ALEXITHYMIA AND SOCIO-EMOTIONAL PROCESSING: A MULTI-MODAL APPROACH

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Alexithymia and Socio-Emotional Processing: A Multi-modal Approach

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I certify that all work submitted for this thesis is my original work. I declare that no other person's work has been used without due acknowledgement. Except where it is clearly stated that I have used some of this material elsewhere, this work has not been presented by me for assessment in any other institution or University. I certify that the data collected for this project are authentic and the investigations were conducted in accordance with the ethics policies and integrity standards of Nanyang Technological University and that the research data are presented honestly and without prejudice.

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This thesis **does not** contain any materials from papers published in peer-reviewed journals or from papers accepted at conferences in which I am listed as an author.

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ACC	-	Anterior Cingulate Cortex
AQ	-	Autism Spectrum Quotient
aToM	-	Affective theory of mind: the ability to understand others' feelings and emotions
BEQ	-	Berkeley Expressivity Questionnaire
cToM	-	Cognitive theory of mind: the ability of making inference about others' mental states such as their thoughts and beliefs
DASS-21	-	Depression Anxiety Stress Scale
DDF	-	Difficulty in describing feelings (subscale of TAS-20)
DIF	-	External-oriented thinking (subscale of TAS-20)
EEG	-	Electroencephalogram
EOT	-	External-oriented thinking (subscale of TAS-20)
FDR	-	False discovery rate
fMRI	-	Functional magnetic resonance imaging
HTAS	-	High alexithymia individuals (TAS-20 ⩾ 61)
HVIC	-	Horizontal and Vertical Individualism and Collectivism Scale
LTAS	-	Low alexithymia individuals (TAS-20 < 52)
mPFC	-	Medial prefrontal cortex
MTAS	-	Medium alexithymia individuals (52 ⩽ TAS-20 < 61)
ROI	-	Region of interest
STS	-	Superior temporal sulcus
TAS-20	-	Toronto Alexithymia Scale
ToM	-	Theory of mind: The ability to infer and understand others' mental states and feelings.

Abstract

Up to one out of five individuals in the general population has alexithymia, a deficit in processing one's own and others' emotions. The mechanism of the deficit in socio-emotional processing of alexithymia is poorly understood. Existing literature has shown that the high alexithymia individuals tend to pay less attention to the eye region of the face and have impaired self-awareness. Since these two processing are important for the evaluation of whether others' emotions, as externalized by emotional faces, are relevant to oneself or not during social interaction, we hypothesize the high alexithymia individuals to have weaker evaluation of self-relevance during socio-emotional processing. More specifically, while the low alexithymia individuals process emotional faces with different gaze directions differently, the high alexithymia individuals might not differentiate emotional faces of different gaze directions in the same way. Therefore, in this thesis, one survey study and three experiments were conducted to examine whether and how alexithymia affects socio-emotional processing.

Our investigation started with a survey study which aimed to explore the epidemiology of alexithymia in Singapore, and this was piloted in the university context. We found that about 1 out of 4 Singapore university students (24%) can be categorized as "alexithymic" (TAS-20 ≥ 61). This alexithymia rate is higher than the reported rate in the literature (10% to 19%; Franz et al., 2008; Mason, Tyson, Jones, & Potts, 2005; Parker, Taylor, & Bagby, 1989; Salminen, Saarijärvi, Äärelä, Toikka, & Kauhanen, 1999). The high alexithymia rate in our sample may due to its cultural orientation or its specific demographic, e.g., being student population rather than general population. On top of that, we further illustrated that alexithymia is closely related to other traits related to socio-emotional processing, such as autistic traits, anxiety and depression. These socio-emotional deficits may

explain the previously reported interpersonal difficulties in alexithymia (Nicolò et al., 2011; Vanheule, Desmet, Meganck, & Bogaerts, 2007).

Next, we further investigate how alexithymia affects socio-emotional processing. In Experiment 1, when being asked to rate how threatened one feel when perceiving the emotional faces, we found that the eye-contact effect of the angry faces was negatively correlated with alexithymia trait, such that the higher the alexithymia trait, the smaller the difference between the threat ratings given to an angry face with direct gaze and with averted gaze (i.e. weaker eye-contact effect in higher levels of alexithymia). This suggests that alexithymia affects the evaluation of self-relevance during social threat processing.

After that, we explored one of the possible causes of the alexithymic impairment in the evaluation of self-relevance – reduced attention to the eye region. In Experiment 2, we showed that the high alexithymia individuals tended to fixate for shorter durations on the eye region of faces, and this eye avoidance was most prominent in the upright angry faces. The greater alexithymic eye avoidance tendency for angry faces indicates that the reduced attention to the eye region in alexithymia is mainly driven by aversion to potential threat that is indicated by eye contact. Furthermore, the result is coherent with our findings in Experiment 1 that alexithymia only affects the evaluation of self-relevance of angry faces. We thus raise the possibility that the alexithymic impairment in the evaluation of self-relevance is related to the reduced attention to eye information.

Lastly, we explored the neural correlates of the alexithymic influences on the evaluation of self-relevance during socio-emotional processing. In Experiment 3, we recorded the EEG signals of subjects while they were perceiving emotional faces with different gaze directions. There were two major findings related to alexithymia. 1) The frontal N1 activation difference for gaze direction was reduced in high alexithymia individuals compared to low alexithymia individuals; and 2) the alexithymic influences on the evaluation of self-relevance during social threat processing was reflected at the frontal N2 component. That is, the frontal N2 activation of the low alexithymia individuals differentiated angry faces with different gaze directions, but the same neural differentiation was absent in the high alexithymia individuals.

Summarizing our findings, we conclude that alexithymia is related to the impairment in the evaluation of self-relevance during social threat processing. This impairment is likely to be related to the reduced attention to eye information in high alexithymia individuals. At the neural level, our findings support that alexithymia is associated with deficit at the subcortico-frontal pathway. The findings are discussed with reference to existing models of socio-emotional processing, and a new model (adapted from existing models) is proposed to incorporate our novel findings on alexithymic influences in socio-emotional processing.

Chapter 1

Introduction and Literature Review

“I (a patient with alexithymia) walk from my room to the day room. A patient is arguing with a nurse about something, and the conflict makes me tense up even more.” (Monroe, 2015, p. 24)

One of the major governing directions of Singapore is to build a caring and cohesive society (Ministry of Finance, 2019; Tan, 2019). A caring and cohesive society relies on a high level of communication and active understanding of others’ feeling at a population level. However, up to one-fifth of the population is shown to have the tendency for alexithymia (Franz et al., 2008; Fukunishi, Berger, Wogan, & Kuboki, 1999; Mason et al., 2005; Salminen et al., 1999), a condition which is associated with deficits in processing emotion of oneself and of others (Grynberg et al., 2012; Lane, Ahern, Schwartz, & Kaszniak, 1997; Larsen, Brand, Bermond, & Hijman, 2003). The prevalence rate could be even higher in countries with Asian culture (Dere, Falk, & Ryder, 2012; Dion, 1996; Lo, 2014). This is a significant amount of population that has received little attention in the field but may potentially hinder the social development of Singapore if ignored.

Typical socio-emotional-related symptoms of alexithymia include the tendency to feel sensitive, anxious and stressful when confronting a social event (Nicolò et al., 2011; Pollatos et al., 2011). These atypical feelings toward social events in turn lead to the atypical social behavior exhibited by the high alexithymia individuals, such as cold and avoidant social strategies (Vanheule et al., 2007), and less collaborative tendency and lack of sociability (Nicolò et al., 2011). Other than the social events that they are directly involved in, they might also have difficulty in processing social events that are not relevant to them. For example, in the opening of this chapter is a quote taken from the diary of the an alexithymic patient (Monroe, 2015); she recorded her intensified feeling of stress when she came across a conflict between another patient and a nurse. The possibility that their feelings are influenced by the self-irrelevant social events indicates that they might be challenged in judging the degree of self-relevance of a social event, and this may be a core deficit in alexithymia.

This thesis thus centers on self-relevance processing in alexithymia to further our understanding on the underlying mechanisms that lead to the atypical socio-emotional processing in alexithymia. Through one survey study and three experiments, we will explore 1) what is the prevalence rate of alexithymia in Singapore and what social and emotional constructs are closely related to alexithymia (Survey Study); 2) how alexithymia may (or may not) modulate attention to and the perception of eye gaze direction, a key indicator of locus of attention and intention, and how that affects self-relevance processing (Experiment 1 & 2); and 3) the neural correlates (event-related potential (ERP) components) related to the atypical self-relevance processing in alexithymia to probe the possible underlying neural substrates that are implicated in alexithymia (Experiment 3).

The significance of this thesis is three-fold. Firstly, this thesis raises the importance of investigating the condition of alexithymia in the Singaporean population, especially Singapore university students. Since alexithymia is commonly associated with more difficulties in interpersonal relationships (Nicolò et al., 2011; Vanheule et al., 2007), the potentially higher prevalence rate of alexithymia in among Singapore university students may be a significant barrier in Singapore’s quest to build a caring and cohesive society (Dere et al., 2012; Dion, 1996; Lo, 2014; Ministry of Finance, 2019; Tan, 2019). Next, it allows us to understand the importance of gaze information and the evaluation of self-relevance during social processing. Although there is an increasing interest in studying gaze perception during social processing in the literature, the current understanding of the topic still falls short of explaining how gaze information is used and integrated during socio-emotional processing (for some recent models and theories, see Conty, George, & Hietanen, 2016; Hietanen, 2018; Hoehl et al., 2009). Our understanding of gaze information processing and the evaluation of self-relevance can be applied to the human-computer interaction, such as for artificial intelligence to use gaze information to facilitate more realistic and effective communication with human. Lastly, this thesis can extend our knowledge about socio-emotional processing in alexithymia. Alexithymia is not only a significant subgroup in the general population, it may also be the underlying cause of the emotional symptoms of multiple clinical conditions, such as autism and schizophrenia (e.g. Aaron, Benson, & Park, 2015; Bird & Cook, 2013). Therefore, efforts to further understand the alexithymic deficits in socio-emotional processing may provide important insights for the formation of intervention strategies that address the emotional symptoms of those clinical conditions.

We will now start with a comprehensive literature review of the studies pertaining to broad socio-emotional processing, alexithymia, and the links between the two. The primary aim of the literature review is to critically review both the well-understood (i.e. findings from past studies) and possible (i.e. implications from past findings) alexithymic deficits in social processing, so as to allow for the identification of gaps in the literature and demonstrate how this thesis serves to address those gaps. The literature review is structured as follows:

1) The nature and symptoms of alexithymia;
2) The schematic frameworks of socio-emotional processing (and we will particularly highlight the processing of emotional faces because it has a significant role in social interaction); and

3) The alexithymic deficits in socio-emotional processing under the reviewed schematic framework.

At the end of the literature review, there will be a summary to consolidate the vast amount of studies and findings discussed, followed by a description of the outstanding issues that will be addressed in this thesis.

1.1. What is alexithymia?

The ability in processing emotion varies across individuals, and those who have difficulty in doing so might be considered as alexithymia. In their original paper, Sifneos (1973) reported many patients with psychosomatic disorder could not verbally express their feelings in an appropriate way. This finding has led the field to recognize and study the condition – alexithymia. Alexithymia literally translates to “no words for feelings” in Greek. Highly alexithymic individuals is characterized by the inability to describe and identify feelings (Sifneos, 1973; Taylor, Bagby, & Parker, 1991). It has also been metaphorically described as “blindsight to emotion” (Lane et al., 1997). Alexithymia is commonly measured by the self-report scale “Toronto Alexithymia Scale” (TAS-20; Bagby, Taylor, & Parker, 1994) which consists of 20 items to measure ones’ 1) difficulty in identifying feelings (DIF; e.g., “I am often confused about what emotion I am feeling.”); 2) difficulty in describing feelings (DDF; e.g., “It is difficult for me to find the right words for my feelings.”); and 3) external-oriented thinking tendency (EOT; e.g., “Being in touch with emotions is essential.” (negatively coded). The reliability of TAS-20 has been replicated in multiple regions of the world and the questionnaire has been translated into different languages (Taylor, Bagby, & Parker, 2003). The recommended cut-off score for “non-alexithymic” is 51 and below, whereas for “alexithymic” is 61 and above (Bagby & Taylor, 1997). Despite its worldwide applicability, cultural differences have been found in alexithymia, such that Asians tend to score higher in TAS-20, especially in its subscale EOT, than non-Asians (Dere et al., 2012; Dion, 1996; Lo, 2014). The cultural differences was shown to be mediated by the endorsement of modernized values and beliefs (Dere et al., 2012), and the adoption of eastern and western values (Dere et al., 2012; Lo, 2014).

Other than TAS-20, Bermond-Vorst alexithymia questionnaire (BVAQ) is another commonly used measure for alexithymia (Vorst & Bermond, 2001). In comparison to TAS-20, BVAQ measured additional two constructs, namely fantasizing and emotionalizing. In comparison between the two measures, it has been suggested that while TAS-20 captured the cognitive aspect of alexithymia, BVAQ covers both the cognitive and the emotional aspects (Larsen et al., 2003; Wingbermühle, Theunissen, Verhoeven, Kessels, & Egger, 2012). However, a number of studies has also raised the issue related the reliability of the BVAQ items (Berthoz & Hill, 2005; Hornsveld & Kraaimaat, 2012; Müller, Bühner, & Ellgring, 2004).

Over the years, there are multiple cognitive and neural models that attempted to explain alexithymia (Donges & Suslow, 2017; Lane et al., 1997; Larsen et al., 2003; Lesser, 1981; Nemiah, 1977; Van der Velde et al., 2013; Wingbermühle et al., 2012). Early proposals suggested that the symptoms of alexithymia may be caused by the disconnection between the left and right hemisphere (Hoppe & Bogen, 1977; Tabibnia & Zaidel, 2005), or between the subcortical structures and the cortical structures (MacLean, 1949; Nemiah, 1977). These early proposals were built based on the assumption that the high alexithymia individuals have an intact experience of emotion but just impair with the ability to verbalize it.

Nonetheless, there is an emerging body of evidence suggests that alexithymia is also associated with atypical autonomic responses toward pain/stress and threatening scenes (Kleiman et al., 2016; Luminet, Rimé, Bagby, & Taylor, 2004; Nyklíček & Vingerhoets, 2000; Pollatos, Schubö, Herbert, Matthias, & Schandry, 2008). These studies have urged the field to re-examine our understanding of alexithymia. In fact, more recent accounts proposed that alexithymia might be related to the deficit in conscious experience of emotional and bodily feelings (Brewer, Cook, & Bird, 2016; Lane et al., 1997; Shah, Hall, Catmur, & Bird, 2016). This proposal is supported by a series of findings demonstrating an inconsistency between the self-report of emotional/bodily experience and the objectively measured physiological responses in alexithymia (Eastabrook, Lanteigne, & Hollenstein, 2013; Herbert, Herbert, & Pollatos, 2011; Pollatos et al., 2011; Shah et al., 2016). Another recent proposal concerns the deviated automatic emotion processing in alexithymia (Donges & Suslow, 2017). The evidence for this model comes from the emotion perception literature. By summarizing the evidences, Donges and Suslow (2017) illustrated that the high alexithymia individuals have more difficulty in rapid and automatic processing of negative emotional stimulus. Neurally, these recent proposals of alexithymia highlighted the alexithymic deficits in the frontal regions, such as insula and anterior cingulate cortex (ACC) (Bird et al., 2010; Lane et al., 1997; Van der Velde et al., 2013; Wingbermühle et al., 2012), the subcortical regions, such as the amygdala (Donges & Suslow, 2017; Reker et al., 2010), and the connectivity between and within these two regions (Mériau et al., 2006; Van der Velde et al., 2013).

Alexithymia is a common comorbidity of autism (Bird & Cook, 2013; Poquérusse, Pastore, Dellantonio, & Esposito, 2018). In the general population, the prevalence rate of alexithymia is 7% to 18% (Franz et al., 2008; Fukunishi et al., 1999; Mason et al., 2005; Salminen et al., 1999), but 48.1% of individuals who are clinically diagnosed with autism fall into the category of severe alexithymia (i.e., TAS-20 ≥ 61; Hill, Berthoz, & Frith, 2004). Furthermore, alexithymia trait is also highly correlated (r ~ .50) with autistic traits in the sub-clinical population (Aaron et al., 2015; Foulkes, Bird, Gökçen, McCrory, & Viding, 2015).

Noticing the close relationship between autism and alexithymia, there is a recent proposal which argues that the socio-emotional deficits in autism or related to autistic traits are caused by their high alexithymia trait (Bird & Cook, 2013). In their eye-tracking study, Bird, Press and Richardson (2011) suggested that attention, indexed by longer fixation duration, to the eye region during face perception was predicted by alexithymia trait but not autism symptom severity. Cook, Brewer, Shah and Bird (2013) also reported that alexithymia explains the insensitivity in emotional face categorization in autism. Other socio-emotional deficits that were traditionally associated with autism or autistic traits, such perception of social reward (Foulkes et al., 2015), production of facial expression (Costa, Steffgen, & Samson, 2017; Trevisan, Bowering, & Birmingham, 2016), perception of emotion vocalization (Heaton et al., 2012) and moral judgement (Brewer et al., 2015b; Patil, Melsbach, Hennig-Fast, & Silani, 2016), were also found to be better explained by alexithymia. Not all autistic deficits, however, can be explained by alexithymia. It has recently been argued that alexithymia does not contribute to the autistic disruption in theory of mind (Bernhardt et al., 2014; Milosavljevic et al., 2016). It seems that the more the emotion processing is involved in a process, the more likely alexithymia will influence the process. In terms of neural correlates, it was shown that alexithymia trait, but not autism symptom severity, predicted insula activation when perceiving others' suffering (Bird et al., 2010). The connectivity between the left insula and left anterior temporo-parietal junction was better explained by alexithymia than autism (Bernhardt et al., 2014).

Yet, how alexithymia affects socio-emotional processing has not been systematically reviewed. To set a framework for the topic, we first reviewed the relevant models that schematically described the components of socio-emotional processing.

1.2. A critical review of relevant models of socio-emotional processing

In the early literature, Bradbury and Fincham (1987) proposed a comprehensive and integrative model which describes the cognitive processes involved in social interaction and the factors that influence these processes. There are four main consecutive components in the model: partner input, primary processing, secondary processing, and behavioral output. Partner input includes the external behaviors one can observe from the social interaction. These behaviors are then processed and evaluated in the primary processing. According to Bradbury and Fincham (1987), behaviors that carry negative value are more alarming and thus reach the subsequent cognitive processing more easily.

There are multiple subcomponents in the primary processing, including valence, level of expectedness, and self-significance. The results of these primary evaluations give rise to the emotional state of the perceiver. The emotional state ranges from very positive to very negative. When the elicited emotional state approaches neutral, no further processing will be engaged, and behaviors will be formed. However, when the primary processing evaluated the observed behaviors as negative, unexpected and self-significant, secondary processing will be initiated. The core idea of secondary processing is to identify the cause of the observed behaviors. The attributed cause of others' behaviors will determine one's internal responses and external behaviors. Behavioral output refers to one's responses to others' behaviors and can be divided into external output (i.e., behavioral expressions) and internal output (i.e., physiological responses). The external output will then trigger the same cognitive processing in others.

Although Bradbury and Fincham (1987) did not provide further description on how the primary processing and secondary processing work individually and interactively, it has been further elaborated in the appraisal theory of emotion (Lazarus, 1991; Moors, Ellsworth, Scherer, & Frijda, 2013; Scherer, 2001), which extended the model to include emotion-inducing stimulus other than social interaction. In the appraisal theory, the primary processing and the secondary processing are termed as “primary appraisal” and “secondary appraisal” (Lazarus, 1991). While the set of appraisals in the appraisal theory of emotion is not exactly the same as the evaluations of Bradbury and Fincham’s (1987) model, there are overlapping components in the two models. For example, the motivational relevance appraisal, which is defined as *“the extent to which there are issues in the encounter about which the person cares or in which he or she has a stake”* (Lazarus, 1991), in the appraisal theory overlaps with the self-significance evaluation in Bradbury and Fincham’s (1987) model. Scherer (2001) metaphorized the appraisal processing as a sequence of checklist: checking each of the appraisals will give rise to the corresponding physiological and behavioral responses. The appraisals are also interacting with each other. The motivational relevance appraisal, for instance, is the first evaluation of the perceived stimuli, and the result of the appraisal will affect the subsequent evaluations such as the implication appraisal and the coping potential appraisal (Moors & Scherer, 2013; Scherer, 2001). One challenge to the appraisal theory however is that the model often lacks neural support, though recently the proponents attempted to provide neural evidence for the model (Cristinzio, N’Diaye, Seeck, Vuilleumier, & Sander, 2010; N’Diaye, Sander, & Vuilleumier, 2009; van Peer, Grandjean, & Scherer, 2014). For example, N’Diaye and colleagues (2009) found that the amygdala activates stronger for angry faces with direct gaze (i.e., self-significant/motivationally relevant social threat) than those with averted gaze (i.e., self-insignificant/motivationally irrelevant social threat), whereas the same neural region activates stronger for fearful faces with averted gaze than those with direct gaze. The authors interpreted the results as the support for the amygdala being part of the neural network for self-relevance appraisal (Sander, Grafman, & Zalla, 2003)

More recent socio-emotional models have been built upon data from neural imaging experiment and clinical studies (Baron-Cohen, 1997; Johnson et al., 2015; Langton, Watt, & Bruce, 2000). One of the most commonly cited models that describes how social interaction is understood and interpreted is Baron-Cohen's (1997) "mindreading" system model. In his model, understanding other's mental state depends on one's evaluation of other's intention and focus of attention. The two evaluations are supervised by two independent cognitive modules, intention detector and eye direction detector, respectively. The results of the two evaluations will then be the inputs to theory of mind mechanism (ToM), the module that is responsible for understanding other's mental state. The "mindreading" system model predicts that the malfunction of any of these modules will lead to socio-emotional deficits observed in clinical conditions. For example, in Baron-Cohen's (1997) point of view, the autistic deficit in understanding social interaction roots from their impairment in shared attention mechanism, a signal relay station between eye direction detector and theory of mind mechanism. Subsequent related models further modified or expanded Baron-Cohen's (1997) work. For instance, Perrett et al. (1994) and Langton et al. (2000) argued that eyes are not the only source of information for the focus of attention evaluation. Other body parts, such as head and body, are also important cues for one's attention focus. ToM has been revised and divided into two sub-modules, cognitive theory of mind (cToM) and affective theory of mind (aToM) (Kalbe et al., 2010; Shamay-Tsoory & Aharon-Peretz, 2007).

An updated socio-emotional model provides concrete neural candidates for each stage of social processing. In their directed attention model of social processing, Hoehl and colleagues (2009) proposed that there are four stages of social processing: 1) detection of face and gaze direction; 2) encoding of facial information; 3) the evaluation of self-relevance of social cues; and 4) attention allocation and intention encoding. Specific neural structures were assigned to each of the stages. For instance, the amygdala and the superior temporal sulcus (STS) involves in Stage 1 and are responsible for detecting biologically significant information and processing gaze information respectively; the fusiform gyrus involves in the Stage 2 on facial information encoding; the medial prefrontal cortex (mPFC) involves in the Stage 3 on the evaluation of self-relevance; and the intraparietal sulcus (IPS) and the STS are responsible for attention allocation and intention encoding respectively in Stage 4. One advantage of Hoehl and colleagues' (2009) model over other models that describe the integration of facial emotion and gaze information during socio-emotional processing (Johnson et al., 2015; Senju & Johnson, 2009) is that it provides a clear temporal information about the sequence of the processing. Other models, in contrast, tend to focus on the topography of the social cue interaction (i.e., where in the brain does the interaction take place? Johnson et al., 2015; Senju & Johnson, 2009). Since our thesis focuses on the effect of alexithymia on each stage of the socio-emotional processing, we will base our discussion on Hoehl and colleagues' (2009) model. In the subsequent section, we are going to briefly review the behavioral measures and the neural correlates of each stage in the direct attention model.

1.2.1. Stage 1: Detection of face and gaze direction

According to Hoehl and colleagues (2009), the first stage of social processing is to detect the social information that is important for social interaction. The social information includes, but not limited to, face, emotion, and gaze direction. Although the early detection of face is an interesting topic (see Awh et al., 2004; Langton, Law, Burton, & Schweinberger, 2008), we would like to focus on the detection of facial emotion and gaze direction in this thesis.

Typical behavioral measures for early emotional face detection are affective priming (Hermans, Spruyt, De Houwer, & Eelen, 2003; Rotteveel, de Groot, Geutskens, & Phaf, 2001; Sweeny, Grabowecky, Suzuki, & Paller, 2009) and emotional attentional blink paradigm (Maratos, Mogg, & Bradley, 2008; Miyazawa & Iwasaki, 2010; Stein, Zwickel, Ritter, Kitzmantel, & Schneider, 2009). Both paradigms involve rapid presentation of emotional faces or neutral faces, and tests the subjects' affective evaluation of a neutral target after being influenced by the face prime (affective priming) or the ability of the subjects in detecting the target face right after being distracted by a face or non-face distractor (emotional attentional blink). Typical findings are that the evaluation of the neutral target is biased toward the valence of the emotional prime (e.g., Rotteveel et al., 2001; Sweeny et al., 2009) and that the emotional faces are more likely to be detected after the distractor (e.g., Maratos et al., 2008; Miyazawa & Iwasaki, 2010). It is noteworthy that in some affective priming studies, the priming effect is apparent even when the prime is not consciously perceived by the subjects because the presentation duration of the prime is extremely short (<100ms) and it is covered by a backward masking (Murphy & Zajonc, 1993; Sweeny et al., 2009). These findings are commonly used as the evidence for rapid and automatic processing of emotional faces (Diano, Celeghin, Bagnis, & Tamietto, 2017; Tamietto & De Gelder, 2010).

Beside facial emotion, gaze direction is also an important social cue that needs to be extracted at the early stage of social processing. One of the important functions of gaze direction in social interaction is to indicate one's focus of attention (Emery, 2000; Langton et al., 2000). By analyzing others' focus of attention, we are able to infer whether oneself is involved in the social events, and predict the upcoming social reward (Hietanen, 2018; Wirth, Sacco, Hugenberg, & Williams, 2010) or social threat (Emery, 2000; Skuse, 2004). Due to the importance of the eyes in social interaction, the brain is "hard-wired" to detect the appearance of eyes and identify the direction of the gaze (Grossmann, 2017; Johnson et al., 2015; Senju & Johnson, 2009). People pay more attention to faces with direct gaze than averted gaze (Böckler, van der Wel, & Welsh, 2014; Doi, Ueda, & Shinohara, 2009; Shirama, 2012; von Grünau & Anston, 1995). The attention bias toward direct gaze can occur even when the perception of the eyes is out of awareness (Chen & Yeh, 2012; Rothkirch, Madipakkam, Rehn, & Sterzer, 2015; Yokoyama, Noguchi, & Kita, 2013), suggesting that the processing of direct gaze is automatic. One study even showed that faces with direct gaze are easier to overcome binocular suppression than those with averted gaze (Stein, Senju, Peelen, & Sterzer, 2011). The attentional bias towards direct gaze has been termed as the "eye contact effect" (Senju & Johnson, 2009).

The automatic processing of emotional face and gaze direction has been associated with the processing at the subcortical pathway (Diano et al., 2017; Johnson et al., 2015; Senju & Johnson, 2009; Tamietto & De Gelder, 2010). The amygdala, one of the most important subcortical structures for automatic emotion processing, activates towards emotional faces even when these faces are masked and not consciously perceived by the subjects (Morris, Öhman, & Dolan, 1998; Nomura et al., 2004; Whalen et al., 1998; Williams, Morris, McGlone, Abbott, & Mattingley, 2004). Furthermore, the connectivity between the amygdala and frontal areas is stronger in masked emotional faces than in masked neutral faces (Monk et al., 2006; Nomura et al., 2004). In comparison, the involvement of the amygdala in gaze processing is still debatable. Kato and colleagues (1999) showed that the amygdala is activated stronger towards faces with direct gaze than those with averted gaze. The connectivity between the amygdala and the fusiform gyrus is stronger for direct gaze than averted gaze (George, Driver, & Dolan, 2001). Furthermore, the amygdala activation for direct gaze remains apparent for the subjects who have cortical blindness and thus no conscious awareness of the direct gaze presented (Burra et al., 2013). However, other studies also reported negative or contradictory findings on the subcortical activation for direct gaze

(Calder et al., 2002; Pageler et al., 2003; Straube, Langohr, Schmidt, Mentzel, & Miltner, 2010; Wicker, Michel, Henaff, & Decety, 1998).

One possible explanation for the inconsistency in the gaze direction literature may be that face emotion and gaze direction are interacting with each other even at the very first stage of the social processing. Multiple studies have demonstrated that the amygdala is more responsive to threatening faces with direct gaze than those with averted gaze and neutral faces regardless of gaze directions (N'Diaye et al., 2009; Sato, Kochiyama, Uono, & Yoshikawa, 2010; Sato, Yoshikawa, Kochiyama, & Matsumura, 2004b; Ziaei et al., 2016; but see Adams, Gordon, Baird, Ambady, & Kleck, 2003; Sauer, Mothes-Lasch, Miltner, & Straube, 2014). Furthermore, while keeping their perceptual ability in differentiating gaze direction, the patients with their amygdala removed were also found not to make emotional rating differentiation between threatening faces with different gaze direction as the control patients (Cristinzio et al., 2010). This agrees with the role of the amygdala in promoting attention and vigilance to the biologically significant stimulus, and at the same time modulate physiological responses accordingly in preparation for the subsequent adaptive behavior (Davis & Whalen, 2001; Janak & Tye, 2015; Pessoa & Adolphs, 2010; Schmitz & Johnson, 2007; Tamietto & De Gelder, 2010). Nonetheless, the face stimuli were presented optimally in all the studies reported. Since amygdala may receive feedback signals from other neural regions at the later stage of the processing (Pessoa & Adolphs, 2010; Stein et al., 2007) and fMRI has a low temporal resolution, whether the reported interaction between facial expression and gaze direction at the amygdala is automatic remain an open question. It is also noteworthy that the amygdala is only responsible for the filter of information, and its preliminary decision on the evaluation of self-relevance based on one's prior experience can possibly be mediated by the decision at the higher-level processing (i.e., Stage 3).

In sum, the processing of facial expression and gaze direction independently is automatic and rapid. There is also evidence showing that the two pieces of information are processed and may interact in the subcortical structures. However, it is unclear whether the facial expression-gaze direction interaction at the subcortical pathway is automatic and rapid or not. Studies that aim to address this question might need to implement subliminal perception task (e.g., via binocular rivalry) on emotional faces with different gaze directions and measure the neural signals from the subcortical regions.

1.2.2. Stage 2: Encoding of facial information

Multiple information is available in faces, such as social attributes and emotion (Todorov, 2012). Social attributes include race (Ito & Urland, 2003; Michel, Corneille, Rossion, Stefanucci, & Proffitt, 2009), gender (Barrett & O'Toole, 2009; Cloutier, Mason, & Macrae, 2005; Ito & Urland, 2003), identity (Grill-Spector & Kanwisher, 2005; Leopold, Rhodes, Muller, & Jeffery, 2005; Rhodes, Jeffery, Clifford, & Leopold, 2007), attractiveness (Olson & Marshuetz, 2005; Rhodes, Jeffery, Watson, Clifford, & Nakayama, 2003), and trustworthiness (Oosterhof & Todorov, 2009; Todorov & Duchaine, 2008; Todorov, Pakrashi, & Oosterhof, 2009). In this review, however, we focus on the encoding of facial emotion.

Emotional face perception is one of the most heavily investigated topics in the field. It follows a hierarchy of processes (Duchaine & Yovel, 2015; Haxby, Hoffman, & Gobbini, 2000), and the higher-level emotional processing is influenced by the local featural processing (e.g., mouth curvature; Xu, Dayan, Lipkin, & Qian, 2008). In their study, for example, Xu, Dayan, Lipkin, and Qian (2008; also see Xu, Liu, Dayan, & Qian, 2012) showed that adapting to a concave curve can adapt the subsequently presented emotional face so that it is judged as happier compared to without any adaptation. In another study, by comparing brief adaptation and prolonged adaptation of emotional face, we showed that high-order emotional evaluation such as emotional valence is only related to late processing (100ms – 1000ms) of emotional faces but not related to early processing (17ms - 50ms) (Sou & Xu, 2019). Early processing of emotional faces may be restricted to the perception of low-level features, such as curvature.

The recognition of emotional face relies on holistic and configural processing. When asked to focus on either the upper or the lower part of the facial expression, incongruent emotional information between the two facial parts impedes the accuracy of emotional categorization (composite effect; Calder & Jansen, 2005; Calder, Keane, Young, & Dean, 2000; Tanaka, Kaiser, Butler, & Le Grand, 2012). Another way to disrupt holistic processing is by inverting the faces (Rossion, 2008; Tanaka & Simonyi, 2016). Face inversion can reduce the accuracy and reaction time for facial expression recognition (Bombari et al., 2013; Calvo & Nummenmaa, 2008; McKelvie, 1995; Prkachin, 2003), slow down the reaction time required to spot the emotional faces in a visual search task (Eastwood, Smilek, & Merikle, 2003; Williams, Moss, Bradshaw, & Mattingley, 2005), and attenuate the composite effect during emotional face recognition (Calder & Jansen, 2005). The holistic effect is more prominent in negative emotions, such as anger and sadness, than in positive emotion, such happiness (Calvo & Nummenmaa, 2008; McKelvie, 1995).

However, it does not mean that featural processing is unnecessary in emotional face perception. It is because facial emotion recognition is shown to be possible even when the available facial features are limited (Calder et al., 2000; Calvo, Fernández-Martín, & Nummenmaa, 2014a; Calvo & Nummenmaa, 2008). Among all facial regions, the information from the eye regions is the most important for successful negative emotional face perception, while the mouth region is necessary for happy face perception (Calder et al., 2000; Calvo et al., 2014a; Calvo & Nummenmaa, 2008; Xu et al., 2008). These are also the facial regions that attract the most attention during emotional face perception: more and longer fixations are placed at the eye regions when the perceived emotional faces are of negative or neutral valence, whereas happy faces attract more and longer fixations at the mouth regions (Eisenbarth & Alpers, 2011; Wagner, Hirsch, Vogel-Farley, Redcay, & Nelson, 2013).

