps to highlight the robustness of the findings.

Second, the studies use off-the-shelf PC game to simulate a complex scenario, which may be limited in their fidelity. The use of PC-based games for research and training of team

SA has been demonstrated to be a promising approach (Baker et al., 1993; Perla et al., 2000; Proctor et al., 2004). Fong (2006) also reported the potential application of commercial off-the-shelf simulation games for military experimentation. She evaluated a first-person shooting game, Delta Force: Black Hawk Down (similar to CS game used in Study 2 and 3), and reported that such games can be useful to generate discussions on issues such as information requirements, sense-making, and command and control. America's Army, another similar first-person shooting game, has been used for recruiting and training tool by the US Army (Zyda, 2005). Soldiers who played the game was reported to earn improved scores on the real-life rifle range (Zyda, 2005). The previous version of Falcon 4.0 (used in Study 4) has been used in other research to evaluate the impact of shared and quality of team mental models (Mathieu et al., 2005) and training methods (Heffner, 1997) on team performance. Peter Bonanni, a graduate of the F-16 Fighter Weapons School and pilot instructor of the Virginia Air National Guard, reviewed that the game realistically mimics the look and feel of real military aircraft, thus allowing pilots to maintain familiarity with the layout of cockpit and throttle controls and to "keep their heads in the game" (see Zyda, 2005). In addition, it allows users to play against computer-generated forces or, in a networked fashion, against other pilots, which facilitates team training opportunities. Falcon 4.0 is the first flight simulation to be adapted to military training among the commercial flight simulation games in the market (Lenoir, 2000). The high realism of the simulator was also commented by the pilots who participated in this research.

Despite of the noted limitations, this research adds values to the literature in terms of contributing to the theory of team SA by addressing three crucial questions: what is team SA, what factors important to team SA, and how to measure team SA. In addition, it provides an empirical support to the cognitive construct of three levels of SA and meta-cognitive aspect of SA – two important concepts that are often discussed in the literature, but are lacking of supporting studies.

9.4 Directions for Future Research

This research has provided the theoretical foundation and measurement approach for research in team SA, and has raised numerous opportunities for future research, including (but not limited) to the followings:

- Replications of the studies presented in this thesis using bigger sample size are required to afford a valid generalization of the findings. For instance, Study 4 has highlighted a possible influence of team composition on team SA, but no strong inference can be drawn due to the limited sample and control of the study. In addition, the study can be expanded to include different ways of aggregating individual scores to a team score, or even to collect a team level response of SA. Extending the studies to other domain such as in military command and control, process control, surgical teams, and other teams working in complex and high risk environment, would be worth doing as well.
- Investigations using the other input factors presented in the integrated framework, such as different level of role inter-dependence and overlap in team members' responsibilities, team size, composition of members with varied personality or cultural background, team structure, system design, physical proximity, etc. In the current research, the teams involved were limited to teams consisted of two members, who have high role interdependence and overlap among team members' responsibilities. Each of the input variables specified in the integrated framework, although was derived from individual SA and team literature, has not been specifically investigated with respect to team SA. Investigating the role and relative significance of the input and process variables on team SA would be useful to select the appropriate and effective ways to enhance the development and maintenance of team SA.
- Improvements to the current methods or development of new methods to assess awareness of teammate's workload and SA status. In addition to the known problems with subjective ratings, this research revealed additional issues of such methods when applied to elicit the awareness of teammate's status, such as the existence of egocentric bias in rating teammate. This problem may be minimized if the sequence of rating is reversed, i.e., rating teammate first and then self. It may also help if the ratings are done on several aspects of teammate's SA instead of just the generalization of teammate's SA, so that the team members are forced to perform the cognitive assessment instead of relying on heuristics. Observation of team members' helping behavior may also be useful to identify whether team members are aware of each

other's need for support. However, this method is limited to observable behavior and sometimes it is possible that a member has the awareness of teammate's status but does not provide any assistance as he does not have the extra resources available to do so. Research in this measurement method will be of a significant contribution to the literature.

- Development of training approaches to enhance team SA. The existing trainings are very much stressed on attention management and development of LTM to facilitate the effective development and maintenance of SA. The high association between level 3 SA and performance shown in Study 4 suggests the need to further research what factors underlie the development of accurate future prediction, and to apply the findings in personnel selection and training. Based on findings, developing training to enhance reasoning ability would be a promising way to move forward. Calibration of perception of own state of situational knowledge in order to minimize confidence bias as an additional training approach that is worth researching, as confidence bias has consistently shown to have strong associations with poor performance. In addition, team training to increase the predictability within a team and enhance effectiveness of information sharing and teamwork behavior, would be an important area to be further researched.

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APPENDIX A

Study 1: Helicopter Combat

Scenarios Write-Up

Six missions were planned for the experiment. Missions in Easy were differentiated by the nature of the mission (see later), while Duckhunt and CSAR were differentiated by geographical layout and enemy deposition.

Easy 1 (Air Recce Mission)

The subjects are required to fly from start point to check point 7 and identify the items. At checkpoint 3, subjects are instructed to orbit overhead and await enemy bounce (2 *LSV* and 1 *OH*). Then at checkpoint 5, they are to eliminate an *OP* (1 infantry) and subsequently take out 2 airborne Chinooks heading easterly.

Easy 2 (Defend LS)

The subjects are required to fly from start point to check point 4, disable the communication facilities (1 comms tower) guarded by 1 AA gun. Thereafter, to move on to defend the LS (past check point 7) against inbound enemies (4 *LSV*).

Duckhunt 1 & 2 (Search and destroy SCUD sites)

The subjects are required to fly from start point to waypoint 5, where they are to locate and destroy 3 SCUD sites, which have been identified along the route. The SCUD sites are medium, light and heavily fortified, and subjects are expected to employ different techniques to accomplish the mission. In addition, other non-mission enemies are planted along the route to act as distracter, and posed as additional threats should the subjects deviate from the intended threats.

CSAR 1 & 2 (Combat Search and Rescue)

The subjects are required to escort the SAR helicopter (Blackhawk) to the crash site, extract the downed pilots and then track out of the theater. Subjects are free to choose any flying formation, as long as their duties are not compromised, i.e. both aircraft to receive minimum firing and not to lose sight of the SAR. The SAR will be traveling at 60kts along the planned route. Substantial attention by the subjects is required to maintain visual/contact with the SAR.

Workload level

The difficulty was assessed by the SME and verified by volunteers who took part in the trials using the NASA TLX rating scale. Workload level assumed by the SME for the pilot and co-pilot in all missions are:

	Easy		Duckhunt		CSAR	
	Pilot	Co-pilot	Pilot	Co-pilot	Pilot	Co-pilot
Mental demand	1	2	4	6	7	6
temporal demand	1	1	2	4	7	7
performance	6	6	5	5	7	5
Effort	1	2	5	5	7	7
Frustration	2	2	3	3	6	6

Scenario Maps

Mission: Easy 1

In this mission, the teams were required to fly from start point to CP3, and take down 2 LSVs and 1 OH. They should then continue to CP 5, taking down 1 infantry and 2 chinook. At CP7, they were asked to check and report their finding. The navigation route was straight forward, except that they had to fly over high terrain from CP5 to CP6.

Scenario Map for Easy 1

Air (Helicopter), LOH: high threat

LSV (Light Strike Vehicle) + Infantry. Low threat, higher mobility, higher firing rate

Mission: Easy 2

In this mission, the teams are required to fly from start point to CP4, disable the communication facilities (1 comms tower) guarded by 1 AA gun. Thereafter, they are to move on to defend the LS (past check point 7) against inbound enemies (4 *LSV*). The navigation route is generally easy and straight forward, except at check point 4, where the teams are supposed to make a sharp right turn and go into a valley to go to CP5.

Scenario Map for Easy 2

LSV (Light Strike Vehicle) + Infantry. Low threat, higher mobility, higher firing rate

AA (Anti-air) guns, medium threat

Mission: Duckhunt 1

The subjects were to fly from start point to CP5. They had to locate and destroy 3 SCUD sites, which have been identified along the route (i.e. at CP2, 3, and 5). The SCUD sites were medium, light and heavy fortified respectively. In addition, other non-mission enemies were planted along the route to act as distracters or posed as additional threats should the subjects deviated from route planned.

Scenario Map for Duckhunt 1

Air (Helicopter), LOH: high threat
Infantry, low threat
Armoured Infantry, medium threat
AA (Anti-air) guns, medium threat
SAM (Surface to Air Missile), very high threat

Mission: Duckhunt 2

In this mission, the teams are required to fly from start point to CP5 and to locate and destroy 3 SCUD sites, i.e. at CP1, 3, and 5. The SCUD sites are medium, light and heavily fortified. In addition, other non-mission enemies are planted along the route to act as distracter, and posed as additional threats should the subjects deviate from the intended threats.

Scenario Map for Duckhunt 2

Air (Helicopter), LOH: high threat
Infantry, low threat
Armoured Infantry, medium threat
AA (Anti-air) guns, medium threat
SAM (Surface to Air Missile), very high threat

Mission: CSAR 1 and 2

In this missions, the teams are tasked to escort a Search and Rescue helicopter who is going to take up downed pilots in the Crash site. The need to keep up with the SAR helicopter while engaging the enemies along the route makes the missions to impose high time pressure to the participants.

Scenario Map for CSAR 1

Scenario Map for CSAR 2

Consent Form

I agree to participate in the research project entitled “Situation Awareness and Team Dynamics of Pilots.” The objectives of the study are to assess team situation awareness and interaction of pilots under various levels of mental workload. The test session will last approximately 1 hour.

I understand that this participation is voluntary. I can withdraw from the test at any time without penalty. I also understand that Ketut Sulistyawati and Freddie Teo may terminate my participation if they feel this is appropriate. I understand that the results of the experiments will be used for study purposes only, and my personal information and data will be kept confidential.

The test has been explained to me as follows:

I will be asked to perform either as a pilot or a co-pilot in the COMANCHE 4 game at the Centre of Human Factors and Ergonomics laboratory. I will perform the assigned tasks. The test will be video taped for data logging purposes.

I understand that the medial risks of the test are minimal, with possible minor strain in eyes, back and neck.

I am informed that I will not be given any compensation for the time and effort I put to the experiment.

I understand that Sulis and Freddie will answer any further questions about the study.

Volunteer Name & Signature / Date

Pre-Experiment Questionnaire

Name : _____

Age : _____

Flying experience:

1. Flying qualification : CAT A / B
Ops / INST / HTI / Test Pilot
2. Flying hours : ____ 00 hours

Gaming experience:

3. Are you a “computer” flight simulator gamer? (Yes / No)

Title played in year 2004 (> 10 hours playing):

4. Do you play any other computer game? (Yes / No)

Title played

5. Have you played COMANCHE4 (> 2 hours)? (Yes / No)

Official Use:

Date/ time: _____

Team : _____ * Captain/ Co-pilot

Interview Questions

This list of questions is to be used for a semi-structured interview at the end of the experiment. Any anomaly observed during the experiment are not listed, but will be asked impromptu by pointing subjects to the critical points and noting their responses.

1. Did the goal setting in your mind affect your decision and action selection?
2. Who made the most decisions? Why? Do you think it was appropriate?
3. What did you do to keep track of the situation and to see the big picture?
4. Did you keep track of your teammate's SA? How did you do that?
5. Why did/ didn't you ask for information from your teammate?
6. When did you get the information, was it in the form you needed?
7. Which part of the task did you think was the most challenging or the worst performance or worst SA? Why did you think so?
8. Did you notice something different/wrong/anomalous during task performance?
9. Did you realize that you and/or your teammate had lost SA during this period of time?
If yes, what made you realize that you had lost SA?
If not, why did you take that action?
10. What is the difference between the team action in a normal and crisis situation?
11. What actions did you ignore?
12. What cues caused you to make that decision? What did you see?
13. What did you think will happen if you didn't do that?
14. Did you consider what your teammate would think/do when you make such a decision?
15. Did you predict that impact would happen when you decided to do that action?

Critical Incidents

Note: the navigation tracings were only conducted for Easy and Duckhunt missions, because in CSAR mission, the participants tend to follow the SAR heli rather than performing the navigation on their own.

Easy 1 Team A

Critical Incident 1	
<i>Situation</i>	Climb unknowingly and too high
<i>Source of error</i>	Poor awareness of flight status The main priority at that point was to escape from enemy fires, such that deviation in navigation was not noticed. Perhaps due to high workload resulted from enemy engagement.
<i>Corrective action</i>	Co-pilot noticed the height deviation and prompted the pilot to “fly lower, you are a bit too high”
<i>Effective behavior</i>	Good monitoring and feedback by the co-pilot
<i>Comment</i>	One of the team members had good awareness of the error, communicated it effectively – provide backup.
Critical Incident 2	
<i>Situation</i>	Missed targets and was being shot by LSV at CP3
<i>Source of error</i>	Poor scanning strategy, thus failed to detect LSV before being detected. They flew over a high terrain, while the enemy was positioned right at the end of the high terrain.
<i>Corrective</i>	Tried to engage, but failed. Decided to escape and continue to CP4

<i>action</i>	
<i>Comment</i>	The team realized that they were at the losing side in the battle vs. LSV, and decided to escape instead. The latter would be a more effective behavior if it was done earlier, before the helicopter was much damaged.