Neurally, the encoding of facial expression has been associated with the STS and the FFA (Duchaine & Yovel, 2015; Haxby et al., 2000). The two temporal areas might serve different functions during emotional face perception. The FFA has been proposed to be responsible for holistic face processing (Yovel, 2016). This proposal is supported by the face inversion effect and the composite face effect in the FFA (Axelrod & Yovel, 2010; Schiltz & Rossion, 2006). Furthermore, the FFA was also found to be less activated when facial features were missing or scrambled (Liu, Harris, & Kanwisher, 2010). Supporting its role in the non-automatic processing of facial expression, the activation of the FFA attenuates when the visual awareness of the face stimulus was suppressed (Tong, Nakayama, Vaughan, & Kanwisher, 1998). The STS, on the other hand, is specialized in processing facial expression (Said, Haxby, & Todorov, 2011). It has been consistently reported that the STS activates toward emotional faces (Engell & Haxby, 2007; LaBar, Crupain, Voyvodic, & McCarthy, 2003; Sato, Kochiyama, Yoshikawa, Naito, & Matsumura, 2004a). On top of that, the STS was also found to have distinctive neural representation for different facial expressions and within emotion the representation in encoded in a graded manner (at least for the left STS) (Said, Moore, Engell, Todorov, & Haxby, 2010; Said, Moore, Norman, Haxby, & Todorov, 2010). Electrophysiologically, the signals from the FFA and the STS are represented as the N170 component in the event-related potentials (ERP) (Pegna, Landis, & Khateb, 2008; Rossion & Jacques, 2012). Previous ERP studies have shown that the activation of the N170 is modulated by the emotion of the faces, such that emotional faces elicit stronger N170 amplitudes than neutral faces (Beltrán & Calvo, 2015; Blechert, Sheppes, Tella, Williams, & Gross, 2012; Calvo & Beltrán, 2014; Jiang et al., 2014; Morel, Ponz, Mercier, Vuilleumier, & George, 2009; Rellecke, Sommer, & Schacht, 2012). Aligning with the holistic processing at the temporal areas, the N170 was found to be responding to the whole face rather than the features of the face (Beltrán & Calvo, 2015; Calvo & Beltrán, 2014). This activation for the emotion appears to be automatic for fearful face perception but other emotional faces remain untested (Pegna, Darque, Berrut, & Khateb, 2011; Pegna et al., 2008; Rellecke et al., 2012). Similar emotional modulation can also be observed in the P200 amplitude (Beltrán & Calvo, 2015; Calvo & Beltrán, 2014; Eimer, Kiss, & Holmes, 2008; Jiang et al., 2014; Rellecke et al., 2012). In contrast to the N170, however, the P200 activates stronger for neutral faces than the emotional faces. Also, the activation of P200 for emotional faces only occur when the emotional faces are consciously seen (Eimer et al., 2008). Some studies suggested that the P200 is related to the processing of spatial relationships among features (Latinus & Taylor, 2006; Mercure, Dick, & Johnson, 2008).

Additionally, the perceptual processing of gaze direction also happens at this stage. Although in their original proposal, Hoehl and colleagues (2009) suggested that gaze direction is encoded at the cortical areas at Stage 1, findings from the fMRI and EEG literature may not agree. Gaze direction differentiation is commonly observed in the activation of the STS (Calder et al., 2007, 2002; Carlin, Calder, Kriegeskorte, Nili, & Rowe, 2011; Ethofer, Gschwind, & Vuilleumier, 2011; George et al., 2001). Furthermore, temporally, averted gaze tends to elicit stronger N170 activation than direct gaze (Itier, Alain, Kovacevic, & McIntosh, 2007; McCrackin & Itier, 2018; Pönkänen, Alhoniemi, Leppänen, & Hietanen, 2011; Puce, Smith, & Allison, 2000; Rossi, Parada, Latinus, & Puce, 2015; Watanabe, Miki, & Kakigi, 2002). All evidence suggests that the perceptual processing of gaze direction is spatially and temporally overlapping with the perceptual encoding of facial expression, because emotional faces were also encoded at the STS (Engell & Haxby, 2007; LaBar et al., 2003; Sato et al., 2004a) and at the N170 (Beltrán & Calvo, 2015; Blechert et al., 2012; Calvo & Beltrán, 2014; Jiang et al., 2014; Morel et al., 2009; Rellecke et al., 2012). This will argue that the encoding of gaze direction is at Stage 2 rather than at Stage 1. The temporal correction also agrees with the hierarchical neural model for face processing proposed by Haxby and colleagues (2000).

1.2.3. Stage 3: The evaluation of self-relevance of social cues

According to Hoehl and colleagues (2009), from this stage onwards, facial expression and gaze direction should be processed concurrently to identify socially important information. The processing of this stage is well-captured by the modulation from the facial emotion on the eye-contact effects in emotional ratings (see Hietanen, 2018). More specifically, the eye-contact effect can be enhanced or reversed by the emotion displayed on the faces, and this emotional modulation depends on the motivational orientation of the emotion (i.e., happiness and anger as approach-oriented emotions, and fear and sad as avoidance-oriented emotions; Adams & Kleck, 2003; Carver & Harmon-Jones, 2009; Rolls, 2006). Happy or angry faces with direct gaze, for instance, are rated as more emotionally intense than those with averted gaze, but fearful face with averted gaze were rated more intense (Marschner, Pannasch, Schulz, & Graupner, 2015; N'Diaye et al., 2009; Sander, Grandjean, Kaiser, Wehrle, & Scherer, 2007; Sauer et al., 2014). The emotion modulation on the eye-contact effect also depends on the intrinsic meaning of the facial expression. Happy faces with direct gaze, for example, are rated as more positive and likeable than those with averted gaze, but the ratings to angry faces show the opposite pattern (Bayliss, Frischen, Fenske, & Tipper, 2007; Marschner et al., 2015; Sauer et al., 2014). These emotion-specific eye-contact effect suggests that the social information is processed based on its self-relevance

(N'Diaye et al., 2009; Sander et al., 2007), i.e. happy face with direct gaze is self-relevant social reward, and angry face with direct gaze is self-relevance social threat, whereas happy faces and angry face with averted gaze are self-irrelevant social information.

The interaction between the eye-contact effect and facial emotion is reflected in the frontal neural activation as well (for the subcortical detection of emotional faces with different gaze directions, see *Stage 1: Detection of face and gaze direction*). As predicted by Hoehl and colleagues (2009), Ewbank, Fox and Calder (2010; reported in the supplementary material) found that the mPFC activates stronger for angry faces with direct gaze than those with averted gaze, and the difference is not apparent in neutral faces or fearful faces. Multiple other frontal regions, such as the insula and the ACC, were also found to be recruited when processing emotional faces with different gaze direction (Ewbank et al., 2010; Ziaei et al., 2016; Ziaei, Ebner, & Burianová, 2017). ERP studies further provided the temporal trajectory for the interaction between facial expression and eye gaze. Klucharev and Sams (2004) found that the two pieces of social information were encoded separately at the early stage of processing (i.e., before 200ms post-stimulus onset) and only interacted at a later stage (i.e., after 300ms post-stimulus onset). Similar findings were reported subsequently, but the time window for the interaction to occur was suggested to be earlier - at the 200 – 400ms or the N2 time window (Conty, Dezecache, Hugueville, & Grezes, 2012; Li et al., 2017; Nomi, Frances, Nguyen, Bastidas, & Troup, 2013). In the neural literature, emotion-modulated eye-contact effects were mostly reported for threat-related facial emotion, e.g., anger and fear. This tendency agrees with Hoehl and colleagues' (2009) description that Stage 3 is mainly for indicating social threat.

Closer observation to the neural correlates that were reported to exhibit emotion-modulated eye-contact effect, i.e., the mPFC, the ACC, the insula, and the amygdala, reveals that they hugely overlap with the neural network that has been proposed for self-referential processing (Conway, Pothos, & Turk, 2016; Hu et al., 2016; Northoff et al., 2006; Sander et al., 2003; Schmitz & Johnson, 2007). In fact, in their latest account for eye-contact effect, Conty and colleagues (2016) proposed that the observed eye-contact effect is due to the activation of self-relevance processing by direct gaze. The evaluation of self-relevance of social cue therefore may follow the neural mechanism of self-referential processing (Hu et al., 2016; Northoff et al., 2006; Schmitz & Johnson, 2007): 1) subcortical structures, such as amygdala, automatically detect potential biologically- and self-relevant social information and orient physiological responses in preparation for rapid reaction (Diano et al., 2017; Sander et al., 2003; Schmitz & Johnson, 2007); 2) the mPFC then valuate the self-relevance of the information (D'Argembeau, 2013; Hu et al., 2016); and 3) base on the decision of mPFC, the ACC and the insula generate conscious sense of feelings and motivation (Craig, 2009; Gu, Hof, Friston, & Fan, 2013; Schmitz & Johnson, 2007).

1.2.4. Stage 4: Attention allocation and intention encoding

In the last stage of Hoehl and colleagues' (2009) model, individuals will decode others' social intention and allocate their attention to the social information that is determined to be socially significant based on the results obtained from the previous three stages.

One's attention is directed by others' gaze direction and this attention orientation can be affected by the facial emotion. Early studies have shown that subjects detect a target faster when its location is correctly cued by the gaze direction of a previously presented face, and this cueing effect was stronger for emotional faces (Bayliss, Schuch, & Tipper, 2010; Fox, Mathews, Calder, & Yiend, 2007; Graham, Friesen, Fichtenholtz, & Labar, 2010; Lassalle & Itier, 2013; Neath, Nilsen, Gittsovich, & Itier, 2013; Pecchinenda, Pes, Ferlazzo, & Zoccolotti, 2008). Such emotion-modulated gaze-orienting effect is related to a later stage of social processing because the emotion modulation attenuates when the face is briefly presented (Graham et al., 2010). Emotional context of the target also affects the emotion-modulated gaze-orienting effect, such that positive target is cued more effectively by the gaze of happy faces and negative target is equally effective by negative face and positive face (Bayliss et al., 2010; Pecchinenda et al., 2008). Neurally, the emotion-modulated gaze-orienting effect is reflected in the parietal P3b which is one of the late stages of visual processing (Fichtenholtz, Hopfinger, Graham, Detwiler, & Labar, 2007).

Another component at Stage 4 is intention encoding, which is commonly examined by measuring one's ability of theory of mind (ToM). The ToM is referred to the ability to infer and understand others' mental states and feelings (Baron-Cohen, Leslie, & Frith, 1985; Premack & Woodruff, 1978). Two types of ToM have been proposed: cToM and aToM (Kalbe et al., 2010; Shamay-Tsoory & Aharon-Peretz, 2007). cToM (also termed as perspective-taking (e.g., Epley, Keysar, Van Boven, & Gilovich, 2004; Surtees, Apperly, & Samson, 2013) or mentalizing (e.g., Frith & Frith, 2006; Luyten & Fonagy, 2015)) is defined as the ability of making inference about others' mental states such as their thoughts and beliefs, while aToM (e.g., Shamay-Tsoory, 2011; Walter, 2012) is related to the ability to understand others' feelings and emotions. Under these definitions, the intention encoding described by Hoehl and colleagues (2009) aligns better with cToM. On top of the distinction between cToM and aToM, there are other dimensions of ToM: automatic vs. controlled, mentalizing oneself vs. other, and mentalizing based on external features vs. internal features (Luyten & Fonagy, 2015). Although different sub-divisions of ToM recruit different parts of the brain, typical neural correlates that are associated with the general ToM include the STS, the mPFC, and the temporo-parietal junction (Frith & Frith, 2006; Luyten & Fonagy, 2015).

1.2.5. Summary of the review on the relevant models of socio-emotional processing

In this section, we have reviewed the literature on the four stages of social processing proposed by Hoehl and colleagues (2009): 1) detection of face and gaze direction; 2) encoding of facial information; 3) the evaluation of self-relevance of social cues; and 4) attention allocation and intention encoding. Each stage is corresponding to a specific neural correlate or a network of neural regions. In the next section, we are going to review the influence of alexithymia on each of the stages.

1.3. Alexithymia and socio-emotional processing

Alexithymia has been associated with multiple interpersonal difficulties, such as exhibiting cold and avoidant social strategies (Vanheule et al., 2007), and less collaborative tendency and lack of sociability (Nicolò et al., 2011). These social problems might be linked to the impairment in the socio-emotional processing in alexithymia. For example, the high alexithymia individuals tend to feel sensitive, anxious and stressful when confronting a social event (Nicolò et al., 2011; Pollatos et al., 2011). As reviewed in the previous section, there are multiple stages in socio-emotional processing. Which stage(s) of the socio-emotional processing is (are) affected by alexithymia? In the following section, we will review the reported alexithymic impairments in different sub-domains of socio-emotional processing, and fit the evidence into the four stages proposed by Hoehl and colleagues (2009).

1.3.1. Alexithymia and detection of face and gaze direction

Evidence in the literature so far does not support that the detection of changes in facial feature is impaired in alexithymia. For example, behaviourally, the sensitivity in detecting the changes in facial expression and facial identity is not affected by alexithymia (Cook et al., 2013; Vermeulen, Luminet, de Sousa, & Campanella, 2008). Furthermore, the ability to detect upright emotional faces and neutral faces among a stream of inverted faces was not affected by alexithymia (Grynberg, Vermeulen, & Luminet, 2014). These studies suggested that the detection and differentiation of low-level facial feature are intact in alexithymia. However, most of these findings sampled in the western population and has not been tested in the eastern countries yet.

However, the early detection of facial expression at a higher level is impaired in alexithymia because the high alexithymia individuals tend to perform worse when the facial expression is presented suboptimally (Grynberg et al., 2012). A most typical example is that when the presentation duration of the facial expression is brief, the emotion identification accuracy was negatively correlated with alexithymia (66ms or 100ms in Ihme et al., 2014b; 1s in Parker, Prkachin, & Prkachin, 2005; 33ms in Prkachin, Casey, & Prkachin, 2009). Similar alexithymic impairment can also be observed when the high spatial frequency information is removed from the facial expression such that the image is blurry or noisy (Brewer, Cook, Cardi, Treasure, & Bird, 2015a; Kätsyri, Saalasti, Tiippana, von Wendt, & Sams, 2008). Other than that, high alexithymia individuals are less sensitive in labelling facial expressions, such that they tend to judge an emotionally ambiguous face as neutral (Cook et al., 2013; Starita, Borhani, Bertini, & Scarpazza, 2018). Although Cook and colleagues (2013) argued that the alexithymic impairment in emotional face perception is linked to the cognitive stage of the processing because the performance of the facial expression change detection task is not affected by alexithymia, another explanation is that the high alexithymia individuals might have weaker emotion detection processing that operates independently from the low-level visual feature discrimination processing.

In terms of the detection of gaze information, no direct evidence is available showing that the high alexithymia individuals are less able to differentiate gaze direction than low alexithymia individuals. However, indirect evidence has shown that they might pay less attention to the eye region of the face during social perception (Bird et al., 2011). In their experiment, Bird and colleagues (2011) asked the subjects who were clinically diagnosed with autism to watch video clips that involve emotional and social interaction between two characters. No explicit emotional task was performed when the video clips were playing, but the subjects were told to pay attention to the clips because the purpose of the study was to examine the effect of the clips on their performance of the subsequent visual attention task. The results showed that the high alexithymia individuals tended to fixate shorter on the eye region than the mouth region, whereas those with low alexithymia trait tended to look longer at the eyes. It is possible that, therefore, the high alexithymia individuals may be less sensitive to gaze information due to their eye avoidance. However, two more recent studies failed to replicate the eye avoidance tendency in alexithymia (Fujiwara, Kube, Rochman, Macrae-Korobkov, & Peynenburg, 2017; Stephenson, Luke, & South, 2019). The discrepancy in the literature might be because of the differences in tasks. While the two studies with negative results implemented either an explicit emotional task (Fujiwara et al., 2017; Stephenson et al., 2019) or a luminance detection task which did not require any attention on socio-emotional information (Stephenson et al., 2019), Bird and colleagues (2011) directed the subjects' implicit attention to the socio-emotional information of the video clips. The alexithymic eye avoidance, therefore, might only be observed when the subjects are implicitly attending to social information, which mirrors closer to real life social interaction than explicit emotional task and luminance detection task.

The impairment in early detection of facial expression, and potentially gaze direction, suggests that alexithymia is related to the deficit in the automatic emotion processing (Donges & Suslow, 2017). It is well-established that amygdala is one of the most important neural candidates for automatic processing of emotion and for emotional significance processing (Diano et al., 2017; Tamietto & De Gelder, 2010). Moreover, it serves an important role of allocating processing resources to stimulus that are high in salience and biological significance (Pessoa & Adolphs, 2010). Evidence supporting the alexithymic amygdala deficit in automatic emotional face perception, however, may need additional examination. Only two out of four identified neuroimaging studies that investigated the neural correlates of brief facial expression perception in alexithymia (Ihme et al., 2014b; Kugel et al., 2008; Reker et al., 2010; Suslow et al., 2016) reported that the amygdala of the high alexithymia individuals is less activated than that of low alexithymia individuals when the presented face was sad (Kugel et al., 2008; Reker et al., 2010). Moreover, none of the studies implementing implicit emotional task reported deactivation of the amygdala in alexithymia (Kano et al., 2003; Mériau et al., 2006). Interestingly, though, the connectivity between the amygdala and the ACC was found to be more prominent in the high alexithymia individuals than low alexithymia during both explicit and implicit emotional face perception tasks (Mériau et al., 2006). The finding is interpreted as the support for the alexithymic excessive attention to emotional information (Donges & Suslow, 2017). The high alexithymia individuals are more attentive to emotional information may be because the processing is more effortful for them.

In sum, early emotion detection is more effortful to the high alexithymia individuals. Also, this population may also pay less attention to the eye region of the faces when encoding facial emotion implicitly. The subcortical hypoactivation account for the impaired early emotion detection in alexithymia needs further investigation. Another possible direction for future studies is to investigate the relationship between the early emotional face detection and the subcortical connectivity with the frontal regions in alexithymia.

1.3.2. Alexithymia and encoding of facial information

Again, in this thesis, we focus on the encoding of facial expression, but not other facial attributes. Although inaccurate recognition of negative facial expression is commonly reported in alexithymia even when the faces were presented optimally (Ihme et al., 2014a; Jongen et al., 2014; Kano et al., 2003; Martínez-Velázquez, Honoré, Zorzi, Ramos-Loyo, & Sequeira, 2017; McDonald & Prkachin, 1990; Parker, Taylor, & Bagby, 1993a; Prkachin et al., 2009; for review, see Grynberg et al., 2012), not much is known about how different in perception are the high alexithymia individuals when perceiving emotional faces. Using a chimeric free vision of facial expression task (i.e., different emotions displayed in the right-side and the left-side of the face), Jessimer and Markham (1997) suggested that the high alexithymia individuals might rely less on left-side of the face when recognizing negative emotional faces. This alexithymic effect however was not found in an earlier study (Berenbaum & Prince, 1994). Furthermore, no studies so far demonstrated that the high alexithymia individuals have the tendency to use featural processing like the autistic individuals. How alexithymia is associated with impaired facial expression encoding, therefore, remain inconclusive.

At the neural level, early EEG studies that investigated the neural differences in emotional face processing showed controversial results. In one study (Vermeulen et al., 2008), the latency of the posterior N250 component was shown to be delayed when discriminating faces from different emotional categories. However, in another study (Campanella et al., 2012), the high alexithymia individuals showed earlier posterior N250 peak when identifying fearful faces. In the fMRI literature, again, controversial findings reported in how the activation at the temporal regions affected by alexithymia during optimal emotional face perception. In one study, the temporal regions (e.g., the FFA and the STS) of the high alexithymia individuals were less activated than those with low alexithymia trait

(Jongen et al., 2014), whereas in another study the same temporal regions were hyper-aroused (Ihme et al., 2014a).

In sum, inconclusive evidence is available for the alexithymic impairment in encoding facial emotion. This may suggest that the effect of alexithymia is minimum at the Stage 2 of Hoehl and colleagues' (2009) model. If the encoding of the facial expression is intact in alexithymia, it would mean that the behavioural impairment in alexithymia is because of the impaired evaluation of the social cues.

1.3.3. Alexithymia and the evaluation of self-relevance

To the best of our knowledge, no studies have directly investigated the ability in evaluating self-relevance of social cues in alexithymia. A number of studies, however, might indirectly suggest that alexithymia is associated with impaired evaluation of self-relevance. First, eyes are more aversive to highly alexithymic individuals. They tend to spend less time on the eye regions of faces (Bird et al., 2011). Since eyes are one of the most important indicators of one's focus of attention (Emery, 2000; Langton et al., 2000), reduced attention to eye regions might lead to insufficient amount of information to evaluate whether oneself is involved in the social event. Secondly, while self-awareness is closely associated with eye-contact effect (Baltazar et al., 2014) - an indicator for the evaluation of self-relevance (Adams et al., 2003; N'Diaye et al., 2009; Sander et al., 2007), impaired self-awareness has been repeatedly shown in alexithymia (Eastabrook et al., 2013; Pollatos et al., 2011; Shah et al., 2016). For example, Shah and colleagues (2016) found that alexithymia is negatively correlated with the accuracy in reporting one's own bodily responses (e.g., heart beat rate). Similarly, other studies showed that the physiological responses and the self-reported stress level of the high alexithymia individuals do not correlate, such that they tend to report stronger stress level but have a weaker objective physiological responses than the low alexithymia individuals (Eastabrook et al., 2013; Pollatos et al., 2011). Their impaired self-awareness suggests that there might be a weaker self-referential processing in alexithymia. For self-referential processing is important to elicit eye-contact effect and thus the evaluation of self-relevance (Conty et al., 2016), we hypothesize that the high alexithymia individuals may have an impaired evaluation of self-relevance of social cues.

Further indirect support may come from the neural evidence. The most commonly reported neural deficits in alexithymia is in the insula (Valdespino, Antezana, Ghane, & Richey, 2017; Van der Velde et al., 2013; Wingbermühle et al., 2012). The insula, which plays an important role in interoceptive awareness (Craig, 2002; Simmons et al., 2013; Zaki, Davis, & Ochsner, 2012), emotional awareness (Sierra & David, 2011; Simmons et al., 2013; Zaki et al., 2012), and self-awareness (Craig, 2009), was found to be less activated in high alexithymia individuals during emotional face perception task or empathy task (Bird et al., 2010; Ihme et al., 2014b; Jongen et al., 2014; Lassalle et al., 2018; Reker et al., 2010). On top of the insula, atypically hypoarousal in the mPFC were also observed in alexithymia when the subjects were perceiving negative emotional stimuli (Deng, Ma, & Tang, 2013; Lassalle et al., 2018; for meta-analysis, see Van der Velde et al., 2013). Other than that, in some cases, the ACC was found to be hyper-aroused when perceiving negative emotional stimulus (Mériau et al., 2006; Moriguchi et al., 2007a; Van der Velde et al., 2013), but others show a different pattern (i.e., hypo-aroused ACC) (Deng et al., 2013; Jongen et al., 2014; Karlsson, Näätänen, & Stenman, 2008). Since these three anterior neural regions - the insula, the ACC and the mPFC - have been shown to be involved in processing emotional faces with different gaze directions (Ewbank et al., 2010; Ziaei et al., 2016, 2017) and are proposed as part of the network of self-referential processing (Conway et al., 2016; Hu et al., 2016; Northoff et al., 2006; Schmitz & Johnson, 2007), it provides further support for our hypothesis that the self-referential processing and thus the evaluation of self-relevance is impaired in alexithymia.

Electroencephalogram (EEG) literature coheres the findings of functional magnetic resonance imaging (fMRI) literature. During emotion perception task, the high alexithymia individuals tends to exhibit a stronger frontal N2 activation towards pictures displaying negative affect (Pollatos & Gramann, 2011; Zhang et al., 2012). The N2 activations towards positive images, in contrast, were not different between high alexithymia subjects and low alexithymia subjects. Since the source of the frontal N2 has been consistently localized at the ACC and the mPFC (for review, see Bocquillon et al., 2014), the frontal N2 findings fit with the fMRI studies which reported a hyper-aroused ACC in alexithymia when perceiving negative emotional stimulus (Mériau et al., 2006; Moriguchi et al., 2007a; Van der Velde et al., 2013). Together, it can be interpreted as that the highly alexithymia individuals require more attentional resource to attend and understand emotional stimulus (Van der Velde et al., 2013).

In sum, although influence of alexithymia in the evaluation of self-relevance of social cues – Stage 3 of social processing (Hoehl et al., 2009) – has yet been directly tested in the literature, there are multiple indirect evidence from both behavioural studies and neural imaging studies suggesting this possibility. If alexithymia is related to impaired evaluation of self-relevance of social cues, there are two possible explanations: 1) the high alexithymia individuals are less attentive to eye information and thus unable to use the information to evaluate self-relevance; and/or 2) the high alexithymia individuals have an impaired self-referential processing and consequentially unable to cognitively evaluate self-relevance.

1.3.4. Alexithymia and attention allocation and intention encoding

The relationship between alexithymia and attention allocation during social processing is not well understood. To the best of our knowledge, no work has been done to investigate how alexithymia influences the emotion-modulated gaze-orienting effect.

However, studies have consistently showed that the emotion-modulated gaze-orienting effect is affected by the anxiety level of the subjects (Fox et al., 2007; Mathews, Fox, Yiend, & Calder, 2003). Since alexithymia is highly associated with anxiety (Berthoz, Consoli, Perez-Diaz, & Jouvent, 1999; Eizaguirre, de Cabezón, de Alda, Olariaga, & Juaniz, 2004; Marchesi, Brusamonti, & Maggini, 2000), we expect that alexithymia may affect the emotion-modulated gaze-orienting effect as anxiety, such that the high alexithymia individuals has reduced emotion-modulated gaze-orienting effect for angry faces but stronger emotion-modulated gaze-orienting effect for fearful faces than those with low alexithymic trait (Fox et al., 2007; Mathews et al., 2003).

On the other hand, in terms of the ability in encoding social intention, there is so far only one study reported the alexithymic deficit in cToM (Moriguchi et al., 2009). Other studies, however, reported an intact cToM ability in alexithymia (Bernhardt et al., 2014; Lane, Hsu, Locke, Ritenbaugh, & Stonnington, 2015; Pluta, Kulesza, Grzegorzewski, & Kucharska, 2018). Since the tasks related to cToM concerns the high-level cognitive deduction of other's mental states, the intact cToM ability in alexithymia suggests that any alexithymic deficits in social processing is not because they have misinterpreted the social situation or others' social intention. Rather, those deficits are most likely lie on the impairments in the experience of internal feelings and emotions (Brewer et al., 2016; Grynberg, Luminet, Corneille, Grèzes, & Berthoz, 2010; Lane et al., 1997; Mul, Stagg, Herbelin, & Aspell, 2018; Shah et al., 2016).

One may think that the intact ToM in alexithymia contradicts with the potential impairment in the evaluation of self-relevance that we have hypothesized, because the two processing shares a number of neural correlates. We however argue that the two do not contradict. It has been proposed that there are distinctive neural correlates for self-representation and for other-representation (Denny, Kober, Wager, & Ochsner, 2012). Whereas information related to oneself activates the ventral part of mPFC, those related to others recruits the dorsal part. Furthermore, one of the dimensions of ToM is to mentalizing self vs. mentalizing other (Luyten & Fonagy, 2015). Mentalizing self involves understanding ones' own bodily and affective states (i.e., self-representation), while mentalizing other involves inhibiting own perspective and cognitively deduce other's thoughts (i.e., other-representation). Under this interpretation, alexithymia may relate to an impaired self-representation and an intact other-representation. Since most of the ToM task involves the activation of other-representation (Saxe & Kanwisher, 2003; Stone, Baron-Cohen, & Knight, 1998), alexithymia does not influence the performance in the tasks. On the other hand, the evaluation of self-relevance involves the activation of self-representation (Conty et al., 2016; Northoff et al., 2006; Schmitz & Johnson, 2007), and thus it is impacted by alexithymia.

1.4. Summary of the literature

This chapter started with introducing the concept of alexithymia, a deficit in processing one's own emotion and others' emotion, and its relationship with autism. Then we reviewed on the models that are relevant to socio-emotional processing. We choose to base our discussion on Hoehl and colleagues' (2009) model because it provides a clear temporal sequence for the stages that take place in socio-emotional processing. Four stages of socio-emotional processing were proposed in their model: 1) detection of face and gaze direction; 2) encoding of facial information; 3) the evaluation of self-relevance of social cues; and 4) attention allocation and intention encoding.

Then we reviewed the literature on how alexithymia influences each of the stages proposed (Figure 1.1). Most literature concerns the effect of alexithymia on Stage 1, Stage 2 and part of Stage 4 of social processing. The alexithymic impairment at Stage 1 includes being less sensitive to facial expression (Brewer et al., 2015a; Cook et al., 2013; Ihme et al., 2014b; Kätsyri et al., 2008; Parker et al., 2005; Prkachin et al., 2009; Starita et al., 2018) and reduced attention to eye information (Bird et al., 2011). These alexithymic behavioural tendency may be associated with the hypo-aroused subcortical pathway for emotion processing (Donges & Suslow, 2017) and the excessive connectivity of the amygdala with the frontal regions (Mériau et al., 2006).

Although the high alexithymia individuals have been repeatedly shown to be less accurate in recognizing facial expression even when the faces are presented optimally (Ihme et al., 2014a; Jongen et al., 2014; Kano et al., 2003; Martínez-Velázquez, Honoré, Zorzi, Ramos-Loyo, & Sequeira, 2017; McDonald & Prkachin, 1990; Parker, Taylor, & Bagby, 1993a; Prkachin et al., 2009; for review, see Grynberg et al., 2012), there is no conclusive evidence showing that they have deviated perceptual strategy from those who with low alexithymia trait. Furthermore, the neural evidence for the alexithymic impairment in the temporal regions, which is the hub for perceptual facial processing (Duchaine & Yovel, 2015; Haxby et al., 2000), is inconsistent. Therefore, we cannot conclude how alexithymia affects Stage 2 of social processing.

More conclusive evidence is received from the investigation on the alexithymic influence on the process of intention encoding (Stage 4). Although the pilot work done by Moriguchi and colleagues (2009) suggested that ToM is impaired in alexithymia, subsequent studies could not replicate the finding (Bernhardt et al., 2014; Lane et al., 2015; Pluta et al., 2018). Thus, it is most likely that the high-level cognitive deduction of other's mental states is unaffected by alexithymia. Nonetheless, little is known about whether alexithymia would affect the top-down attention allocation during social processing. Future studies are urged to investigate in this direction.

Surprisingly, no study has been done on whether and how alexithymia affects the evaluation of self-relevance during social processing (Stage 3), despite multiple indirect evidence pointing to the possible impairment. We have summarized the existing evidence from the behavioural studies and neural imaging studies that indirectly suggested the potential impairment of the evaluation of self-relevance in alexithymia. These evidences include that: 1) the high alexithymia individuals exhibit eye avoidance tendency during social processing (Bird et al., 2011); 2) alexithymia is associated with impaired self-awareness (Eastabrook et al., 2013; Pollatos et al., 2011; Shah et al., 2016); and 3) most of the neural correlates related to alexithymia is part of the neural network for self-referential processing (Conway et al., 2016; Hu et al., 2016; Northoff et al., 2006; Schmitz & Johnson, 2007). Based on the evidence, we hypothesize that the high alexithymia individuals have impaired detection of facial emotion and gaze direction (Stage 1) and the evaluation of self-relevance during socio-emotional processing (Stage 3), but intact facial information encoding (Stage 2) and deliberative intention encoding (i.e., ToM; Stage 4) (Figure 1.1e). In this thesis, we attempt to provide evidence for the alexithymic impairments at Stage 1 and Stage 3 of socio-emotional processing and propose a mechanism that connects these impairments based on our findings.

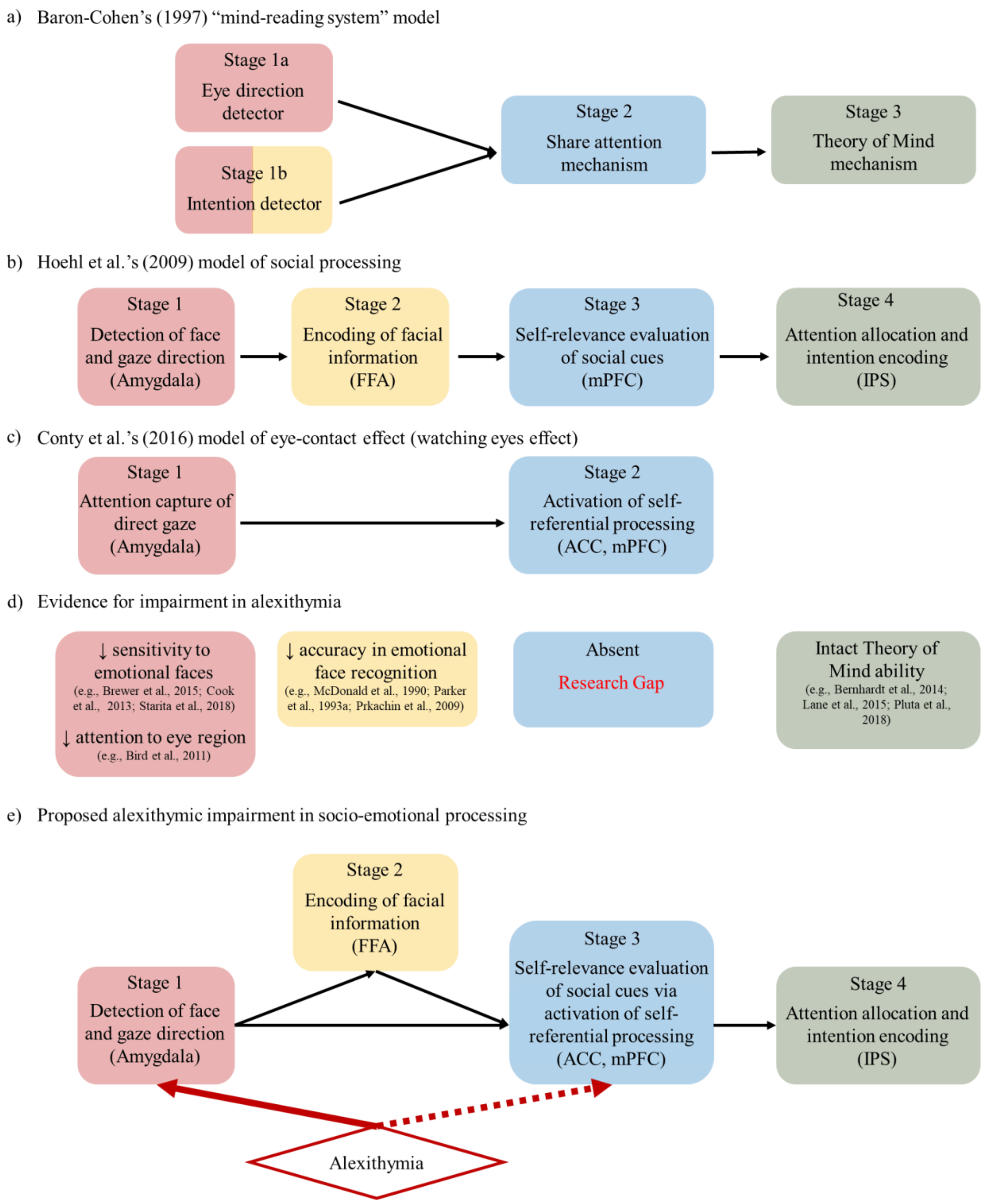

Figure 1.1. Major schematic models on socio-emotional processing (a-c), evidences indicating the alexithymic impairments at each stage of Hoehl and colleagues' (2009) model (d), and our proposed model for alexithymic impairement in socio-emotional processing (e). The neural correlates that are proposed to be associated with a stage is indicated in brackets. Our proposed model is primarily adapted from Hoehl and colleagues' (2009; b) model while incorporating the elements from Baron-Cohen's (1997; a) model and Conty and colleagues' (2016; c) model. More specifically, a direct pathway from Stage 1 to Stage 3 is added to capture the rapid processing of intentionality and self-relevance of social cues in the subcortico-frontal pathway (see Johnson et al., 2015). Red solid line

indicates the alexithymic impairment that is well-documented in the literature. Red dotted line indicates the alexithymic impairment that we proposed after reviewing the existing literature. Consistent evidence has shown that alexithymia has impairment at Stage 1. At Stage 2, however, no conclusive evidence shows that HTAS has deviated perceptual strategy from LTAS. Next, although no studies directly address the alexithymic impairment at Stage 3, indirect evidence suggests the possibility that HTAS may have difficulty at this stage. Lastly, most evidence supports the intact ToM (Stage 4) in alexithymia. Through this thesis, we propose that alexithymia is related to the impairment in the subcortico-frontal pathway (i.e., Stage 1 and Stage 3) of socio-emotional processing.