Easy 1 Team B

Critical Incident 1	
<i>Situation</i>	Climbed to locate enemy
<i>Source of error</i>	Poor/no continuous assessment on altitude The main priority was to search for infantry, did not realize the deviation in navigation.
<i>Corrective action</i>	None, back to appropriate altitude only after ATC dismiss search of infantry and proceed to CP7
<i>Comment</i>	In dynamic environment, continuous assessment is required. Failure to do so, even in a short period, can lead to error
Critical Incident 2	
<i>Situation</i>	Missed OH and shot by LSV at CP3
<i>Source of error</i>	Poor visual scanning OH was not detected at all. Miss in the first attempt to shoot LSV, leading to open confrontation
Critical Incident 2	
<i>Situation</i>	Missed infantry at CP7
<i>Source of error</i>	Poor visual scanning Flew around but still could not find INF

Easy 1 Team C

Critical Incident 1	
Situation	Climbed towards enemy locality, continued climbing despite hearing gunshots firing, and did not descend immediately after engagement
Source of error	Poor/no continuous assessment on altitude Did not realize that they were climbing too high
Corrective action	None
Critical Incident 2	
Situation	Missed OH at CP7
Source of error	Poor visual scanning OH was not detected at all.

Easy 1 Team D

Critical Incident 1	
<i>Situation</i>	Almost made a wrong turn to CP2
<i>Source of error</i>	Poor communication Too much information was given at the same time, e.g. “070 to CP1, after that just continue straight 060 to CP2” Information to CP2 was given too early, e.g. “after CP2 turn left 340” was said far before the turn was supposed to be done
<i>Corrective action</i>	Copilot corrected the turn by saying “after CP2!”
<i>Effective behavior</i>	Copilot monitored the aircraft heading and pilot’s action, and provided feedback on the erroneous behavior
Critical Incident 2	
<i>Situation</i>	Did not take enemy at CP3, shot by LSV. This leads to much time wasted due to corrective actions done.
<i>Source of error</i>	Inaccurate mental model regarding mission objective
<i>Corrective action</i>	Upon reaching CP4, the pilot realized that they were supposed to take down enemy. He questioned copilot, which then confirmed by copilot that they had made a mistake
<i>Effective behavior</i>	Pilot questioned the improper actions taken
<i>Comment</i>	Using team can provide backup to each other’s actions. Poor performance is resulted if none of the members realized the errors committed.

Easy 1 Team E

Critical Incident 1	
Situation	Climbed over high terrain, did not take the lowest ground
Source of error	No close guidance was given by the co-pilot. Reliance on the pointer shown on screen, which was showing linear direction to checkpoints, but not necessarily the best route to take
Comment	The operators should have the correct mental model of the system used, including their capabilities and limitations.
Critical Incident 2	
Situation	Involved in open contact at CP3
Possible cause	Did not try to hide and engage to minimize contact which can lead to damages
Source of error	Poor strategy to contact threats

Easy 1 Team F

Critical Incident 1

<i>Situation</i>	Pilot got confused on which direction to go
<i>Source of error</i>	Miscommunication Use of pointer word (i.e., this) with improper shared understanding on what it refers to, CP : then... high ground on the right... CP : keep this high ground on the right... P : keep this high ground on the right? CP : no, no... right, right P : Keep on the right? CP : Keep it on your right P : Keep it on the right?
<i>Corrective action</i>	The copilot guided the navigation closely to turn left to CP2

Critical Incident 2

<i>Situation</i>	Did not turn to CP5 and climbed up to high terrain.
<i>Source of error</i>	Information was given too late
<i>Corrective action</i>	Copilot provided corrective navigation to turn 330 to CP5
<i>Comment</i>	Communication should be analyzed within context of incident, as such as shown in this incident. It was true that the copilot provided the navigation information, but when it was too late, erroneous action might had been committed.

Easy 2 Team A

Critical Incident 1

<i>Situation</i>	Did not make a sharp turn into the valley as per planned route, but instead deviating to the opposite direction. The team was too engrossed in engaging the enemy at CP4. No navigation guidance was given by copilot as he was busy contacting the enemy.
<i>Source of error</i>	Poor planning, no contingency plan.
<i>Comment</i>	The roles are mutually exclusive and very interdependent. Poor performance of one member can drag the overall team performance down.

Critical Incident 2

<i>Situation</i>	Ineffective engagement of enemy The team noticed the existence of enemy prior of enemy engagement (good SA), but enemy engagement was not effective, random fire. Pilot flying unsteadily, making aiming enemy difficult.
<i>Source of error</i>	Poor equipment handling
<i>Comment</i>	Performance outcome does not only dependent on SA, but also on action execution.

Critical Incident 3

<i>Situation</i>	The helicopter was shot by enemy at CP4. They went across high ground, and the enemy was just behind the high ground. The enemy detected the helicopter and started firing.
<i>Source of error</i>	Was not aware of existence of enemy
<i>Corrective action</i>	Searched for source of fire and fired back

<i>Comment</i>	This is an example of data driven information processing, where the attention is directed due to the perceived fire.
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Easy 2 Team B

Critical Incident 1	
<i>Situation</i>	Did not enter valley (left of track), hence climbed to compensate
<i>Source of error</i>	Poor planning, no contingency plan.
<i>Comment</i>	<p>There seems to be a shift in priority from navigation to enemy engagement at CP4. During enemy engagement period, the teams had less extra resources to plan their next heading due to high workload. Without planning, they would have high chance to perform badly, as the navigation from CP4 to CP5 is difficult.</p> <p>The two activities (enemy engagement and intense navigation) are mentally demanding. When these demands exceed the members' capacity, their ability to attend both activities well is degraded, and the performance of one or both actions will be impaired.</p> <p>The question is: if the route after enemy engagement is straight forward, will their performance still degrade? When compared to the similar situation in Easy 1 mission, where the teams were supposed to take down enemies at CP3, none of the teams had problem with navigation from CP3 to CP4, which happened to be straight forward.</p> <p>Therefore, contingency planning is necessary for effective performance in high workload and non-routine situation.</p>

Easy 2 Team C

Critical Incident 1

<i>Situation</i>	<p>Did not enter the valley (left of track), hence climbed over the high ground. The copilot has reminded the pilot to go 5 o'clock direction into a tight valley, see transcribed communication below:</p> <p>CP : 5 o'clock the tower, went to the other side CP : that's a tight valley CP : now we fly right 3 o'clock CP : I say right 3 o'clock</p> <p>However, the pilot did not follow the navigation guidance given. The co-pilot asked the pilot to turn right but was ignored by the pilot.</p>
<i>Source of error</i>	<p>Inattention to communication: either because he did not attend to it, or did not understand the instruction. If he did not understand, he should have asked the copilot to clarify, but no request for clarification was done.</p> <p>Inaccurate mental model of equipment: another reason is because the pilot saw a pointer guiding to CP6, which he mistakenly thought it was pointing to the next check point (CP5).</p>
<i>Corrective action</i>	The copilot insisted on turning to 3 o'clock direction, correcting false heading, but some deviations from the route have been committed.
<i>Effective behavior</i>	In this situation, the co-pilot had accurate SA, and communicated what he thought should be done based on this SA. Should the co-pilot not insist to turn to the right, they would have missed CP5.
<i>Comment</i>	For comprehension, SA relates back to knowledge contained in mental model. Although situation is assessed well, but if mental model is inaccurate, inaccurate comprehension and future projection will occur. Thus, accurate mental model is necessary but not sufficient for accurate SA development. A technical support system should be designed well to

	<p>support the users to develop accurate mental model of it.</p> <p>In teamwork, situation assessment does not only include assessing the task and equipment, but also the teammate, so that the member can provide feedback or backup if the actions of the teammate are erroneous. Whenever teammate's thought or action is not consistent with own expectation, this discrepancy should be communicated to clarify each other's understanding of situation.</p>
Critical Incident 2	
<i>Situation</i>	<p>Did not take the lowest ground</p> <p>The pilot followed the direction given by the copilot to go straight to CP7. They should always bear in mind that it is not advisable to go over high ground.</p>
<i>Source of error</i>	No close guidance was given by co-pilot.

Easy 2 Team D

Critical Incident 1	
<i>Situation</i>	The team overshot (missed the valley entrance) after engaging enemy at CP4.
<i>Source of error</i>	The navigation guide was given a bit too late, as the copilot was busy engaging enemy at CP4.
<i>Corrective action</i>	The copilot guided the pilot to turn back and fly into the valley
<i>Effective behavior</i>	Fast correction by copilot.
<i>Comment</i>	This situation shows some kind of error correction. After enemy engagement, the co-pilot got back to the iteration of navigation task and

	<p>realized that they were not on the right track.</p> <p>One of the two members must have good SA to realize that they are in the wrong path. The copilot can assess the pilot's action by relating the helicopter heading and the flight path shown on the map. The pilot can assess the copilot's action by relating the navigation information provided and the waypoint marker shown on the screen.</p>
Critical Incident 2	
<i>Situation</i>	Shot by enemies at CP 4 and 7
<i>Source of error</i>	Poor perception of enemy location

Easy 2 Team E

Critical Incident 1	
<i>Situation</i>	Did not enter the valley (right of track), hence climbed over the high ground, made few wrong turns before finally reached CP5. The co-pilot did not provide accurate navigation, creating confusion to the pilot: “Go slightly to the South... eh... North... Westerly”.
<i>Source of error</i>	<p>Poor awareness of both members.</p> <p>The co-pilot was not able to locate the helicopter position on the map, thus was confused on the direction they supposed to go. The pilot was also unaware of the situation. The several corrective directions given by the co-pilot was a cue that he did not comprehend the situation well. If the pilot had noticed this, he could provide a backup and assist the co-pilot.</p>
<i>Comment</i>	An individual can identify his teammates' level of awareness by assessing the behavior of teammates and relate their behavior with his knowledge of effective/ineffective behavior required to perform the task.

	But, to do this, he must be in a good state of SA. This issue should be addressed if peer assessment is used for SA measurement, because a person is not in a good position to rate the other person's SA if he is not having a good SA. Similarly for self rated SA measurement, a person may not know that he is not having good SA (a phenomenon <i>a drunken does not know that he is drunk</i>).
Critical Incident 2	
<i>Situation</i>	Slowed down at CP6, searching for enemy
<i>Source of error</i>	Inaccurate mental model of the mission The pilot thought CP6 was the last CP, the copilot did not correct

Easy 2 Team F

Critical Incident 1	
<i>Situation</i>	The team did not follow the route planned
<i>Source of error</i>	No close guidance by the copilot. The pilot did not even follow the pointer.
<i>Corrective action</i>	The copilot corrected the wrong heading by requesting the pilot to turn right.
<i>Effective behavior</i>	The copilot assessed the incorrect behavior of the pilot and corrected it.
Critical Incident 2	
<i>Situation</i>	Did not turn into the valley
<i>Source of error</i>	No close guidance by the co-pilot
<i>Corrective action</i>	The copilot guided closely to turn back and into the valley
Critical Incident 3	

<i>Situation</i>	Went to the wrong direction
<i>Source of error</i>	No/inaccurate navigation by co-pilot The copilot was not aware on their wrong heading
<i>Corrective action</i>	The pilot noticed something was not right, and prompted to the copilot that the pointer was actually pointing to the right.
<i>Effective behavior</i>	The pilot communicated his uneasiness
<i>Comment</i>	Assessment of teammate's behavior and own expectation is important. When they do not tally, most likely something is going wrong. The question is who. Communicating this uneasiness can help to resolve the issue.
Critical Incident 4	
<i>Situation</i>	Contacted by enemy at CP7
<i>Source of error</i>	Poor assessment of enemy location

Duckhunt 1 Team A

Critical Incident 1	
<i>Situation</i>	CP1 was located behind a high terrain, where the team should hug the left of high ground. The pilot went to the right searching for lowest ground to go to CP1.
<i>Source of error</i>	The copilot did not provide close guidance. Insufficient support in navigation by the copilot.
<i>Corrective action</i>	The copilot corrected by asking the pilot to turn left, when he noticed the wrong heading

<i>Comment</i>	Since the terrain in this mission is generally more difficult, close guidance by copilot is required to ensure the helicopter in the correct heading and flying at the lowest ground.
Critical Incident 2	
<i>Situation</i>	Searched for enemy at CP2, and then climbed over high terrain to reach CP3.
<i>Source of error</i>	Lost track of position. Took easiest way (the one that requires the least mental effort) to reach next CP. Co-pilot did not attempt to recover the error.
<i>Comment</i>	Under time pressure, it is possible that the selection of action is done without considering the consequences of all the possible options, but by selecting the available option and select it if it seems to result in acceptable outcome. Experts may have the appropriate action readily available in their selection, thus differing them with novices.
Critical Incident 3	
<i>Situation</i>	Unsure where to go
<i>Source of error</i>	No navigation guidance was given by the copilot Insufficient support by the copilot

Duckhunt 1 Team B

Critical Incident 1	
<i>Situation</i>	Climbed on high terrain after enemy engagement at CP2
<i>Source of error</i>	No navigation given by co-pilot.
Critical Incident 2	
<i>Situation</i>	Climbed over high terrain to go straight to CP5, while the route planned

	required the team to go by hugging the high ground on the right
<i>Source of error</i>	The copilot did not provide any navigation guidance. Insufficient support by the copilot.