1.5. Outstanding Questions to be Addressed in the Present Work

Why is it important to study alexithymia, especially in the context of Singapore? Building a caring and cohesive society is one of Singapore's key goals (Ministry of Finance, 2019; Tan, 2019). One of the keys to achieving this aim is dependent on effective interpersonal communication and an active understanding of others' feeling at a societal level. Yet, literature shows that compared to non-Asians, Asians tend to score higher in alexithymia (Dere et al., 2012; Dion, 1996; Lo, 2014), a trait that is associated with a number of interpersonal difficulties (Nicolò et al., 2011; Vanheule et al., 2007). If the population of Singapore, an Asian country, has a high prevalence rate of alexithymia, it could be a major barrier to the promotion of social care and cohesion. We therefore made preliminary attempt to investigate the epidemiology of alexithymia in Singapore, starting with the university students. At the same time, this study aims to examine which socio-emotional constructs alexithymia is closely associated with in order to guide our subsequent investigation.

As reviewed in the previous sections, the state-of-the-art studies have concerned how alexithymia has affected the processing in the first two stages of Hoehl and colleagues' (2009) model, the detection of face and eye information, and the encoding of facial information. Little is known, however, about whether and how alexithymia influences the third stage of social processing, i.e., the processing of self-relevance of social information.

We therefore conducted three experiments in this thesis aims to address this question. More specifically, Experiment 1 sets the foundation by exploring the relationship between alexithymia and the evaluation of self-relevance during social processing. In the experiment, subjects were asked to make judgements on the emotional or neutral faces with different gaze directions. The ability to evaluate self-relevance is operationally defined as the eye-contact effect (i.e., the rating difference between faces with direct gaze and averted gaze). Since it has been suggested that gaze direction and facial expression are processed jointly at Stage 3 to provide reliable signal of threat, on top of the emotion recognition task and emotion intensity rating, we also asked the subjects to rate how threatened they felt towards the faces so as to better capture the function of this stage. In addition, previous studies which investigated the integrative perception of facial expression and gaze direction did not make an attempt at dissociating the detection of gaze direction and the evaluation of self-relevance during social processing. In order to differentiate the two processing, we designed a question that was not related to the subjects themselves (so that the evaluation of self-relevance was avoided) but tasked the subjects with the use of gaze information. If alexithymia impacts the processing at the evaluation of self-relevance stage, we expect that the eye-contact effect should reduce in the high alexithymia individuals and the reduction should be specific to emotional faces, espcially those that indicate threat, e.g., angry faces, and specific to the question that is self-threat related.

Experiment 2 and Experiment 3 were designed to explore the cognitive-behavioral mechanism and the neural mechanism of the impaired evaluation of self-relevance during social threat processing found in Experiment 1 respectively. Since a reduction in fixation duration at the eye region during face perception was shown in alexithymia, one possible mechanism for the alexithymic impairment in the evaluation of self-relevance is that the later processing stage cannot receive sufficient gaze information from the earlier stages. To test this possibility, in Experiment 2, we attempted to replicate the alexithymic eye avoidance and additionally tested whether it would be modulated by the emotion of the face. Since in Experiment 1 we found that alexithymic impairment in the evaluation of self-relevance is specific to angry faces, the eye avoidance should also be specific to angry faces if the two alexithymic phenomena are related.

Experiment 3 concerns with the temporal trajectory of the alexithymic impairment of the evaluation of self-relevance during social processing. We investigated at which temporal stage (early stage: ~120ms; early-mid stage: ~170ms; late-mid stage: ~250ms; late stage: ~300ms) of neural processing by EEG reflects the reduction in eye-contact effect of angry faces observed in Experiment 1. Additionally, we explored whether the alexithymic influence on the evaluation of self-relevance occurs at the posterior and/or anterior region of the brain. This spatial information from EEG will allow us to draw comparison with the fMRI literature. The neural mechanism of the social processing can be inferred, and we can pinpoint the neural regions and neural network that are most likely to be implicated in alexithymia.

Lastly, autism is known to have a very close relationship with alexithymia (Bird & Cook, 2013; Poquérusse et al., 2018). Most studies, however, concerned the clinical population. In this thesis, we also attempted to test the “alexithymia hypothesis” of autistic tendency in the general population. Autistic tendency is considered a continuous spectrum rather than a category in the general population, and in the lower end of the spectrum lies the individuals with ASD (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001; Lundström et al., 2012; Wakabayashi, Tojo, Baron-Cohen, & Wheelwright, 2004). More importantly, typically developed individuals with high autistic traits tend to share similar behavioral tendencies with those who are diagnosed with autism (Losh et al., 2009). Evidence from limited literature showed that children diagnosed with autism might have impaired integrative perception of facial expression and gaze direction (Akechi et al., 2009, 2010). On top of replicating the finding, we also tested whether alexithymia can explain such autistic impairment, if any. If alexithymia is a better predictor than autistic traits, we will provide further support for the “alexithymia hypothesis”.

Taken together, the four studies in this thesis will illustrate the importance of studying alexithymia in Singapore, and how the evaluation of self-relevance in socio-emotional processing is affected by alexithymia. Our results will further our understanding of the underlying core deficits in alexithymia (Figure 1.2), a trait that affects up to 19% of the population.

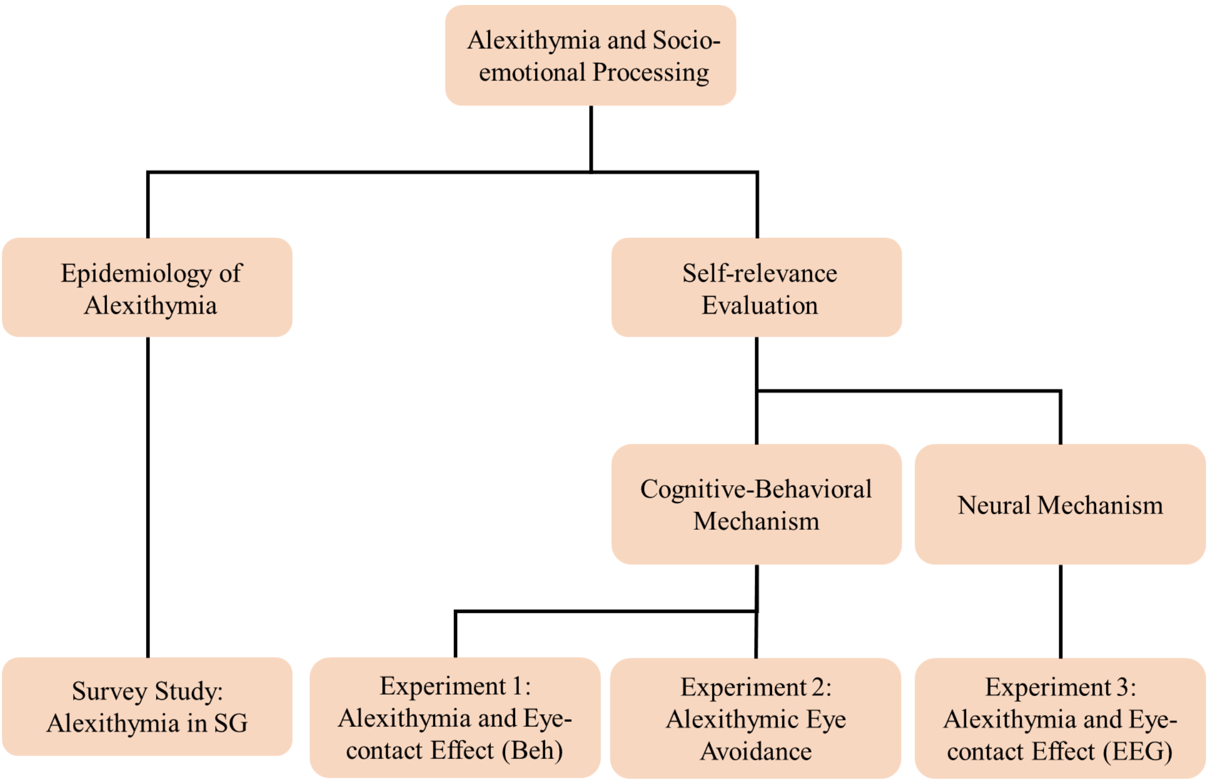

Figure 1.2. Framework for the four proposed studies in this thesis.

Chapter 2

Survey Study. Alexithymia in General Population of Singapore and its Relationship with Socio-Emotional Constructs

2.1. Introduction

Alexithymia, characterized by the inability to describe and identify feelings (Sifneos, 1973; Taylor et al., 1991), is a construct that is proposed to be related to deficits in socio-emotional processing (Grynberg et al., 2010; Lane et al., 1997; Larsen et al., 2003). The interpersonal relationship of the individuals who are high in alexithymia is disrupted by this deficit. For example, they tend to adopt cold and avoidant social strategies (Vanheule et al., 2007) and are less collaborative and sociable (Nicolò et al., 2011). These deviated social behaviours may be because of their atypical emotional feelings, like the tendency to feel sensitive, anxious and stressful, during social interaction (Nicolò et al., 2011; Pollatos et al., 2011).

Alexithymia, nonetheless, is not a rare condition in the population. In the western countries, the prevalence rate of alexithymia is 10% to 19% (10% in Germany, Franz et al., 2008; 18% in UK, Mason et al., 2005; 13% in Australia, McGillivray, Becerra, & Harms, 2017; 19% in Canada, Parker, Taylor, & Bagby, 1989; 13% in Finland, Salminen et al., 1999). This rate could be even higher in countries with Asian culture. Cultural differences have been found in alexithymia, such that Asians tend to score higher in TAS-20, especially in its subscale External oriented thinking (EOT), than non-Asians (Dere et al., 2012; Dion, 1996; Lo, 2014). The cultural differences was shown to be mediated by the endorsement of modernized values and beliefs (Dere et al., 2012), and the adoption of eastern and western values (Dere et al., 2012; Lo, 2014). Although not directly tested so far, due to the cultural differences in alexithymia, Asian countries, such as Singapore, might have a higher prevalence rate in alexithymia than the western countries.

On top of the degree of alexithymia, we are also interested in examining the reliability of TAS-20, a scale measuring the degree of alexithymia, in the context of Singapore. To date, there are no studies that tested the applicability of TAS-20 in the Singapore. Since Singapore is a multilingual country with English as the primary working language, we would expect that the reliability of the English version of TAS-20 in Singapore should not be different from those in the western countries where English is also their primary language (e.g., US, Australia, and Canada; Bagby, Parker, & Taylor, 1994; Culhane, Morera, Watson, & Millsap, 2009; Gignac, Palmer, & Stough, 2007; McGillivray et al., 2017; Parker, Eastabrook, Keefer, & Wood, 2010; Parker, Michael Bagby, Taylor, Endler, & Schmitz, 1993; Preece, Becerra, Robinson, & Dandy, 2018). Yet, we cannot exclude the possibility that the cultural backgrounds and the increased use of other languages (e.g., Chinese, Malay, and Tamil) in daily life may influence the reliability of TAS-20 in Singapore. One study conducted in Malaysia which has a similar education language background as Singapore used TAS-20 scale to investigate cultural differences in alexithymia (Le, Berenbaum, & Raghavan, 2002). However, this study did not report the reliability of TAS-20 in their Malaysian sample. Therefore, the second aim of this study is to verify the applicability of TAS-20 via examining its internal reliability in the Singapore university students.

Another important question that is going to be addressed in this chapter is the association of alexithymia with different social constructs, i.e., autistic traits (AQ-28), emotional expressivity (Berkeley Expressivity Questionnaire (BEQ)), and emotional constructs, i.e., depression, anxiety and stress (Depression Anxiety Stress Scale (DASS-21)). Alexithymia has been consistently related to emotional deficits (Eizaguirre et al., 2004;

Ghorbani, Khosravani, Sharifi Bastan, & Jamaati Ardakani, 2017; Li, Zhang, Guo, & Zhang, 2015; Swart, Kortekaas, & Aleman, 2009) and deviation in social behaviours (Nicolò et al., 2011; Vanheule et al., 2007). However, since these two types of deficits are commonly related (Kupferberg, Bicks, & Hasler, 2016; Lopes, Salovey, Côté, & Beers, 2005; Segrin, 1996; Wei, Vogel, Ku, & Zakalik, 2005), it is not clear whether their relationships with alexithymia can be explained by each other. This survey study, therefore, attempted to answer this question.

In this preliminary study, our primary aim is to investigate the alexithymia rate among Singapore university students. Second, we attempted to examine the applicability of the English version of TAS-20 in Singapore so as to justify its application in our other studies. A simultaneous data collection was conducted in UK to compare the cultural differences. Due to the time limits, we would not report the details of findings of the UK sample here. Lastly, we investigated the relationship of alexithymia with social constructs and emotional constructs. This will set the foundation for our subsequent investigation in the socio-emotional processing in alexithymia.

2.2. Methods

2.2.1. Participants

In total, seven hundred and twenty-eight responses were received from the UK and Singapore pool. Since our collaborators cannot officially confirm whether we can report the data from the UK sample before the deadline of the thesis submission, we only focus on the sample obtained from Singapore in this study. Responses from subjects who did not complete the questionnaire, who were not a student, who were not within 21 to 40 years old, or who indicated to have a clinical diagnosis were excluded from the analysis, resulting a total of two hundred and two responses included in the analysis. Table 2.1 illustrates the demographic information of the responses which were included in the analysis. Informed consents were obtained from the subjects before the questionnaire. This study was approved by the Institutional Review Board (IRB) at Nanyang Technological University, Singapore, by the Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving human subjects.

	SG
N	202
Gender (F/M)	123/79
Age	22.85 (2.15) [21 – 33]
Ethnicity	
White	2
Chinese	182
Indian	4
Malay	4
Others	10
First Language	
English	64
Mandarin Chinese	118
Malay	4
Tamil	3
Others	13
Education level	
High School	66
University but not graduate yet	103
Associate degree (2 year)	3
Bachelors (4 year)	25
M.Sc.	5
AQ-28	12.80 (4.33) [2 – 24]

DASS-21	
Depression	11.87 (8.85) [0 – 40]
Anxiety	11.28 (7.22) [0 – 32]
Stress	13.55 (7.18) [0 – 36]
TAS-20	51.20 (10.62) [26 – 77]
BEQ	71.84 (13.58) [39 – 105]
HVIC	
HI	26.07 (4.72) [14 – 36]
VI	21.67 (5.36) [4 – 35]
HC	25.93 (5.00) [6 – 36]
VC	26.07 (5.46) [8 – 36]

Table 2.1. Demographic information of the participants in Survey Study. AQ-28 – Autism-Spectrum Quotient – Short Version; DASS-21 – Depression Anxiety Stress Scale; TAS-20 – Toronto Alexithymia Scale; BEQ – Berkeley Expressivity Questionnaire; HVIC – Horizontal and Vertical Individualism and Collectivism Scale; HI – Horizontal Individualism; VI – Vertical Individualism; HC – Horizontal Collectivism; VC – Vertical Collectivism. Standard deviations are shown in parentheses. Range of the scores are shown in square brackets.

2.2.2. Apparatus

AQ-28. The Autism Spectrum Quotient – Short Version (AQ-28; Hoekstra et al., 2011; Kuenssberg, Murray, Booth, & McKenzie, 2014) has 28 items to measure one's autistic tendency. It has five subscales: Social Skills (e.g., "I find social situation easy"), Attention Switching (e.g., "I find it easy to do more than one thing at once" [negatively coded]), Routine (e.g., "New situations make me anxious"), Imagination (e.g., "I find making up stories easy" [negatively coded]), and Numbers/Patterns (e.g., "I am fascinated by numbers"). Participants responded to the questions in a 4-point scale (1 = "Definitely agree"; 2 = "Slightly agree"; 3 = "Slightly disagree"; 4 = "Definitely disagree"). AQ-28 was shown to exhibit high internal reliability (Cronback's alpha = .77 to .84) (Hoekstra et al., 2011; Kuenssberg et al., 2014).

DASS-21. Depression Anxiety Stress Scale (DASS-21; Lovibond & Lovibond, 1995) has 21 items to assess one's levels of depression (e.g., "I couldn't seem to experience any positive feeling at all"), anxiety (e.g., "I experienced trembling"), and stress (e.g., "I tended to over-react to situations") over the last week before the administration of the questionnaire. Participants responded to the questions in a 4-point scale (0 = "Did not apply to me at all"; 1 = "Applied to me to some degree, or some of the time"; 2 = "Applied to me to a considerable degree, or a good part of time"; 3 = "Applied to me very much, or most of the time"). DASS-21 was shown to exhibit high internal reliability (Cronback's alpha = .70 to .94) (Antony, Bieling, Enns, & Swinson, 1998; Oei, Sawang, Goh, & Mukhtar, 2013).

TAS-20. Toronto Alexithymia Scale (TAS-20; Bagby, Taylor, & Parker, 1994) has 20 items to assess one's level of alexithymia. It has three subscales: Difficulty in describing feelings (DDF; e.g., "It is difficult for me to find the right words for my feelings"), Difficulty in identifying feelings (DIF; e.g., "I am often confused about what emotion I am feeling"), and External oriented thinking (EOT; e.g., "Being in touch with emotions is essential" [negatively coded]). Participants responded to the questions in a 5-point Likert scale (1 = "Strongly disagree"; 2 = "Moderately disagree"; 3 = "Neither disagree nor agree"; 4 = "Moderately agree"; 5 = "Strongly agree"). The calculation of the TAS-20 total score, DDF subscale score, DIF subscale score, and EOT subscale score followed the instructions of the scale manual. After negatively coding some of the items, scores of all items were added together to obtain the total score of TAS-20. Scores of DDF, DIF, and EOT were the results of the summation of scores of subsets of items. DDF and DIF of the English version of TAS-20 have been reported to have consistently high internal reliability (Cronback's alpha = .75

to .87), but EOT was shown be less internally consistent (Cronback's alpha = .64 to .74) (Bagby et al., 1994a; Gignac et al., 2007; Parker et al., 2010; Preece et al., 2018).

BEQ. Berkeley Expressivity Questionnaire (BEQ; Gross & John, 1997) has 16 items to assess one's tendency to express emotion. It has three subscales: Negative expressivity (e.g., "It is difficult for me to hide my fear"), Positive expressivity (e.g., "I laugh out loud when someone tells me a joke that I think is funny"), and Impulse strength (e.g., "I experience my emotions very strongly"). Participants responded to the questions in a 7-point Likert scale (1 = "Strongly disagree"; 4 = "Neutral"; 7 = "Strongly agree"). The total score of BEQ was shown to have high internal reliability (Cronback's alpha = .82 to .85) (Dobbs, Sloan, & Karpinski, 2007; Gross & John, 1995). While Impulse strength also exhibit high internal reliability (Cronback's alpha = .73 to .78), the internal reliabilities of Negative expressivity (Cronback's alpha = .63 to .72) and Positive expressivity (Cronback's alpha = .63 to .71) was relatively lower (Dobbs et al., 2007; Gross & John, 1995).

HVIC. Horizontal and Vertical Individualism and Collectivism Scale (HVIC; Triandis & Gelfand, 1998) has 16 items to assess one's collectivism and individualism. It has four subscales: Horizontal individualism (HI; e.g., "I rely on myself most of the time; I rarely rely on others."), Vertical individualism (VI; e.g., "Winning is everything."), Horizontal collectivism (HC; e.g., "I feel good when I cooperate with others."), and Vertical collectivism (VC; e.g., "Parents and children must stay together as much as possible."). Participants responded to the questions in a 9-point Likert scale (1 = "Never or definitely no"; 9 = "Always or definitely yes"). VI (Cronback's alpha = .71 to .75) and VC (Cronback's alpha = .66 to .69) exhibited highest internal reliabilities, and HI (Cronback's alpha = .57 to .66) and HC (Cronback's alpha = .57) were shown to have lower internal reliabilities (Klassen, 2004).

2.2.3. Procedure

After giving their consents for participation, the respondents were first asked to complete a set of questions related to their demographic information (see Table 2.1). After that, the questionnaires of interest (AQ-28, DASS-21, TAS-20, BEQ, HVIC, and IAS (a to-be-published questionnaire related to interoceptive awareness developed by our collaborators, so the details of the questionnaire are not available yet)) were administrated in random order. All questions, except age (since it is a sensitive information. For other questions about sensitive information, such as gender and ethnicity, "Other" was available as an option), could not be skipped. After the completion of questionnaire, the respondents were debriefed about the purpose of the study.

2.2.4. Data analysis

The internal reliabilities of TAS-20 and its subscales were assessed by calculating their Cronback's alpha coefficients. We also calculated the inter-item correlation to investigate which items of the scale were not consistent with the rest of the items.

To investigate how alexithymia associates with different socio-emotional constructs, we performed linear regression analysis to predict TAS-20 with socio-emotional constructs controlling for age and gender. Any construct has a Variance Inflation Factor (VIF) value over 3.3 will be excluded from the model due to the introduction of collinearity (Akinwande, Dikko, & Samson, 2015; Kock; & Lynn, 2012; Midi, Sarkar, & Rana, 2010; Petter, Straub, & Rai, 2007).

SPSS Statistics 25 (IBM, NY, USA) was used for data analysis.

2.3. Results

In general, in the Singapore university student sample, the English version of TAS-20 scale has a high internal reliability (Cronback's alpha = .85). Among the three subscales, the reliabilities of DIF and DDF were the highest (Cronback's alpha = .86 and .75 respectively), while EOT had the lowest reliability (Cronback's alpha = .53). Our results were comparable with the reports from the western countries (Bagby et al., 1994a; Gignac et al., 2007; Parker et al., 2010; Preece et al., 2018). Interestingly, we found that the prevalence rate of alexithymia in Singapore university student is 24% and is higher than the rates previously reported in the other countries (10% to 19%) (Germany: Franz et al., 2008; UK: Mason et al., 2005; Canada: Parker et al., 1989; Finland: Salminen et al., 1999). This could be because of our sample's cultural orientation or specific demographic, e.g., being student population rather than general population. Lastly, we showed that alexithymia is related to deficits in both social constructs and emotional constructs.

2.3.1. Reliability of TAS-20 in Singapore university student sample

For TAS-20 total score, the Cronback's alpha coefficient was .85 suggesting that it has a high internal reliability. However, we spotted several items that had poor mean inter-item correlations. These items include Q5 ("I prefer to analyze problems rather than just describe them."; mean inter-item correlation = .07), Q10 ("Being in touch with emotions is essential."; mean inter-item correlation = .14), Q16 ("I prefer to watch "light" entertainment shows rather than psychological dramas."; mean inter-item correlation = .09), Q18 ("I can feel close to someone, even in moments of silence."; mean inter-item correlation = .08), Q19 ("I find examination of my feelings useful in solving personal problems."; mean inter-item correlation = .10), and Q20 ("Looking for hidden meanings in movies or plays distracts from their enjoyment."; mean inter-item correlation = .10). Interestingly, most of these questions (i.e., Q5, Q10, Q18, and Q19) are negatively coded and are loaded in EOT.

Separating by the TAS-20 subscales, the Cronback's alpha coefficients of DIF, DDF, and EOT were .86, .75, and .53 respectively. The mean inter-item correlations of the DIF and DDF items were .47 and .38 respectively, indicating that they had a good internal reliability. In contrast, EOT had a poor mean inter-item correlation (.13). The low correlation was driven by items include Q5 (mean inter-item correlation = .12), Q18 (mean inter-item correlation = .11) and Q20 (mean inter-item correlation = .04). This indicates that the EOT might not be well represented by all its items in the Singapore university students. Other studies in western countries also found that the EOT is less internally consistent than the other two subscales (Cronback's alpha = .64 to .74; Bagby et al., 1994a; Gignac et al., 2007; Parker et al., 2010; Preece et al., 2018).

In sum, in general, the TAS-20 has a high internal reliability which is comparable with those reported in the western countries (Cronback's alpha = .75 to .87; Bagby et al., 1994a; Gignac et al., 2007; Parker et al., 2010; Preece et al., 2018) in the Singapore university students. One of its subscales, the EOT, has a poor internal reliability. However, the same observation has also been reported in studies conducted in other samples (Bagby et al., 1994a; Gignac et al., 2007; Parker et al., 2010; Preece et al., 2018). Therefore, the English version of TAS-20 (especially its subscales DIF and DDF) has a high applicability in the Singapore university students.

2.3.2. Prevalence of alexithymia in Singapore university students

According to the traditional cut-off scores (≥ 61 in TAS-20) (Bagby et al., 1994b), the prevalence of alexithymia in the Singapore university students is 24% (LTAS (TAS-20 < 52) = 53%; MTAS (52 ⩽ TAS-20 < 61) = 23%). This prevalence rate was higher than those reported in other countries (10% in Germany, Franz et al., 2008; 18% in UK, Mason et al., 2005; 13% in Australia, McGillivray, Becerra, & Harms, 2017; 19% in Canada, Parker, Taylor, & Bagby, 1989; 13% in Finland, Salminen et al., 1999). While it might implicate a cultural difference in alexithymia (Dere et al., 2012; Dion, 1996; Lo, 2014), the higher rate of alexithymia in our sample might also be because of the differences in the population demography, e.g., students vs. working adults. Further discussion on different possible explanation to our findings will be discussed in *2.4. Discussion*.

2.3.3. Association of alexithymia with other socio-emotional constructs

Alexithymia was found to be correlated with most of the socio-emotional constructs (see Appendix I). Multiple linear regression analysis (Model 1 in Table 2.2) predicting TAS-20 scores with different socio-emotional constructs controlling for age and gender showed that alexithymia was significantly predicted by AQ-28 (β = .32, $t(186)$ = 4.93, p < .001), emotion expressivity (BEQ) (β = -.18, $t(186)$ = 2.87, p = .005), depression (β = .18, $t(186)$ = 2.19, p = .030), and horizontal individualism (β = -.14, $t(186)$ = 2.37, p = .019). Although none of the VIF values of predictors exceeded 3.3, suggesting a low level of collinearity in the regression model, stress appeared to have a relatively higher VIF value than other predictors. This might suggest that stress was confounding other factors at a certain degree. This was confirmed by the stepwise linear regression analysis which included all potential predictors (Model 2 in Table 2.2). In this model, we found that, on top of the predictors that found significant in Model 1, anxiety was also significantly predicted TAS-20 scores (β = .20, $t(190)$ = 2.71, p = .007) when stress was excluded from the model. This may suggest that the relationship between anxiety and alexithymia is confounded by stress. In general, we found that alexithymia is associated with both social constructs (i.e., autistic traits and emotion expressivity) and emotional constructs (i.e., depression and stress). Cultural values, i.e., individualism, is also related to alexithymia traits.

	Model 1				Model 2			
	β	*t*	*p*	VIF	*β*	*t*	*p*	VIF
AQ-28	.32	4.93	< .001	1.35	.33	5.29	< .001	1.21
BEQ	-.18	2.87	.005	1.29	-.17	2.82	.005	1.17
HI	-.14	-2.37	.019	1.12	-.12	2.08	.039	1.03
VI	.10	1.58	.115	1.14				
HC	.02	.34	.737	1.60				
VC	-.05	.80	.423	1.39				
Depression	.18	2.19	.030	2.19	.24	3.15	.002	1.80
Stress	.13	1.32	.188	2.82				
Anxiety	.13	1.52	.132	2.47	.20	2.71	.007	1.78
R^2		.41				.40		

Table 2.2. Summary of simple linear regression analysis (Model 1; $F(11, 186) = 11.94$, $p < .001$) and stepwise linear regression analysis (Model 2; $F(7, 190) = 17.97$, $p < .001$) predicting TAS-20 scores after controlling for age and gender. VIF – Variance Inflation Factor; BEQ – Berkeley Expressivity Scale; HI – Horizontal Individualism; VI – Vertical Individualism; HC – Horizontal Collectivism; VC – Vertical Collectivism.

2.4. Discussion

The Survey Study investigated the prevalence of alexithymia in Singapore and compared it with that of the western countries. We found that around 24% of the respondents were categorized as “alexithymic” among our sample of Singapore university students. This prevalence rate was higher than the reported values in other countries (10% to 19%; Franz et al., 2008; Mason, Tyson, Jones, & Potts, 2005; Parker, Taylor, & Bagby, 1989; Salminen, Saarijärvi, Äärelä, Toikka, & Kauhanen, 1999). Next, we examined how alexithymia is associated with other socio-emotional constructs. Alexithymia was found to be associated with both social constructs and emotional constructs.

One possible explanation to the higher alexithymia rate in Singapore university students than in other reports is the cultural differences in alexithymia (Dere et al., 2012; Dion, 1996; Lo, 2014). These studies demonstrated that the cultural differences in alexithymia is mediated by the endorsement of modernized values and beliefs (Dere et al., 2012), and the adoption of eastern and western values (Dere et al., 2012; Lo, 2014). More specifically, those who tend to adopt more traditional and Asian values and beliefs also tend to have higher alexithymia. Interestingly, among the three subscales of alexithymia, cultural difference was most consistently observed in EOT (Dere et al., 2012; Ryder et al., 2008). Since EOT concerns one's degree in attending to emotion and the emotional aspect of the world (Coffey, Berenbaum, & Kerns, 2003; Donges & Suslow, 2017), Asians might be less active in attending to their own emotions in order to fit into the social context (Mesquita & Albert, 2007).

Nonetheless, it should be acknowledged that other factors may also contribute to the observed high alexithymia rate in our sample. One key potential factor is the differences in subject demographics between our sample and the samples of other studies that reported alexithymia rate. For example, while most of those studies sampled general population who were mostly working adults (Franz et al., 2008; Hintikka et al., 2004; McGillivray et al., 2017; Salminen et al., 1999), we only sampled university students. One study conducted in UK sampled university students and reported an alexithymia rate of 18% (Mason et al., 2005). Although this alexithymia rate in UK university students is higher than the reported rate in the general population of Germany (10%; Franz et al., 2008), Finland (10% to 13%; Hintikka et al., 2004; Salminen et al., 1999), and Australia (13%; McGillivray et al., 2017), it is still lower than the rate in our sample. Yet, since no other studies recruited university student population reported the prevalence rate of alexithymia, whether this 6% difference between our sample and the UK sample (Mason et al., 2005) reaches statistical significance remains unclear.

In order to further understand how culture and population demographic affect alexithymia level, we summarized and contrasted the published mean TAS-20 scores by cultural orientations and demographic information (Figure 2.1). We found that there was no significant difference in TAS-20 scores between western-oriented cultures (Dere et al., 2012; Franz et al., 2008; Hintikka et al., 2004; Le et al., 2002; Loiselle & Cossette, 2001; Mason et al., 2005; McGillivray et al., 2017; Salminen et al., 1999; Tsaousis et al., 2010) and eastern-oriented cultures (Dere et al., 2012; Le et al., 2002; Moriguchi et al., 2007b; Pandey, Mandal, Taylor, & Parker, 1996; Sang, Chung, Hyo, & Sung, 2009; Zhu et al., 2007) ($t(16) = 1.31$, $p = .208$). In contrast, there is a trend that the student population (Dere et al., 2012; Le et al., 2002; Loiselle & Cossette, 2001; Mason et al., 2005; Pandey et al., 1996; Sang et al., 2009; Tsaousis et al., 2010) has higher TAS-20 scores than the general population (Franz et al., 2008; Hintikka et al., 2004; McGillivray et al., 2017; Moriguchi et al., 2007b; Salminen et al., 1999; Zhu et al., 2007) although the trend does not reach significance ($t(16) = 1.78$, $p = .094$). Therefore, with the available data from the literature, we are not able to conclude that whether the high alexithymia rate in our sample is due to the dominance in eastern-oriented culture or the sample being student population.

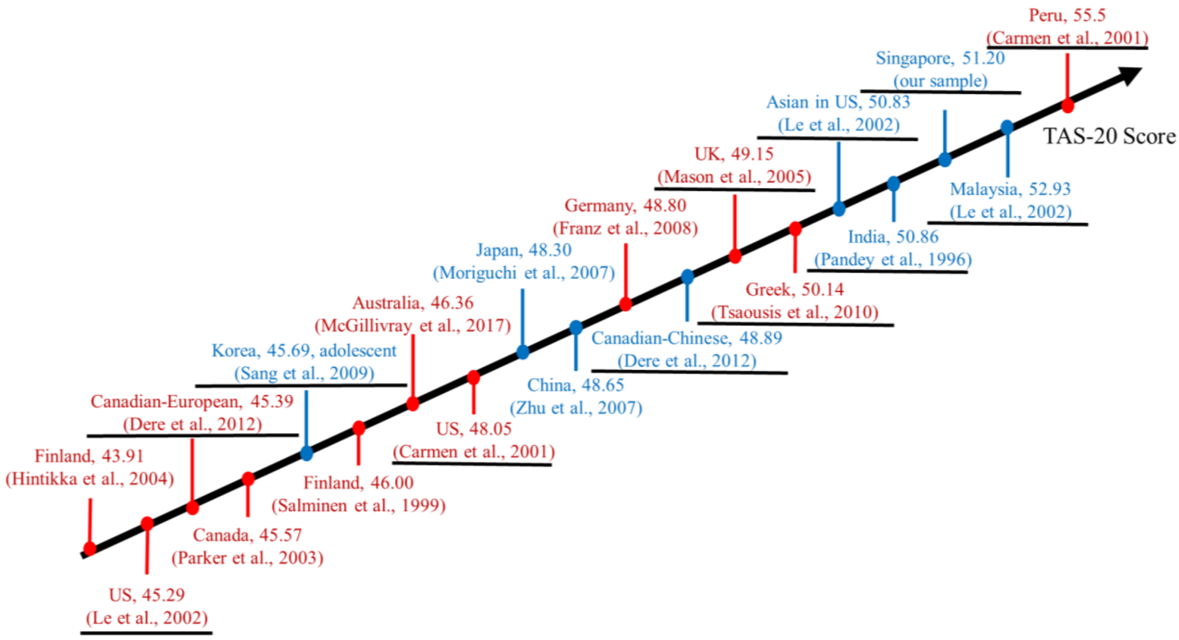

Figure 2.1. Summary of TAS-20 scores reported in different countries/population. Red font indicates western-oriented culture. Blue font indicates eastern-oriented culture. Underscored indicates student population was sampled, otherwise general population was sampled.

Other than cultural differences and demographic differences, we also need to be cautious when interpreting the finding due to the low internal reliability of EOT (Cronback's alpha coefficient = .53). The low internal reliability may indicate that not all of the items loaded in EOT represent the same concept. Although this phenomenon is more severe in our sample, similar reports can also be found in other reports (Bagby et al., 1994a; Gignac et al., 2007; Parker et al., 2010; Preece et al., 2018). In an attempt to solve the weak internal reliability of EOT, some theorists have proposed to separate EOT into two independent subscales (Gignac et al., 2007; Haviland & Reise, 1996). This proposal however is not commonly adopted in the field. Nonetheless, due to the low internal reliability of EOT in our sample, we cannot exclude the possibility that the EOT score is overestimated in our sample. This possibility can be directly tested when we include the UK sample and repeat the comparison in TAS-20 score after excluding the items with exceptionally low inter-item correlations.

Lastly, we demonstrated that alexithymia is associated with deficits in both social constructs and emotional constructs. The finding is coherent with the models which proposed that alexithymia is a deficit in emotion processing (Lane et al., 1997; Larsen et al., 2003). Experimental evidence showed that high alexithymia individuals tend to be less accurate in reporting their emotional feelings, and may even over-exaggerate their feelings during social events (Eastabrook et al., 2013; Pollatos et al., 2011). This provides the foundation for us to study their deficits in socio-emotional processing in the subsequent chapters.

One limitation of our study is that most of our subjects were from Nanyang Technological University. It is possible that, therefore, our findings may not be applicable to the entire university student population in Singapore. For example, in the academic year 2018 – 19, the proportion of undergraduates enrolled in science-related major was more in NTU (~61%; https://www.ntu.edu.sg/AboutNTU/CorporateInfo/FactsFigures/Documents/NTU_glance_2018.pdf) than in NUS (~55%; http://www.nus.edu.sg/registrar/info/statistics/ug-enrol-20182019.pdf). Since previous literature has shown that students from science major tend to score higher in autistic traits than those from non-science major (Baron-Cohen et al., 2001) and autistic traits are highly correlated with alexithymia trait (Bird & Cook, 2013; Kinnaird, Stewart, & Tchanturia, 2019), the alexithymia rate observed in this study may be affected by the site where we collected our data. On top of that, it is also possible that our sample may interpret some items in the scale in a different way from the participants of other studies, especially those from the western countries. To achieve a better validation of TAS-20 scale in

Singapore, future qualitative studies are needed to obtain the subject's interpretations of the items via interview and contrast with those obtained from the western population.

In sum (Table 2.3), in Survey Study, we found that Singapore university students have an alexithymia rate of 24% which is relatively high compared to those that have been reported in the literature in other countries. This could be because of the cultural orientation or the specific demographic of our sample, e.g., being student population rather than general population. This urges us to have a better understand of alexithymia so as to facilitate social cohesion in Singapore. Furthermore, we found that alexithymia is related to deficit in both social constructs and emotional constructs. This forms the foundation and set the direction for our experiments in the following chapters.

Major finding
1. Singapore university students (majority sampled in NTU) has an alexithymia rate of 24%
2. Alexithymia is related to both the deficit in social processing and emotional processing

Table 2.3. Summary of finding in Survey Study

Chapter 3

Experiment 1. Emotion-specific Eye-Contact Effect in Alexithymia

3.1. Overview

Interpreting social interaction and understanding others' social intention accurately allow us to make appropriate reaction to the present social situation. Gaze direction is an important facial cue that allows one to perform such social interpretation, especially when others are displaying facial emotion, because it indicates whether the social event is relevant to oneself or not (Emery, 2000; Langton et al., 2000). Therefore, inefficient processing of gaze direction and/or integrating the gaze information with other social cues, such as facial emotion, may lead one to have difficulty in daily social interaction. In the general population, individuals who are high in alexithymia traits, which prevalence rate is 10% - 19% (Franz et al., 2008; Mason et al., 2005; McGillivray et al., 2017; Parker et al., 1989; Salminen et al., 1999) in western countries and 24% in Singapore university students (see Survey Study), were shown to associate with reduced attention to eye regions during face perception (Bird et al., 2011). This eye avoidance tendency may cause them to be unable to evaluate the degree of self-relevance in a social interaction.

The evaluation of self-relevance is the processing to identify stimuli that are related to oneself (Northoff et al., 2006). The concept of "self" differs in different domains (Northoff et al., 2006). Broadly speaking, there are three major domains of "self": "physical self", "social-value of self", and "interpersonal self" (Sugiura, 2013). "Physical self" relates to one's own material existence in the external world and includes the processing of own face (e.g., Kircher et al., 2001; Sugiura et al., 2012), and own name (Tacikowski, Cygan, &

Nowicka, 2014; Zhao, Wu, Zimmer, & Fu, 2011) etc. "Social-value of self" concerns one's own social status, attributes, and others' evaluation on oneself. It is commonly studied by asking subjects to categorize adjectives that are related to oneself from those that are related to others (e.g., Kelley et al., 2002; Schmitz, Kawahara-Baccus, & Johnson, 2004). Lastly, "interpersonal self", which is the focus of this thesis, is associated with the awareness that whether one is involved in a social interaction or social situation. The processing of "interpersonal self" is studied by contrasting behavior or neural activation when one is perceiving direct gaze vs. averted gaze (e.g., Baltazar et al., 2014; Conty, George, & Hietanen, 2016), perceiving emotional images when instructed to judge their own feelings vs. to judge the location of the scene in the image (e.g., Gusnard, Akbudak, Shulman, & Raichle, 2001), and perceiving emotional images when instructed to judge their own feelings vs. to judge the feelings of the people in the images (e.g., Ochsner et al., 2004).

Does alexithymia affect the evaluation of self-relevance in socio-emotional processing? Experiment 1 attempts to address this question by examining the relationship between the gaze-related evaluation differences in emotional faces and alexithymia trait. We assessed the evaluation of self-relevance ability with the strength of eye-contact effect (Conty et al., 2016; Senju & Johnson, 2009) – the difference between the judgement of the faces with direct gaze and that of the faces with averted gaze. Face with direct gaze is self-relevant because the gaze direction indicates that the observer of the face falls into the communicator's focus of attention and is the potential target of the social interaction, whereas averted gaze suggests that the observer may not be included in the social interaction (N'Diaye et al., 2009; Sander et al., 2007).

Although the effect of gaze direction on the perception of facial emotion is commonly reported in the literature (Bayliss et al., 2007; Marschner et al., 2015; N'Diaye et al., 2009;

Sander et al., 2007; Sauer et al., 2014), how its influence varies across different emotions is rarely systematically investigated. Another contribution of Experiment 1 therefore is to identify the aspects (e.g., categorization accuracy, emotional intensity, potential threat imposed) of emotional face processing that is affected by gaze direction in different emotions. Since the processing of facial expression can vary across emotions (Fusar-Poli et al., 2009) and different facial expressions impose different social meanings (e.g., happy faces as social reward, and angry faces as social threat), we do not expect gaze direction to affect the perception of all facial emotions, or affect them all of them in the same way. Our thorough investigation of the influence of gaze on different facial emotions can be guide for the experimental design of the future studies. For example, if gaze direction mainly affects the level of perceived threat of angry faces, an attentional task will be recommended to study the eye-contact effect in angry faces in the future because attention should be biased towards threat (Bradley, Mogg, Falla, & Hamilton, 1998; Fox, Russo, & Dutton, 2002).

"Self" is a concept that has been commonly ignored in the alexithymia literature on socio-emotional processing, even though alexithymia originates from the deficit in understanding and expressing the emotion of oneself (Lesser, 1981; Taylor et al., 1991). In light of this negligence, Experiment 1 explores whether the ability in evaluating the extent of self-involvement in a social interaction is affected by alexithymia traits. It sets the foundation for our subsequent investigation on how alexithymia influences the evaluation of self-relevance when subjects process a social stimulus. Furthermore, the results from this experiment allow us to pinpoint the emotions of which the evaluation of self-relevance has been affected by alexithymia, such that in our subsequent experiments we can focus on a reduced set of emotions that has been piloted in this experiment.

Previous studies have demonstrated that, unlike typically developing children who reacted faster to fearful faces with averted gaze than those with direct gaze, children with autism reacted similarly towards the fearful faces with different gaze directions (Akechi et al., 2009). Subsequent ERP study found that the motivational congruent conditions (angry faces with direct gaze and fearful faces with averted gaze) elicited stronger N170 than incongruent conditions (angry faces with averted gaze and fearful faces with direct gaze) in the typically developing children (Akechi et al., 2010). Consistent with their behavioural findings, this motivational congruence-related enhancement in N170 amplitude was not observed in the ASD children. Since autism and autistic traits are closely related to alexithymia (Aaron et al., 2015; Foulkes et al., 2015; Hill et al., 2004) and alexithymia has been found to explain different emotional deficits in autism (Bird & Cook, 2013), we also measured the subjects' autistic traits and investigated if they confound the alexithymic deficit in the evaluation of self-relevance.

Besides rating the potential threat imposed on themselves by facial expression, we also asked the subjects to imagine another person sitting on their left-hand side (i.e., where the faces with averted gaze were looking) and rate how threatened this imaginary person feel when they perceive the faces. This additional question aims at tasking the subjects' gaze perception and their ability in identifying the communicator's focus of attention without activating the evaluation of self-relevance. We adopt Hoehl and colleagues' (2009) and Hietanen's (2018) view that the perception of gaze direction and the inference of other's focus of attention precedes self-relevance processing. If the inference of other's focus of attention is disrupted in alexithymia, we expect to observe that a diminished eye-contact effect both when the high alexithymia individuals were rating their own feeling of threat and when they were rating the imaginary person's feeling. Otherwise, if self-relevance evaluation is impaired but the ability in perceiving other's focus of attention remains intact in alexithymia, the diminished eye-contact effect is expected only when the high alexithymia individuals were rating their own feeling of threat.

In this experiment, we hypothesize that the processing of self-relevance evaluation in alexithymia is disrupted. Therefore, it is predicted that the higher the alexithymia trait is, the weaker the eye-contact effect will be. Moreover, since alexithymia has a strong association with the deficits in emotion processing, we expect that the correlation between the alexithymia trait and the eye-contact effect will be more prominent when the face is emotional. Lastly, if alexithymia only impairs self-relevance evaluation but leave the perception of other's focus of attention intact, the weakened eye-contact effect in alexithymia should only be observed when the subjects were rating their own feeling, but not when they were rating the feeling of the imaginary person.

3.2. Methods

3.2.1. Participants

Sixty-one subjects were recruited and consented to participate. Sixty subjects (38 females, mean age = 23.07), with normal or corrected-to-normal vision, were included in the analysis. One subject did not complete the experiment and thus data from this subject was not included in the analysis. Previous similar studies used relatively fewer subjects (e.g., 21-36, in Adams & Kleck, 2003; N'Diaye, Sander, & Vuilleumier, 2009; Sander et al., 2007; Sato, Kochiyama, Uono, & Yoshikawa, 2010), but since we are investigating individual differences, we recruited more subjects to cover individuals at the extreme ends of the two personality traits. Table 3.1 illustrates the demographic information of the participants whose data were included in the analysis. Informed consents were obtained from the subjects before the experiments. This study was approved by the Institutional Review Board (IRB) at

Nanyang Technological University, Singapore, by the Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving human subjects.

N	60
Gender (F/M)	38/22
Age	23.07 (3.23)
TAS-20	49.97 (11.53)
AQ	21.42 (6.74)

Table 3.1. Demographic information of the participants in Experiment 1. AQ – Autism-Spectrum Quotient scores; TAS-20 – Toronto Alexithymia Scale scores. Standard deviations are shown in brackets.

3.2.2. Apparatus

The experiment was conducted on HP ProDesk with the screen HP Elite E201 (resolution = 1600 pixels x 900 pixels; refresh rate = 60 Hz). The distance of the screen from the participants was about 56 cm. The experiment was designed and carried out on the online platform TESTABLE (www.testable.org).

3.2.3. Stimulus

Faces of six identities (three females) were selected from the Nanyang Facial Emotional Expression [N-FEE] Database (Yap et al., 2016). Five emotions (i.e., Angry, Happy, Fearful, Sad and Neutral) were included for each identity. The selected faces were all in grey scale, of the same size (5.6° × 7.9° at 56cm screen distance) and with face region shadowed. To create faces with averted gaze, we shifted the locations of the pupils for each facial image to the left by around 0.2° (0.2cm). Therefore, there are 60 faces in total (6 identities × 5 emotions × 2 gaze directions). The image manipulation was done with Photoshop CS5 (Adobe System Inc., CA, USA)

3.2.4. Procedure

The experiment was conducted in a computer lab and a maximum number of 9 subjects could do the task simultaneously. The subjects were asked to complete the Toronto Alexithymia Scale (TAS-20; Bagby, Taylor, & Parker, 1994) and the Autism-Spectrum Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001) questionnaires before the behavioural task. Before the behavioural experiment, the subjects were instructed to imagine that there was another person sitting on their left-hand side, where the faces with averted gaze were looking. In each trial of the behavioural task (see Figure 3.1), a face stimulus was presented on the screen and the subjects were asked to, sequentially, identify the emotion of the face (accuracy), to rate the emotional intensity of the face (intensity rating), to rate how threatening the face was to them (self-threat rating), and to rate how threatening the face was to the imaginary person when he/she saw the face at their angle (other-threat rating). All ratings were made on a 9-point Likert scale. Each face stimulus was only presented once for the entire experiment, resulting in 60 trials (6 identities × 5 emotions × 2 gaze directions) in total.

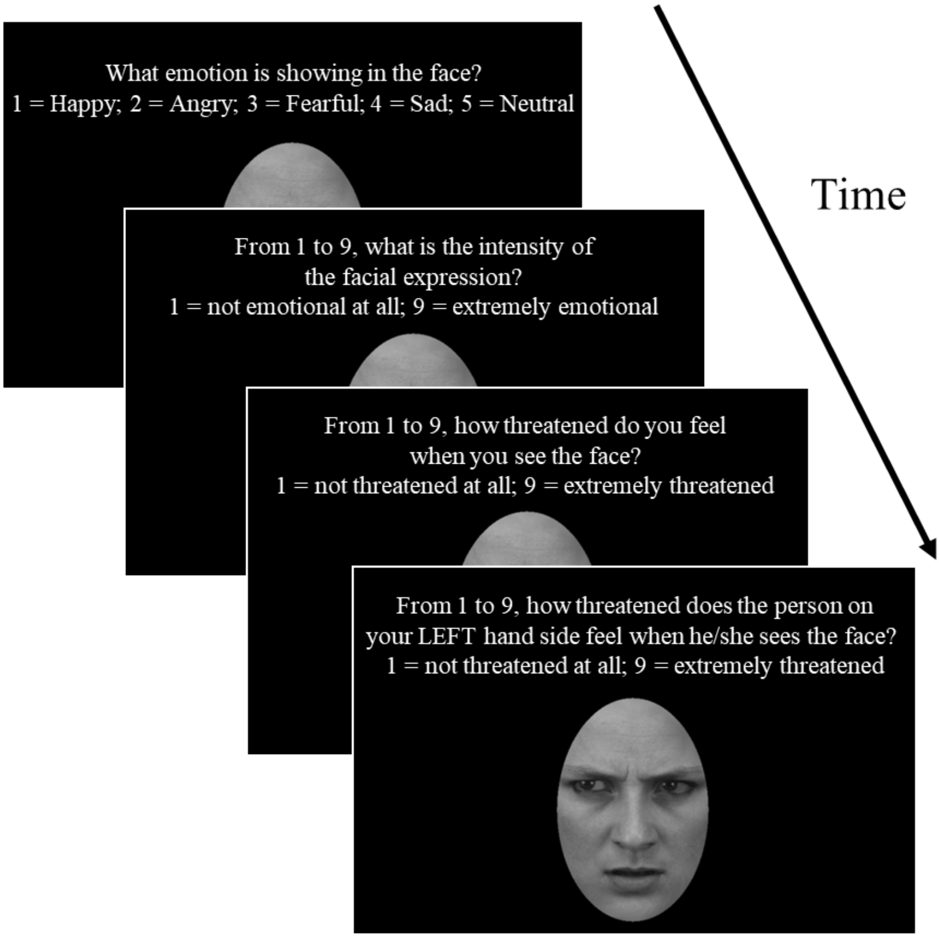

Figure 3.1. Trial Sequence of Experiment 1. An angry/happy/fearful/sad/neutral face with direct/averted gaze was presented at the center. The participants were required to, sequentially, identify the emotion of the face, rate the intensity of the emotion, rate how threatened they feel by the face, and how threatened an imaginary person on their left-hand side feels by the same face. Faces from KDEF database are used for demonstration because pictures from the N-FEE Database (Yap et al., 2016) are not allowed for publication.

3.2.5. Data analysis

To examine whether eye-contact effect is emotion specific, 2-way analysis of variance (ANOVA) models were conducted with within-subject variables *Emotion* (Neutral vs. Angry vs. Happy vs. Fearful vs. Sad) and *Gaze Direction* (Direct vs. Averted) on the subjects' accuracy, intensity rating, self-threat rating, and other-threat rating respectively.

The definitions of the two types of eye-contact effects are as follows:

Eye-contact effect =

rating of faces with direct gaze – rating of faces with averted gaze

Emotion-specific eye-contact effect =

eye-contact effect of emotional face – eye contact effect of neutral face

To test whether self-relevance evaluation during social perception is modulated by the subjects' alexithymia trait, we correlated the eye-contact effects of the neutral faces and the emotion-specific eye-contact effects with the subjects' TAS-20 scores. To minimize the number of correlations, we only tested the emotion-specific eye-contact effects that were significant. Non-parametric Spearman's correlation analysis was used because the eye-contact effects were not all normally distributed. Greenhouse-Geisser correction (when sphericity assumption is violated) and Holms-Bonferroni correction (for multiple pairwise comparisons and correlations) were applied when appropriate. SPSS Statistics 25 (IBM, NY, USA) and Matlab R2018a (Mathworks, MA, USA) were used for data analysis.

3.3. Results

Overall, we found that gaze direction modulates the recognition accuracies and the threat ratings of the emotional faces. Among all of the significant emotion-specific eye-contact effects, only that of angry faces was correlated with the alexithymia trait, such that the higher TAS-20 one scores, the more likely one would feel equally threatened by angry faces with different gaze directions. AQ scores, however, did not predict any of the eye-contact effects.

3.3.1. Emotion-specific eye-contact effect

For recognition accuracy (Figure 3.2a), two-way analysis of variance (ANOVA) revealed significant main effects of *Emotion* ($F(3.21, 189.23) = 15.58$, $p < .001$, Greenhouse-Geisser-corrected), *Gaze Direction* ($F(1, 59) = 4.29$, $p = .043$), and interaction effect of *Emotion* × *Gaze Direction* ($F(3.22, 190.20) = 8.86$, $p < .001$, Greenhouse-Geisser-corrected). To further examine the main effect of *Emotion*, happy face was more accurately recognized than the others (ps < .001, Holms-Bonferroni-corrected), whereas neutral face was less accurately recognized than all the other faces (ps < .05, Holms-Bonferroni-corrected). In the main effect of gaze, faces with direct gaze were also more accurately recognized than those with averted gaze ($t(59) = 2.07$, $p = .003$). To further investigate the interaction effect, we found that the eye-contact effect of fearful faces is significantly different from that of neutral faces ($t(59) = 4.77$, $p < .001$, Holms-Bonferroni-corrected), that of happy faces ($t(59) = 3.30$, $p = .016$, Holms-Bonferroni-corrected), and that of sad faces ($t(59) = 6.49$, $p < .001$, Holms-Bonferroni-corrected), such that the reversed eye-contact effect of fearful faces (i.e., faces with averted gaze were more accurately recognized than those with direct gaze) was stronger than these faces. The reversed eye-contact effect of sad faces was also stronger than that of happy faces ($t(59) = 2.95$, $p = .035$, Holms-Bonferroni-corrected)

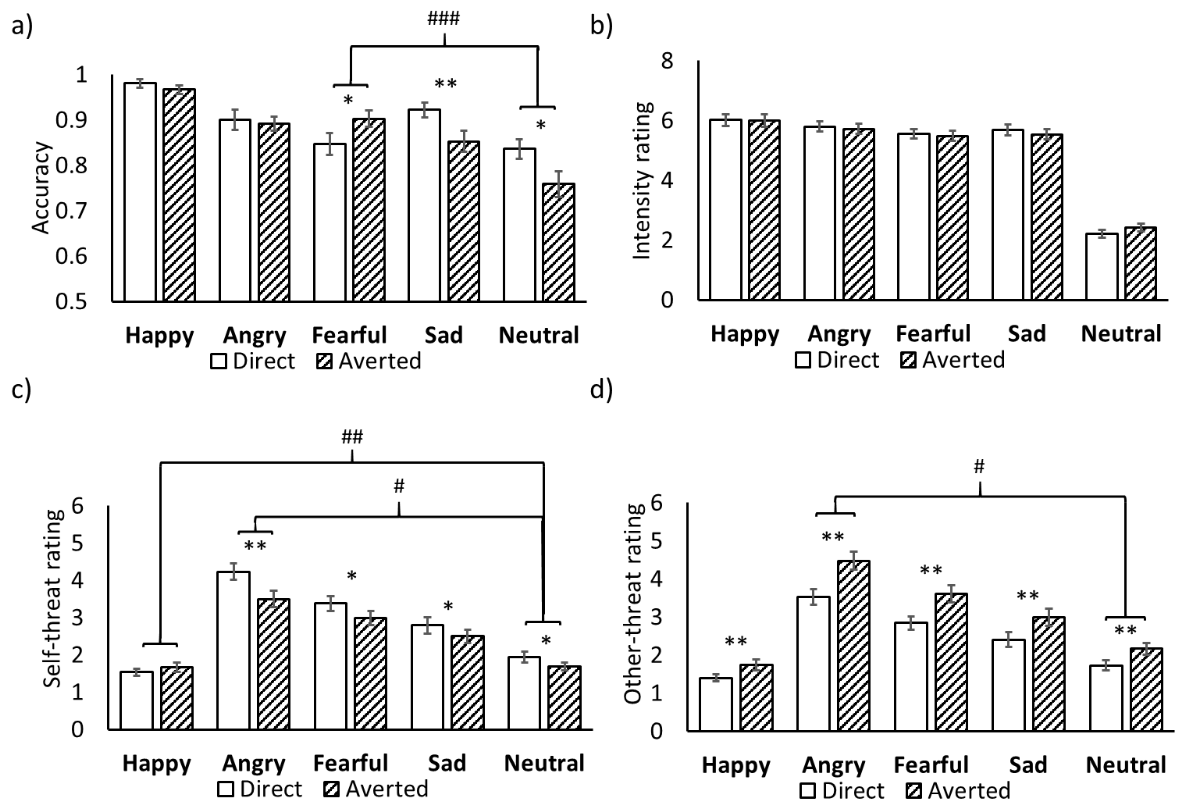

Figure 3.2. Summary of behavioral responses. Response in a) accuracy, b) intensity rating, c) self-threat rating, and d) other-threat rating from Experiment 1. Asterisk (*) indicates significant difference between gaze direction conditions (i.e. eye-contact effect). * $p < .05$, ** $p < .01$, *** $p < .001$. Hashtag (#) indicates significant difference between the eye-contact effect of the emotional faces and that of neutral faces (i.e. emotion-specific eye-contact effect). # $p < .05$, ## $p < .01$, ### $p < .001$. Error bars indicate the standard errors of mean.

The ANOVA on the intensity ratings (Figure 3.2b) of the faces revealed a significant main effect of *Emotion* (F(2.34, 138.01) = 192,02, $p < .001$, Greenhouse-Geisser-corrected). *Post-hoc* analyses showed that happy faces were rated to be more intense than fearful (t(59) = 3.81, $p = .002$, Holms-Bonferroni-corrected), sad (t(59) = 3.09, $p = .015$, Holms-Bonferroni-corrected) and neutral faces (t(59) = 16.42, $p < .001$, Holms-Bonferroni-corrected). Neutral faces were rated less intense than all emotional faces (ps < .001, Holms-Bonferroni-corrected). None of the other main effect nor interaction effect was significant (ps > .05).

In the ANOVA on the self-threat ratings, both main effects of *Emotion* ($F(2.57, 151.47) = 73.94$, $p < .001$, Greenhouse-Geisser-corrected) and *Gaze Direction* ($F(1, 59) = 23.01$, $p < .001$) were found significant (Figure 3.2c). Explaining the main effect of *Emotion*, angry faces were rated as more threatening to oneself than all other faces (*p*s < .001, Holms-Bonferroni-corrected) and happy faces were rated to be less threatening than all other faces (*p*s < .05, Holms-Bonferroni-corrected). Also, faces with direct gaze were rated as more threatening than those with averted gaze ($t(59) = 4.80$, $p < .001$). The interaction *Emotion* × *Gaze Direction* was found to be significant ($F(3.39, 199.77) = 9.26$, $p < .001$, Greenhouse-Geisser-corrected). *Post-hoc* analyses revealed that the interaction effect could be caused by the eye-contact effect of happy faces was significantly less than that of all the other faces (*ps* < .010, Holms-Bonferroni-corrected). On top of that, the eye-contact effect of angry faces was significantly more than that of neutral faces ($t(59) = 2.87$, $p = .035$, Holms-Bonferroni-corrected), that of happy faces ($t(59) = 6.03$, $p < .001$, Holms-Bonferroni-corrected), and that of sad faces ($t(59) = 2.78$, $p = .036$, Holms-Bonferroni-corrected).

Lastly, in the ANOVA on other-threat ratings (Figure 3.2d), the main effects of *Emotion* ($F(2.68, 158.10) = 79.14$, $p < .001$, Greenhouse-Geisser-corrected) and *Gaze Direction* ($F(1, 59) = 36.23$, $p < .001$) again were significant. Angry faces were rated as more threatening to the imaginary person to the left-hand side of the subjects than all other faces (*p*s < .001, Holms-Bonferroni-corrected). Happy faces, on the other hand, were rated as less threatening than all other faces (*p*s < .001, Holms-Bonferroni-corrected). To explain the significant *Gaze Direction* main effect, faces with averted gaze (i.e., looking at the imaginary person) were rated as more threatening to the imaginary person than those with direct gaze (i.e., looking away from the imaginary person) ($t(59) = 6.02$, $p < .001$). On top of the main effects, there was a significant *Emotion* × *Gaze Direction* interaction effect ($F(3.31, 195.04) = 5.25$, $p = .001$, Greenhouse-Geisser-corrected). The interaction could be caused by the eye-contact effect of angry faces was significantly stronger than that of neutral faces ($t(59) = 2.94$, $p = .045$, Holms-Bonferroni-corrected) and that of happy faces ($t(59) = 3.24$, $p = .020$, Holms-Bonferroni-corrected).

3.3.2. Alexithymia mediates the emotion-specific eye-contact effect

To examine the correlation of personability traits, we found significant correlation between TAS-20 scores and AQ scores ($r = .540$, $p < .001$). Age was not correlated with TAS-20 scores ($r = -.24$, $p = .062$) nor AQ scores ($r = -.15$, $p = .246$). TAS-20 scores were also not correlated with the categorization accuracies, the intensity ratings, the self-threat ratings and the other-threat ratings of each emotional face averaged across gaze directions after correcting for multiple correlations (ps > .05).

Then, we examined whether autistic traits mediate the eye-contact effects of neutral faces, and correlated the eye-contact effects in accuracy, intensity rating, and self-threat rating of the neutral faces with the two traits. None of the correlations were significantly correlated with AQ scores (ps > .05). Similarly, none of the eye-contacts of neutral faces were correlated with TAS-20 scores (ps > .05). This suggests that neither alexithymia trait nor autistic traits affect the eye-contact effects of neutral faces.

Next, we investigated whether the emotion-specific eye-contact effects that were significant (i.e., fear-specific eye-contact effect in accuracy, happiness-specific eye-contact effect in self-threat rating, and anger-specific eye-contact effect in self-threat rating) were mediated by the two personality traits. Again, none of the correlations were significant for AQ scores (ps > .05). In contrast, the anger-specific eye-contact effect in self-threat rating (eye-contact effect of angry faces - eye-contact effect of neutral faces; $r_s = -.36$, $p = .015$, Holms-Bonferroni-corrected, Figure 3.3a) was significantly correlated with TAS-20 scores. This suggests that the lower TAS-20 score one has, the stronger the eye-contact effect of angry faces is compared to that of neutral faces. This indicates that the high alexithymia subjects may have difficulty in deciphering the intention of anger expressed by gaze direction.

Since the eye-contact effect of neutral faces did not relate to TAS-20 scores, the significant correlation in the anger-specific eye-contact effect is most likely driven by the eye-contact effect of angry faces. It was confirmed by the subsequently found significant correlation between the eye-contact effect of angry faces and TAS-20 scores ($r_s = -.28$, $p = .033$, Figure 3.3b). The correlation indicates that the higher TAS-20 score one has, the weaker the eye-contact effect of angry faces, i.e., less differentiable between angry faces with different gaze directions. It can be visualized by isolating the subjects with low alexithymia trait (LTAS; TAS-20 < 52, n = 29), those with medium alexithymia trait (MTAS; 52 ≤ TAS-20 < 61, n = 20) and those with high alexithymia trait (HTAS; TAS-20 ≥ 61, n = 11) (Bagby & Taylor, 1997). For LTAS, the self-threat rating of angry faces with direct gaze (3.89 units) was significantly higher than those with averted gaze (2.90 units; $t(28) = 5.44$, $p < .001$, Holms-Bonferroni-corrected, Figure 3.3c). However, the rating differences were not significant in MTAS (direct vs averted: 4.42 units vs. 3.90 units; $t(19) = 1.77$, $p = .094$) and HTAS (direct vs averted: 4.80 units vs. 4.32 units; $t(10) = 1.75$, $p = .111$, Figure 3.3d).

Partial correlation showed that the relationship between alexithymia and anger-specific eye-contact effect remained significant even after the effect of AQ scores was partialled-out ($r_s = -.39$, $p = .002$). The correlation between the eye-contact effect of angry faces and TAS-20, on the other hand, was slightly reduced after partialling-out the effect of AQ ($r_s = -.24$, $p = .073$). This suggests that autistic traits have minimum effect in explaining the alexithymic influence on self-relevance evaluation.

Then, we correlated anger-specific eye-contact effect in other-threat rating with TAS-20 scores to examine whether alexithymia affects one's ability to perceive others' focus of attention. The correlation was found to be not significant (r_s = -.06, p = .638), suggesting that the alexithymic individuals' perception of others' focus of attention was intact.

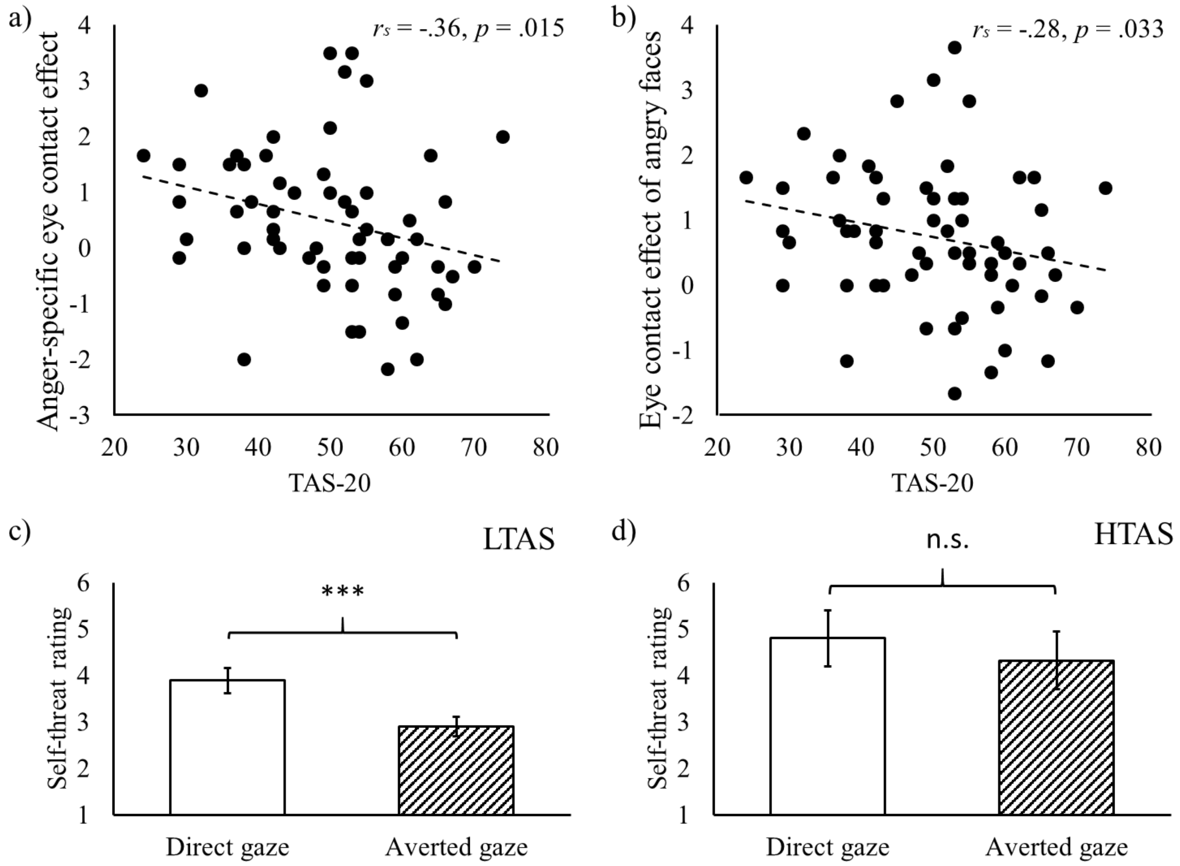

Figure 3.3. The top panels show the scatter plots between the TAS-20 scores and a) the anger-specific eye-contact effect; and b) the eye-contact effect of angry faces in self-threat rating. Spearman's correlation is reported. In (a), positive values indicate stronger eye-contact effect in angry faces than in neutral faces, and negative values indicates otherwise. The *p*-value was corrected for multiple correlations. In (b), positive values indicate angry faces with direct gaze were rated more threatening to oneself than those with averted gaze, and negative values indicates otherwise. (b) is a follow-up analysis based on (a) so no correction was applied to the *p*-value. The bottom panels show the bar graphs illustrating the eye-contact effects of angry faces in self-threat rating c) in LTAS (TAS-20 < 52); and d) in HTAS (TAS-20 ⩾ 61). n.s., $p > .05$; ***, $p < .001$. Error bars indicate the standard errors of mean.

3.3.3. Effect of task familiarity in alexithymic influence on anger-specific eye-contact effect

To explore whether task familiarity affect the alexithymic reduction in eye-contact effect in angry faces, we correlated TAS-20 scores with the anger-specific eye-contact effects in the first half of the task and the second half of the task separately. After correcting for multiple correlations, none of the correlations with anger-specific eye-contact effects were significant. Therefore, we report the results that did not apply any correction in the following and thus one has to be cautious when interpreting the results. We found that in the first half of the task, TAS-20 scores were not correlated with neither anger-specific eye-contact effects in both self-threat rating ($r_s = -.19$, $p = .176$) and other-threat rating ($r_s = -.11$, $p = .458$). In contrast, in the second half of the task, TAS-20 scores were significantly correlated with the anger-specific eye-contact effect in self-threat rating ($r_s = -.27$, $p = .046$) and marginally correlated with that in other-threat rating ($r_s = -.25$, $p = .060$). Further analyses revealed that the significant correlations with the anger-specific eye-contact effect in self-threat rating may be driven by the marginally significant correlation between TAS-20 scores and eye-contact effect of angry faces ($r_s = -.23$, $p = .076$). The correlation between TAS-20 scores and eye-contact effect of neutral faces in self-threat rating, on the other hand, was not significant ($r_s = .01$, $p = .927$). In contrast, the marginally significant correlations with the anger-specific eye-contact effect in other-threat rating may be driven by the significant correlation between TAS-20 scores and eye-contact effect of neutral faces ($r_s = .34$, $p = .010$). The correlation between TAS-20 scores and eye-contact effect of angry faces in other-threat rating, on the other hand, was not significant ($r_s = .06$, $p = .671$).