Duckhunt 1 Team C

Critical Incident 1	
<i>Situation</i>	Climbed up to confirm threats
<i>Source of error</i>	Inappropriate strategy for information search
Critical Incident 2	
<i>Situation</i>	Did not engage enemy at CP2.
<i>Source of error</i>	Incomplete mental model regarding the mission objective
<i>Corrective action</i>	None

Duckhunt 1 Team D

Critical Incident 1	
Situation	Climbed up to go directly to CP3 The team was hovering around CP2 engaging SCUD site, and was drifted away from CP2. The copilot provided only general heading to CP3: "hit Easterly back"
Source of error	Insufficient navigation guidance from the copilot
Critical Incident 2 & 3	
Situation	Went off track from the route planned
Source of error	Disorientation, The copilot provided inaccurate navigation
Corrective action	The pilot followed navigation pointers, but as result they did not fly on the lowest ground

Duckhunt 1 Team E

Critical Incident 1	
<i>Situation</i>	Climbed up to high terrain after drifting away at CP2 due to enemy search and engagement. The copilot only provided general direction: "CP3 155 heading"
<i>Source of error</i>	Insufficient navigation guides from the copilot
Critical Incident 2	
<i>Situation</i>	Climbed up to high ground after engaging enemy at CP3.
<i>Source of error</i>	Lack of navigation guide from the copilot Insufficient navigation guides from the copilot
<i>Corrective action</i>	The copilot corrected the wrong heading: "270, to the left side"
Critical Incident 3	
<i>Situation</i>	Effective enemy engagement at CP3 Both members assessed the situation well and communicated every threat detected. Communication was clear. The copilot had good weapon handling, and the pilot supported by flying the helicopter level and steady, and headed it the enemy target.
<i>Effective behavior</i>	Good SA, good communication, good execution.
<i>Comment</i>	Effective performance in this type of task require supports from both members.

Duckhunt 1 Team F

Critical Incident 1	
<i>Situation</i>	This is the only team that follow the route planned closely, especially from CP3 to CP4
<i>Possible cause</i>	The copilot always provided very detailed, clear, and readily used navigation information
<i>Effective behavior</i>	Effective communication, especially in phrasing of navigation guides
<i>Comment</i>	Effective communication, especially for navigation guidance, is the one with accurate content, phrased clearly, complete, and easily understood, and presented at the correct timing according to the need.
Critical Incident 2	
<i>Situation</i>	<p>Did not attempt to destroy SCUD site at CP2.</p> <p>The pilot noticed an enemy and said it out: “visual one enemy 1 o’clock”, but the copilot responded by saying: “the icon is white, should I fire?”</p> <p>Both may not aware of the mission objective, and when the icon is colored white on the electronic map (white indicates friendly), they continued the mission without further check.</p>
<i>Source of error</i>	Inaccurate mental model of the mission

Duckhunt 2 Team A

Critical Incident 1

<i>Situation</i>	Climbed up directly to reach CP3, did not hug around to maintain flying on lowest ground
<i>Source of error</i>	The copilot asked to pop up instead of hug around Improper action selection

Critical Incident 2

<i>Situation</i>	Drifted away from the planned route Shifting of priority to enemy engagement, attempting to engage enemies between CP4 and CP5
<i>Source of error</i>	Inaccurate mental model They were not briefed to take those enemies
<i>Comment</i>	Correct task prioritization is important in combat environment.

Critical Incident 2

<i>Situation</i>	The teams were supposed to take down 1 helicopter and 3 infantries at CP1 (SCUD Site 1). However, after shot down enemy helicopter, they deviated slightly to the right. They did not see/detect the enemy site (the infantries), although gunshots were heard.
<i>Source of error</i>	Poor assessment of enemy location
<i>Comment</i>	This is an example of having accurate mental model (knowing the existence of the enemy) but low situation awareness (did not perceive the enemy location). The electronic map seems to be ineffective to convey the enemy information to the pilots when the helicopter is flying fast and unstable, because the terrain color displayed on the map changes according to the height of the helicopter (red for the same level and

	higher, green for lower level). The technical support should be designed to assist the team members to develop situation awareness. The technical support should convey the information in an effective manner, so that the information is easy and fast to search and comprehend. For example, the color of the enemy should be distinct and easy to detect and not blend with the surrounding terrain (e.g. bright yellow).
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Duckhunt 2 Team B

Critical Incident 1	
<i>Situation</i>	Climbed over high ground, did not skirt around
<i>Source of error</i>	The copilot did not provide navigation guidance, the pilot flew based on pointer shown Insufficient navigation guidance by the copilot
Critical Incident 2	
<i>Situation</i>	Climbed over high ground to go straight to CP3
<i>Source of error</i>	The copilot asked the pilot to pop up Inappropriate navigation guide, improper selection of action
Critical Incident 3	
<i>Situation</i>	From CP4 to CP5, the teams are supposed to hug to the right of the high ground before CP3. The team however went right of the track and climbed to compensate. As a result, the enemy can detect them easily and result in confrontation with enemy that are not planned to be engaged. The terrain is difficult as there are many high grounds surrounding the path. The co-pilot, however, provided little assistance in guiding the pilot on following the flight path.
<i>Source of</i>	Copilot did not provide close navigation guidance

<i>error</i>	Insufficient support by the copilot
<i>Comment</i>	<p>It can be because the co-pilot did not exactly know the current location of the helicopter and could not locate it on the map, thus was not able to provide sufficient navigation guides to the pilot. The electronic map was not helpful, as it does not provide information about the current location of the helicopter with respect to the suggested flight path. The electronic map does not support for navigation error correction. In this case, the electronic map should provide information on the suggested flight path that the team should follow, rather than imposing such difficult navigation tasks merely to the co-pilot. The electronic map should also allow easy and fast error correction to be made, once the team made the wrong turn (e.g. arrow guidance to the correct path).</p> <p>It is important for both members to maintain SA about the surrounding situation, especially in such life threatening situations. The technical system should be designed to support fast and accurate decision making and actions. It should also assist team members to check if their actions are accurate, and to support corrective actions.</p>

Duckhunt 2 Team C

Critical Incident 1	
<i>Situation</i>	Climbed up on high ground straight to CP1
<i>Source of error</i>	No navigation was given by the copilot Insufficient support by the copilot
Critical Incident 2	
<i>Situation</i>	Deviated from the planned route to the left as they attempted to engage enemies

<i>Source of error</i>	Misperception of existence of threat
<i>Corrective action</i>	Realized that the detected threat was friendly forces
Critical Incident 3	
<i>Situation</i>	<p>After shot down enemy helicopter, they commented on the enemy's incompetence, and then continued to CP2 without locating the infantries in Site 1.</p> <p>Both members seemed to forget their assigned goals. None of them called out that they were supposed to locate enemy at Site 1 (CP1). The enemy site is not exactly along the route, but they were required to fly further in to the West to locate it. Since they did not realize their goal (incomplete mental model) and the enemy was not seen (except for flying enemy helicopter that was detected by team B), they did not attempt to search for the enemy.</p>
<i>Source of error</i>	Incomplete mental model of the mission
<i>Comment</i>	<p>SA is both top-down (goal-driven) and bottom-up (data-driven). Mental model, which includes the mission goals, directs attention to scan the environment and look for information. If mental model is incomplete (thus hinder exploration of the environment) and the environment does not offer ready-to-use data, SA suffers. When all members do not have a complete or accurate mental model, nobody can provide backup for their wrong actions, and team performance becomes ineffective.</p>

Duckhunt 2 Team D

Critical Incident 1	
<i>Situation</i>	The team followed the route planned well
<i>Possible cause</i>	The copilot provided close guidance of navigation, and the information is accurate, straight forward and easily understood.
<i>Effective behavior</i>	Good support by the copilot

Duckhunt 2 Team E

Critical Incident 1	
<i>Situation</i>	Climbed on high ground straight to CP1
<i>Source of error</i>	The copilot did not provide navigation guide Insufficient support by the copilot
Critical Incident 2	
<i>Situation</i>	Hugged to the wrong side of the high ground
<i>Source of error</i>	No navigation was given by the copilot. The copilot seemed to lost his orientation for a while, and regained it back soon afterwards. Insufficient support by the copilot
<i>Corrective action</i>	The copilot quickly guided the navigation once he could locate their location with respect to the map (big picture)
Critical Incident 3	
<i>Situation</i>	Deviated right from the planned route. Climbed on high grounds to reach CP5 The copilot instructed to keep to the right of all high ground, but the pilot overshot.
<i>Source of error</i>	Ineffective phrasing of communication of navigation information

Critical Incident 4	
<i>Situation</i>	The teams were supposed to take down 4 infantryries at CP3 (SCUD Site 2). However, they did not locate SCUD Site 2.
<i>Source of error</i>	Both members seemed to forget their assigned goal. None of them called out that they were supposed to locate enemy at Site 2. The enemy site is not exactly along the route, but they were required to fly further in to the West to locate it. Since they did not realize their goal (incomplete mental model) and the enemy is not seen, they did not attempt to search for the enemy. Incomplete mental model of the mission

Duckhunt 2 Team F

Critical Incident 1	
<i>Situation</i>	Climbed on high ground straight to CP1
<i>Source of error</i>	The copilot did not provide navigation guide Insufficient support by the copilot
Critical Incident 2	
<i>Situation</i>	After destroying SCUD Site 1, they did not go directly do CP2 but spent some time at CP1 figuring out where to go. The co-pilot was not aware of their location. He did not realize that they had passed CP1 and had destroyed SCUD Site 1. The pilot noticed the co-pilot <i>unawareness</i> and updated the co-pilot's mental model of the situation. See their transcribed conversation below:

	<p>Time Originator Radio Transmission</p> <p>01:13 Co-pilot going to CP 1</p> <p>01:21 Pilot 3 o'clock</p> <p>01:28 Co-pilot let's go 335</p> <p>01:38 Co-pilot We got to go to CP 1 first</p> <p>01:43 Pilot Left.. enemy</p> <p>01:48 Co-pilot The soldier</p> <p>01:58 Co-pilot We got to go to the SCUD</p> <p>01:59 Pilot We destoryed already</p> <p>01:59 Co-pilot oo... ok, go back to south easterly direction to CP2</p>
<i>Source of error</i>	Poor awareness of own location
<i>Comment</i>	If one member aware of the <i>unawareness</i> of the other member, he can feedback and help to update the SA of this member. Team SA can thus be compensated. Communication was found helpful to provide cue that a person is losing his awareness.
Critical Incident 3	
<i>Situation</i>	Deviated from the planned route
<i>Source of error</i>	The copilot did not provide navigation guide Insufficient support by the copilot
Critical Incident 4	
<i>Situation</i>	Was shot down at SCUD Site 3. When approaching the last locality, the team was aware of the enemies (and objective) ahead, but the threat level was not emphasized. The pilot roamed into the detection range and RWR gear indicated a spike, which the copilot alerted the pilot to mask the aircraft in order to break lock. The pilot, who did not have the awareness of the threat, did not adopt a positive evasive action and absorbed a hit by the SAM. The co-pilot raised his voice to convey the seriousness of the situation, but to no avail, the second SAM hit the aircraft and the team failed the mission. At this point, the pilot was still unaware of what and who hit him.
<i>Source of error</i>	The failure of scanning the electronic map or the RWR gear by the pilot was the primary failure. He was not aware, first of all, the strength and precise location of the enemies before advancing. Secondly, he was not aware when he was being locked on. Thirdly, he did not comprehend the warning of the co-pilot, and finally, was not aware of what hit him. The copilot failed in warning the pilot the threats before advancing into enemy locality. Poor comprehension of situation. Inattention to teammate's suggestions/communication
<i>Comment</i>	The pilot argued that the copilot will pass him the necessary information seemed futile. The pilot did not actively make use of the electronic map and this may have limited his ability to maintain good SA. The co-pilot on the other hand had much higher SA, but could not do much to salvage the situation. Should the pilot followed the copilot's suggestion, the severity of effects would be lower. Thus, for team situation awareness, good teamwork behavior is one necessary condition.

CSAR 1

Team A	
<i>Situation</i>	After SAR landed, crew focused their attention on surrounding threats and lost awareness that SAR helicopter had took off.
<i>Source of error</i>	Poor monitoring of SAR status, too focused on enemy engagement
<i>Corrective action</i>	Pilot called out to confirm whether SAR had took off. Co-pilot then took a while to re-orient the SAR
Team B	
<i>Situation</i>	Attempted to go in as a lead formation, but was lost. Turned back to locate SAR but could not find it. Disregarded enemies along the route.
<i>Source of error</i>	Poor monitoring of SAR status, disoriented
Team C	
<i>Situation</i>	After SAR landed, crews were still saturated on engaging the threats, and did not see that the SAR took off and flew pass them. Pilot queried on SAR status, but no response by co-pilot. They were confused to see the dawn helicopter at LZ, and thought that SAR was downed. Co-pilot suggested that the Blackhawk seen was not SAR. Co-pilot provided navigation to CP5, but was questioned by pilot. Both got confused and lost.
<i>Source of error</i>	Poor monitoring of SAR status, poor mental model of the mission.
Team E	
<i>Situation</i>	Saw SAR but they were slow and did not join up. When saw the downed heli, co-pilot thought that it was SAR. Pilot replied that it was not. Moved forward and engaged AA, completely distracted and lost.
<i>Source of error</i>	Poor mental model of the mission.