3.4. Discussion

Experiment 1 explored whether alexithymia affects self-relevance evaluation in socio-emotional processing. We found significant eye-contact effects in most of the behavioural measures (accuracy, self-threat rating, and other-threat rating) except for the intensity rating. Furthermore, gaze direction imposes different effects on categorization accuracy for different emotions, such that direct gaze increased accuracy in sad and neutral faces more than averted gaze, but the opposite was found in fearful faces. Consistent trend of the gaze direction effect was observed in most of the emotions for self-threat rating: direct gaze increased the self-threat rating for angry, fearful, sad and neutral faces. The opposite trend was observed in all emotions for other-threat rating. Aligned with our hypothesis, the magnitude of the emotion-specific eye-contact effect was associated with the alexithymia trait. The alexithymic influence in eye-contact effect was observed in the self-threat rating of the angry faces: the higher the subject scores in TAS-20, the weaker the anger-specific eye-contact effect is.

In the literature reporting eye-contact effect, faces with direct gaze tend to attract more attention than faces with averted gaze (Böckler et al., 2014; Doi et al., 2009; Shirama, 2012; von Grünau & Anston, 1995). Hietanen (2018) argues that the attention bias towards direct gaze because it generates more affiliative responses in the perceiver. Our results however contradict the affiliative eye contact hypothesis. We found that neutral faces looking at the perceiver tend to be rated as more threatening that those that looking away from the perceiver. Similar results were also reported in previous studies (Hietanen, Leppänen, Peltola, Linna-aho, & Ruuhiala, 2008; Pönkänen et al., 2011; Sauer et al., 2014). Hietanen and colleagues (2008; also see Pönkänen et al., 2011) for example, reported that subjects rate neutral faces with averted gaze as more pleasant than those with direct gaze. Of note, the affiliative eye contact hypothesis is based on evidence from behavioural paradigm with implicit measures, such as the affective priming paradigm, and neural imaging techniques

(Hietanen, 2018). Hietanen (2018) attempted to explain the discrepancy found between the explicit measures and the implicit measures by suggesting 1) that individuals' explicit responses may not fully reflect their implicit affective response, and 2) that explicit measures may reflect one's negative feeling of the self-directed attention caused by the direct gaze, whereas implicit measures capture the positive automatic responses towards direct gaze because it promotes potential social interaction and cooperation.

Another explanation to the discrepancy between our findings and the affiliative eye contact hypothesis may be the cultural differences in the social appraisal of eye contact. Recent studies suggest that there might be cultural differences in eye contact effect during face perception. For example, Akechi and colleagues (2013) recorded the heart rate and looking time of Finnish participants and Japanese participants when they were rating emotional faces that were either looking at the participants or looking away from them. The authors found that while the eye contact effect in physiological responses and looking time did not differ across cultures, the Japanese participants, but not the Finnish participants, tended to rate the neutral faces with direct gaze as angrier and sadder than those with averted gaze. In contrast, the Finnish participants, but not the Japanese participants tended to rate the faces with direct gaze as more approachable than those with averted gaze. The authors argued that the results suggest that the cultural differences in eye fixation during face perception is due to cultural norm rather than physiological differences. Another study from Uono and Hietanen (2015) partially replicated the findings from Akechi and colleagues (2013), such that they found that the Japanese participants rated the faces with averted gaze as more dominant than the Finnish participants. Therefore, it is possible that affiliative eye contact hypothesis is only applicable to Westerners while to East Asians eye contact is aversive and threatening.

Despite the inconsistent findings in non-emotional eye-contact effect between explicit measures and implicit measures, studies using either measures have well-documented that eye-contact effect is modulated by facial emotion (Bayliss et al., 2007; Marschner et al., 2015; N'Diaye et al., 2009; Sander et al., 2007; Sauer et al., 2014). The emotional modulation of eye-contact effect was suggested to depend on the motivational orientation of the facial emotion (i.e., happiness and anger as approach-oriented emotions, while sadness and fear are avoidance-oriented emotion; Adams, Gordon, Baird, Ambady, & Kleck, 2003; Adams & Kleck, 2003; Carver & Harmon-Jones, 2009; Rolls, 2006). In a similar vein, Adams and Kleck (2003) postulated that direct gaze is associated with approach-oriented motivation and averted gaze is associated with avoidance-oriented motivation. An enhancement in responses is expected when the motivational orientation of the gaze direction is coherent with the facial emotion, such as direct gaze for approach-oriented emotions (e.g., happy and angry) and averted gaze for avoidance-oriented emotions (e.g., sadness and fearful). However, our findings did not fully support this hypothesis. In fact, the emotional modulation in eye-contact effect depends on the questions that were asked to the subjects. For example, subjects rated angry faces with direct gaze as more threatening than those with averted gaze, but the difference was not found when they were asked to rate the intensity of the facial emotion. Likewise, subjects categorized fearful faces with averted gaze more accurately than those with direct gaze, but fearful faces with direct gaze were rated as more threatening than those with averted gaze.

One possible explanation to our findings is that gaze direction modulates the social meaning of the facial emotion. For instance, angry faces signal potential social threat, but the averted gaze reduce the threat that the face is signalling because it suggests that oneself is not the target of the threat (N'Diaye et al., 2009; Sander et al., 2007). Gaze direction therefore only modulates the rating to the angry faces when the question is related to social threat.

Happy faces, on the other hand, do not imply any social threat so gaze direction has minimum effect on their ratings in threat-related questions. If our explanation is true, we would expect gaze direction to modulate ratings of happy faces when the question is related to social reward. Lastly, unlike the gaze effects in angry faces and happy faces, gaze direction affects the categorization accuracy of fearful faces. According to the appraisal theory of emotion (Scherer, 2001), gaze aversion is part of the expression when the situation is unpleasant and one has no effective coping strategy. Gaze aversion, therefore, is part of a typical fearful face and this explains why subjects tended to miscategorise the fearful faces with direct gaze as other negative emotions.

Up to now, whether the eye-contact effect of emotions is related to any personality traits is rarely explored in the literature. Since high alexithymia individuals were found to pay less attention to the eye region than low alexithymia individuals, we hypothesized that the emotional eye-contact effect would be reduced in the high alexithymia individuals. Aligning with our hypothesis, the eye-contact effect related to angry faces in self-threat rating was found to decrease as one's TAS-20 score increased. In other words, the low alexithymia individuals felt more threatened when the angry faces were looking at them compared to those that were looking away from them, whereas such rating difference between different gaze directions was reduced in the highly alexithymic individuals. Interestingly, when the highly alexithymic individuals were asked to imagine how others felt towards the angry faces with different gaze directions, they performed similarly to the low alexithymia group. This suggests that the highly alexithymic individuals may have an intact gaze perception as well as the ability in inferring focus of attention from the aggressor's eye gaze. It seems that their impaired self-relevance evaluation when perceiving angry faces is a cognitive deficit rather than a perceptual deficit. In other words, they feel threatened even though they know the aggression is not targeted at them. Eye-contact effect has been associated with the activation of the self-referential processing (Conty et al., 2016), which is defined as the process that "concerns stimuli that are experienced as strongly related to one's own person" (Northoff et al., 2006). Frontal regions such as the insula and the mPFC are commonly associated to the neural networks of the self-referential processing (Conway et al., 2016; Hu et al., 2016; Jenkins, Macrae, & Mitchell, 2008; Moeller & Goldstein, 2014; Northoff et al., 2006; Schmitz & Johnson, 2007). Therefore, the impaired self-relevance evaluation in alexithymia we found in this experiment agrees with the literature showing that these frontal regions of highly alexithymic individuals tend to be less activated when the subjects perceive negative emotional images (Deng, Ma, & Tang, 2013; Jongen et al., 2014; Lassalle et al., 2018; for meta-analysis, see Van der Velde et al., 2013). Interestingly, exploratory analysis on the time course of this alexithymic reduction in eye-contact effect during social threat processing showed that it may be more prominent in the second half of the experiment, i.e., when the subjects were more familiar with the task and when prolonged exposure to emotion processing is necessary. It suggests that perhaps the impairment in self-relevance evaluation in high alexithymia individuals is related to their early disengagement from gaze processing during social situation. However, this possibility need further evaluation as the current task is not designed to test this hypothesis. Together, it appears that alexithymia might relate to the difficulty in using self as the reference for socio-emotional processing.

Although it is intriguing to interpret our findings as evidence for impaired self-relevance processing but intact focus of attention inference in alexithymia, we also need to consider another possibility - that the absence of the relationship between alexithymia and the anger-specific eye-contact effect in other-threat rating is due to the order of the question presentation. In the experiment, since the other-threat rating question is always presented after the self-threat rating question, the faces were processed longer when answering the other-threat rating question. The extra processing time may allow the highly alexithymic individuals to gather enough information to infer focus of attention from the face's eye gaze for the other-threat rating question, and thus they can perform the same as the low alexithymic individuals. This possibility is indirectly supported by previous studies showing that the high alexithymia individuals are particularly impaired in identifying briefly presented facial emotions and are less sensitive in emotional face categorization than the low alexithymia individuals (Cook et al., 2013; Ihme et al., 2014b; Parker et al., 2005; Prkachin et al., 2009; Starita et al., 2018). The highly alexithymic population therefore might take longer to process facial information to acquire emotional information, but if enough time is given, they can perform as well as the low alexithymia individuals. In a similar vein, the high alexithymia individual may need more time to acquire gaze information and use it for social decision making.

Surprisingly, in contrast to Akechi and colleagues' (2009, 2010) findings, we showed no evidence for autistic traits correlating with emotion-specific eye-contact effects. Since the experimental designs of this study and Akechi and colleagues' (2009, 2010) work are different, one possible explanation for the absence of autistic effect is that the autistic individuals identify and rate the faces similarly to the non-autistic individuals as shown in our study, but the processing of emotional faces with motivational-incongruent gaze direction is more effortful to the autistic individuals, as indicated by the slower reaction time in Akechi and colleague (2009). Other than the difference in paradigm, our subjects were also of a subclinical adult population, while clinically autistic children were recruited in Akechi and colleagues (2009, 2010). Another possible reason for this finding therefore is that the autistic symptom severity of our subjects was not as high as the subjects in Akechi and colleagues' (2009, 2010) study. The impairment in emotion-specific eye-contact effects might only be prominent in the individuals who have extremely high autistic traits.

Although our results show a promising direction for understanding alexithymia, they need to be interpreted with caution due to limitations in this experiment. An outstanding limitation is that our correlation findings (e.g., correlation between TAS-20 scores and anger-specific eye-contact effect) survived Holms-Bonferroni correction only when it was analysed with non-parametric Spearman's correction. Although the main reason for us to apply Spearman's correlation rather than Pearson's correlation was that the distributions of the eye-contact effects were not normal, this also points to the possibility that there might be outliers in our data. In fact, based on Cook's distance (cutoff = 4/(n-p) = 0.069) and DFBETA (cutoff = $2/n^{1/2}$ = 0.258) (Fox, 1991), there were two outliers identified. If excluding these two outliers from the analysis, the correlation between alexithymia and the anger-specific eye-contact effect in self-threat rating would become significant even when Pearson's correlation was applied (r = -.38, p = .012, Holms-Bonferroni-corrected).

In sum (Table 3.2), in Experiment 1, we found that the highly alexithymic individuals have a reduced anger-specific eye-contact effect in self-threat rating. Alexithymia therefore is associated with deficit in self-relevance evaluation during angry face perception. One unresolved question is that whether this deficit is related to their reduced attention to the eye region (e.g., Bird, Press, & Richardson, 2011). If the two alexithymic behavioural tendencies are related, the alexithymic eye avoidance should be extended to and even more prominent in angry faces. In Experiment 2, we aimed to test this hypothesis.

Major finding
1. Alexithymia is related to the reduced self-relevance evaluation, indexed by the magnitude of eye-contact effect, during social threat (angry face) perception

Table 3.2. Summary of finding in Experiment 1

Chapter 4

Experiment 2. Emotion Specificity and Face Orientation Specificity of Eye avoidance in Alexithymia

4.1. Overview

In Experiment 1 we have demonstrated that alexithymia affects the evaluation of self-relevance during emotional face perception. One possible explanation to the impaired self-relevance evaluation in alexithymia is that the high alexithymia individuals attend less to the eye region than those with low alexithymia trait (Bird et al., 2011), since attention to the eye region is critical for identifying others' focus of attention. As a result of this reduced attention to the eye region, the high alexithymia individuals are unable to differentiate between emotional faces that are targeting them and those that are not.

Where we fixate during face perception has been a hot topic that attracts many researchers to investigate in decades. Early studies have demonstrated that more and longer fixations were put at the eye regions than other facial features of the face during face perception (Althoff & Cohen, 1999; Barton, Radcliffe, Cherkasova, Edelman, & Intriligator, 2006; Xu & Tanaka, 2013). Interestingly, during facial emotion perception, Eisenbarth and Alpers (2011) showed that subjects put longer fixations at both eyes and mouth than other facial features, and no differences were found between the two regions. Furthermore, the eye movements are emotion specific such that larger eye-to-mouth ratio in fixation duration when perceiving fearful faces and sad faces than happy faces (Eisenbarth & Alpers, 2011).

Nonetheless, more recent studies have suggested that the eye movement pattern of the early fixations (i.e., first three fixations; first fixation can occur within 350ms post-stimulus presentation (Or, Peterson, & Eckstein, 2015)) is different from that of the later fixations.

While the later fixations land on the exact location of the eyes, the early fixations may land slightly below the eye regions (Hsiao & Cottrell, 2008; Peterson & Eckstein, 2012). Such behavior was found to be independent from task (e.g., facial identity vs facial emotion; Peterson & Eckstein, 2012), face familiarity (Or et al., 2015; Peterson & Eckstein, 2012, 2013), face presentation duration (Peterson & Eckstein, 2012; small but significant difference in the average location of first fixations between short presentation and long presetnation was found in Or et al., 2015, such that the fixations were higher in short presentation than long presentation), and subjects' culture (e.g., Western Caucasian vs. Eastern Asian; Or et al., 2015). The location for the first fixation was shown to be optimized for facial recognition because when the subjects were forced to fixate at a location that was different from the preferred location (i.e., right below the eye region), their recognition accuracy dropped significantly (Or et al., 2015; Peterson & Eckstein, 2012, 2013). In fact, looking right below the eye regions during face perception fits with the prediction of Optimal Foveated Strategy (Or et al., 2015; Peterson & Eckstein, 2012), which describes the way of an ideal observer who integrates all facial information optimally while taking into account that the perceptual sensitivity reduces as the information locates away from the fovea. The fitting to Optimal Foveated Strategy implicates that 1) both eyes and mouth are important for accurate face recognition; 2) information from both eyes and mouth is considered when placing the first fixation; and 3) the information from the eyes is more important than that from the mouth. Based on their findings, the authors argued a functional difference in the early eye movements and late eye movements, such that the late eye movements represent default social behavior that encourage making eye contact, while early eye movements are used to obtain important task relevant information (Or et al., 2015; Peterson & Eckstein, 2012, 2013). The proposal is further supported by their subsequent finding that the preferred first fixation location can be modulated by the information richness of certain facial features during a face learning task (i.e., downward shift in preferred first fixation location in a face discrimation task after learning that the faces differed only in the shape of the mouth, but not in the eyes and other facial features constant in a; Peterson & Eckstein, 2014). Comparable findings can also be found in research studying facial emotion perception. It was found that the omission of eye information significantly reduced the accuracy in recognizing negative emotional faces, whereas the omission of mouth information impeded the recognition of positive emotional faces (Calder, Keane, Young, & Dean, 2000; Calvo, Fernández-Martín, & Nummenmaa, 2014; Calvo & Nummenmaa, 2008; also see Xu, Dayan, Lipkin, & Qian, 2008). The increased importance of mouth information may result in a significantly lower preferred first fixation location during facial emotion perception than facial identity perception (Peterson & Eckstein, 2012).

Eye avoidance during face perception has been reported in highly autistic/alexithymic individuals. Broadly defined, eye avoidance means reduced attention to the eye region, indexed by a smaller number of fixations or shorter fixation duration to the eye region (see Tanaka & Sung, 2016). In the early literature, eye avoidance was most commonly reported in the adults or children who were diagnosed with autism (e.g., Dalton et al., 2005; Jones, Carr, & Klin, 2008; Papagiannopoulou, Chitty, Hermens, Hickie, & Lagopoulos, 2014; Pelphrey et al., 2002; Riby & Hancock, 2008; Speer, Cook, McMahon, & Clark, 2007). Recently, some studies showed that eye avoidance tendency is not only observed in clinical autism, but also in healthy subjects who have high autistic traits (Stephenson et al., 2019). Populations with high autistic traits were also found to need more time to orient fixations to the eye region (Kleberg et al., 2017). Despite the large number of studies that reported the autistic eye avoidance, inconsistent findings were not uncommon (e.g., Chawarska & Shic, 2009; Fletcher-Watson et al., 2009; Neumann et al., 2006; Rutherford & Towns, 2008; for review, see Cuve, Gao, & Fuse, 2018). To address the divergent findings, Bird, Press, and Richardson

(2011) proposed the “alexithymia hypothesis” which argues that the socio-emotional deficits of autism are due to alexithymia, and not autism *per se*. Alexithymia is characterized by the inability to describe and identify feelings (Sifneos, 1973; Taylor et al., 1991) and is a common comorbidity of autism (Bird & Cook, 2013; Poquérusse et al., 2018). In support of their “alexithymia hypothesis” of autistic eye avoidance, Bird, Press, and Richardson (2011) showed that longer fixation duration to the eye regions during face perception was predicted by the alexithymia trait but not the autism symptom severity in the adults with ASD.

Multiple models have been proposed to explain the eye avoidance tendency in autism, but it has not been formally verified if these models can be applied to alexithymia. One explanation is that the highly autistic population has overly aroused physiological responses, and they thus may have a greater tendency to avoid the feeling of threat, the hyperarousal account (Corden, Chilvers, & Skuse, 2008; Joseph, Ehrman, McNally, & Keehn, 2008; Wang et al., 2018; for a review on the autistic literature, see Cuve et al., 2018), which is signaled by direct gaze (Emery, 2000; Skuse, 2004). This hyperarousal account predicts that the autistic eye avoidance should be more prominent in emotional faces that signal social threat, i.e., angry faces than those do not, i.e., neutral or happy faces. Another possible explanation, the hypoarousal account, is that the hypo-aroused activity in the amygdala of these populations might lead them to be uninterested in the potential social interaction or fail to understand the social meaning signaled by eye contact (for reviews on autistic literature, see Cuve et al., 2018; Dawson, Webb, & Mcpartland, 2005; Grelotti, Gauthier, & Schultz, 2002; Vanheule, Desmet, Meganck, & Bogaerts, 2007). The second explanation is backed by the finding that direct gaze elicited stronger feeling of social inclusion than averted gaze in typically developed individuals (Wirth et al., 2010). If the highly autistic population is not motivated by the potential social interaction, then the highly autistic population should avoid the eye region regardless of facial emotion. Given the close relationship between autism and alexithymia (Bird & Cook, 2013; Poquérusse et al., 2018), we expect that the abovementioned models can be extended to at least partially explain eye avoidance tendency in alexithymia.

On top of the two social avoidance accounts, we also explored whether the eye avoidance tendency in highly autistic/alexithymic population is related to the disruption in efficient processing of faces, the efficient processing account. Highly autistic/alexithymic individuals have been shown to have interpersonal problem such that they are more anxious in social situation and they tend to distant themselves from social interaction (Lamport & Turner, 2014; Nicolò et al., 2011; Vanheule et al., 2007; Wainer, Ingersoll, & Hopwood, 2011). However, social experience is vital to form an efficient process to match the face stimuli to the internal face scheme or face dimension to facilitate face perception (Rakover, 2013; Valentine, Lewis, & Hills, 2016). The autistic/alexithymic individuals' difficulty in face-to-face interaction may cause them to have mal-developed processing of face scheme matching processing. Therefore, they may need to reduce attention to the eye region and increase attention to the mouth region to process the entire face. We attempted to address this possibility by inverting the face stimuli.

Perceiving inverted faces may affect how facial features are scanned (Barton et al., 2006; Xu & Tanaka, 2013). In their study, Barton and colleagues (2006) showed that more fixations were put at the mouth region in inverted faces than in upright faces. Similar findings were also presented by Xu and Tanaka (2013), whose study showed that longer fixation durations were spent on the eye region of the upright faces than the inverted faces, and the opposite trend was observed in the mouth region. It was proposed that we are less efficient and less experienced in processing faces in atypical orientation, i.e., inverted face, than those in normal orientation, i.e., upright faces (Bartlett & Searcy, 1993; Farah, Wilson, Drain, &

Tanaka, 1998; Ge, Wang, McCleery, & Lee, 2006). Perception of inverted face tends to affect the application of face scheme and disrupt configural processing during face perception (Freire, Lee, & Symons, 2000; Leder & Bruce, 2000; Rakover, 2013). Without these efficient strategies for face processing, the subjects needed to attend to each facial feature individually, in contrast to a more holistic attention in upright faces. In light of the high similarity between the eye movement tendency of the healthy subjects when perceiving inverted faces and that of the highly autistic/alexithymic individuals when perceiving upright faces, we hypothesize that the two phenomena may root from the same cause – inefficient face scheme matching process (Rakover, 2013). If our hypothesis is true, we should observe that the autistic/alexithymic eye avoidance would be attenuated when the face is inverted.

In this experiment, we primarily aimed at investigating the relationships of eye avoidance with alexithymia trait and autistic traits. More specifically, we asked these questions: 1) Is eye avoidance associated with alexithymia trait and/or autistic traits? 2) Is eye avoidance emotion specific? 3) Is eye avoidance face orientation specific? Based on the results from previous study (Bird et al., 2011), we hypothesize that eye avoidance is associated with alexithymia trait rather than autistic traits. Furthermore, based on two findings in our previous experiment that 1) angry faces were rated as more threatening than happy faces and neutral faces; and 2) there was a reduction in eye-contact effect in angry faces but not in happy faces and neutral faces in alexithymia, we hypothesize that the eye avoidance in alexithymia is specific to angry faces, supporting the hyperarousal account. Lastly, if the autistic/alexithymic eye avoidance is associated with the lack of social experience and disrupted efficient system for face processing, the association between autistic traits/alexithymia trait and eye avoidance should be attenuated when the faces are inverted. We chose neutral faces as our baseline condition. Happy faces and angry faces were chosen because they are representative of socially rewarding and socially threatening emotions respectively, and they differed in their nature of association with alexithymia in Experiment 1. Furthermore, these two facial expressions are the most commonly seen in daily social interaction in the population of young adults (Calvo, Gutiérrez-García, Fernández-Martín, & Nummenmaa, 2014b). Fearful faces were not tested because fear is related to environmental and contextual threat, rather than social threat which is the interest of this thesis (Adams et al., 2003; Sander et al., 2007).

4.2. Methods

4.2.1. Participants

Thirty-nine subjects were recruited and consented to participate. Five of them were recruited from local junior college as the participants of the Nanyang Research Programme, while the rest were recruited from Nanyang Technological University. Thirty-six subjects (22 females, mean age = 22.47), with normal or corrected-to-normal vision, were included in the analyses. One subject did not proceed to the main experiment because connection failure between the EyeLink host computer and the experimental computer and the other two subjects because of eye movement calibration failure. Using the correlation coefficient of Bird, Press and Richardson (2011; r = -.681), power analysis showed that fourteen subjects were sufficient to observe the effect. We recruited more subjects to cover individuals at the extreme ends of the trait. Due to unexpected connection problem with EyeLink host computer during experiment, the eye movement data of eight trials of one subject was lost. The data from the remaining trials of that subject was kept in the analysis. Table 4.1 illustrates the demographic information of the participants. Informed consents were obtained from the subjects before the experiments. This study was approved by the Institutional Review Board (IRB) at Nanyang Technological University, Singapore, by the Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving human subjects.

N	36
Gender (F/M)	22/14
Age	22.47 (3.79)
TAS-20	48.06 (10.08)
AQ	21.58 (6.34)

Table 4.1. Demographic information of the participants in Experiment 2. AQ – Autism-Spectrum Quotient scores; TAS-20 – Toronto Alexithymia Scale scores. Standard deviations are shown in brackets.

4.2.2. Apparatus

The experiment was performed on iMac computer (Apple Inc., CA) with screen SyncMaster (resolution = 1024 pixels × 768 pixels; refreshing rate = 85 Hz). The distance of the screen from the participants was 57 cm. The experiment was designed and carried out with Psychtoolbox-3 for Matlab (Brainard, 1997; Kleiner, Brainard, & Pelli, 2007; Pelli, 1997). The binocular eye movement of the subjects were recorded at 500 Hz using Eyelink II (SR Research Ltd, Ottawa, Canada). The eye tracker was controlled using the EyeLink Toolbox for Matlab (Cornelissen, Peters, & Palmer, 2002). A 9-point calibration routine was conducted before each session, with a mean error of no more than 0.5° of visual angle. The average accuracy of the eye-tracker was 0.5º with a spatial resolution of < 0.01º root mean square (RMS). The saccade velocity threshold was 35°/sec, and the saccade acceleration threshold was 9500 $°/sec^2$.

4.2.3. Stimulus

Stimuli were modified from Experiment 1 (see Chapter 3). Only the angry faces, happy faces, and neutral faces were used in this experiment. All faces were with direct gaze. We also slightly resized the faces to standardize the vertical locations of their eyes, and so did the locations of their mouths. The average eye to mouth distance was 4.6° (SD = 0.17°). The average distance from fixation to eye was 2.27° (SD = 0.10°) and that from fixation to mouth was 2.33° (SD = 0.10°). The purpose of the location standardization of the facial features is to allow the application of a standardized area of interest (AOI) map on all of the face stimuli. The faces were then cropped into a 7.5cm × 7.5cm (7.5º × 7.5º) square shape. Inverted faces were generated by rotating the faces by 180º. Scramble faces were generated by randomizing the phase spectra of the upright faces. The inclusion of scramble faces is to serve the purpose of another study which concerns the relationship between visual saliency and eye movement, so this condition was not included in the data analysis in this report. The image manipulations were performed using Photoshop CS5 (Adobe System Inc.) and Matlab R2018b.

4.2.4. Procedure

In the eye-tracking task, subjects were asked to perform a one-back task (repetition detection task). In their study, Bird and colleagues' (2011) study implemented a passive viewing design, but in our study we used a one-back task to maximize subjects' attention to the facial stimulus while keeping the processing of emotion optional. The summary of the trial sequence is demonstrated in Figure 4.1. In each trial, the subjects needed to fixate on the fixation dot (0.35º radius) at the center of the screen for 1 second. After that, the target was presented at the center for 2 seconds. When the target was on the screen, the fixation dot would not be present and the subjects were instructed to look at anywhere they want. The recording of subjects' eye movements started 100ms before the presentation of the target. The task of the subjects was to identify whether the image at the current trial was exactly the same as the one in the previous trial as fast as possible once the target appeared (e.g., "Different" should be pressed if an upright face is followed by the inverted version of the same face). The target would stay on the screen even after the subjects pressed the button. The button assignment was randomized among subjects, such that half of the subjects should press "z" for "Same" and "m" for "Different", whereas the other half was assigned with the opposite button press. After the target left the screen, a 500ms feedback was displayed to the subjects: "Correct" if the subjects responded correctly, "Wrong" if the subjects responded wrongly, and "No Response" if the subjects did not press any button. Each target stimulus was repeated 4 times in the entire experiment, resulting 216 trials (4 rep × 6 identities × 3 emotions × 3 presentation conditions). Out of the 216 trials, 25% were the "Same" trials while the rest were "Different" trials. The trial sequence was pseudo-randomized by the computer under the "25% Same trials" condition. The subjects took a 5-minute break every 35 trials and their eye movements were recalibrated after every break. Before data collection, each participant practiced the experiment with house images instead of faces as targets for a few trials until they feel comfortable with the task.

After the eye-tracking experiment, except the first five subjects (because they participated in the experiment before the decision to implement the stimulus validation was made), the rest of the subjects were asked to identify the emotion (angry, fearful, happy, sad, disgust, surprise, or neutral), and rate the valence and intensity of the facial emotion in a 7-point Likert scale (valence: 1 = "very negative", 7 = "very positive; intensity": 1 = "not emotional at all", 7 = "very emotional"). All the upright faces presented in the eye-tracking experiment were included. Finally, the subjects were asked to complete the TAS-20 (Bagby et al., 1994b) and the AQ (Baron-Cohen et al., 2001) questionnaires.

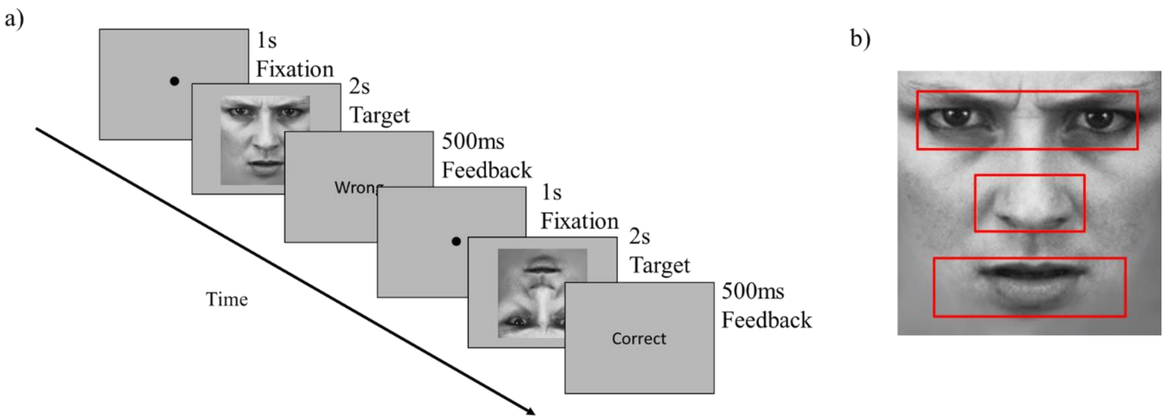

Figure 4.1. a) Trial Sequence in Experiment 3. An upright/inverted angry/happy/neutral/scrambled face was presented at the center for 2s. The participants were required to answer yes/no for whether the target is the same as the one in the previous trial by pressing the "z" or "m" key as fast as possible without sacrificing accuracy. After the 2s target presentation, feedback was given to the subjects and it was followed by 1s of Inter-Trial-Interval. b) Area of interests (AOIs) of the eye regions, the nose region and the mouth region defined for data analysis. Faces from KDEF database are used for demonstration because pictures from the N-FEE Database (Yap et al., 2016) are not allowed for publication.

4.2.5. Data analysis

Subjects' fixation locations and fixation durations were extracted according to the in-built algorithm of Eyelink II. All fixation locations were adjusted based on the location of the last fixation took place before presentation of the target (i.e., within the 100ms pre-target window when the subjects were fixating at the fixation dot). If no fixation was recorded within the 100ms pre-target window, the trial was excluded from the analysis. On average, around 1% (range: 0 – 28 trials) of the trials were excluded per subject. Two subjects had an exceptional number of trials removed due to the above reason (28 trials and 19 trials). Since majority of the trials of the two subjects were retained, we kept them in the analysis. The AOIs for the eye regions, for the mouth region, and for the nose were defined such that it covers the respective facial features of all faces. The three AOIs for the inverted faces were 180° rotated from that for the upright faces.

For each facial feature, we derived the average fixation duration spent on it. Each index of the AOIs was modelled by repeated-measure 2-way ANOVA with within-subject variables *Emotion* (Neutral vs. Angry vs. Happy) and *Orientation* (Upright vs. Inverted). After that, to examine how the two personality traits affect one's eye movement on faces with different emotions, we correlated the TAS-20 scores and AQ scores with the average fixation durations on each AOIs of the angry faces (average across all angry faces), the happy faces (average across all happy faces) and the neutral faces (average across all neutral faces). Likewise, to examine how the two personality traits affect one's eye movement on faces with different orientations, we correlated the TAS-20 scores and AQ scores with the average fixation durations on each AOIs of the upright faces (average across all upright faces) and of the inverted faces (average across all inverted faces). Then, to investigate whether emotion modulation on eye avoidance showed different patterns in upright and inverted faces, TAS-20 score and AQ scores were correlated with the average fixation durations on each AOIs of each condition (i.e., upright angry, upright happy, upright neutral, inverted angry, inverted happy, and inverted neutral). Since we found that age was correlated with both TAS-20 scores and AQ scores, all correlations were conducted using partial correlation analysis with age as control variable. Lastly, additional partial correlations were conducted to investigate whether the eye movement tendency of one personality trait can be explained by the other personality trait.

To generate the fixation heatmaps, we plotted all fixations within the 2-second face presentation time into a 1024 × 768 matrix. Each fixation was then smoothed with a Gaussian kernel σ = 11.4 pixels because foveated region has a diameter of 2° (Blais, Jack, Scheepers, Fiset, & Caldara, 2008; Jack, Blais, Scheepers, Schyns, & Caldara, 2009).

In terms of the results from the stimulus validation task, the recognition accuracy, the valence and the intensity of the emotional faces were contrasted with each other via repeated-measure *t*-tests.

Greenhouse-Geisser correction (when the sphericity assumption is violated) and Holms-Bonferroni correction (for multiple pairwise comparisons) were applied when appropriate. SPSS Statistics 25 (IBM, NY, USA) and Matlab R2018a (Mathworks, MA, USA) were used for data analysis.

4.3. Results

Unexpectedly, the correlation between TAS-20 scores and AQ scores did not reach significance ($r = .19$, $p = .28$). Also, age was negatively correlated with both TAS-20 scores ($r = -.33$, $p = .048$) and AQ scores ($r = -.38$, $p = .022$). In the stimulus validation task, the happy faces (mean = 89.78%) were recognized more accurately than the angry faces (mean = 62.37%; $t(30) = 8.08$, $p < .001$, Holms-Bonferroni-corrected) and the neutral faces (mean = 70.97%; $t(30) = 4.43$, $p < .001$, Holms-Bonferroni-corrected). Furthermore, the neutral faces were also recognized more accurately than the angry faces ($t(30) = 2.12$, $p = .043$, Holms-Bonferroni-corrected). The fact that the angry faces were recognized less accurately than in Experiment 1 is probably because there was an additional option “Disgust” which was absent in Experiment 1. The chance for our subjects to miscategorise the angry faces as disgust face was 26.08% (SD = 16.06%). The confusion between angry faces and disgust faces is well-documented in the literature, and it has been suggested that they should be combined as one category (Calvo & Nummenmaa, 2016; Jack, Garrod, & Schyns, 2014; Tottenham et al., 2009). The angry faces (mean = 2.58) were rated as more negative than both the neutral faces (mean = 3.81; $t(30) = 8.98$, $p < .001$, Holms-Bonferroni-corrected) and the happy faces (mean = 5.90; $t(30) = 15.48$, $p < .001$, Holms-Bonferroni-corrected). The happy faces were also rated as more positive than the neutral faces ($t(30) = 12.82$, $p < .001$, Holms-Bonferroni-corrected). Both angry faces (mean = 4.63; $t(30) = 5.30$, $p < .001$, Holms-Bonferroni-corrected) and happy faces (mean = 5.50; $t(30) = 9.86$, $p < .001$, Holms-Bonferroni-corrected) were rated as more intense than the neutral faces (mean = 3.02). The happy faces were also rated as more intense than the angry faces ($t(30) = 4.35$, $p < .001$, Holms-Bonferroni-corrected). The recognition accuracies, valence ratings and the intensity ratings of all emotional faces were not significantly correlated with TAS-20 scores or AQ scores after correcting for multiple correlations (*p*s > .05). In terms of the accuracy of the one-back task, the mean accuracy was 92.72% (SD = 2.60%).

4.3.1. Emotion-specific fixation pattern

Significant main effects of *Emotion* were found in the ANOVAs modelling the fixation durations placed on the eye regions ($F(2, 70) = 13.46$, $p < .001$), the mouth region ($F(2, 70) = 6.41$, $p = .003$, Figure 4.2a left panel), and the nose region ($F(2, 70) = 9.82$, $p < .001$, Figure 4.2a right panel). *Post-hoc* pairwise comparison showed that shorter fixation durations were placed at the eye region in happy faces (240.62ms) than in angry faces (307.09ms; $t(35) = 4.63$, $p < .001$, Holms-Bonferroni-corrected) and in neutral faces (300.45ms; $t(35) = 4.64$, $p < .001$, Holms-Bonferroni-corrected). Shorter fixations were put at the mouth region of the neutral faces (165.36ms) than both happy faces (212.94ms; $t(35) = 3.13$, $p = .008$, Holms-Bonferroni-corrected) and angry faces (208.83ms; $t(35) = 3.58$, $p = .003$, Holms-Bonferroni-corrected), but no duration difference at the mouth region was found between the two emotional faces (*p*s > .05). Lastly, the nose region was fixated longer in neutral faces (486.68ms) than in angry faces (410.95ms; $t(35) = 5.28$, $p < .001$, Holms-

Bonferroni-corrected) and in happy faces (433.23ms; $t(35) = 2.96$, $p = .010$, Holms-Bonferroni-corrected).

In sum, the subjects fixated the shortest on the eye region of happy faces and at the mouth region of neutral faces. Also, the nose region of the neutral faces was fixated longer than those of the emotional faces.

4.3.2. Orientation-specific eye movement

The main effects of *Orientation* were significant in the ANOVAs modelling the fixation durations placed on the eye regions ($F(1, 35) = 28.71$, $p < .001$) and the mouth region ($F(1, 35) = 18.30$, $p < .001$), but not in that of the nose region ($F(1, 35) = 0.39$, $p = .539$). *Post-hoc* pairwise comparisons showed that longer fixations were placed at the eye regions (Upright vs Inverted: 351.93ms vs. 213.50ms; $t(35) = 5.36$, $p < .001$) and shorter at the mouth region of the upright faces than the inverted faces (Upright vs Inverted: 134.60ms vs. 256.82ms; $t(35) = 4.28$, $p < .001$). Therefore, subjects spent more time looking at the eye regions of the upright faces and at the mouth region of the inverted faces.

4.3.3. Emotion-specific fixation pattern modulated by face orientation

The ANOVA on the fixation durations placed on the eye regions revealed significant *Emotion* × *Orientation* interaction effects ($F(2, 70) = 4.83$, $p = .011$, Figure 4.2b), but not on the mouth region and the nose region (ps > .05). *Post-hoc* pairwise comparisons showed that, when the faces were inverted, subjects spent longer fixation duration at the eye regions of the angry faces (258.25ms) than those of the happy faces (162.39ms; $t(35) = 6.11$, $p < .001$, Holms-Bonferroni-corrected) and the neutral faces (219.87ms; $t(35) = 2.45$, $p = .020$, Holms-Bonferroni-corrected), but such fixation duration differences were not observed when the faces were upright (ps > .05).

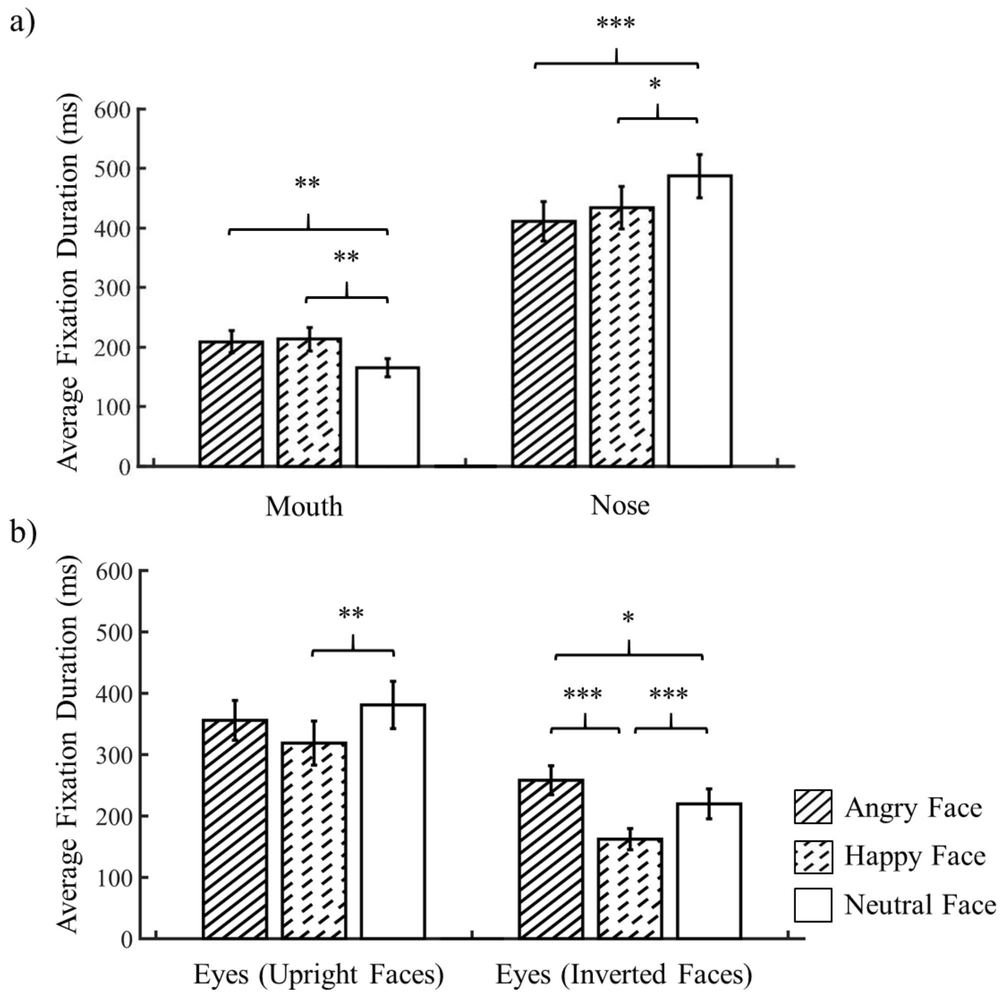

Figure 4.2. Summary of fixation duration on each AOI. a) Main effect of *Emotion* on the average fixation durations at the mouth region (left panel) and at the nose region (right panel). b) Interaction effect of *Emotion* × *Orientation* on the average fixation durations at the eye regions. The left panel shows the results of the upright faces and the right panel shows the results of the inverted faces. * $p < .05$, ** $p < .01$, *** $p < .001$.

4.3.4. Emotion modulation and orientation modulation of eye avoidance in alexithymia

As reported in Bird and colleagues (2011), TAS-20 scores were negatively correlated with the fixation duration spent on the eye region ($r = -.47$, $p = .004$), indicating the eye avoidance tendency of alexithymia. Interestingly, there was a significant correlation between

TAS-20 scores and the fixation durations on nose region (r = .34, p = .048), suggesting the highly TAS-20 score one had, the longer they fixated on the nose region. The correlations of the fixation durations on the mouth region (r = -.18, p = .311) with TAS-20 scores, however, did not reach significance. AQ scores, on the other hand, were not correlated with the fixation durations on any AOIs (ps > .05).

Next, we investigated the emotion modulation of eye avoidance in alexithymia. TAS-20 scores correlated with the fixation durations on eye regions of faces with different emotional categories (Angry: r = -.45, p = .012; Happy: r = -.48, p = .012; Neutral: r = -.42, p = .012, Holms-Bonferroni-corrected). Therefore, the general alexithymic eye avoidance is not modulated by facial emotion. Then, to examine the orientation modulation of eye avoidance in alexithymia, we correlated TAS-20 scores with the fixation durations on eye regions of faces with different orientations, and both correlations reached significance (Upright: r = -.49, p = .006; Inverted: r = -.34, p = .043, Holms-Bonferroni-corrected). The general eye avoidance in alexithymia thus may not be related to social experience.

Lastly, we explored whether the eye avoidance in alexithymia is specific to certain face conditions. Among all face conditions, only the fixation durations on the eye regions in the angry faces (r = -.55, p = .004, Holms-Bonferroni-corrected, Figure 4.3a) and the happy faces (r = -.47, p = .025, Holms-Bonferroni-corrected, Figure 4.3b) were significantly correlated with TAS-20 scores, but not those of the other faces (ps > .05). Nonetheless, some correlations may be driven by outliers. To account for the effects caused by potential outliers, we re-ran the analysis using Spearman's correlation analysis which is more robust against outliers (Pernet, Wilcox, & Rousselet, 2013). Spearman's correlation analysis showed that only the fixation durations on the eye regions in the angry faces remained significant (r_s = -.49, p = .018, Holms-Bonferroni-corrected, Figure 4.3a). Therefore, the eye avoidance is more prominent when alexithymics perceive upright angry faces and this suggests that the avoidance may be related to their feeling of social threat when fixating at the eye regions.

Partial correlation revealed that the TAS-20 scores remained to significantly and negatively correlate with the fixation duration on the eye regions of the upright angry faces (r_s = -.49, p = .018, Holms-Bonferroni-corrected) even after the effect of AQ scores was partialled-out, suggesting that the alexithymic influence was not due to the autistic effect. Therefore, the higher the alexithymia, the less time spent fixating on eye regions of upright angry faces.

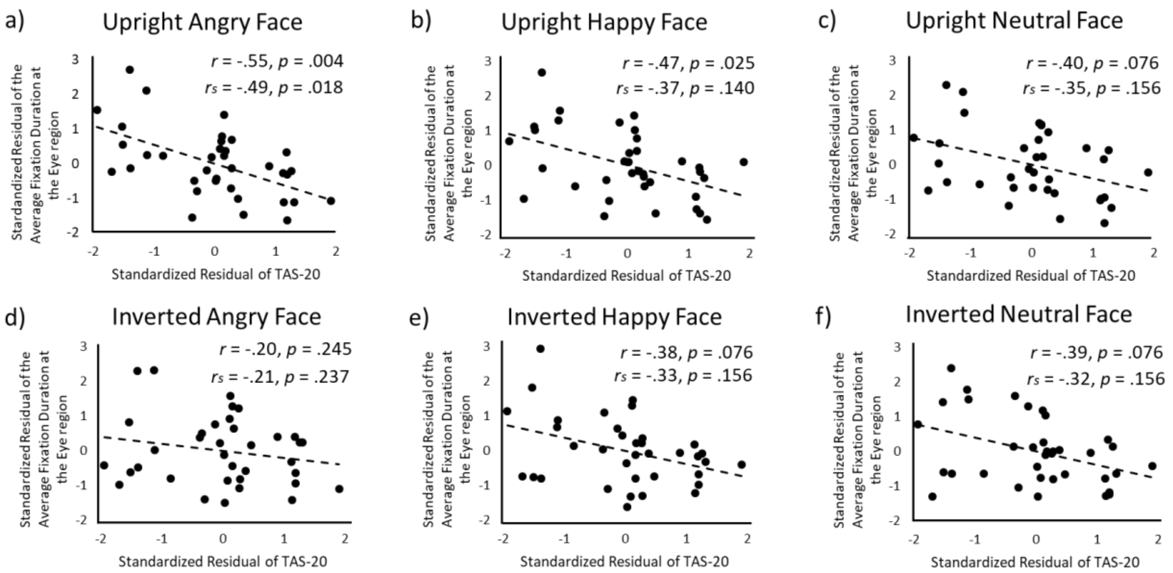

Figure 4.3. Scatter plots between the TAS-20 score and the average fixation duration at the eye regions of a) the upright angry faces; b) the upright happy faces; c) the upright neutral faces; d) the inverted angry faces; e) the inverted happy faces; f) the inverted neutral faces. *r* indicates Pearson's correlation coefficient. r_s indicates Spearman's correlation coefficient. The *p*-values reported have been Holms-Bonferroni-corrected.

4.3.5. Early and late eye movements on different face conditions

To understand the temporal trajectory of the fixation locations, we generated the fixation heatmaps of different face condition at different time stamps. The results showed that when the faces were upright (Figure 4.4), the subjects tended to first fixate at the bottom of the eyes, especially the left eye, at around 350ms to 500ms. After that, the fixations moved to mouth region as well as the centre of the right eye. For neutral faces, fixations on the mouth region were placed later than angry faces and happy faces (Angry & Happy, 500ms to 750ms vs. Neutral, 1000ms). Our findings of the eye movements in the early time window matches with the literature that studied the early fixation pattern on faces which showed that early fixations land slightly below the eye regions (Hsiao & Cottrell, 2008; Peterson & Eckstein, 2012). In contrast, for inverted faces (Figure 4.5), fixations were mostly placed on the mouth region. For inverted angry faces and inverted neutral faces, fixation to the eye region occurred at around 500ms to 750ms. In comparison, fewer and later fixations were placed on the eye region of inverted happy faces.

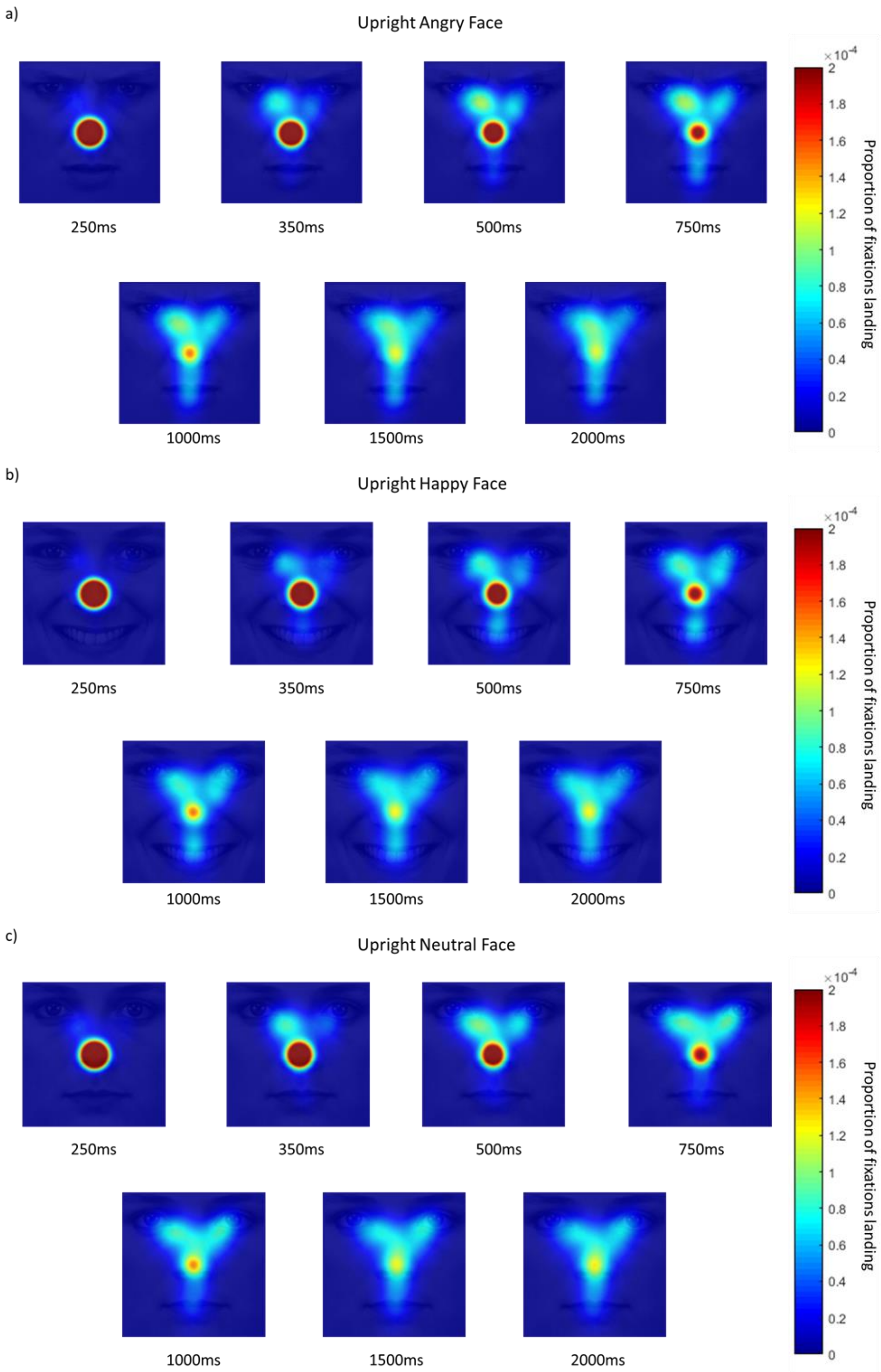

Figure 4.4. Fixation heatmap of a) upright angry face condition; b) upright happy face condition; and c) upright neutral face condition from 250ms to 2000ms after face stimulus presentation.

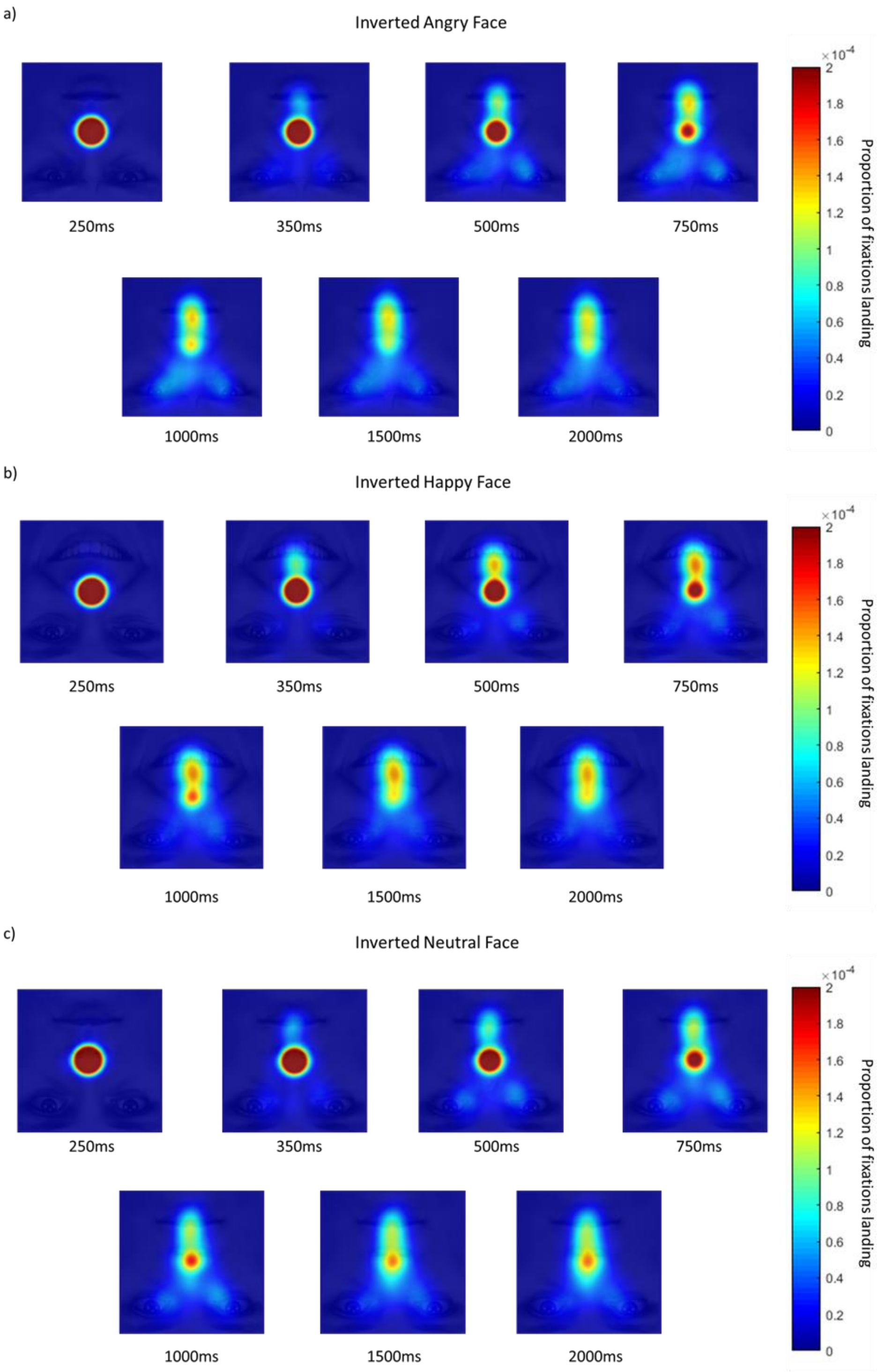

Figure 4.5. Fixation heatmap of a) inverted angry face condition; b) inverted happy face condition; and c) inverted neutral face condition from 250ms to 2000ms after face stimulus presentation.

4.3.6. Early and late eye avoidance in alexithymia

In order to examine whether the observed alexithymic eye avoidance was related to early eye movements or later eye movements, we computed the correlations between TAS-20 scores and average fixation duration at the eye region in different face conditions from 250ms to 2000ms after face stimulus presentation. Using Pearson's correlation (Figure 4.6a), we found that alexithymic eye avoidance was only significant in upright angry face condition (1500ms: $r = -.49$, $p = .018$; 2000ms: $r = -.55$, $p = .004$, Holms-Bonferroni-corrected) and upright happy face condition (1500ms: $r = -.47$, $p = .023$; 2000ms: $r = -.47$, $p = .025$, Holms-Bonferroni-corrected) at and after 1500ms post-stimulus presentation. However, again, the correlations might be driven by outliers. To account for the effects caused by potential outliers, we re-ran the analysis using Spearman's correlation analysis which is more robust against outliers (Pernet et al., 2013). The results (Figure 4.6b) showed that the alexithymic eye avoidance only reached significant in upright angry face condition at 2000ms post-stimulus presentation ($r_s = -.49$, $p = .018$, Holms-Bonferroni-corrected). Our findings therefore suggest that alexithymic eye avoidance is related to later eye movements, which is associated with social norm behaviour (Or et al., 2015; Peterson & Eckstein, 2013). Nonetheless, our results do not have concrete evidence to conclude that whether alexithymic eye avoidance is related or not related to early eye movements, i.e., first fixations. It is because although not significant, there was a trend of alexithymic eye avoidance before 1500ms post-stimulus presentation, especially in the upright angry face condition. The negative results in early alexithymic eye avoidance may be due to that our experimental design is not sensitive in detecting early eye movements. Future studies should modify the paradigm based on the literature on first fixations during face perception (Hsiao & Cottrell, 2008; Or et al., 2015; Peterson & Eckstein, 2012, 2013).

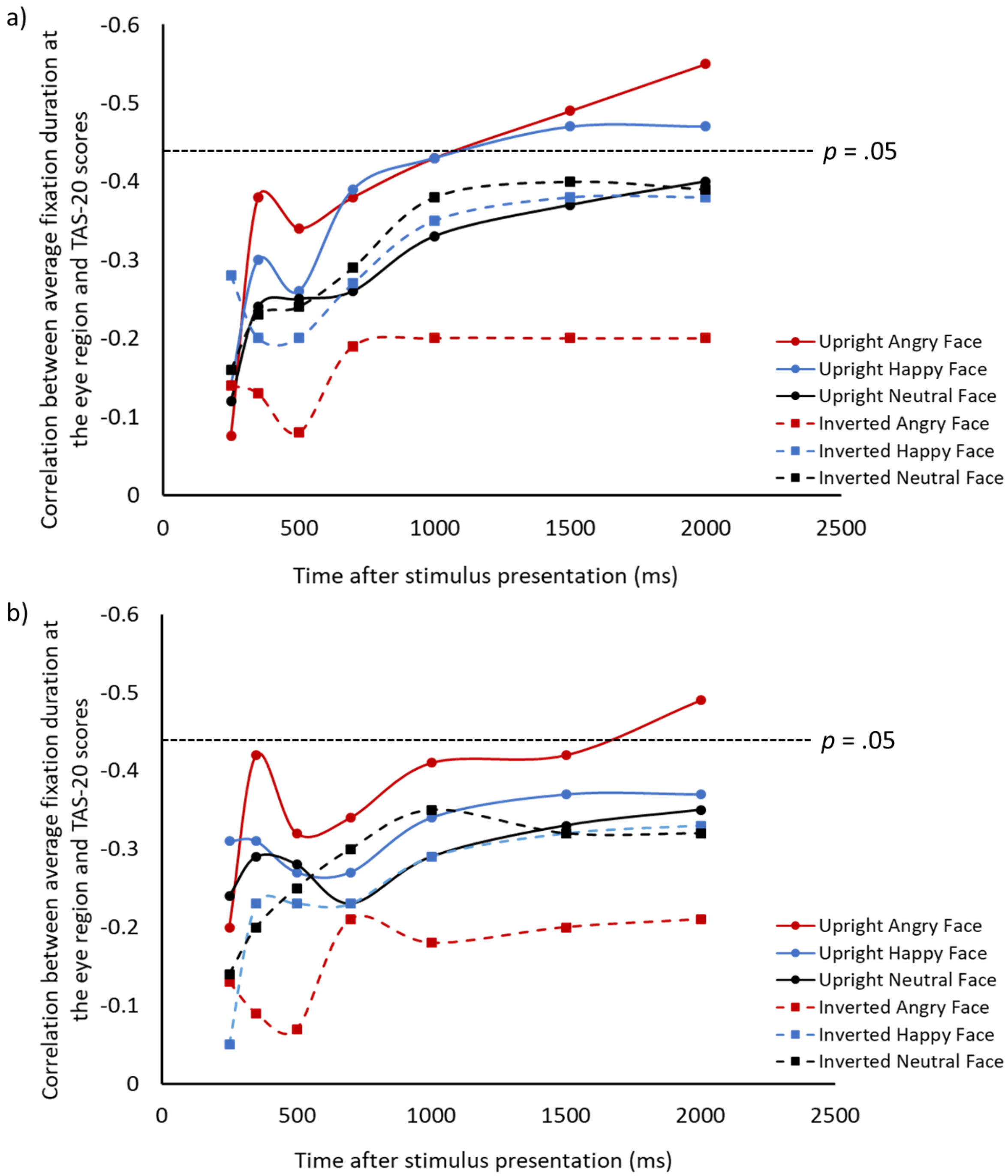

Figure 4.6. Alexithymic eye avoidance in different face conditions from 250ms to 2000ms after face stimulus presentation a) with Pearson's correlation analysis; and b) with Spearman's correlation analysis. The correlations were controlled for age. The horizontal dashed line indicates $r = .44$ where $p = .05$.

4.4. Discussion

In Experiment 2, we investigated the relationship of eye avoidance with alexithymia trait and autistic traits. On top of that, we examined the emotion specificity and the face orientation specificity of the eye avoidance. We found that the alexithymia trait, but not autistic traits, was related to eye avoidance. The eye avoidance in alexithymia was more prominent in upright angry faces.

In the literature, although plenty of studies have demonstrated that autism and autistic traits have been associated with eye avoidance during face perception (Dalton et al., 2005; Jones et al., 2008; Kleberg et al., 2017; Papagiannopoulou et al., 2014; Pelphrey et al., 2002; Riby & Hancock, 2008; Speer et al., 2007; Stephenson et al., 2019), inconsistent findings are also commonly reported (for review, see Cuve et al., 2018). Bird and colleagues (2011) proposed "alexithymia hypothesis" which suggests that eye avoidance is associated with alexithymia which is a comorbidity of autism (Bird & Cook, 2013; Poquérusse et al., 2018). Our findings support the "alexithymia hypothesis" of eye avoidance and extend the hypothesis to the general population. We showed that the alexithymia trait, but not autistic traits, predicts eye avoidance in the general population. This implicates that alexithymia not only mediates the symptoms in the individuals who are diagnosed with autism, it also affects how the typically developed individuals attend to the facial features.

Why do high alexithymia individuals exhibit eye avoidance? In the hyperarousal account, it is suggested that the high alexithymia individuals are aversive to making eye contact (Corden et al., 2008; Joseph et al., 2008; Wang et al., 2018; for a review of the same account from the autistic literature, see Cuve et al., 2018) because it implies social threat (Emery, 2000; Skuse, 2004). This account predicts that the high alexithymia individuals tend to avoid the eye information from angry faces. The second account, the hypoarousal account, suggests that the high alexithymia individuals exhibit eye avoidance because they fail to understand the social meaning of the facial features and are less motivated in processing socio-emotional information, including eye information (for reviews of the same account from the autistic literature, Cuve et al., 2018; Dawson et al., 2005; Grelotti et al., 2002) . This account predicts that alexithymic eye avoidance should be observed regardless of emotion. Lastly, the third account, the efficient processing account (Rakover, 2013) proposed that the eye fixation tendency of the typically developed individuals is due to the automatic and efficient face scheme matching process which is learned through social experience. Since the high alexithymia individuals have less social experience due to their social avoidance tendency (Nicolò et al., 2011; Vanheule et al., 2007), their face scheme application may be mal-developed. This account predicts that the alexithymic eye avoidance should be face orientation specific. Our findings showed that the high alexithymia individuals tend to avoid eye information especially in the upright angry faces. This fits with both the hyperarousal account and the efficient processing account. The two accounts are not mutually exclusive. It is possible that since the high alexithymia individuals have the tendency to avoid eye information from the angry faces, they are unable to develop an efficient face scheme matching process specific for angry face. The mal-developed face scheme matching process, in turn, further exacerbate the eye avoidance tendency in alexithymia. Being hyper-aroused by the eyes of the angry face in alexithymia may be corroborated by previous studies which reported that the high alexithymia individuals have a tendency to be emotionally sensitive during social interaction (Nicolò et al., 2011) and a heightened self-rated worry and negative emotions during social stress (Eastabrook et al., 2013; Pollatos et al., 2011). This is further supported by our finding that the alexithymic eye avoidance in upright angry face condition was more prominent in the later eye movements which may represent social norm behavior like maintaining eye contact during social interaction (Or et al., 2015; Peterson & Eckstein, 2012, 2013).

At first sight, one may think that our explanation is contradictory to the general observation that the amygdala is hypo-aroused in alexithymia when perceiving negative emotion (Donges & Suslow, 2017; Reker et al., 2010). The discrepancy can be resolved when we consider that alexithymia is commonly associated with impaired interoceptive awareness (Brewer et al., 2016; Shah et al., 2016). In fact, it was also found that the physiological responses of the high alexithymia individuals are not coupling with their self-report emotional responses indicating that they have impaired emotion awareness as well (Eastabrook et al., 2013; Pollatos et al., 2011). Therefore, it is possible for the high alexithymia individuals to have a hypo-aroused neural activation but a hyper-aroused behavioral response. This mind-body dissonance nonetheless might put a challenge to studies that attempt to investigate the neural markers for certain alexithymic behaviors.

The current finding of the alexithymic eye avoidance in upright angry faces might help to explain our observations in Experiment 1 in this thesis, in which we showed that alexithymia is associated with impaired self-relevance evaluation during social threat processing, as indexed by the reduced difference in threat ratings between angry faces with different gaze directions. One possibility is that since the high alexithymia individuals look less at the eye regions of the angry faces, they are unable to identify others' focus of attention accurately from the gaze direction. They therefore feel equally threatened by angry faces that are looking away from them as those that are looking at them. Nonetheless, two more recent studies implementing explicit emotional task failed to find alexithymia eye avoidance (Fujiwara et al., 2017; Stephenson et al., 2019). The contrast between these two studies with our current study and Bird and colleagues' (Bird et al., 2011) study suggests the possibility that the alexithymic eye avoidance may only occur during implicit emotional tasks. If true, the alexithymic impairment in self-relevance evaluation may not directly relate to the alexithymic eye avoidance reported in this study. The direct relationship between eye avoidance and the impaired self-relevance evaluation therefore needs further verification.

Some limitations need to be taken into consideration when interpreting the results in this experiment. First, the correlation between the alexithymia trait and the autistic traits did not reach significance in our subjects. Since our premise assumed the two traits are associated as guided by previous studies and our own previous experiments, we are not sure how generalizable our findings are to other pools of subjects who have the two traits related. In our other studies with larger sample size, the two traits were usually very closely related. This might suggest that their relationship can only be revealed with a larger sample size. Secondly, it is noteworthy that there is a trend for eye avoidance in alexithymia for all faces, but only that of the angry face was strong enough to reach significance after correcting for multiple correlations. This suggests that eye avoidance is most prominently observed in angry faces but may also be present in other faces. Lastly, our findings may be affected by "center bias" that introduced by placing the fixation cross at the center of the face stimulus. Some researchers suggested that placing the start position of eye movements at the nose region may allow the subjects to accumulate facial information without initiating the first fixation (Arizpe, Kravitz, Yovel, & Baker, 2012; Hsiao & Cottrell, 2008; Or et al., 2015; Peterson & Eckstein, 2012). For example, Arizpe, Kravitz, Yovel, and Baker (2012) found that when the start position was at the center of the face, the onset of the first fixations was significantly later than when the start position was at the peripheral positions. The authors suggested that the delayed first fixation onset supports that facial information processing was initiated before the initiation of first fixation. This may affect the time course of the alexithymic eye avoidance, such that it occurs at an earlier time window than what has been found in this thesis (1500ms to 2000ms post-stimulus presentation). To systematically investigate whether alexithymia affects early eye movements, future studies should modify the paradigm based on the literature on first fixations during face perception (Hsiao & Cottrell, 2008; Or et al., 2015; Peterson & Eckstein, 2012, 2013).

In sum (Table 4.2), in Experiment 2, we demonstrated that the tendency to avoid looking at eyes is associated with alexithymia, but not autistic traits. Also, the alexithymic eye avoidance is most prominently observed in upright angry faces, but not in other upright faces and inverted angry faces. This suggests that the alexithymic eye avoidance might be associated with the aversion against eye-contact and the lack of experience in processing social threat in alexithymia. In Experiment 1, the behavioral deficit of self-relevance evaluation in alexithymia were also only found in angry faces, the attention to the eye regions in the angry faces therefore might be, at least partially, associated with the self-relevance evaluation of the same faces in alexithymia.