CSAR 2

Team B	
<i>Situation</i>	Pilot did not realized that the helicopter has strayed forwarded, more time taken than necessary to engage AA.
<i>Source of error</i>	Poor weapon handling, poor monitoring of SAR status
<i>Corrective action</i>	Pilot called out lost of visual with SAR, suggested to broke off engagement and back track to search for SAR.
Team F	
<i>Situation</i>	Attempted to destroy all threats instead of mission objective, lost visual with SAR and did not attempt to recover the situation.
<i>Source of error</i>	Poor monitoring of SAR status, poor mental model of the mission.

APPENDIX B

Study 2: Counter-Strike

Consent Form

1. **Nature and Purpose:** I have been asked to participate as a subject in a research project to explore the factors influencing Situation Awareness in individual and team missions. The experiment will be conducted at the Center of Human Factors and Ergonomics, School of Mechanical and Aerospace Engineering, Nanyang Technological University, 50 Nanyang Avenue Singapore 639798. Approximately 16 subjects will participate in this study.
2. **Test Procedure:** I have been informed that the study consists of two sessions: pre-test and main test. These will be conducted in two separate days: one day for the pre-test (approximately 1/2 hour), and another day for the main test (approximately 2 hours). The study will be recorded for data logging purposes.
2. **Discomfort and Risk:** I understand that the medical risks of the test are minimal. Risk would be equivalent to playing an arcade game. There might be a possibility of neck and back discomfort and slight dizziness after the test.
3. **Benefits:** I am informed that I will not be given any compensation for my participation. However, the winning team will be given a prize (original gaming software) as a reward. The winning team will be judged by the experimenters and their decision is final.
4. **Declaration:** I declare that I have not taken alcohol in the last 24 hours and am currently not under any medication. Any personal information provided by me for this test is true.
5. **Entitlements and confidentiality:**
 - a. If an unanticipated event (medical misadventure) occurs during my participation on this study, I will be informed. I understand that the results of the experiments will be used for study purposes only, and my personal information and data will be kept confidential.
 - b. The decision to participate in this research is completely voluntary on my part. I understand the purpose of the study and the objective of the experiment. I understand that Ketut Sulistyawati and Leong Xianrong, Timothy, students from Center of Human Factors and Ergonomics, School of MAE, NTU, 50 Nanyang Avenue, Singapore 639798 (tel: 67905894) will be available to answer any query concerning procedures throughout this study. I understand that if significant new findings develop from this research, which may relate to my decision to continue participation, I will be informed.
 - c. I understand that I may withdraw this consent at any time and discontinue further participation in this study without prejudice to my entitlements. I also understand that Sulis and Timothy may terminate my participation in this study if they feel this to be in my best interest.

Date

Participant Name and Signature

Pre-Test Questionnaire

Part 1: Background Information

Name : _____

Age : _____ Gender: M / F

Occupation : _____

National Service: Y / N

If yes: Combat / Service

CS Playing Experience: _____ (yrs) _____ (total hours played in the last 1 month)

Favorite Maps:

☐ cs_assault	☐ cs_oilrig	☐ de_arstrip	☐ de_piranesi
☐ cs_estate	☐ cs_747	☐ de_aztec	☐ de_prodigy
☐ cs_italy	☐ cs_backalley	☐ de_cbble	☐ de_storm
☐ cs_office	☐ de_vertigo	☐ de_chateau	☐ de_survivor
☐ cs_siege	☐ de_dust	☐ de_inferno	☐ de_torn
☐ cs_havana	☐ de_dust 2	☐ de_nuke	☐ de_train

Other 1st Player Shooting Games: _____

Part 2: General Knowledge

1. What is the maximum amount of money in your account?

Ans: _____

2. How many hostages are there in hostage rescue maps?

Ans: _____

3. How many flash bangs can one carry?

Ans: _____

4. How many rounds are there in the cheaper shotgun?

Ans: _____

5. How much is the cheapest 'Terrorist' rifle?

- a. \$2500
- b. \$3500
- c. \$3100
- d. \$2700

6. Which is the cheapest 'Counter-Terrorist' Rifle?
- a. Krieg 550
 - b. Steyr Aug
 - c. Colt M4A1
 - d. H&K G36
7. Which of the following is not a terrorist group?
- a. Artic Avenger
 - b. L337 Krew
 - c. Rambo Elite
 - d. Phoenix Connection
8. What advantage does the standard issue terrorist pistol have over the counter-terrorist equivalent?
- a. Silencer
 - b. Burst-fire mode
 - c. Scope
 - d. Dual pistols
9. Which of these is not a route by the counter-terrorists into the warehouse on 'cs_assault'?
- a. Down to the car park, and up the elevator
 - b. Round to the right, through the small side door
 - c. Round to the left, through the main sliding door
 - d. Up the ladder to the roof, down through the vent
10. Name the following weapons:

Ans: _____

Ans: _____

Ans: _____

Ans: _____

Part 3: Observer's Rating

Observed Behavior		Score
1	Does the player configure his command keys or use shortcuts for the controls?	_____
2	Does the player reload the weapon appropriately?	_____
3	Does the player move efficiently throughout the map?	_____
4	Does the player have any strategy when contacting the enemies?	_____
5	Does the player make the best use of his weapons and equipment?	_____
6	Does the player fire effectively? i.e. no random firing and good posture while firing	_____
7	Does the player often check his surrounding?	_____
Total score _____		

✂-----

NASA TLX: Paired Comparison

Instruction: This part requires you to assess the relative importance of the six factors in determining how much workload you experienced. For each of the 15 pairs of rating scales presented, **CIRCLE** the scale title that represents the **MORE IMPORTANT CONTRIBUTOR** to workload for the task you have performed. Do refer to the rating scales description provided if necessary.

Example: Physical Demand vs. Effort

Mental Demand	vs.	Physical Demand	Physical Demand	vs.	Performance
Temporal Demand	vs.	Performance	Performance	vs.	Frustration Level
Mental Demand	vs.	Effort	Physical Demand	vs.	Temporal Demand
Physical Demand	vs.	Frustration Level	Temporal Demand	vs.	Effort
Mental Demand	vs.	Temporal Demand	Mental Demand	vs.	Performance
Effort	vs.	Frustration Level	Effort	vs.	Performance
Physical Demand	vs.	Effort	Mental Demand	vs.	Frustration Level
Temporal Demand	vs.	Frustration Level			

Mission: _____

Play As: Terrorist 1 / Terrorist 2 / Counter-terrorist 1 / Counter-terrorist 2

Situation Awareness Assessment

Instruction: The experimenters will playback the recorded mission you've just completed and will pause it at several sections. Based on your awareness at that point in time, answer the following questions:

1. In the following map, indicate:

- the location of all players
- the direction of their movement

2. At this point, what weapon did you think each player was using?

- Selection: 1 – pistol
2 – shotgun
3 – short machine gun
4 – rifle
5 – machine gun
6 – other (please specify)

Terrorist 1:

Counter-terrorist 1:

Terrorist 2:

Counter-terrorist 2:

3. Indicate the players' activity at this point:

- Selection: 1 – searching for enemy
2 – reloading weapon
3 – contacting the enemy
4 – camping
5 – running away
6 – other (please specify)

Terrorist 1:

Terrorist 2:

Counter-terrorist 1:

Counter-terrorist 2:

4. Indicate the number of players that were still alive at this time:

___ terrorist(s) still alive
___ counter-terrorist(s) still alive

Subjective Awareness Assessment Rating

Instruction: Please evaluate the mission by marking each scale at the point which matches your experience and which you believe matches your teammate's and the overall team experience.

To what extent were **you** aware of the team situation?

1	2	3	4	5	6	7
1- I had no idea what was going on.				7- I understood what was going on very well		

To what extent was **your teammate** aware of the team situation?

1	2	3	4	5	6	7
1- He had no idea what was going on.				7- He understood what was going on very well		

Subjective Workload Assessment Rating

Instruction: Please evaluate the mission by marking each scale at the point which matches your experience and which you believe matches your teammate's experience. Please note that the descriptor for "Performance" goes from "good" on the left to "bad" on the right. Consider each scale individually. Do refer to the rating scales description provided if necessary.

My:

Mental Demand

Physical Demand

Temporal Demand

Performance

Effort

Frustration Level

My teammate's:

Mental Demand

Physical Demand

Temporal Demand

Performance

Effort

Frustration Level

Mental Demand	How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration Level	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and competent did you feel during the task?

Subjective Rating of Teamwork Behavior

Instruction: Please evaluate your and your teammate's behavior according to the following scale:

I _____

always passed important information to my teammate	1	2	3	4	5	6	7
fully understand the team strategy	1	2	3	4	5	6	7
fully understand the team goal(s)	1	2	3	4	5	6	7
fully understand my role(s) in the team	1	2	3	4	5	6	7
always executed my duties as prior agreed upon	1	2	3	4	5	6	7
always assist my teammate whenever needed	1	2	3	4	5	6	7
always regard the opinions of my teammate with respect	1	2	3	4	5	6	7
always provide feedback readily and voluntarily	1	2	3	4	5	6	7
always seek feedback when the need arises	1	2	3	4	5	6	7
always monitor my teammate, such that I was able to step in when he was not able to perform	1	2	3	4	5	6	7

My teammate _____

always passed important information to me	1	2	3	4	5	6	7
fully understand the team strategy	1	2	3	4	5	6	7
fully understand the team goal(s)	1	2	3	4	5	6	7
fully understand his role(s) in the team	1	2	3	4	5	6	7
always executed his duties as prior agreed upon	1	2	3	4	5	6	7
always assist me whenever needed	1	2	3	4	5	6	7
always regard my opinions with respect	1	2	3	4	5	6	7
always provide feedback readily and voluntarily	1	2	3	4	5	6	7
always seek feedback when the need arises	1	2	3	4	5	6	7
always monitor me, such that he was able to step in when I was not able to perform	1	2	3	4	5	6	7

Instruction: Please evaluate the overall experiment by marking each scale at the point which matches your experience.

9. Additional comments:

Result

Team No.	Experience	Performance	SA _{Own}	SA _{Teammate}	SA Self-rating	WL Aware	SA Aware	Overall Teamwork	CAST
1	11.50	515	.82	.92	5.75	1.95	.38	6.35	62.48
2	6.50	400	.76	.89	6.25	.27	.63	5.90	50.72
3	8.00	681	.78	.90	5.38	.35	1.00	5.78	72.15
4	8.50	700	.80	.96	5.75	.80	2.25	6.15	72.90
5	3.50	476	.73	.83	5.38	1.10	1.88	5.83	47.07
6	6.50	909	.80	.75	5.88	2.30	.88	5.83	57.15
7	7.50	100	.78	.68	5.13	2.17	1.38	5.55	40.34
8	6.50	100	.89	.94	5.75	.72	.38	5.73	55.30
9	1.50	0	.82	.79	4.63	.15	1.25	5.28	52.94
10	.50	100	.61	.64	4.75	2.15	2.13	5.18	50.77

APPENDIX C

Study 3: Counter-Strike

Consent Form

1. **Nature and Purpose:** I have been asked to participate as a subject in a research project aimed to explore the factors influencing Situation Awareness in individual and team missions. The experiment will be conducted at the Center of Human Factors and Ergonomics, School of Mechanical and Aerospace Engineering, Nanyang Technological University, 50 Nanyang Avenue Singapore 639798. Approximately 32 subjects will participate in this study.
2. **Test Procedure:** I have been informed that the study consists of two sessions: cognitive test and Counter-Strike test. The overall experiment will take approximately 3 hours. The study will be recorded for data logging purposes.
2. **Discomfort and Risk:** I understand that the medical risks of the test are minimal. Risk would be equivalent to playing an arcade game.
3. **Benefits:** I am informed that I will be given S\$30 for my full participation in the study.
4. **Declaration:** I declare that I have not taken alcohol in the last 24 hours and am currently not under any medication. Any personal information provided by me for this test is true.
5. **Entitlements and confidentiality:**
 - a. If an unanticipated event (medical misadventure) occurs during my participation on this study, I will be informed. I understand that the results of the experiments will be used for study purposes only, and my personal information and data will be kept confidential.
 - b. The decision to participate in this research is completely voluntary on my part. I understand the purpose of the study and the objective of the experiment. I understand that Ketut Sulistyawati, a student from Center of Human Factors and Ergonomics, School of MAE, NTU, 50 Nanyang Avenue, Singapore 639798 (tel: 67905894) will be available to answer any query concerning procedures throughout this study. I understand that if significant new findings develop from this research, which may relate to my decision to continue participation, I will be informed.
 - c. I understand that I may withdraw this consent at any time and discontinue further participation in this study. I also understand that Sulis may terminate my participation in this study if she feels this to be in my best interest.

Date

Participant Name and Signature

Pre-Test Questionnaire

Part 1: Background Information

Name : _____

Age : _____ Gender: M / F

Education : _____

CS Playing Experience : _____ years

CS Playing Frequency : _____ hours per week

CS Playing in the last 1 month: _____ hours

Frequently played map(s):

☐ cs_assault	☐ cs_oilrig	☐ de_arstrip	☐ de_piranesi
☐ cs_estate	☐ cs_747	☐ de_aztec	☐ de_prodigy
☐ cs_italy	☐ cs_backalley	☐ de_cbble	☐ de_storm
☐ cs_office	☐ de_vertigo	☐ de_chateau	☐ de_survivor
☐ cs_siege	☐ de_dust	☐ de_inferno	☐ de_torn
☐ cs_havana	☐ de_dust 2	☐ de_nuke	☐ de_train

Other 1st Player Shooting Games played: _____

Do you know any of the other players in this experiment? Yes / No

If yes, fill in the following table:

Name	1.	2.	3.
Years known	years	years	years
How do you get to know him/her?			
Ever played CS with?	Yes / No	Yes / No	Yes / No
If yes, how often?	hrs/mth	hrs/mth	hrs/mth
If yes, usually play with 1/2/3 as:	Team / opponent / both	Team / opponent / both	Team / opponent / both

1. What is the maximum amount of money in your account? _____
2. How many hostages are there in hostage rescue maps? _____
3. How many flash bangs can one carry? _____
4. How many rounds are there in the cheaper shotgun? _____
5. How much is the cheapest 'Terrorist' rifle?
 - a. \$2500
 - b. \$3500
 - c. \$3100
 - d. \$2700
6. Which is the cheapest 'Counter-Terrorist' Rifle?
 - a. Kreig 550
 - b. Steyr Aug
 - c. Colt M4A1
 - d. H&K G36
7. Which of the following is not a terrorist group?
 - a. Artic Avenger
 - b. L337 Krew
 - c. Rambo Elite
 - d. Phoenix Connection
8. What advantage does the standard issue terrorist pistol have over the counter-terrorist equivalent?
 - a. Silencer
 - b. Burst-fire mode
 - c. Scope
 - d. Dual pistols
9. Which of these is not a route by the counter-terrorists into the warehouse on 'cs_assault'?
 - a. Down to the car park, and up the elevator
 - b. Round to the right, through the small side door
 - c. Round to the left, through the main sliding door
 - d. Up the ladder to the roof, down through the vent

Part 2: CS Knowledge

10. Name the following weapons:

Ans: _____

Ans: _____

Ans: _____

Ans: _____

Individual Mission

Workload	
1. How much workload/stress do you feel?	
underloaded ; I could cope with much more additional demand	<div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div> <div>overloaded; I could not cope with the task</div>

Awareness	
1. To what extent are you aware of the overall situation?	
I have no idea what is going on.	<div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div> <div>I understand what is going on very well</div>

Continue →

For the **CURRENT POINT IN TIME**:

Confidence:

1. On the map (right) indicate the location of all players and the direction of their movement		<p>Confidence: My location: ☐ Lo ☐ Hi Opponent's: ☐ Lo ☐ Hi</p>
2. What is each player doing? e.g., I am searching, Opponent is hiding/camping I am Opponent is	☐ Lo ☐ Hi ☐ Lo ☐ Hi	
3. Estimate the blood level of each player: My blood : Opponent's:	☐ Lo ☐ Hi ☐ Lo ☐ Hi	
4. What weapon is each player using? e.g., pistol, shotgun, short machine gun, rifle, machine gun My weapon : Opponent's:	☐ Lo ☐ Hi ☐ Lo ☐ Hi	
5. Is the opponent player within your weapon's reach? <div style="text-align: right;">Yes / No</div>	☐ Lo ☐ Hi	

Continue →

Based on your understanding of current situation, predict what is going to happen in **THE NEXT 10 SECONDS**

Confidence:

1. On the map (right) estimate the location of the opponent and the direction of their movement

2. Estimate the blood level of each player:

My blood :

☐ Lo ☐ Hi

Opponent's:

☐ Lo ☐ Hi

3. Will the opponent player be within your weapon's reach?
Yes / No

☐ Lo ☐ Hi

Confidence:

My location: ☐ Lo ☐ Hi

Opponent's: ☐ Lo ☐ Hi

Team Mission

Workload

1. How much workload/stress do **you** feel?

underloaded; I could cope with much more additional demand

overloaded; I could not cope with the task

2. How much workload/stress do you think **your teammate** feels?

underloaded; he could cope with much more additional demand

overloaded; he could not cope with the task

Awareness

1. To what extent are **you** aware of the overall situation?

I have **no idea** what is going on.

I **understand** what is going on **very well**

2. To what extent is **your teammate** aware of the situation?

He has **no idea** what is going on.

He **understands** what is going on **very well**

Continue →

For the **CURRENT POINT IN TIME:**

Confidence:

1. On the map (right) indicate the location of all players and the direction of their movement	
2. Which opponent player that is of a higher threat to me : Opponent 1 / Opponent 2 / None / Both to my teammate: Opponent 1 / Opponent 2 / None / Both	☐ Lo ☐ Hi ☐ Lo ☐ Hi
3. What is each player doing?	
I am	☐ Lo ☐ Hi
My teammate is	☐ Lo ☐ Hi
Opponent 1 is	☐ Lo ☐ Hi
Opponent 2 is	☐ Lo ☐ Hi
4. Estimate the blood level of each player:	
My blood:	☐ Lo ☐ Hi
My teammate's:	☐ Lo ☐ Hi
Opponent 1's:	☐ Lo ☐ Hi
Opponent 2's:	☐ Lo ☐ Hi
5. What weapon is each player using? e.g., pistol, shotgun, short machine gun, rifle, machine gun	
My weapon:	☐ Lo ☐ Hi
My teammate's:	☐ Lo ☐ Hi
Opponent 1's:	☐ Lo ☐ Hi
Opponent 2's:	☐ Lo ☐ Hi
6. Which opponent player is within your weapon's reach? Opponent 1 / Opponent 2 / None / Both	☐ Lo ☐ Hi

Confidence:

My location: ☐ Lo ☐ Hi
 Teammate's: ☐ Lo ☐ Hi

Opponent 1: ☐ Lo ☐ Hi
 Opponent 2: ☐ Lo ☐ Hi

Based on your understanding of current situation, predict what is going to happen in **THE NEXT 10 SECONDS**

Confidence:

1. On the map (right) estimate the location of all players and the direction of their movement	
2. Which opponent player that will be of a higher threat to me : Opponent 1 / Opponent 2 / None / Both to my teammate: Opponent 1 / Opponent 2 / None / Both	☐ Lo ☐ Hi ☐ Lo ☐ Hi
4. Estimate the blood level of each player: My blood: My teammate's: Opponent 1's: Opponent 2's:	☐ Lo ☐ Hi ☐ Lo ☐ Hi ☐ Lo ☐ Hi ☐ Lo ☐ Hi
5. Which opponent player will be within your weapon's reach? Opponent 1 / Opponent 2 / None / Both	☐ Lo ☐ Hi

Confidence:

My location: ☐ Lo ☐ Hi
 Teammate's: ☐ Lo ☐ Hi

Opponent 1: ☐ Lo ☐ Hi
 Opponent 2: ☐ Lo ☐ Hi

Result

Participant #	Session #	Play as	Experience	Play with opponent	Hidden Figure	Number Comparison	Cube Comparison	Form Board	Auditory Number	Building Memory	Figure Classification	Following Direction	Math Aptitude
1	1	T	7	2	16	12	9	85	13	10.75	88	10	9.5
2	2	CT	6	3	16	16	20	67	15	10.75	100	8.75	10.5
3	1	T	12	2	15	20	17	70	8	12	57	7.5	12
4	2	CT	7	3	12	17	19	90	7	12	51	7.5	10.75
5	3	T	7	1	7.75	17	13	61	7	10.75	67.5	8.75	9.5
6	4	CT	9	2	11	19	13	75	7	10.75	79	7.5	10.5
7	3	T	8	1	10.5	24	14	54	6	8.5	78.5	5.75	4.25
8	4	CT	7	2	9	16	5	65	7	10.75	106	7.5	6.75
9	5	T	12	3	6	14	9	58	8	8.25	42	2.75	6.75
10	6	CT	12	1	2	12	2	25	7	8.5	29	4.5	5.75
11	5	T	13	3	10	16	11	70	13	5.75	63	7.5	3.5
12	6	CT	11	1	9	17	14	69	10	9.5	63	1	1.25
13	7	T	6	2	11	15	6	86	10	9.5	73.5	5	7.75
14	8	CT	6	1	7.75	13	10	61	8	10.75	73	7.5	8.75
15	7	T	6	2	7	13	11	50	8	7	71.5	5.75	7
16	8	CT	10	1	5	13	8	65	5	10.75	42.5	8.75	5.25
17	9	T	6	2	3.25	12	5	29	10	9.5	30	8.75	2.75
18	10	CT	8	3	10.75	12	14	75	9	12	80	7.5	8.5
19	9	T	8	2	11.5	16	5	89	5	9.5	62	6	5.5
20	10	CT	6	3	0.5	11	15	85	4	12	46	6.5	4.5
21	11	T	10	1	16	20	19	81	10	10.75	100	12	13
22	12	CT	10	1	13.5	15	17	83	12	10.75	102.5	8.75	11.25
23	11	T	5	1	7	14	1	49	9	7	38.5	7.5	4
24	12	CT	9	1	9.25	8	3	78	7	4.5	40	5.5	7.75
25	13	T	7	3	12	17	17	30	10	9.75	88	7.5	10.75
26	14	CT	6	2	10	20	10	102	5	10.75	101	8.75	12
27	13	T	7	3	11	17	7	56	7	12	62	7.5	11
28	14	CT	8	2	2.75	19	11	12	11	10.75	52	7.5	5.5
29	15	T	7	1	16	12	10	83	13	12	88.5	8.75	8.75
30	16	CT	13	1	16	14	17	105	9	8.25	99	10	5.25
31	15	T	4	1	6	16	18	26	8	8.25	42	3.75	8
32	16	CT	11	1	8.75	16	14	87	17	12	100	7.5	8.75

Partici pant #	Session #	Play as	SAGAT 1 / 2	SAGAT 3	Conf level 1 / 2	Conf level 3	Over-conf Bias 1 / 2	Over-conf Bias 3	Abs Conf Bias 1 / 2	Abs Conf Bias 3	Self Rating of SA
1	1	T	.86	.31	.66	.62	-.20	.31	.20	.31	6.00
2	2	CT	.71	.81	.58	.54	-.13	-.27	.13	.27	4.00
3	1	T	.94	.81	.70	.66	-.25	-.15	.25	.15	6.00
4	2	CT	.76	.38	.66	.62	-.11	.25	.11	.25	6.00
5	3	T	.78	.63	.62	.58	-.16	-.04	.16	.04	7.00
6	4	CT	.89	.69	.84	.81	-.05	.12	.05	.12	6.50
7	3	T	.67	.50	.46	.47	-.20	-.03	.20	.03	4.00
8	4	CT	.78	.50	.50	.50	-.28	.00	.28	.00	4.50
9	5	T	.50	.50	.92	1.00	.42	.50	.42	.50	7.00
10	6	CT	.89	.81	.94	.75	.06	-.06	.06	.06	7.00
11	5	T	.72	.44	.94	.13	.22	-.31	.22	.31	7.00
12	6	CT	.58	.25	1.00	1.00	.42	.75	.42	.75	7.00
13	7	T	.65	.13	.44	.25	-.20	.13	.20	.13	3.50
14	8	CT	.76	.63	.82	.75	.06	.13	.06	.13	7.00
15	7	T	.71	.25	.56	.00	-.15	-.25	.15	.25	4.00
16	8	CT	.82	.44	.83	.67	.01	.23	.01	.23	4.50
17	9	T	.67	.56	.61	.63	-.06	.06	.06	.06	6.00
18	10	CT	.83	.50	.94	1.00	.11	.50	.11	.50	6.50
19	9	T	.83	.63	.89	.50	.06	-.13	.06	.13	7.00
20	10	CT	.89	.75	.94	1.00	.05	.25	.05	.25	1.00
21	11	T	.89	.44	.83	.43	-.06	-.01	.06	.01	5.00
22	12	CT	.72	.44	.94	.50	.22	.06	.22	.06	5.50
23	11	T	.83	.63	.81	.38	-.02	-.25	.02	.25	5.50
24	12	CT	.67	.63	.93	.86	.26	.23	.26	.23	7.00
25	13	T	.83	.75	.83	.63	.00	-.13	.00	.13	5.00
26	14	CT	.83	.31	1.00	.75	.17	.44	.17	.44	6.00
27	13	T	.61	.88	.94	.50	.33	-.38	.33	.38	4.00
28	14	CT	.72	.25	.89	.50	.17	.25	.17	.25	4.50
29	15	T	.83	.75	.83	.63	.00	-.13	.00	.13	6.50
30	16	CT	.72	.75	.94	.71	.22	-.04	.22	.04	6.50
31	15	T	.94	.44	1.00	.71	.06	.28	.06	.28	7.00
32	16	CT	.83	.88	.89	.50	.06	-.38	.06	.38	6.50