Major findings
1. Alexithymic eye avoidance is more prominent in upright angry faces than happy or neutral faces

Table 4.2. Summary of findings in Experiment 2

Chapter 5

Experiment 3. Time-course of Self-relevance Evaluation during Social Processing in Alexithymia: An EEG Study

5.1. Overview

In the previous two experiments we have demonstrated that alexithymia affects self-relevance evaluation during social threat processing. Experiment 3 further asks at which temporal stage of the emotional face perception is the self-relevance evaluation affected by alexithymia. We chose neutral faces as our baseline condition. Happy faces and angry faces were chosen because they are representative of socially rewarding and socially threatening emotions respectively, and they differed in their nature of association with alexithymia in Experiment 1. Furthermore, these two facial expressions are the most commonly seen in daily social interaction in the population of young adults (Calvo et al., 2014b). Fearful faces were not used because fear is related to environmental and contextual threat, rather than social threat which we are interested in this thesis (Adams et al., 2003; Sander et al., 2007).

Previous studies showed that gaze difference in ERP activation during emotional face perception occurs at around 200ms to 400ms post-stimulus onset at both temporal (Klucharev & Sams, 2004; Nomi et al., 2013) and frontal regions (Conty et al., 2012; Li et al., 2017). We thus focus on the ERP components that emerges before 400ms post-stimulus onset, i.e., P1 (occipital), N1 (frontal), N170 (temporal), VPP (frontal), P200 (temporal), N2 (frontal), P3a (frontal) and P3b (parietal). Based on the literature, we expect to observe eye-contact effect in emotional faces at P200, N2, P3a, and P3b. The earlier components, in contrast, might be related to the processing of emotion or gaze direction independently (Conty et al., 2012; Klucharev & Sams, 2004; Nomi et al., 2013).

In the fMRI literature, alexithymia has been associated with neural deficits both in the temporal regions such as the FFA and the STS and in the frontal regions, such as insula, ACC, and mPFC during emotional face perception (Ihme et al., 2014b, 2014a; Kano et al., 2003; Mériau et al., 2006; Reker et al., 2010). In the EEG literature, in contrast, most of the studies showed alexithymic differences in the N2b component which peaks at 250 – 350ms at the occipito-temporal regions during negative emotional face perception (Campanella et al., 2012; Vermeulen et al., 2008). Nonetheless, during the perception of negative images, the frontal VPP and N2 activation were also found to be stronger in alexithymia (Franz, Schaefer, Schneider, Sitte, & Bachor, 2004; Pollatos et al., 2008; Zhang et al., 2012). Thus, we hypothesize that the alexithymic influence on the eye-contact effect of emotional faces would occur at both the occipito-temporal regions and the frontal regions. According to our findings in Experiment 1, we expect to observe that the eye-contact effect in angry faces to be reduced in the highly alexithymic individuals, as compared to those with low alexithymia trait.

Literature on autism showed that children with autism do not show gaze-emotion interaction at the N170 activation as the typically developing children (Akechi et al., 2010). This finding suggests that autism might influence eye-contact effect in emotional faces at the neural level. Since alexithymia is a common comorbidity of autism (Bird & Cook, 2013; Poquérusse et al., 2018), it is possible that the alexithymic influences in self-relevance evaluation during social processing at the neural level can be explained by autistic traits to a certain degree. To investigate this possibility, we measured the subjects' autistic traits and partialed-out its effect on the observed alexithymic influences in self-relevance evaluation to illuminate the effect that is unique to alexithymia.

5.2. Methods

5.2.1. Participants

Three hundred students from Nanyang Technological University, Singapore were screened with the TAS-20 questionnaire (Bagby et al., 1994b). Respondents with TAS-20 scores lower than or equal to 51 (low alexithymia individuals; LTAS) and with scores higher than or equal to 61 (high alexithymia individuals; HTAS) were invited to participate this experiment (Bagby & Taylor, 1997). Forty-two subjects were recruited and consented to participate. Thirty-nine subjects (28 females, mean age = 23.26, 20 HTAS), with normal or corrected-to-normal vision, were included in the analysis. Data of one HTAS subject and one LTAS subject were excluded from the analysis due to low signal-to-noise ratio, and another HTAS subject terminated the experiment midway because he fell asleep during the task. The number of subjects was comparable to or more than similar studies that chose subjects with extreme trait scores (Li et al., 2017; Pollatos & Gramann, 2011; Vermeulen et al., 2008). The demographic information of the participants is summarized in Table 5.1. This study was approved by the Institutional Review Board (IRB) at Nanyang Technological University, Singapore, by the Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving human subjects.

	LTAS	HTAS	*p*
N	19	20	
Gender (F/M)	14/5	14/6	.798
Age	24.05 (3.95)	22.50 (2.04)	.138
TAS-20	39.11 (6.52)	67.35 (4.22)	<.001

	LTAS	HTAS	*p*
AQ	19.00 (5.10)	25.85 (6.77)	.001

Table 5.1. Demographic information of the participants in Experiment 3. LTAS – low alexithymia individuals; HTAS – high alexithymia individuals; AQ – autistic traits; TAS-20 – Toronto alexithymia scale. Standard deviations are shown in brackets. The third column indicates the *p*-value of the comparison between LTAS and HTAS.

5.2.2. Apparatus

The experiment was performed on DELL Optiplex 780 (resolution = 1280 pixels x 1024 pixels; refreshing rate = 60 Hz). The distance of the screen from the participants was roughly 145 cm. The experiment was implemented in Eprime2 (Psychology Software Tools, Inc., PA, USA).

5.2.3. Stimulus

Stimuli were adopted from Experiment 1 (see Chapter 3). Only the angry faces, happy faces, and neutral faces were used in this experiment. The angry and happy faces were chosen based on their behavioural dissociation in Experiment 1 and their different social meanings during social interaction. The neutral face is the baseline for comparisons with the emotional faces.

5.2.4. Procedure

The experiment was conducted in a soundproof lab. The subjects were asked to complete the Autism-Spectrum Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001) questionnaires before doing the EEG experiment. In the EEG task, subjects were asked to perform a face/gaze decision task. The summary of the trial sequence is demonstrated in Figure 5.1. In each trial, a face stimulus (3.4° × 4.8°) was presented at the center of the screen for 150ms. A probe then appeared following a 650ms inter-stimulus-interval (ISI). The probe asked for a decision on the face's emotion or gaze direction. There were five possible probes: "Angry Face?", "Happy Face?", "Neutral Face?", "Central Gaze?", and "Left Gaze?". If the probe was "Angry Face?", for example, the subjects should press the mouse key to respond whether the face was angry (left mouse key) or not (right mouse key), as fast and accurate as possible. Each face stimulus was repeated 5 times in one block and each time followed by one of the five probes. The ITI varied between 1s to 2s. There are three identical blocks in total. There were 180 trials per block (5 rep × 6 identities × 3 emotions × 2 gaze directions) and 540 trials in total. The face stimuli were presented in a pseudo-randomized order within each block.

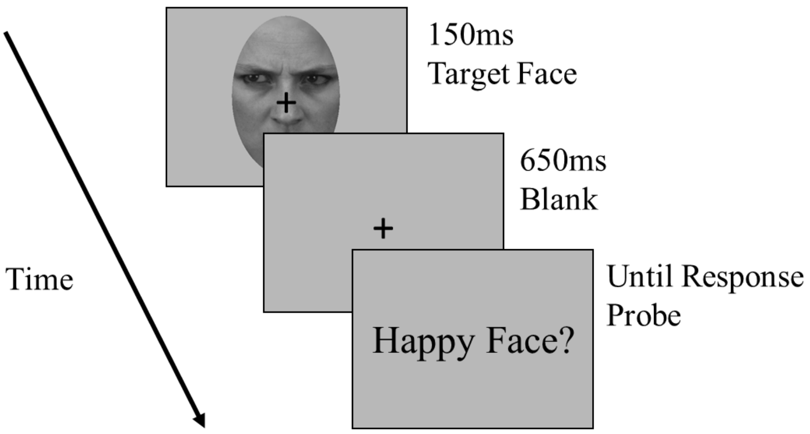

Figure 5.1. Trial Sequence for happy probe in Experiment 3. An angry/happy/neutral face with direct/averted gaze was presented at the center for 150ms. The probe for response appeared after 650ms of ISI. The participants were required to answer yes/no by pressing the left/right mouse key, respectively, as fast as possible without sacrificing accuracy. Faces from KDEF database are used for demonstration because pictures from the N-FEE Database (Yap et al., 2016) are not allowed for publication.

5.2.5. EEG data acquisition and preprocessing

Subjects' brain wave activities were recorded by a 64-channel EEG using Hydrocel Geodesic Sensor Net (Electrical Geodesics Inc., Eugene, Oregon) with online reference to the vertex electrode. Data was sampled at 1000 Hz. Electrode impedances were maintained below 50 kΩ. We used EEGlab toolbox (Delorme & Makeig, 2004) in Matlab R2018a for signal preprocessing. Spline interpolation was applied to the channels with no signal, or extremely high impedance during acquisition. No subjects' data had more than three channels with the abovementioned condition. The data was then detrended, referenced to the common average, digitally band-pass filtered (0.1 – 30 Hz), and epoched from -200ms pre-stimulus onset to 800ms post-stimulus onset, and thus a total epoch of 1000ms was included. Artifact due to eye blink was identified and removed using Independent Component Analysis (Jung et al., 2000). Moreover, we rejected trials with abnormal voltage that exceeded +/-100 µV in any channel. After baseline removal (-200ms to 0ms), we averaged the signals for each condition.

In the region of interest (ROI) analysis, our ERP components of interest were the P1, the N170, the P200, and the P3b at the posterior channels, and the N1, the VPP, the N2, and the P3a at the anterior regions (see Figure 5.2a). The ERPs were analysed based on their mean amplitudes over their time windows. The time window was chosen based on the global field power plot (Figure 5.2b). The P1 was identified as the positive peak at the occipital channels (Oz (E37), O1 (E35) and O2 (E39)) within the time window of 65 - 151ms. The N170 and the P200 were identified as the negative peak and positive peak at the occipito-temporal channels (Left: P7 (E30), PO7 (E32); Right: P8 (E44), PO8 (E43)) within the time windows of 151 – 215ms and 205 - 287ms respectively. The P3b was identified as the positive peak at the parietal channels (P1 (E33), Pz (E36), P2 (E38), and CPz (E34)) within the time windows of 345 – 460ms. The N1 was identified as the negative peak at the mid-frontal channels (F1 (E3), Fz (E6), F2 (E9), and AFz (E8)) within the time window of 65 - 151ms. The VPP and the N2 were identified as the positive and negative peaks at the same mid-frontal channels within the time windows of 151 – 205ms and 205 – 287ms respectively. The P3a was identified as the positive peak at the mid-frontal channels with the time window of 345 – 460ms. Since previous ERP studies on emotional face perception in alexithymia reported alexithymic latency differences in the posterior N250 component (Campanella et al., 2012; Vermeulen et al., 2008), we additionally extracted the peaks and the latency of the N250 at the occipito-temporal channels within the time window 287 – 343ms. We extracted the mean amplitudes of the ERP components of interest using ERPlab (Lopez-Calderon & Luck, 2014), a plug-in of the EEGlab toolbox.

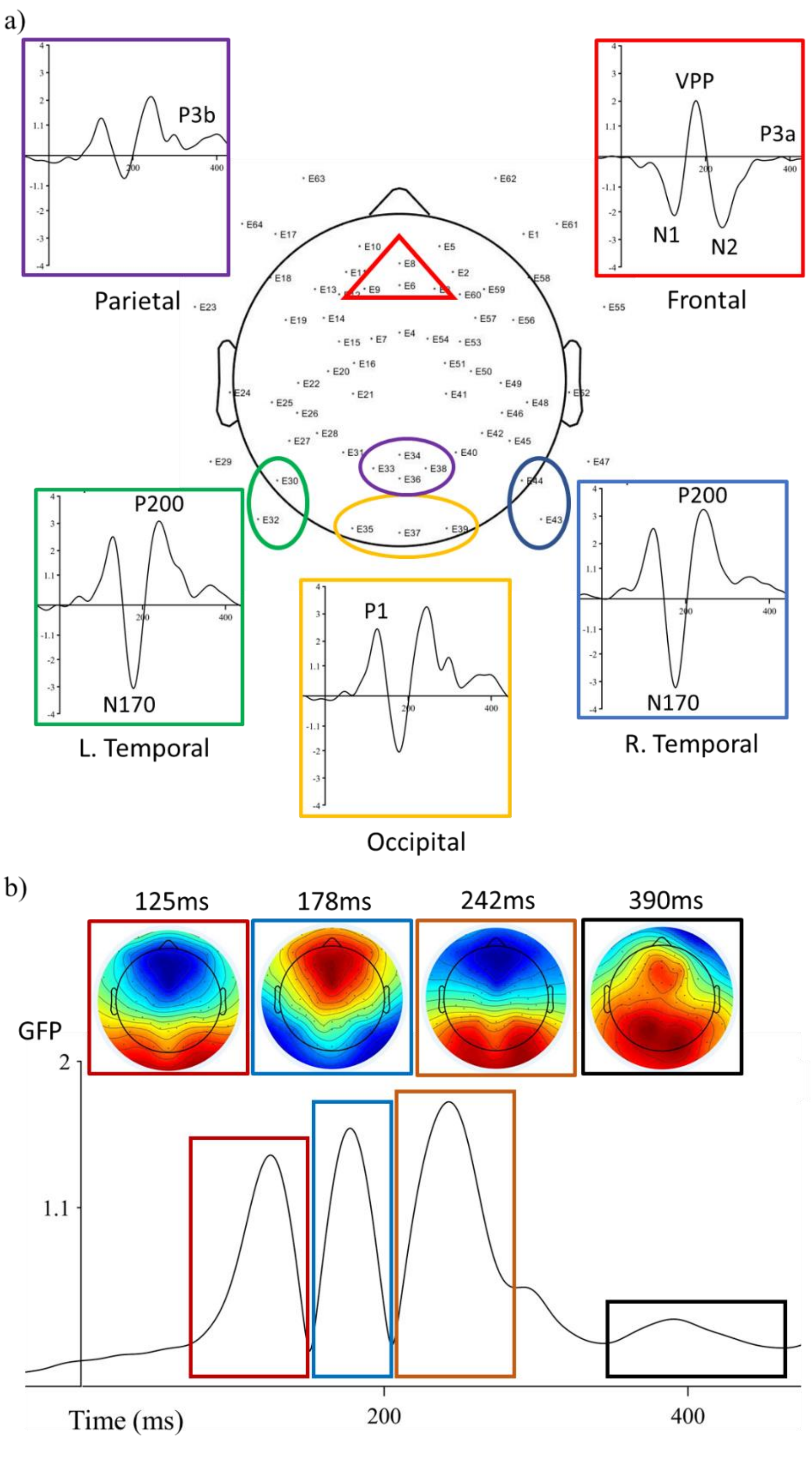

Figure 5.2. a) Topographic map for the ERPs of interest and b) the global field power plot that indicates the time windows for each ERP component. The P1 is located at the occipital channels (Oz (E37), O1 (E35) and O2 (E39)) within the time window of 65 - 151ms. The N170 and the P200 are located at the occipito-temporal channels (Left: P7 (E30), PO7 (E32); Right: P8 (E44), PO8 (E43)) within the time windows of 151 – 205ms and 205 - 287ms respectively. The N1,

the VPP, the N2, and the P3a are located at the frontal channels (F1 (E3), Fz (E6), F2 (E9), and AFz (E8)) within the time windows of 65 - 151ms, 151 – 205ms, 205 – 287ms, and 345 – 460ms respectively. The P3b is located at the parietal channels (P1 (E33), Pz (E36), P2 (E38), and CPz (E34)) within the time window of 345 – 460ms.

5.2.6. Data analysis

For EEG data, we focused on the mean amplitudes in the analysis because previous study showed that mean amplitude is a more reliable measure than peak amplitude (Clayson, Baldwin, & Larson, 2013; Luck, 2014). We first presented the ROI analysis. For the P1, the N1, the VPP, the N2, the P3a, and the P3b, mixed 3-way ANOVAs with within-subject variable *Emotion* (Neutral vs. Angry vs. Happy) and *Gaze Direction* (Direct vs. Averted), and a between-subject variable *TAS Group* (LTAS vs. HTAS) were conducted. For N170 and P200, an additional within-subject variable *Hemisphere* (Left vs. Right) was also included in the ANOVA models.

After that, to examine whether the alexithymic influence in the neural activities in the perception of emotional faces with different gaze directions can be explained by autistic traits, we ran linear regressions (*TAS group* is a categorical variable rather than continuous variable, so linear regression is more appropriate than partial correlation) on the eye-contact effects (direct gaze – averted gaze) with *TAS group* as the predicting variable and AQ as the covariate. The analysis was only done in the ERP components that found significant difference among the TAS groups. Since AQ scores affected the relationship between *TAS group* and the eye-contact effect of angry faces at the frontal N2, we additionally ran a mediation analysis to investigate how AQ scores mediated the relationship.

Lastly, to explore the relationship among alexithymia, the early gaze difference at the frontal N1 and the subsequent eye-contact effect of angry faces at the frontal N2, we ran a mediation analysis with these three variables included.

As the exploratory analyses, we ran a whole brain analysis which included all channels to explore the effect of *TAS Group* on the channels outside of the regions of interest. Whole brain analyses were conducted by applying 3-way (*Emotion* × *Gaze Direction* × *TAS Group)* ANOVAs on all the channels and corrected the results using Benjamini-Hochberg false discovery rate (FDR) method.

Behavioural data was divided according to the probe contents. To examine whether the subjects categorized the faces correctly and whether there were group differences between HTAS and LTAS, 3-way ANOVA models were conducted with within-subject variables *Emotion* (Neutral vs. Angry vs. Happy) and *Gaze Direction* (Direct vs. Averted), and the between-subject variable *TAS group* (LTAS vs. HTAS) on the subjects' proportions of "Yes" responses to each probe.

Greenhouse-Geisser correction (when sphericity assumption is violated) and Holms-Bonferroni correction (for multiple pairwise comparisons) were applied when appropriate. SPSS Statistics 25 (IBM, NY, USA) and Matlab R2018a (Mathworks, MA, USA) were used for data analysis.

5.3. Results

Overall, gaze direction is processed earlier than emotion in the temporal areas, such as N170 for gaze vs P200 for emotion (Figure 5.3). Emotion is also processed in the frontal areas at the N2. Emotion and gaze interact as early as at the N1 in the frontal areas. While LTAS processes gaze direction at both the temporal areas (N170) and the frontal areas (N1), HTAS processes gaze direction only at the temporal areas (N170). Compared to LTAS, HTAS also displayed reduced neural differentiation between angry faces with different gaze directions (N2), and an increase in neural differentiation between happy faces with different gaze directions (VPP) in the frontal areas.

5.3.1. Gaze direction is processed as early as at the N170 in temporal areas

We observed a marginally significant main effect of *Gaze Direction* ($F(1, 37) = 3.89$, $p = .056$) at the N170 by ANOVA. Faces with averted gaze elicited more negative N170 than those with direct gaze (-2.02 vs. -1.91 µV). N170 has been suggested to be related to processing/detecting the onset of eyes rather than faces (Burra, Baker, & George, 2017; Conty, N'Diaye, Tijus, & George, 2007; McCrackin & Itier, 2018; Pönkänen et al., 2011; Rossi et al., 2015). Aligning with the eye detection hypothesis, multiple studies have reported that N170 amplitude is modulated by the gaze direction of the face (see Discussion).

5.3.2. Emotion is processed later than gaze direction in the temporal (P200), and the frontal areas (N2)

The effect of *Emotion* was significant in the P200 amplitudes ANOVA ($F(2, 74) = 17.97$, $p < .001$). Neutral faces (2.13 µV) activated stronger P200 amplitudes than angry faces (1.71 µV; $t(38) = 5.72$, $p < .001$, Holms-Bonferroni-corrected) and happy faces (2.00 µV; $t(38) = 2.09$, $p = .043$, Holms-Bonferroni-corrected). The P200 amplitudes were also significantly more positive towards happy faces than towards angry faces ($t(38) = 3.75$, $p = .001$, Holms-Bonferroni-corrected). Thus, it takes around 240ms for the temporal region to process emotion information and to distinguish different emotions after the onset of the face stimuli.

Furthermore, the interaction effect *Emotion* × *Hemisphere* was also found to be significant in the P200 amplitude ANOVA ($F(1.58, 58.36) = 3.62$, $p = .043$, Greenhouse-

Geisser corrected). In both hemispheres, angry faces (right hemisphere: 1.69 μV; left hemisphere: 1.72 μV) activated weaker P200 amplitudes than the neutral faces (right hemisphere: 2.22 μV, $t(38) = 5.30$, $p < .001$, Holms-Bonferroni-corrected; left hemisphere: 2.04 μV, $t(38) = 3.95$, $p < .001$, Holms-Bonferroni-corrected). For the happy faces, on the other hands, while they (2.11 μV) were not differentiable from the neutral faces in the right hemisphere ($t(38) = 1.63$, $p = .112$), they elicited weaker P200 activation than the neutral faces at the left hemisphere (1.89 μV, $t(38) = 2.06$, $p = .092$, Holms-Bonferroni-corrected; $p = .046$, uncorrected) though it did not survive correction for multiple comparison. Furthermore, while the angry faces elicited weaker P200 amplitude than happy faces in the right hemisphere ($t(38) = 4.48$, $p < .001$, Holms-Bonferroni-corrected), the two faces were not differentiable in the left hemisphere ($t(38) = 1.68$, $p = .101$). Therefore, the perception of angry faces recruits both hemispheres, whereas that of the happy faces recruits only the left hemisphere.

This emotion information processing in the temporal areas coincides with the emotion processing in the frontal areas. ANOVA revealed a significant *Emotion* main effect ($F(2, 74) = 5.66$, $p = .005$) in the N2 amplitudes. Neutral faces elicit more negative N2 amplitudes than angry faces (-1.66 vs. -1.32 μV; $t(38) = 3.09$, $p = .012$, Holms-Bonferroni-corrected). None of the other comparisons reached significance (*ps* > .05).

5.3.3. Early and late processing of self-relevant emotional faces at the frontal areas (N1) and at the parietal areas (P3b) respectively

Significant *Emotion* × *Gaze Direction* interaction effect was found at the N1 at the frontal channels ($F(2, 74) = 3.27$, $p = .044$). Stronger eye-contact effect was observed at the N1 activation for angry faces (Direct vs Averted: -0.97 vs. -1.12 μV) than for neutral faces (Direct vs. Averted: -1.12 vs. -0.94 μV; $t(38) = 2.34$, $p = .024$, uncorrected) and for happy faces (Direct vs. Averted: -1.08 vs. -0.98 µV; $t(38) = 2.22$, $p = .033$, uncorrected). The eye-contact effect for happy faces did not differ from that for neutral faces ($t(38) = 0.55$, $p = .587$). Although the significant results did not survive the correction for multiple comparisons, such early differentiation of angry faces with different gaze directions is reasonable as gaze direction may play a more important role or may be of more ecological significance in angry faces than in neutral faces because it indicates whether oneself is the target of the potential threat.

At the parietal channels, *Emotion* × *Gaze Direction* interaction effect was also found to be significant ($F(2, 74) = 9.84$, $p < .001$). Angry faces with direct gaze (0.11 µV) was found to elicit significantly weaker P3b amplitudes than those with averted gaze (0.43 µV; $t(38) = 3.67$, $p = .002$, Holms-Bonferroni-corrected). The P3b activation difference between gaze directions was not found in either happy faces (Direct vs. Averted: 0.19 vs. 0.21 µV) or neutral faces (Direct vs. Averted: 0.48 vs. 0.27 µV; *p*s > .05).

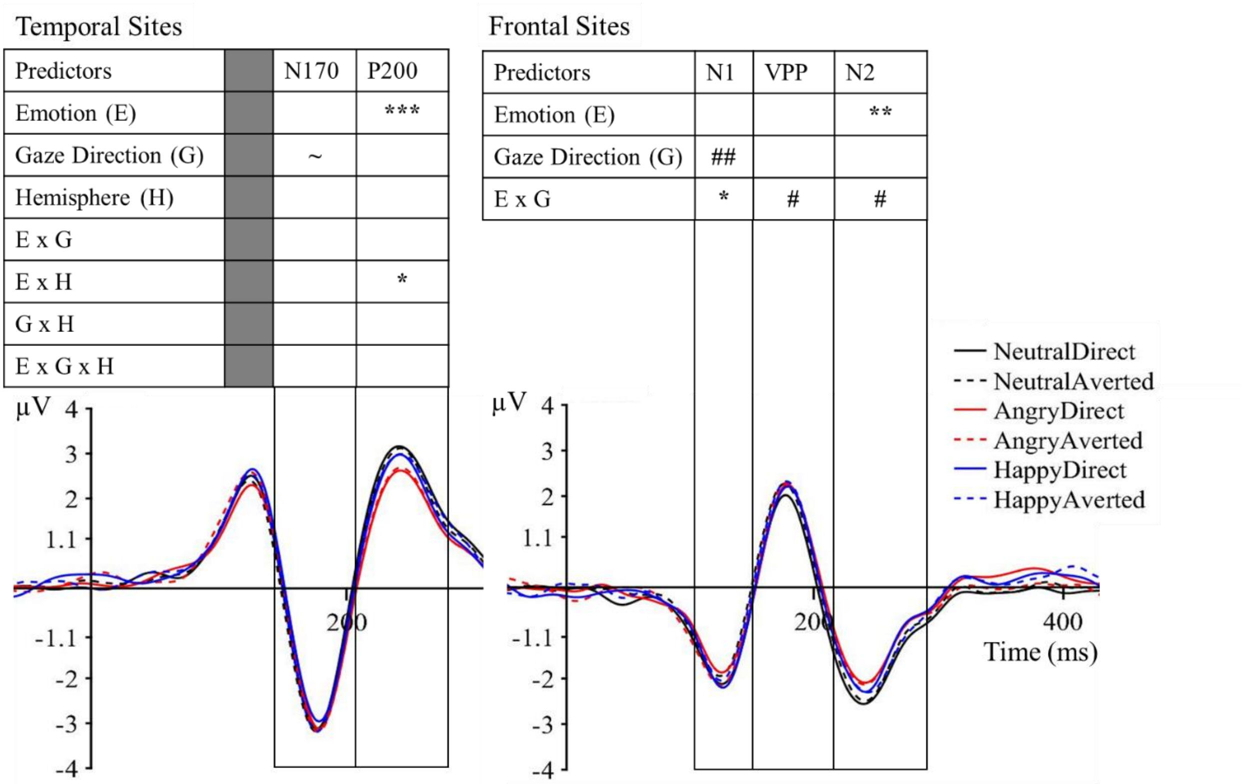

Figure 5.3. The tables illustrate the result summary of the ANOVA models on the ERP mean amplitudes of the temporal (left panel) and the frontal (right panel) electrode sites respectively. Asterisk (*) indicates that the main effects or the interaction effects were significant. Hashtag (#) indicate that a significant interaction with *TAS Group*. For instance, at the frontal VPP, the interaction effect of *Emotion* × *Gaze Direction* × *TAS Group* was significant, but the *Emotion* × *Gaze Direction* interaction effect was not. ~, $p < .06$; *, #, $p < .05$; **, ##, $p < .01$; ***, $p < .001$.

5.3.4. Alexithymia modulates the neural differentiation between faces with different gaze directions at the frontal areas (N1)

There was also a significant *Gaze Direction* × *TAS Group* interaction effect ($F(1, 37) = 8.37$, $p = .006$), such that the LTAS tended to have more negative N1 activation for faces with averted gaze (-0.90 µV) than those with direct gaze (-0.71 µV; $t(18) = 2.29$, $p = .034$; Figure 5.4a), while such activation differences did not occur in the HTAS ($t(19) = 2.02$, $p = .058$; Figure 5.4b). Linear regression analysis showed that the addition of AQ scores did not affect the effect of *TAS Group* in predicting the eye-contact effect in the N1 activation (excluding AQ scores: *Beta* = -.43, $p = .006$; including AQ scores: *Beta* = -.46, $p = .012$). It suggests that the alexithymic effect on the processing of gaze directions in the N1 activation was not due to the autistic effect.

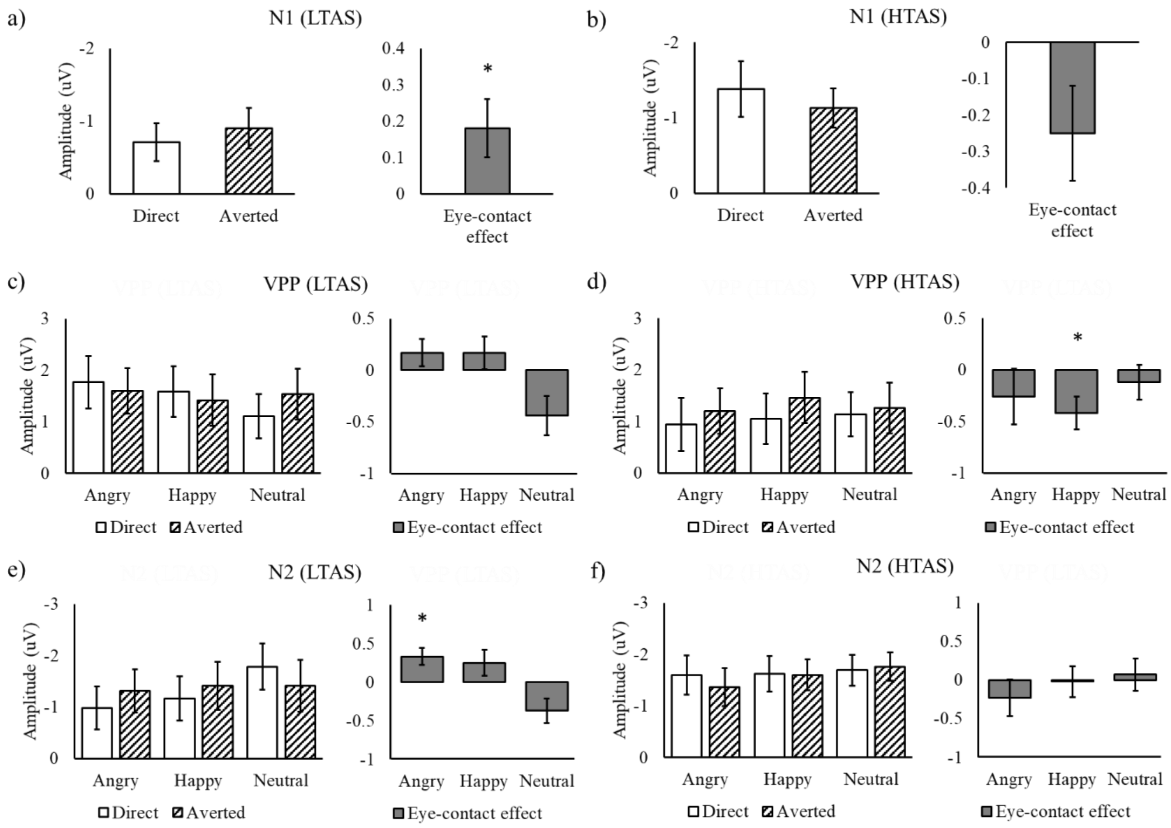

Figure 5.4. Demonstration of the modulation on the mean amplitudes of N1 (top panels), VPP (middle panels) and N2 (bottom panels) from *Emotion* and *Gaze Direction* in LTAS (left panels) and HTAS (right panels). Eye-contact effects were derived by subtracting the activation towards averted-gazed faces from that towards direct-gazed faces. For example, in LTAS, the N2 activation for direct-gazed angry faces was -0.98µV and that for averted-gazed angry faces was -1.31µV. Thus the eye-contact effect in the N2 of angry faces was 0.33µV. The error bar indexes the standard errors of mean of the activation. Asterisk (*) indicates significant difference between faces with different gaze directions. *, $p < .05$.

5.3.5. Alexithymia modulates the processing of self-relevant emotional faces at the frontal areas

We then investigated the association between alexithymia and the processing of self-relevant emotional faces. Overall, we found that alexithymia affects neural differentiation of self-relevant emotional faces and self-irrelevant emotional faces at the VPP and the N2.

VPP: There was a significant *Emotion* × *Gaze Direction* × *TAS Group* interaction ($F(2, 74) = 4.90$, $p = .010$) at the VPP. The interaction is driven by the significant eye-contact effect in happy faces in HTAS (Direct vs. Averted: 1.05 vs. 1.46 μV; $t(19) = 2.66$, $p = .045$, Holms-Bonferroni-corrected, Figure 5.4d), but not in LTAS (Direct vs. Averted: 1.59 vs. 1.42 μV; $t(18) = 1.05$, $p > .05$, Figure 5.4c). Linear regression analysis showed that the addition of AQ scores did not affect the effect of *TAS Group* in predicting the eye-contact effect of happy faces in the VPP activation (excluding AQ scores: *Beta* = -.39, $p = .013$; including AQ scores: *Beta* = -.44, $p = .017$). It suggests that the alexithymic effect on the processing of gaze directions of happy faces in the VPP activation was not due to the autistic effect.

N2: We found a significant *Emotion* × *Gaze Direction* × *TAS Group* interaction ($F(2, 74) = 4.31$, $p = .017$) at the N2. ANOVAs showed that whereas the interaction effect *Emotion* × *Gaze Direction* was significant in LTAS ($F(2, 36) = 9.17$, $p = .001$; see Figure 5.4e), it was not significant in HTAS ($F(2, 38) = 0.56$, $p = .576$; see Figure 5.4f). The significant *Emotion* × *Gaze Direction* interaction effect in LTAS may be caused by the significant gaze direction effect in angry faces (Direct vs Averted: -0.98 vs. -1.31 μV; $t(18) = 2.96$, $p = .024$, Holms-Bonferroni-corrected), but not in happy faces (Direct vs Averted: -1.16 vs. -1.41 μV; $t(18) = 1.44$, $p = .168$) nor neutral faces (Direct vs Averted: -1.78 vs. -1.41 μV; $t(18) = 2.25$, $p = .074$, Holms-Bonferroni-corrected). Linear regression analysis showed that the addition of AQ scores improved the model predicting the eye-contact effect of angry faces in the N2 activation (*TAS Group* as the only predictor: $F(1, 37) = 4.43$, $p = .042$; *TAS Group* and *AQ* as predictors: $F(2, 36) = 5.42$, $p = .009$, R square change = .13, $p = .021$). We ran a mediation analysis and found that the effect of *TAS Group* on the eye-contact effect of angry faces in the N2 activation was mediated by the AQ scores of the subjects (see Figure 5.5), such that individuals with high autistic traits tend to have stronger eye-contact effect than those with low autistic traits after controlling for *TAS group*.

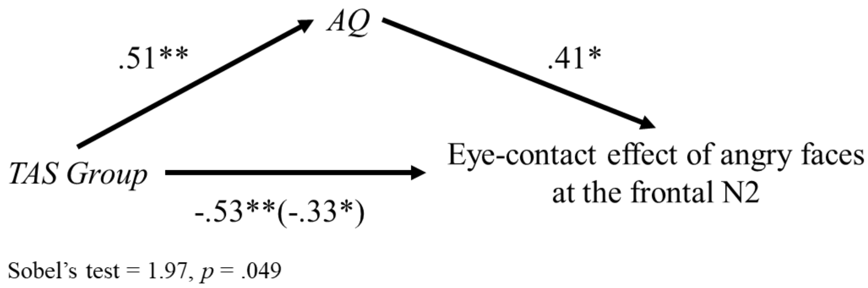

Figure 5.5. Mediation effect of AQ score on the relationship between TAS Group and eye-contact effect of angry faces at the frontal N2. Positive values pointing to the eye-contact effect indicates positive relationship, e.g., higher AQ scores predicts stronger eye-contact effect; Negative values pointing to the eye-contact effect indicates negative relationship, e.g., HTAS group predicts weaker eye-contact effect than LTAS group. Standardized coefficients are reported. *, $p < .05$; **, $p < .01$.