Team #	Session #	Play as	Play with tmate	Play with opponent	SAGAT Own	SAGAT Tmate	SA Self-rating	Over-conf Bias	Abs Conf Bias	WL Aware	SA Aware	CAST	Team-work	Performance
1	1	T	3	3	.78	.53	4.25	.26	.26	1.00	.50	.66	5.83	27.60
2	2	CT	2	3	.77	.88	5.50	-.02	.12	.25	.25	.59	5.45	51.45
3	1	T	1	2	.72	.53	4.50	.01	.28	.00	.25	.54	4.58	66.10
4	2	CT	2	2	.69	.60	3.50	-.07	.18	.00	.75	.39	4.28	22.10
5	3	T	4	2	.81	.85	6.25	.09	.13	.25	1.25	.72	6.80	49.80
6	4	CT	4	2	.82	.70	7.00	.11	.11	.25	.00	.71	6.48	37.55
7	3	T	1	1	.52	.53	5.00	-.10	.23	1.25	.75	.56	5.18	65.25
8	4	CT	2	1	.71	.55	4.00	-.11	.11	.00	.25	.40	4.93	15.80
9	5	T	2	3	.80	.60	5.25	.03	.03	1.25	.75	.63	4.78	45.00
10	6	CT	3	3	.64	.63	6.50	.16	.16	.50	.50	.46	5.63	41.45
11	5	T	2	1	.80	.70	5.75	.00	.08	.50	.25	.59	5.80	77.60
12	6	CT	2	1	.71	.75	5.25	.02	.30	1.00	1.25	.41	5.18	36.80
13	7	T	3	1	.76	.75	4.75	.05	.15	1.50	1.75	.52	4.43	35.45
14	8	CT	3	3	.73	.73	4.00	.00	.05	1.00	.75	.41	4.20	51.70
15	7	T	1	3	.74	.63	3.75	-.09	.22	.25	1.50	.61	5.05	46.15
16	8	CT	1	1	.74	.65	5.00	.02	.19	1.00	1.00	.62	4.65	30.85

APPENDIX D

Study 4: Air Combat (F16)

Mission Design

Mission 1 (individual)

Number of adversaries : 2 x MiG-29A
Type of Munitions : 2 x AIM-7M, 2 x AIM-9M, 1 x Low Alt
Camera, 570 x 20mm M61
Expected time to complete : 5 minutes
Mission goal : Destroy enemy's recon aircraft
Number of freeze : 2
Freeze 1: 1 minutes after start of mission
Freeze 2: 30 nm from adversaries
Freeze 3: 10 seconds after first weapon launch

Mission 2 (individual)

Number of adversaries	: 1 x MiG29A
Type of Munitions	: 4 x R-60, 2 x R-73 Mod 1, 150 x 30mm GSH-301
Number of adversaries	: 2 x F-5E
Type of Munitions	: 4 x AIM-9P, 560 x 20mm M39-2
Expected time to complete	: 10 minutes
Mission goal	: Sweep Mission. Kill all enemies.
Number of freeze	: 4
Freeze 1:	30 nm from adversaries
Freeze 2:	10 seconds after first weapon launch
Freeze 3:	30 seconds after enemy engagement at ST4-5
Freeze 4:	30 nm from adversaries

Mission 3 (team)

Number of adversaries	: 2 x MiG-29A
Type of Munitions	: 2 x R-27T, 2 x R-73 Mod 1, 2 x FAB-500/UKB, 150 x 30mm GSH-301
Expected time to complete	: 10 minutes
Mission goal	: Prevent enemies from destroying Refinery (HVA)
Number of freeze	: 2
Freeze 1: 30 nm from adversaries	
Freeze 2: 10 seconds after first weapon launch

Mission 4 (team)

Number of adversaries : 2 x F/A-18C
Type of Munitions : 2 x AIM-120B, 2 x AIM-9M, 570 x 20mm M61
Number of adversaries : 2 x F-5E
Type of Munitions : 4 x AIM-9P, 560 x 20mm M39-2
Expected time to complete : 5 minutes
Mission goal : Sweep Mission. Kill all enemies
Number of freeze : 2
Freeze 1: 30 nm from adversaries
Freeze 2: 10 seconds after first weapon launch
Freeze 3: 30 seconds after enemy engagement at ST4-5
Freeze 4: 30 nm from adversaries

Instruction

IMPORTANT: Please make sure you have understood the instruction clearly. If you have any doubt, please clarify with the experimenter before you start the test.

- You will be asked to perform two air combat missions individually. Each mission will take about 15-30 minutes to complete.
- You will first be briefed on the objective of the mission. You will then be given enough time to study the navigation route used in the mission, and an additional of 1 minute to do a mission plan in the team mission.
- The mission will be paused several times to elicit your awareness of the situation. The experimenter will shout “Freeze” during the freeze time, and you can observe that the game is paused.
- When you hear the freeze command from the experimenter, turn away from the computer screen, face the table positioned behind you, and begin to answer the questionnaire provided after the experimenter instructed “Start”.
- You will first be asked to rate your workload at the point of freeze using 7-point scale (1 for very low and 7 for very high workload), followed by a set of questions regarding your mission. The part on the left asks about your knowledge regarding the situation happening in the simulation. The part on the right asks your confidence level on the answer you provided for each of the question. Please remember to fill in the confidence rating for each of your answer. If you *really* do not know the answer of any question, you can leave it and the confidence rating blank.

Example:

Rate **your workload** level at this point:

Rate **your SA** level at this point:

		Confidence Level
1	At this point, what is your Altitude : ft	☐ Low ☐ High

- When the time is up, the experimenter will shout “Time is up” and you can turn back to face the computer screen, get ready with the controls, and resume the mission when the experimenter say “Resume”.

Consent Form

1. **Nature and Purpose:** I have been asked to participate as a subject in a research project aimed to investigate factors that affect situation awareness in individual and team missions. The experiment will be conducted at the Center of Human Factors and Ergonomics, School of Mechanical and Aerospace Engineering, Nanyang Technological University, 50 Nanyang Avenue Singapore 639798.
2. **Test Procedure:** I have been informed that the study consists of two sessions: test of SA in simulated individual and team missions and test of cognitive abilities. Each session will take about 2 hours to complete. The experiment will be recorded for data logging purposes.
2. **Discomfort and Risk:** I understand that the medical risks of the test are minimal. Risk would be equivalent to playing an arcade game. However, there might be a possibility of neck and back discomfort and slight dizziness after the test.
3. **Benefits:** I am informed that I will be given S\$100 for my participation in the study.
4. **Declaration:** I declare that I have not taken alcohol in the last 24 hours and am currently not under any medication. Any personal information provided by me for this test is true.
5. **Entitlements and confidentiality:**
 - a. If an unanticipated event (medical misadventure) occurs during my participation on this study, I will be informed. I understand that the results of the experiments will be used for study purposes only, and my personal information and data will be kept confidential.
 - b. The decision to participate in this research is completely voluntary on my part. I understand that Ketut Sulistyawati, Stephen Wee, and Andrew Keong, students from the Center of Human Factors and Ergonomics, School of MAE, NTU, 50 Nanyang Avenue, Singapore 639798 (tel: 67905894) will be available to answer any query concerning procedures throughout this study. I understand that if significant new findings develop from this research, which may relate to my decision to continue participation, I will be informed.
 - c. I understand that I may withdraw this consent at any time and discontinue further participation in this study without prejudice to my entitlements. I also understand that the experimenters may terminate my participation in this study if they feel this to be in my best interest.

Date

Participant Name and Signature

Demographic Information

Name	:	
Gender	:	
Age	:	

Flying Experience

Do you have any flying experience? Yes / No

If yes,

Type of aircraft flown	:	Military / Commercial /General
Please specify:	:	
Qualification	:	Category: A / B / C / D
	:	Instructor / Operational / Trainee
Flying hours	:	hours

Flight Simulator Gaming Experience

Do you have any experience in flight simulator game? Yes / No

If yes,

Name of flight simulator game	:	
Playing frequency	:	hours/week
No. of years of play	:	years

Other Gaming Experience

Do you play other computer game? Yes / No

If yes,

Name of game	:	
Playing frequency	:	hours/week
No. of years of play	:	years

Type A: M1 F1

Rate **your workload** level at this point:

①—②—③—④—⑤—⑥—⑦
very low very high

Rate **your SA** level at this point:

①—②—③—④—⑤—⑥—⑦
very low very high

		Confidence Level
1.	At this point, what is your Location : _____Nm _____ of STP _____ (eg. 20Nm South of STP 4) _____ Altitude : _____ ft _____ Heading : _____ deg _____ Airspeed : _____ kias _____	☐ Low ☐ High ☐ Low ☐ High ☐ Low ☐ High ☐ Low ☐ High
2.	What is the current time? _____	☐ Low ☐ High
3.	Will you reach the CAP point (SP 3) on time (based on current flight parameters and barring any engagements)? ☐ Yes ☐ No _____	☐ Low ☐ High
4a.	Any enemy aircraft detected? ☐ Yes ☐ No _____	☐ Low ☐ High
4b.	If yes, how many? Specify groups or a/c. _____	☐ Low ☐ High
If you answered “yes” to question 4, please complete questions 5 – 13. Otherwise, you may stop here.		
5.	At this point, what is the status of:	
Enemy 1		
5a.	Altitude : _____ ft _____	☐ Low ☐ High
5b.	Bearing : _____	☐ Low ☐ High
5c.	Range : _____	☐ Low ☐ High
Enemy 2		
5d.	Altitude : _____ ft _____	☐ Low ☐ High
5e.	Bearing : _____	☐ Low ☐ High
5f.	Range : _____	☐ Low ☐ High
Enemy 3		
5g.	Altitude : _____ ft _____	☐ Low ☐ High
5h.	Bearing : _____	☐ Low ☐ High
5i.	Range : _____	☐ Low ☐ High

Continue →

Enemy 4					
5j.	Altitude	:	ft	_____→	☐ Low ☐ High
5k.	Bearing	:		_____→	☐ Low ☐ High
5l.	Range	:		_____→	☐ Low ☐ High
6.	Which enemy is of a higher threat to you? ☐ 1 ☐ 2 ☐ 3 ☐ 4 _____→				☐ Low ☐ High
7.	Are you spiked? ☐ Yes ☐ No _____→				☐ Low ☐ High
8.	Is there a missile launched at you? ☐ Yes ☐ No _____→				☐ Low ☐ High
9.	Is the enemy within your weapon's envelope?				
9a.	Enemy 1:	☐ Yes ☐ No		_____→	☐ Low ☐ High
9b.	Enemy 2:	☐ Yes ☐ No		_____→	☐ Low ☐ High
9c.	Enemy 3:	☐ Yes ☐ No		_____→	☐ Low ☐ High
9d.	Enemy 4:	☐ Yes ☐ No		_____→	☐ Low ☐ High
10.	Are you able to achieve FLO (with current flight parameters)? ☐ Yes ☐ No _____→ Why?				☐ Low ☐ High
11.	Will you be able to take shots within the next 10 seconds? ☐ Yes ☐ No _____→ Why?				☐ Low ☐ High
12.	Will the bandit take shots within the next 30 seconds? ☐ Yes ☐ No _____→ Why?				☐ Low ☐ High

--- end ---

Type B: M1 F2, M2 F1, M2 F4

Rate **your workload** level at this point:

①—②—③—④—⑤—⑥—⑦
very low very high

Rate **your SA** level at this point:

①—②—③—④—⑤—⑥—⑦
very low very high

		Confidence Level	
1.	At this point, what is your Location : _____Nm _____ of STP _____ (eg. 20Nm South of STP 4) Altitude : _____ ft Heading : _____ deg Airspeed : _____ kias	_____→	☐ Low ☐ High ☐ Low ☐ High ☐ Low ☐ High ☐ Low ☐ High
2a.	Any enemy aircraft detected? ☐ Yes ☐ No	_____→	☐ Low ☐ High
2b.	If yes, how many? Specify groups or a/c.	_____→	☐ Low ☐ High
If you answered “yes” to question 2, please complete questions 3 – 11. Otherwise, you may stop here.			
3.	At this point, what is the status of:		
Enemy 1			
3a.	Altitude : _____ ft	_____→	☐ Low ☐ High
3b.	Bearing : _____	_____→	☐ Low ☐ High
3c.	Range : _____	_____→	☐ Low ☐ High
Enemy 2			
3d.	Altitude : _____ ft	_____→	☐ Low ☐ High
3e.	Bearing : _____	_____→	☐ Low ☐ High
3f.	Range : _____	_____→	☐ Low ☐ High
Enemy 3			
3g.	Altitude : _____ ft	_____→	☐ Low ☐ High
3h.	Bearing : _____	_____→	☐ Low ☐ High
3i.	Range : _____	_____→	☐ Low ☐ High
Enemy 4			
3j.	Altitude : _____ ft	_____→	☐ Low ☐ High
3k.	Bearing : _____	_____→	☐ Low ☐ High
3l.	Range : _____	_____→	☐ Low ☐ High

Continue →

4.	Which enemy is of a higher threat to you? ☐ 1 ☐ 2 ☐ 3 ☐ 4 _____ →	☐ Low ☐ High
5.	Are you spiked? ☐ Yes ☐ No _____ →	☐ Low ☐ High
6.	Are you in the bandits weapon's envelope?	
6a.	Enemy 1: ☐ Yes ☐ No _____ →	☐ Low ☐ High
6b.	Enemy 2: ☐ Yes ☐ No _____ →	☐ Low ☐ High
6c.	Enemy 3: ☐ Yes ☐ No _____ →	☐ Low ☐ High
6d.	Enemy 4: ☐ Yes ☐ No _____ →	☐ Low ☐ High
7.	Is the enemy within your weapon's envelope?	
7a.	Enemy 1: ☐ Yes ☐ No _____ →	☐ Low ☐ High
7b.	Enemy 2: ☐ Yes ☐ No _____ →	☐ Low ☐ High
7c.	Enemy 3: ☐ Yes ☐ No _____ →	☐ Low ☐ High
7d.	Enemy 4: ☐ Yes ☐ No _____ →	☐ Low ☐ High
8.	Are you able to achieve FLO (with current flight parameters)? ☐ Yes ☐ No _____ → Why?	☐ Low ☐ High
9.	Will you be able to take shots within the next 10 seconds? ☐ Yes ☐ No _____ → Why?	☐ Low ☐ High
10.	Will the bandit take shots within the next 30 seconds? ☐ Yes ☐ No _____ → Why?	☐ Low ☐ High

--- end ---

Type C: M1 F3, M2 F2

Rate **your workload** level at this point:

①—②—③—④—⑤—⑥—⑦
very low very high

Rate **your SA** level at this point:

①—②—③—④—⑤—⑥—⑦
very low very high

				Confidence Level	
1. At this point, what is your					
Altitude	:	ft	_____→	☐ Low	☐ High
Heading	:	deg	_____→	☐ Low	☐ High
Airspeed	:	kias	_____→	☐ Low	☐ High
2. How many enemy aircraft detected? Specify groups or a/c.					
				_____→	☐ Low ☐ High
3. At this point, what is the status of:					
Enemy 1					
3a.	Altitude	:	ft	_____→	☐ Low ☐ High
3b.	Bearing	:		_____→	☐ Low ☐ High
3c.	Range	:		_____→	☐ Low ☐ High
Enemy 2					
3d.	Altitude	:	ft	_____→	☐ Low ☐ High
3e.	Bearing	:		_____→	☐ Low ☐ High
3f.	Range	:		_____→	☐ Low ☐ High
Enemy 3					
3g.	Altitude	:	ft	_____→	☐ Low ☐ High
3h.	Bearing	:		_____→	☐ Low ☐ High
3i.	Range	:		_____→	☐ Low ☐ High
Enemy 4					
3j.	Altitude	:	ft	_____→	☐ Low ☐ High
3k.	Bearing	:		_____→	☐ Low ☐ High
3l.	Range	:		_____→	☐ Low ☐ High
4. Which enemy is of a higher threat to you?					
☐ 1 ☐ 2 ☐ 3 ☐ 4				_____→	☐ Low ☐ High
5. Are you spiked? ☐ Yes ☐ No					
				_____→	☐ Low ☐ High

Continue →

6. Are you in the bandits weapon's envelope?				
6a. Enemy 1:	☐ Yes	☐ No	_____→	☐ Low ☐ High
6b. Enemy 2:	☐ Yes	☐ No	_____→	☐ Low ☐ High
6c. Enemy 3:	☐ Yes	☐ No	_____→	☐ Low ☐ High
6d. Enemy 4:	☐ Yes	☐ No	_____→	☐ Low ☐ High
7. Did you achieve FLO?				
	☐ Yes	☐ No	_____→	☐ Low ☐ High
8. Will the bandit take shots within the next 10 seconds?				
	☐ Yes	☐ No	_____→	☐ Low ☐ High
Why?				
9. At pitbull, what tactic do you anticipate you can employ (E.g Skate or Banzai)?				
Why?			_____→	☐ Low ☐ High

--- end ---

Type D: M2 F3

Rate **your workload** level at this point:

①—②—③—④—⑤—⑥—⑦
very low very high

Rate **your SA** level at this point:

①—②—③—④—⑤—⑥—⑦
very low very high

		Confidence Level
1.	At this point, what is your Location : ____Nm ____ of STP ____ (eg. 20Nm South of STP 4) Altitude : ft Heading : deg Airspeed : kias	☐ Low ☐ High ☐ Low ☐ High ☐ Low ☐ High ☐ Low ☐ High
2.	What is the current time?	☐ Low ☐ High
3.	Will you be able to reach the assigned steerpoint (SP 5) on time (based on current flight parameters and barring any engagements)? ☐ Yes ☐ No	☐ Low ☐ High
4.	At this point, amount of weapons remaining?	
4a.	____ AIM-120B	☐ Low ☐ High
4b.	____ AIM-9	☐ Low ☐ High
5a.	Any enemy aircraft detected? ☐ Yes ☐ No	☐ Low ☐ High
5b.	If yes, how many? Specify groups or a/c.	☐ Low ☐ High
If you answered “yes” to question 5, please complete questions 6 – 13. Otherwise, you may stop here.		
6.	At this point, what is the status of:	
Enemy 1		
6a.	Altitude : ft	☐ Low ☐ High
6b.	Bearing :	☐ Low ☐ High
6c.	Range :	☐ Low ☐ High
Enemy 2		
6d.	Altitude : ft	☐ Low ☐ High
6e.	Bearing :	☐ Low ☐ High
6f.	Range :	☐ Low ☐ High

Continue →

Enemy 3					
6g.	Altitude	:	ft	_____→	☐ Low ☐ High
6h.	Bearing	:		_____→	☐ Low ☐ High
6i.	Range	:		_____→	☐ Low ☐ High
Enemy 4					
6j.	Altitude	:	ft	_____→	☐ Low ☐ High
6k.	Bearing	:		_____→	☐ Low ☐ High
6l.	Range	:		_____→	☐ Low ☐ High
7.	Which enemy is of a higher threat to you? ☐ 1 ☐ 2 ☐ 3 ☐ 4 _____→				☐ Low ☐ High
8.	Are you spiked? ☐ Yes ☐ No _____→				☐ Low ☐ High
9.	Is there a missile launched at you? ☐ Yes ☐ No _____→				☐ Low ☐ High
10.	Is the enemy within your weapon's envelope?				
10a.	Enemy 1:	☐ Yes ☐ No		_____→	☐ Low ☐ High
10b.	Enemy 2:	☐ Yes ☐ No		_____→	☐ Low ☐ High
10c.	Enemy 3:	☐ Yes ☐ No		_____→	☐ Low ☐ High
10d.	Enemy 4:	☐ Yes ☐ No		_____→	☐ Low ☐ High
11.	Are you able to achieve FLO (with current flight parameters)? ☐ Yes ☐ No _____→ Why?				☐ Low ☐ High
12.	Will you be able to take shots within the next 10 seconds? ☐ Yes ☐ No _____→ Why?				☐ Low ☐ High
13.	Will the bandit take shots within the next 30 seconds? ☐ Yes ☐ No _____→ Why?				☐ Low ☐ High

Type E: M3 F1, M4 F1, M4 F4

<p>Rate your workload level:</p> <p style="text-align: center;">① — ② — ③ — ④ — ⑤ — ⑥ — ⑦</p> <p style="text-align: center;">very low very high</p>	<p>Estimate your SA level:</p> <p style="text-align: center;">① — ② — ③ — ④ — ⑤ — ⑥ — ⑦</p> <p style="text-align: center;">very low very high</p>
<p>Rate teammate's workload level:</p> <p style="text-align: center;">① — ② — ③ — ④ — ⑤ — ⑥ — ⑦</p> <p style="text-align: center;">very low very high</p>	<p>Estimate your teammate's SA level:</p> <p style="text-align: center;">① — ② — ③ — ④ — ⑤ — ⑥ — ⑦</p> <p style="text-align: center;">very low very high</p>

<p>1a. At this point, what is your</p> <p style="margin-left: 20px;">Location : _____Nm _____ of STP _____ →</p> <p style="margin-left: 40px;">(eg. 20Nm South of STP 4)</p> <p style="margin-left: 20px;">Altitude : _____ ft →</p> <p style="margin-left: 20px;">Heading : _____ deg →</p> <p style="margin-left: 20px;">Airspeed : _____ kias →</p> <p>1b. your teammate's position (eg. 2 Nm Southwest, high) →</p>	<p>Confidence Level</p> <p>☐ Low ☐ High</p> <p>☐ Low ☐ High</p> <p>☐ Low ☐ High</p> <p>☐ Low ☐ High</p> <p>☐ Low ☐ High</p>
<p>2a. Any enemy aircraft detected?</p> <p style="margin-left: 20px;">☐ Yes ☐ No →</p> <p>2b. Number of enemy aircraft detected? Specify groups or a/c. →</p>	<p>☐ Low ☐ High</p> <p>☐ Low ☐ High</p>
<p>If you answered “yes” to question 2, please complete questions 3 – 10. Otherwise, you may stop here.</p>	
<p>3. At this point, what is the status of:</p> <p style="margin-left: 20px;">Enemy 1</p> <p>3a. Altitude : _____ ft →</p> <p>3b. Bearing : _____ →</p> <p>3c. Range : _____ →</p> <p style="margin-left: 20px;">Enemy 2</p> <p>3d. Altitude : _____ ft →</p> <p>3e. Bearing : _____ →</p> <p>3f. Range : _____ →</p>	<p>☐ Low ☐ High</p> <p>☐ Low ☐ High</p> <p>☐ Low ☐ High</p> <p>☐ Low ☐ High</p> <p>☐ Low ☐ High</p> <p>☐ Low ☐ High</p>

Continue →

Enemy 3							
3g.	Altitude	:	ft	_____→	☐ Low	☐ High	
3h.	Bearing	:		_____→	☐ Low	☐ High	
3i.	Range	:		_____→	☐ Low	☐ High	
Enemy 4							
3j.	Altitude	:	ft	_____→	☐ Low	☐ High	
3k.	Bearing	:		_____→	☐ Low	☐ High	
3l.	Range	:		_____→	☐ Low	☐ High	
4a.	Which enemy is of a higher threat to you ?						
	☐ 1	☐ 2	☐ 3	☐ 4	_____→	☐ Low ☐ High	
4b.	Which enemy is of a higher threat to your teammate ?						
	☐ 1	☐ 2	☐ 3	☐ 4	_____→	☐ Low ☐ High	
5a.	Are you spiked?		☐ Yes ☐ No	_____→	☐ Low	☐ High	
5b.	Is your teammate spiked?		☐ Yes ☐ No	_____→	☐ Low	☐ High	
6a.	Are you in the bandits weapon's envelope?						
i.	Enemy 1:	☐ Yes ☐ No	_____→	☐ Low	☐ High		
ii.	Enemy 2:	☐ Yes ☐ No	_____→	☐ Low	☐ High		
iii.	Enemy 3:	☐ Yes ☐ No	_____→	☐ Low	☐ High		
iv.	Enemy 4:	☐ Yes ☐ No	_____→	☐ Low	☐ High		
6b.	Is your teammate in the bandits weapon's envelope?						
i.	Enemy 1:	☐ Yes ☐ No	_____→	☐ Low	☐ High		
ii.	Enemy 2:	☐ Yes ☐ No	_____→	☐ Low	☐ High		
iii.	Enemy 3:	☐ Yes ☐ No	_____→	☐ Low	☐ High		
iv.	Enemy 4:	☐ Yes ☐ No	_____→	☐ Low	☐ High		
7a.	Is the enemy within your weapon's envelope?						
i.	Enemy 1:	☐ Yes ☐ No	_____→	☐ Low	☐ High		
ii.	Enemy 2:	☐ Yes ☐ No	_____→	☐ Low	☐ High		
iii.	Enemy 3:	☐ Yes ☐ No	_____→	☐ Low	☐ High		
iv.	Enemy 4:	☐ Yes ☐ No	_____→	☐ Low	☐ High		
7b.	Is the enemy within your teammates weapon's envelope?						
i.	Enemy 1:	☐ Yes ☐ No	_____→	☐ Low	☐ High		
ii.	Enemy 2:	☐ Yes ☐ No	_____→	☐ Low	☐ High		
iii.	Enemy 3:	☐ Yes ☐ No	_____→	☐ Low	☐ High		
iv.	Enemy 4:	☐ Yes ☐ No	_____→	☐ Low	☐ High		

Continue →

Type F: M3 F2, M4 F2

Rate your workload level:				Estimate your SA level:

Rate teammate's workload level:				Estimate your teammate's SA level:

					Confidence Level		
1.	At this point, what is your Altitude : ft _____ Heading : deg _____ Airspeed : kias _____				☐ Low	☐ High	
2.	Number of enemy aircraft detected? Specify groups or a/c. _____ →				☐ Low	☐ High	
3.	At this point, what is the status of:						
	Enemy 1						
3a.	Altitude :	ft	_____ →	☐ Low	☐ High		
3b.	Bearing :		_____ →	☐ Low	☐ High		
3c.	Range :		_____ →	☐ Low	☐ High		
	Enemy 2						
3d.	Altitude :	ft	_____ →	☐ Low	☐ High		
3e.	Bearing :		_____ →	☐ Low	☐ High		
3f.	Range :		_____ →	☐ Low	☐ High		
	Enemy 3						
3g.	Altitude :	ft	_____ →	☐ Low	☐ High		
3h.	Bearing :		_____ →	☐ Low	☐ High		
3i.	Range :		_____ →	☐ Low	☐ High		
	Enemy 4						
3j.	Altitude :	ft	_____ →	☐ Low	☐ High		
3k.	Bearing :		_____ →	☐ Low	☐ High		
3l.	Range :		_____ →	☐ Low	☐ High		

4a.	Which enemy is of a higher threat to you ? ☐ 1 ☐ 2 ☐ 3 ☐ 4 _____ →	☐ Low ☐ High
4b.	Which enemy is of a higher threat to your teammate ? ☐ 1 ☐ 2 ☐ 3 ☐ 4 _____ →	☐ Low ☐ High
5a.	Are you spiked? ☐ Yes ☐ No _____ →	☐ Low ☐ High
5b.	Is your teammate spiked? ☐ Yes ☐ No _____ →	☐ Low ☐ High
6a.	Are you in the bandits weapon's envelope?	
i.	Enemy 1: ☐ Yes ☐ No _____ →	☐ Low ☐ High
ii.	Enemy 2: ☐ Yes ☐ No _____ →	☐ Low ☐ High
iii.	Enemy 3: ☐ Yes ☐ No _____ →	☐ Low ☐ High
iv.	Enemy 4: ☐ Yes ☐ No _____ →	☐ Low ☐ High
6b.	Is your teammate in the bandits weapon's envelope?	
i.	Enemy 1: ☐ Yes ☐ No _____ →	☐ Low ☐ High
ii.	Enemy 2: ☐ Yes ☐ No _____ →	☐ Low ☐ High
iii.	Enemy 3: ☐ Yes ☐ No _____ →	☐ Low ☐ High
iv.	Enemy 4: ☐ Yes ☐ No _____ →	☐ Low ☐ High
7.	Did your formation achieve FLO? ☐ Yes ☐ No _____ →	☐ Low ☐ High
8.	Will the bandits be able to take shots within the next 10 seconds? ☐ Yes ☐ No _____ → Why?	☐ Low ☐ High
9.	At pitbull, what tactic do you anticipate your formation can employ (E.g Skate or Banzai)? _____ Why?	☐ Low ☐ High
10.	Do you anticipate any bandit threat reactions? ☐ Yes ☐ No _____ → Why?	☐ Low ☐ High
11.	Do you anticipate executing a retargeting plan? _____ Why?	☐ Low ☐ High

--- end ---

Type G: M4 F3

Rate your workload level:		Estimate your SA level:	
①—②—③—④—⑤—⑥—⑦ very low very high		①—②—③—④—⑤—⑥—⑦ very low very high	
Rate teammate's workload level:		Estimate your teammate's SA level:	
①—②—③—④—⑤—⑥—⑦ very low very high		①—②—③—④—⑤—⑥—⑦ very low very high	
1a. At this point, what is your Location : _____Nm_____ of STP _____ → (eg. 20Nm South of STP 4) Altitude : _____ft → Heading : _____deg → Airspeed : _____kias →			Confidence Level ☐ Low ☐ High ☐ Low ☐ High ☐ Low ☐ High ☐ Low ☐ High
1b. your teammate's position (eg. 2 Nm Southwest, high) _____ →			☐ Low ☐ High
2. What is the current time? _____ →			☐ Low ☐ High
3. Will your formation be able to reach the assigned steerpoint (SP 4) on time (based on current flight parameters and barring any engagements)? ☐ Yes ☐ No _____ →			☐ Low ☐ High
4a. At this point, amount of weapons remaining? i. _____ AIM-120B _____ → ii. _____ AIM-9 _____ →			☐ Low ☐ High ☐ Low ☐ High
4b. At this point, amount of teammate's weapons remaining? i. _____ AIM-120B _____ → ii. _____ AIM-9 _____ →			☐ Low ☐ High ☐ Low ☐ High
5a. Any enemy aircraft detected? ☐ Yes ☐ No _____ →			☐ Low ☐ High
5b. Numbers of enemy aircrafts detected? Specify groups or a/c. _____ →			☐ Low ☐ High

Continue →

If you answered “yes” to question 5, please complete questions 6 – 13. Otherwise, you may stop here.		
6.	At this point, what is the status of:	
Enemy 1		
6a.	Altitude : ft _____	☐ Low ☐ High
6b.	Bearing : _____	☐ Low ☐ High
6c.	Range : _____	☐ Low ☐ High
Enemy 2		
6d.	Altitude : ft _____	☐ Low ☐ High
6e.	Bearing : _____	☐ Low ☐ High
6f.	Range : _____	☐ Low ☐ High
Enemy 3		
6g.	Altitude : ft _____	☐ Low ☐ High
6h.	Bearing : _____	☐ Low ☐ High
6i.	Range : _____	☐ Low ☐ High
Enemy 4		
6j.	Altitude : ft _____	☐ Low ☐ High
6k.	Bearing : _____	☐ Low ☐ High
6l.	Range : _____	☐ Low ☐ High
7a.	Which enemy is of a higher threat to you ? ☐ 1 ☐ 2 ☐ 3 ☐ 4 _____	☐ Low ☐ High
7b.	Which enemy is of a higher threat to your teammate ? ☐ 1 ☐ 2 ☐ 3 ☐ 4 _____	☐ Low ☐ High
8a.	Are you spiked? ☐ Yes ☐ No _____	☐ Low ☐ High
8b.	Is your teammate spiked? ☐ Yes ☐ No _____	☐ Low ☐ High
9a.	Is there a missile launched at you? ☐ Yes ☐ No _____	☐ Low ☐ High
9b.	Is there a missile launched at your teammate? ☐ Yes ☐ No _____	☐ Low ☐ High
10a.	Is the enemy within your weapon’s envelope?	
i.	Enemy 1: ☐ Yes ☐ No _____	☐ Low ☐ High
ii.	Enemy 2: ☐ Yes ☐ No _____	☐ Low ☐ High
iii.	Enemy 3: ☐ Yes ☐ No _____	☐ Low ☐ High
iv.	Enemy 4: ☐ Yes ☐ No _____	☐ Low ☐ High

Continue →

10b.	Is the enemy within your teammates weapon's envelope?		
i.	Enemy 1: ☐ Yes ☐ No	_____→	☐ Low ☐ High
ii.	Enemy 2: ☐ Yes ☐ No	_____→	☐ Low ☐ High
iii.	Enemy 3: ☐ Yes ☐ No	_____→	☐ Low ☐ High
iv.	Enemy 4: ☐ Yes ☐ No	_____→	☐ Low ☐ High
11.	Is your formation able to achieve FLO (with current flight parameters and throttle setting)? ☐ Yes ☐ No Why?	_____→	☐ Low ☐ High
12a.	Will you be able to take shots within the next 10 seconds? ☐ Yes ☐ No Why?	_____→	☐ Low ☐ High
12b.	Will your teammate be able to take shots within the next 10 seconds? ☐ Yes ☐ No Why?	_____→	☐ Low ☐ High
13.	Will the bandits be able to take shots within the next 30 seconds? ☐ Yes ☐ No Why?	_____→	☐ Low ☐ High

--- end ---

SAGAT Scoring

Positional / Temporal Scoring guidelines

Question	Condition	Tolerance	Score
Location / Range	Cruising, no enemy engagement	≤ 2 nm	10
		3 - 5 nm	5
		>5 nm	0
		Inaccurate heading ($>45^\circ$)	-5 from range score
	Within 30 nm with adversaries	≤ 5 nm	10
		5 - 10 nm	5
		> 10 nm	0
		Inaccurate heading ($>45^\circ$)	-5 from range score
Altitude	Cruising, no enemy engagement	≤ 1000	10
		1000 - 2000	5
		>2000	0
	Within 30 nm with adversaries	≤ 2000	10
		2000 - 4000	5
		>4000	0
Heading / Bearing	Cruising, no enemy engagement	$\leq 10^\circ$	10
		$10^\circ - 20^\circ$	5
		$> 20^\circ$	0
	Within 30 nm with adversaries	$\leq 20^\circ$	10
		$20^\circ - 40^\circ$	5
		$> 40^\circ$	0
Airspeed	Cruising, no enemy engagement	≤ 20	10
		20 - 50	5
		>50	0
	Within 30 nm with adversaries	≤ 40	10
		40 - 80	5
		>80	0
Time	Cruising, no enemy engagement	≤ 30 seconds	10
		30 – 60 seconds	5
		> 60 seconds	0

Result

Partici- pant #	Experi- ence	Hidden Figure	Number Comparison	Cube Comparison	Form Board	Auditory Number	Visual Number	Building Memory	Figure Classification	Following Direction	Math Aptitude
1	1200	-	-	-	-	-	-	-	-	-	-
2	600	9	17	3	70	10	12	8.25	39.5	8.75	3.75
3	1100	2.75	15	10	90	10	9	9.5	83	5	3.25
4	780	7.75	13	19	58	7	13	6.25	58	6.25	9.5
5	1500	9.25	19	5	56	12	10	10.75	63	1.25	3
6	1700	14.75	13	12	55	13	10	12	64.5	9	7.5
7	800	6.5	22	13	81	14	13	10.75	92	7.5	7.5
8	500	10.75	16	0	63	15	16	9.75	59.5	6.25	4
9	2600	6.5	18	17	88	16	16	2	68.5	7.5	2.75
10	390	12	15	17	84	15	13	10.75	96	7.5	6
11	1100	3.25	17	21	65	15	15	9.5	46	8.75	9
12	1200	10.75	15	11	74	6	9	3	55	7.5	7.75

Partici pant #	SAGA T level 1	SAGA T level 2	SAGA T level 3	Conf level 1	Conf level 2	Conf level 3	Over- conf Bias 1	Over- conf Bias 2	Over- conf Bias 3	Abs Conf Bias 1	Abs Conf Bias 2	Abs Conf Bias 3	Self Rating of SA	Kill enemy	Shot by enemy
1	.69	.86	.25	.69	1.00	.50	.00	.14	.25	.00	.14	.25	4.50	2.50	2.00
2	.73	.69	.38	.77	.85	1.00	.04	.16	.63	.04	.16	.63	4.33	4.00	3.00
3	.64	.89	.75	.60	.75	1.00	-.04	-.14	.25	.04	.14	.25	5.33	5.00	.00
4	.71	.83	.75	.89	.89	1.00	.19	.06	.25	.19	.06	.25	6.83	3.00	2.00
5	.63	.66	.44	.55	.82	1.00	-.08	.17	.56	.08	.17	.56	4.67	4.00	2.00
6	.86	.86	.94	.82	.79	1.00	-.04	-.07	.06	.04	.07	.06	5.50	5.00	.00
7	.79	.95	.90	.78	.89	1.00	-.01	-.06	.10	.01	.06	.10	5.29	3.00	2.00
8	.74	.66	.64	.63	.82	.89	-.11	.16	.25	.11	.16	.25	4.71	4.00	1.00
9	.60	.85	.72	.91	.90	1.00	.31	.05	.28	.31	.05	.28	4.29	4.00	2.00
10	.64	.44	.31	.72	.75	.17	.08	.31	-.15	.08	.31	.15	4.83	4.00	1.00
11	.66	.95	.83	.75	.83	1.00	.09	-.11	.17	.09	.11	.17	6.14	3.00	1.00
12	.74	1.00	.70	.86	.90	1.00	.12	-.10	.30	.12	.10	.30	6.00	4.00	2.00

Team #	Team Type	SAGAT Own	SAGAT Tmate	SA Self-rating	Over-conf Bias	Abs Conf Bias	WL Aware	SA Aware	TARGETs : info	TARGETs : acknowledgement	TARGETs : anticipatory	TARGETs : feedback	Kill enemy	Shot by enemy
1	3	.64	.68	4.08	.24	.24	.75	.75	.66	.56	.62	.57	5	4
2	2	.75	.74	6.50	.10	.10	2.75	.83	.58	.78	.58	.83	6	1
3	1	.91	.80	4.33	-.20	.20	.50	1.08	.79	.60	.69	.83	6	1
4	2	.72	.81	4.75	.01	.12	1.75	1.17	.76	.22	.60	.67	6	1
5	3	.62	.52	4.17	.24	.24	.92	1.25	.54	.20	.60	.33	6	4
6	1	.69	.83	5.17	.18	.18	.75	1.75	.70	.28	.51	.40	5	5
7	1	.78	.82	5.33	.14	.14	1.25	1.83	.64	.61	.79	.75	6	1
8	2	.69	.76	4.42	.03	.17	1.25	.58	.65	.45	.68	.57	6	2

APPENDIX E

Cognitive Test

Description of Cognitive Test

1. Hidden Figure Test

The subject is asked to decide which of five geometrical figures is embedded in a complex pattern.

2. Number Comparison Test

The subject inspects pairs of multi-digit numbers and indicates whether the two numbers in each pair are the same or different.

3. Cube Comparison Test

Each item presents two drawings of a cube. Assuming no cube can have two faces alike, the subject is to indicate which present drawings that cannot be of the same cube.

4. Form Board Test

Each item presents five shaded drawings of pieces, some or all of which can be put together to form a figure presented in outline form. The task is to indicate which of the pieces, when fitted together, would form the outline.

5. Visual Number Span Test (modified)

A conventional digit span test with digits in a series of varying length is presented on a computer screen, one number per second, for the subject to see. The subject is to remember and then reproduce the numbers in the correct order.

6. Auditory Letter Span Test

Similar to Visual Number Span Test, but letters are used instead of digits, and the digits are being read instead of shown on a screen.

7. Building Memory

The subject is asked to indicate the location of a number of buildings seen on a previously studied map.

8. Figure Classification

Each item presents two or three groups containing three geometrical figures that are alike in accordance with some rule. The second row of each item contains eight test figures. The task is to discover the rules and assign each test figure to one of the groups.

9. Following Direction

The subject is asked to determine the point in a matrix of letters that would be reached by following a complex set of directions.

10. Mathematic Aptitude Test

This consists of five-choice word problems requiring arithmetic or very simple algebraic concepts only.