5.3.6. Gaze difference at the frontal N1 explains the alexithymic difference in the eye-contact effect of angry faces at the frontal N2

We ran a regression analysis on the eye-contact effect of angry faces at the frontal N2 with TAS Group and the gaze difference at the frontal N1 to explore the relationship between the three variables. We found that that the addition of the N1 gaze difference improved the model predicting the eye-contact effect of angry faces in the N2 activation by *TAS Group* (*TAS Group* as the only predictor: $F(1, 37) = 4.43$, $p = .042$; *TAS Group* and *N1 Gaze Difference* as predictors: $F(2, 36) = 16.38$, $p < .001$, R square change = .37, $p < .001$). We ran a mediation analysis and found that the effect of *TAS Group* on the eye-contact effect of angry faces in the N2 activation was mediated by the N1 gaze difference (see Figure 5.6), such that *TAS group* affects the eye-contact effect of angry faces in the N2 activation indirectly through the N1 gaze difference.

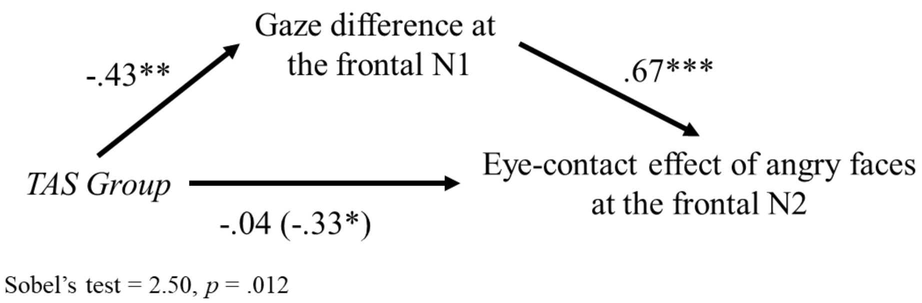

Figure 5.6. Mediation effect of the gaze difference at the frontal N1 on the relationship between TAS Group and eye-contact effect of angry faces at the frontal N2. Positive values pointing to the eye-contact effect indicates positive relationship, e.g., stronger gaze difference at the frontal N1 predicts stronger eye-contact effect of angry face at the frontal N2; Negative values pointing to the eye-contact effect indicates negative relationship, e.g., HTAS group predicts weaker gaze difference at the frontal N1 than LTAS group. Standardized coefficients are reported. *, $p < .05$; **, $p < .01$, ***, $p < .001$.

5.3.7. Alexithymic effect on the temporal N250

Since previous ERP studies on emotional face perception in alexithymia mostly reported an alexithymic difference in N250 peak latency, we additionally included the analysis on the N250 peak amplitudes and peak latencies. In terms of the peak amplitude, only the *Hemisphere* × *TAS Group* interaction was significant ($F(1, 37) = 6.34$, $p = .016$). The interaction effect was due to the more negative going N250 activation at the left hemisphere (-0.37 µV) than at the right hemisphere in LTAS (0.20 µV; $t(18) = 2.39$, $p = .028$), but not in HTAS (Left hemisphere vs. Right hemisphere: -0.08 µV vs. -.34 µV, $t(19) = 1.14$, $p = .270$). No other main effects nor interaction effects were significant (*p*s > .05). In terms of the peak latency, only the main effect of *Hemisphere* was significant ($F(1, 37) = 7.65$, $p = .009$). The main effect suggests that the N250 at the right hemisphere (317.02ms) peaked earlier than at the left hemisphere (321.43ms). No other main effects nor interaction effects were significant (*p*s > .05).

5.3.8. Exploratory whole-brain analysis

The whole brain analysis revealed similar results as the ROI analysis. Emotion was found to be processed at both the frontal channels (E4, E6, E7, and E9) and temporal channels (E29, E30, E32, E39, E 40, E43, E44, E47, and E52) in the time window 205ms to 287ms. Averaging across the frontal channels the found the main effect *Emotion* significant ($F(2,74) = 8.36$, $p = .001$), *post-hoc* analysis revealed that neutral faces (M = -1.41 μV) elicited more negative N2 than both angry faces (M = -1.05 μV; $t(38) = 3.68$, $p = .003$, Holm-Bonferroni corrected) and happy faces (M = -1.18 μV; $t(38) = 2.74$, $p = .018$, Holm-Bonferroni corrected). The N2 activations for angry faces and happy faces, however, did not differ from each other ($t(38) = 1.64$, $p = .110$).

Next, we averaged the left temporal channels (E29, E30, E32) and the right temporal channels (E43, E44, E47) with the main effect *Emotion* significant and overlapped across hemispheres. The main effect of Emotion can be explained by the less positive P200 activation for angry faces (M = 1.40 μV) than for neutral faces (M = 1.82 μV; $t(38) = 5.94$, $p < .001$, Holm-Bonferroni corrected) and happy faces (M = 1.70 μV; $t(38) = 4.15$, $p < .001$, Holm-Bonferroni corrected). Furthermore, the amplitude difference in P200 activation was also significant between neutral faces and happy faces ($t(38) = 2.07$, $p = .045$, Holm-Bonferroni corrected). On the other hand, the interaction effect of *Emotion* × *Hemisphere* was not significant ($F(1.55,57.27) = 3.00$, $p = .070$, Greenhouse-Geisser corrected). This suggested that in terms of activation amplitudes, the processing of emotion did not differ across hemisphere. However, considering there are more channels at the right temporal regions (E39, E40, E43, E44, E47, and E52) that found the main effect *Emotion* significant than at the left temporal regions (E29, E30, and E32), the right hemisphere might have a wider range of neural regions that process emotions. The findings provide support for Right

Hemisphere Hypothesis of emotion processing at the posterior regions (Borod et al., 1998; Killgore & Yurgelun-Todd, 2007).

Furthermore, alexithymia appears to affect face processing differently at different time windows. In the time window 65ms to 151ms, no main effects or interaction effects survived Benjamini-Hochberg correction for multiple comparison at an FDR of 5%. With a more liberal FDR of 10%, *Gaze Direction* × *TAS group* interaction effect was significant at the frontal channel E8 ($F(1, 37) = 12.10$, $p = .001$; Figure 5.7a). *Post-hoc* analysis showed that faces with direct gaze (M = -0.65 µV) elicited weaker frontal N1 activation than those with averted gaze (M = -0.91 µV; $t(18) = 2.68$, $p = .015$) in LTAS, but the pattern was reversed in HTAS (Direct gaze = -1.56; Averted gaze = -1.21; $t(19) = 2.43$, $p = .025$).

In the time window 151ms to 205ms, the interaction effect *Emotion* × *Gaze Direction* × *TAS group* was found in the frontal channels (E5, E6, E8, E10) and an occipital channel (E37) after applying Benjamini-Hochberg correction at an FDR of 5% (Figure 5.7b). Averaging the frontal channels E5, E6, E8, and E10, we found that the significant *Emotion* × *Gaze Direction* × *TAS group* interaction ($F(2, 74) = 8.76$, $p < .001$) was driven by the significant eye-contact effect in happy faces in HTAS (Direct vs. Averted: 0.97 vs. 1.55 µV; $t(19) = 3.05$, $p = .021$, Holms-Bonferroni corrected), but not in LTAS (Direct vs. Averted: 1.74 vs. 1.49 µV; $t(18) = 1.34$, $p = .197$). We also observed a significant eye-contact effect in neutral faces in LTAS (Direct vs. Averted: 1.07 vs. 1.68 µV; $t(18) = 2.87$, $p = .030$, Holms-Bonferroni corrected), but not in HTAS (Direct vs. Averted: 1.23 vs. 1.27 µV; $t(19) = 0.16$, $p = .875$). In the occipital channel (E37), happy faces (M = -0.99 µV) elicited more negative N170 than neutral faces (-0.64 µV) when the gaze was direct ($t(18) = 3.27$, $p = .024$, Holms-Bonferroni corrected), but no N170 activation difference was observed in the two faces when the gaze was averted (Neutral vs. Happy: -0.96 vs. -0.78 µV; $t(18) = 1.11$, $p = .280$). In contrast, neutral faces and happy faces were not differentiated either when the gaze was direct (Neutral vs. Happy: -1.44 vs. -1.15 µV; $t(19) = 1.87$, $p = .070$) or when it was averted (Neutral vs. Happy: -1.26 vs. -1.41 µV; $t(19) = 0.99$, $p = .335$) in HTAS.

In the time window 205ms to 287ms, the interaction effect *Emotion × Gaze Direction × TAS group* was found only in the frontal channels (E6, E8, E10, E18) when FDR was set to be 10% (Figure 5.7c). ANOVA revealed a significant *Emotion × Gaze Direction × TAS group × Channel* ($F(3.18, 117.52) = 8.41$, $p < .001$, Greenhouse-Geisser corrected), suggesting that the patterns for the *Emotion × Gaze Direction × TAS group* interaction effect differed across channels. We observed three different types of alexithymic influences in different channels. 1) For the two posterior midline channels, E6 and E8, the *Emotion × Gaze Direction × TAS group* interaction effect was mainly driven by the fact that angry faces with averted gaze (E6 = -1.36 µV; E8 = -1.37 µV) elicited more negative N2 activation than those with direct gaze (E6 = -0.98 µV; $t(18) = 2.78$, $p = .036$, Holms-Bonferroni corrected; E8 = -0.96 µV; $t(18) = 3.03$, $p = .021$, Holms-Bonferroni corrected) in LTAS, but not in HTAS (E6: Direct vs. Averted: -1.70 vs. -1.37 µV; $t(19) = 1.30$, $p = .208$; E8: Direct vs. Averted: -1.90 vs. -1.44 µV; $t(19) = 1.64$, $p = .118$).

2) For the anterior midline channel, E10, the *Emotion × Gaze Direction × TAS group* interaction effect was mainly driven by the fact that neutral faces with direct gaze (M = -1.84 µV) elicited marginally more negative N2 activation than those with averted gaze (M = -1.24 µV; $t(18) = 2.60$, $p = .054$, Holms-Bonferroni corrected) in LTAS, but not in HTAS (Direct vs. Averted: -1.68 vs. -1.85 µV; $t(19) = 0.67$, $p = .510$).

3) For the left frontal channel, E18, the *Emotion × Gaze Direction × TAS group* interaction effect was mainly driven by the fact that angry faces with averted gaze (M = -0.90 µV) elicited marginally more negative N2 activation than those with direct gaze (M = -0.52

μV; $t(19) = 2.58$, $p = .054$, Holms-Bonferroni corrected) in HTAS, but not in LTAS (Direct vs. Averted: -0.96 vs. -0.74 μV; $t(18) = 1.50$, $p = .152$). In general, HTAS appears to use left frontal regions to differentiate angry faces with different gaze direction rather than using the midline frontal regions as LTAS does.

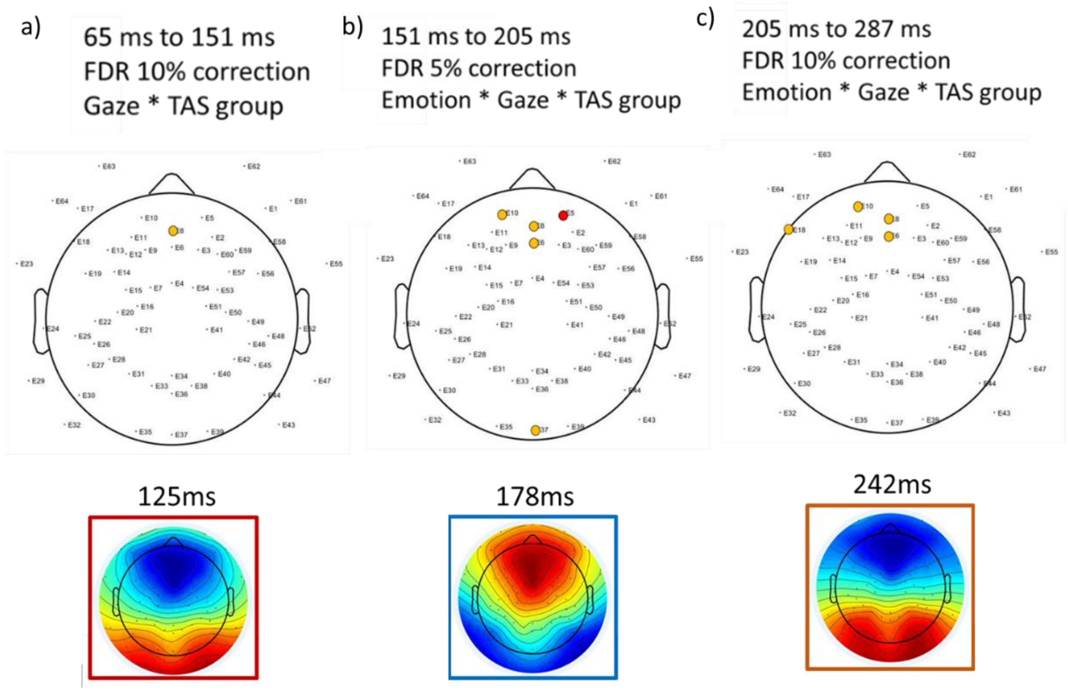

Figure 5.7. Results related to *TAS Group* in the whole-brain analysis using Benjamini-Hochberg FDR method as correction for multiple comparisons. Channels with yellow color indicate $p < .05$; Channels with orange color indicate $p < .01$; and Channels with red color indicate $p < .001$. a) *Gaze Direction* × *TAS group* interaction effect was significant at the frontal channel E8 in the time window 65ms to 151ms when FDR rate was set to be 10%. No significances survived in any channels when more stringent FDR rate (5%) was set; b) *Emotion* × *Gaze Direction* × *TAS group* interaction effect was significant at frontal channels E5, E6, E8, and E10, and occipital channel E37 in the time window 151ms to 205ms when FDR rate was set to be 5%; c) *Emotion* × *Gaze Direction* × *TAS group* interaction effect was significant at frontal channels E6, E8, E10, and E18 in the time window 205ms to 287ms when FDR rate was set to be 10%. No significances survived in any channels when a more stringent FDR rate (5%) was applied.

5.3.8. Behavioural data

In general, the subjects achieved 91.4% (SD = 5.1%) accuracy in the task. No significant difference in task accuracy was found between LTAS (mean = 92.6%; SD = 4.2%) and HTAS (mean = 90.2%; SD = 5.7%; $t(37) = 1.51$, $p = .140$). Details of the analyses on the behavioural data are illustrated in Appendix II.

There was a significant *Gaze Direction* × *TAS Group* interaction effect in the ANOVA of “Central Gaze” probe ($F(1,37) = 4.17$, $p = .048$). The interaction was explained by that the gaze effect in identification accuracy was smaller in HTAS (Direct Gaze vs. Averted Gaze: 90.4% vs. 15.8%) compared to LTAS (Direct Gaze vs. Averted Gaze: 93.6% vs. 9.0%). No other main effects nor interaction effects related to *TAS Group* were found significant (*p*s > .05). In sum, this suggests that HTAS is more likely to confuse gaze direction than LTAS, especially when the gaze is averted (i.e., they have a higher tendency to identify the averted gaze as direct gaze).

5.4. Discussion

Experiment 3 investigated the neural mechanism and the temporal trajectory of the evaluation of self-relevance in emotional face perception and its association with alexithymia. We found that gaze direction is processed at around 170ms after stimulus onset at the temporal areas (N170). For LTAS, gaze direction can be processed even earlier, at 120ms at the frontal areas (N1). After that, emotions are differentiated at around 240ms after stimulus onset at the temporal areas (P200) and the frontal areas (N2). Interestingly, emotion-gaze interaction was observed at as early as N1 at the frontal areas, such that the eye-contact effect of angry faces was stronger than that of neutral faces and happy faces. Similar emotion-gaze interaction was also found in the later stage of the processing at the parietal areas. At the P3b, the activation to angry faces was differentiated from the neutral faces only when the faces were with direct gaze. Furthermore, partially aligning with our hypothesis, alexithymia influences the evaluation of self-relevance in emotional face perception only at the frontal areas (VPP and N2). More specifically, angry faces, but not neutral nor happy faces, with different gaze directions were differentiated at the N2 in LTAS but not in HTAS. On the other hand, happy faces, but not other faces, with different gaze directions were differentiated at the VPP in HTAS but not in LTAS.

Literature on eye-contact effect showed that the neural differentiation in gaze direction can occur at around 170ms after stimulus onset at the temporal areas (Burra, Baker, & George, 2017; Conty, N'Diaye, Tijus, & George, 2007; Klucharev & Sams, 2004; Latinus et al., 2014; McCrackin & Itier, 2018; Pönkänen, Alhoniemi, Leppänen, & Hietanen, 2011; Rossi, Parada, Latinus, & Puce, 2015). While the eye-contact effect in this 170ms time window is replicated in our study, we further found that gaze direction can be processed at even as early as around 120ms after stimulus onset at the frontal areas (N1) in the low alexithymia individuals. More specifically, faces with averted gaze elicited stronger N1 amplitudes than faces with direct gaze. Since the frontal N1 has been associated with attentional engagement to the stimulus (Hillyard & Anllo-Vento, 1998; Luck & Kappenman, 2012) and stronger N1 was found in effortful task than in effortless task (Benikos, Johnstone, & Roodenrys, 2013; Mulert et al., 2008), one interpretation to the finding is that attending to faces with averted gaze is more effortful than to those with direct gaze. The fast detection of gaze direction matches with the first-track modulator model of eye gaze perception (Johnson et al., 2015; Senju & Johnson, 2009) which proposed the eye-contact effect is a result of a fast modulation at the subcortical pathway, e.g., amygdala, and a slow information processing at the cortical pathway, e.g., temporal cortex. Our observation of the frontal N1 differentiation of gaze direction might be reflecting the subcortical-to-frontal feedforward signals (Cremers et al., 2010; Kim et al., 2011; Sato, Kochiyama, Uono, Yoshikawa, & Toichi, 2017).

The slow processing cortical pathway for gaze direction is supported by our N170 findings. Consistent with the majority of the previous studies, stronger ERP activation was found in faces with averted gaze than in direct gaze (Itier et al., 2007; McCrackin & Itier, 2018; Pönkänen et al., 2011; Puce et al., 2000; Rossi et al., 2015; Watanabe et al., 2002). Since the N170 has been associated with eye detection and attention to eyes in face perception (Kloth, Itier, & Schweinberger, 2013; McPartland, Cheung, Perszyk, & Mayes, 2010; Nemrodov, Anderson, Preston, & Itier, 2014; Parkington & Itier, 2018), the gaze modulation in the temporal N170 might be indicating increased attention to eye regions when the gaze is averted.

Overall, emotion is processed later than gaze direction. In contrast to early ERP studies (Aarts & Pourtois, 2012; Blechert et al., 2012; Calvo & Beltrán, 2014; Jiang et al., 2014; Morel et al., 2009; Rellecke et al., 2012; Smith, 2012), the N170 was not responsive to emotion categories. Instead, we showed that emotion is processed and categorized at the temporal P200 (~240ms PSO). Similar emotion effect at the P200 was also reported in other studies (Beltrán & Calvo, 2015; Calvo & Beltrán, 2014; Williams, Palmer, Liddell, Song, & Gordon, 2006). P200 has been suggested to be related to the processing of spatial relationships among features (Latinus & Taylor, 2006; Mercure et al., 2008). Emotional faces, therefore, may require more spatial relationship processing than neutral faces (Bombari et al., 2013; Calder & Jansen, 2005; Calvo & Nummenmaa, 2008; McKelvie, 1995; Prkachin, 2003). We also found that while the P200 activation at the right hemisphere only differentiated angry faces from the neutral faces, that at the left hemisphere differentiated both happy faces and angry faces from the neutral faces. The hemispheric difference in processing emotional faces fit with the valence hypothesis of emotion perception (Adolphs, Jansari, & Tranel, 2001; Killgore & Yurgelun-Todd, 2007; Prete, Laeng, Fabri, Foschi, & Tommasi, 2015), which proposed that the right hemisphere is specialized in processing negative emotions while the left hemisphere processes positive emotions. On top of the processing at the temporal regions, angry faces were also analyzed at the frontal N2. Similar findings (i.e., weaker N2 amplitude in angry faces than in other emotional faces) were reported in previous studies in which the subjects were perceiving the emotional faces under low working memory load (Van Dillen & Derks, 2012) and when the task was non-incentivized (Wu, Müller, Zhou, & Wei, 2019). The emotional differences were attenuated once the working memory load was increased or the task became incentivized. Together with the literature indicating that the N2 is associated with attentional control (Dennis & Chen, 2009; Folstein & Van Petten, 2008; Zhang & Lu, 2012), the reduced N2 activation of angry faces may suggest that social threat captures attention more automatically and thus is less effortful than processing neutral faces.

The anger-specific eye-contact effect occurred as early as 120ms after stimulus onset at the frontal regions (N1). This could mean that subjects responded differently towards gaze information in angry faces than in neutral faces and in happy faces at the very early processing stage. While it seems to be contradictory to our earlier finding that emotion is not differentiated until the P200 (~240ms), we posit that this effect at the N1 may not be related to emotion processing *per se*, especially since this effect is specific to angry faces only. Rather, this effect may be driven by the rapid detection of biologically significant threat (Diano, Celeghin, Bagnis, & Tamietto, 2017; Tamietto & De Gelder, 2010; but see Pessoa & Adolphs, 2010) . The anger-specific eye-contact effect in the N1 activation might be the result of feedforward signals to the frontal regions from the subcortical pathway (Cremers et al., 2010; Kim et al., 2011; Sato et al., 2017). Our findings reconcile with the previous studies suggesting that the rapid processing at the subcortical pathway not only processes gaze and emotion individually, but also provide early interaction for the two types of information (Adams et al., 2003; N'Diaye et al., 2009; Sato et al., 2010, 2004b; Ziaei et al., 2016). Nonetheless, the same effect was not observed when we conducted whole brain analysis with 10% false discovery rate correction. This raises the possibility that the observed early face-gaze interaction at N1 could be a false positive and thus one should not over-interpreting the finding. Taken together, angry faces with direct gaze, which is a self-relevant and biologically significant social threat, may be processed at such an early time window.

Our hypotheses related to alexithymia are supported. We found that 1) HTAS tends to process gaze direction later than LTAS; 2) HTAS has attenuated self-relevance processing for angry faces, and has stronger self-relevance processing for happy faces at the midline frontal areas (N2 and VPP respectively). According to the ROI analysis, in contrast to LTAS who recruits both the frontal N1 and the temporal N170 for gaze direction processing, HTAS only relies on the cortical pathway. If the N1 activation reflects the subcortical-to-frontal feedforward signals (Cremers et al., 2010; Kim et al., 2011; Sato et al., 2017), our findings will support the proposal that alexithymic symptoms are partially attributed to the subcortical deficits (Donges & Suslow, 2017). Some studies showed a hypo-aroused amygdala in alexithymia during suboptimal negative face perception (Kugel et al., 2008; Reker et al., 2010; but see Ihme et al., 2014b; Suslow et al., 2016). Since the amygdala is also responsible in directing one's attention to self-relevant information (Schmitz & Johnson, 2007), its hypoactivity in alexithymia may affect the early automatic processing of gaze direction and thus causes the HTAS to pay less attention to eye information.

Yet, exploratory whole brain analysis showed that the alexithymic influence on gaze processing at the early time window may be apparent in only one frontal channel (E8) and

HTAS tended to have stronger N1 activation towards direct gaze than averted gaze. While the results from the whole brain analysis appeared to be slightly different from the ROI analysis, both results suggested that HTAS may require more attentional resources to process direct gaze than LTAS. Since the whole brain analysis aimed to explore alexithymic effect that may be missed in the ROI analysis rather than confirming its results, we based our discussion primarily on the findings from the ROI analysis.

On top of its influence on early gaze processing, alexithymia was also found to disrupt the evaluation of self-relevance in angry face perception at the frontal N2, which has been associated with the interaction between facial expression and eye gaze (Li et al., 2017; for ERP activation for emotional eye-contact effect at the frontal region with an equivalent time window, see Conty et al., 2012). The frontal N2 activation was weaker towards angry faces with direct gaze than those with averted gaze in LTAS, but it was equally strong in the two conditions in HTAS. Because N2 is related to attentional control (Dennis & Chen, 2009; Folstein & Van Petten, 2008; Zhang & Lu, 2012), our findings suggest that self-relevant angry faces require less attentional control and thus are less effortful to process than self-irrelevant angry faces in LTAS. In contrast, the angry faces with different gaze directions are equally effortful to process in HTAS. It is coherent with our findings in Experiment 1 in which the anger-specific eye-contact effect in self-threat rating reduced as the subjects' alexithymia scores increase. The frontal N2 has been repeatedly source localized at the mPFC and the ACC (for review, see Bocquillon et al., 2014), which are the frontal areas that have been commonly associated with alexithymia (Deng et al., 2013; Jongen et al., 2014; Lassalle et al., 2018; Van der Velde et al., 2013; Wingbermühle et al., 2012).These frontal regions are proposed to be part of the self-referential processing network (Hu et al., 2016; Northoff et al., 2006; Schmitz & Johnson, 2007). Combining our ERP findings and the previous fMRI studies, alexithymia might influence the cognitive evaluation of the self-relevance information during perception of social threat.

Interestingly, exploratory whole brain analysis showed that although their midline frontal face-gaze interaction may be disrupted, HTAS may recruit the left frontal region to process angry faces with different gaze directions. Since the left frontal regions are commonly associated with cognitive reasoning (Christoff et al., 2001; Goel & Dolan, 2004; Hampshire, Thompson, Duncan, & Owen, 2011; Parsons, 2001) whereas the midline frontal regions are related to affective processing (Etkin, Egner, & Kalisch, 2011; Harris, McClure, Van Den Bos, Cohen, & Fiske, 2007; Stevens, Hurley, & Taber, 2014), it is possible that HTAS may recruit cognitive reasoning rather than affective processing (as in LTAS) to evaluate self-relevance in a social condition. This possibility is coherent with the characteristic of alexithymia that they are impaired in processing their own feelings and emotions (Brewer et al., 2016; Lane et al., 1997; Shah et al., 2016). Perhaps HTAS has learnt not to rely on their own unreliable feelings and emotions, and instead use reasoning to deduce and understand what is happening in a social situation. The possible over-reliance on cognitive reasoning during social interaction in alexithymia may worth future research attention.

Other than disrupted evaluation of self-relevance, there are other possible explanations to our findings of alexithymic modulation on N2 activation. A typical functional significance associated with the frontal N2 is to identify perceptual conflict and incongruence (for a review, see Folstein & Van Petten, 2008). Stronger frontal N2 negativity was observed when a target was perceptually incongruent with the previously presented stimuli during a mismatch identification task (Kuldkepp, Kreegipuu, Raidvee, Näätänen, & Allik, 2013; Wang, Cui, Wang, Tian, & Zhang, 2004). In a similar vein, emotional faces whose occurrence was incongruent to expectation or environmental context also tended to elicit stronger N2 amplitudes (Lin, Schulz, & Straube, 2016; Xu et al., 2015; Yuan et al., 2012). Another explanation to our findings, thus, is that HTAS might have impaired ability in processing the motivational congruence of multiple sources of social information (e.g., angry face matches with direct gaze, in which both pieces of information are approach-oriented; Harmon-Jones, Harmon-Jones, & Price, 2013; Rolls, 2006). If this explanation is true, we should expect the same alexithymic disruption to be observed in happy face, which is also approach-oriented. However, our results showed that gaze effect in happy faces was not significant in N2 activation in LTAS nor HTAS. Impairment in processing motivational congruence, therefore, cannot fully account for the alexithymic modulation on the N2 activation.

Interestingly, we found that alexithymic influence on the eye-contact effect of angry face at the frontal N2 is mediated by the gaze difference at the frontal N1. The mediation relationship suggests that the alexithymic impairment in the evaluation of self-relevance during social threat processing may be explained by their reduced early attention to the eye information. This links our previous findings in Experiment 1 and Experiment 2, in which we showed that high alexithymic individuals tend to feel equally threatened by angry faces with different gaze directions (Experiment 1) and pay less attention to the eye region of angry face (Experiment 2). Nonetheless, this mechanism cannot fully explain our findings in Experiment 1 that the high alexithymia individuals are able to use the gaze information to inform their decisions in other tasks that do not require the evaluation of self-relevance (e.g., reporting how other feels towards the angry faces with different gaze directions). We therefore cannot exclude the possibility that the alexithymic impairment in the evaluation of self-relevance is partially because of the deficit in a high-level cognitive processing, e.g, self-referential processing, such that the impairment would be sustained even if gaze direction is accurately perceived by the high alexithymia individuals.

In Experiment 1, we did not find that alexithymia was related to the evaluation of self-relevance of happy faces. It is therefore unexpected that there was a neural difference between HTAS and LTAS when processing happy faces with different gaze directions. In general, the VPP activation at the frontal areas differentiate the happy faces with different gaze directions only in HTAS. More specifically, happy faces with averted gaze elicited stronger VPP activation than those with direct gaze in HTAS. One of the neural correlates that has been localized for the VPP is the ACC (other neural correlates includes the temporal areas and the parietal areas; Pourtois, Debatisse, Despland, & De Gelder, 2002; Rossion et al., 1999; Watters, Harris, & Williams, 2018; Williams et al., 2006). The ACC at the same time is responsible for reward processing, especially the reward received by oneself (Fareri & Delgado, 2014; Lockwood, Apps, Roiser, & Viding, 2015; Vassena, Krebs, Silvetti, Fias, & Verguts, 2014). Therefore, one interpretation of our finding would be that the HTAS distinguishes the reward values of the happy faces with different gaze directions, whereas LTAS does not distinguish among happy faces with different gaze directions, but finds them all equally rewarding. Nonetheless, previous studies tend to show that the activation of the VPP is more positive towards stronger rewards than weaker rewards (Chen & Wei, 2019; Marini, Marzi, & Viggiano, 2011; Wu et al., 2019). It would then suggest that the HTAS might consider happy faces with averted gaze as more rewarding than those with direct gaze, which may be counterintuitive. Future studies are required to further investigate how social reward is processed in alexithymia (e.g., Goerlich et al., 2017).

We did not, however, observe the alexithymic latency differences in the N250 component that have been reported in the previous studies (Campanella et al., 2012;

Vermeulen et al., 2008). This may be because of the differences in the paradigm adopted. Previous studies adopted the oddball paradigm, whereas our experiment adopted a simple perceptual paradigm. The major difference between the two paradigm is that the oddball paradigm requires the subjects to compare the presented face with the norm of a series of faces that have been presented previously. The oddball may further stress the subjects' face memory and need more attentional resources than a simple perceptual task. This may suggest that matching the perceived face with the face norm is more effortful in alexithymia (Valentine, 2001). Further studies are necessary to explore this possibility.

Another interesting finding is that autistic traits predict stronger eye-contact effect of angry faces at the frontal N2 after controlling for alexithymia trait. In both Experiment 1 and Experiment 3, autistic traits were shown to be unrelated to the eye-contact effect of angry faces behaviourally. One explanation to the discrepancy between the behavioural data and the neural data is that the highly functional adults with high autistic traits might have developed strategies to compensate for their impairments in emotion processing (Livingston & Happé, 2017). Therefore, the highly autistic individuals might need extra effort and neural activation to achieve the same behavior as the individuals with low autistic traits. This possibility also explains why we cannot replicate the previous studies showing neural and behavioral impairment in facial expression – gaze direction interaction in clinically autistic children (Akechi et al., 2009, 2010). Similar findings were reported in previous studies investigating autistic impairment in Theory of Mind task (ToM). It was found that although younger adults with autism tended to have difficulty in performing ToM, there was not such autistic difference in the older adults (age > 50) (Lever & Geurts, 2016). Furthermore, in the autistic population that perform the ToM task similar to the typically developed population, atypical eye movement and hyper-aroused frontal activations were observed (Senju, Southgate, White, & Frith, 2009; White, Frith, Rellecke, Al-Noor, & Gilbert, 2014), suggesting that they are either using different strategies to complete the task or that the task was more effortful to them than the typically developed individuals.

The alexithymic neural differences in processing emotional faces with different gaze directions found in this experiment can potentially link with our findings in Experiment 1, but one needs to be cautious when interpreting the results due to the limitations in this experiment. First, the behavioural paradigm of Experiment 3 was different from that of Experiment 1. While both paradigms were explicit emotional tasks involving identification of facial expression identification, the Experiment 3 paradigm did not ask the subjects to rate the threat they felt from the emotional faces as in Experiment 1. As such, we cannot make direct connection between the findings in the two experiments. However, of all the ERP components examined, only the N2 demonstrated the alexithymic reduction in eye-contact effect of angry faces as shown in Experiment 1 using behavioural measure. Therefore, we posit that the eye-contact effect of the N2 activation in this experiment and the eye-contact effect in the self-threat rating observed in Experiment 1 are related. Secondly, although our data clearly showed neural differentiations between emotional faces with different gaze directions, we cannot precisely pinpoint which perceptual or cognitive process is driving the neural differentiations. We can only make inferences based on the existing literature. Since there is limited past research on the same topic, and one ERP component can be implicated in many different processes, there may be other possible interpretations. However, our current interpretation is the one that best explains the current data in conjunction with the behavioural data in Experiment 1.

In sum (see Table 5.2), in Experiment 3, we found that, LTAS individuals showed gaze effect in early neural activities at the frontal N1, and gaze effect for angry faces at the frontal N2. In comparison, HTAS did not show such effects. Such impairment in gaze effect in neural activities may indicate the possible reasons of the impaired behavioural differences between the two groups of participants observed in Experiment 1 & 2. On the other hand, the gaze effect in happy faces were observed in the frontal VPP for HTAS but not LTAS. Alexithymia therefore is associated with deficit in early detection of gaze direction, and in the evaluation of self-relevance during emotional face perception at the neural level.

Major findings
1. Alexithymia is linked to a reduced eye-contact effect at the frontal N1
2. Alexithymia is linked to an increased eye-contact effect of happy faces at the frontal VPP
3. Alexithymia is linked to a reduced eye-contact effect at the midline frontal N2

Table 5.2. Summary of findings in Experiment 3

Chapter 6

General Discussion

Throughout this thesis, we investigated the question: Does alexithymia affect socio-emotional processing, and if it does, through what mechanism? The summary of the findings in all experiments is shown int Table 6.1. In Survey Study, we showed that the Singapore university students have an alexithymia rate of 24%. Also, alexithymia is related to both the deficit in social processing and emotional processing. Next, we have demonstrated that alexithymia reduces eye-contact effect of angry faces behaviourally (Experiment 1), suggesting that the condition is related to a deficit in the evaluation of self-relevance in socio-emotional processing. In Experiment 2, we found that the high alexithymia individuals tend to have shorter fixation duration at the eye region of the face especially when it is an angry face. This reduction in attention to the eye information may explain the alexithymic deficit in the evaluation of self-relevance because the high alexithymia individuals may not have sufficient information for inferring others' focus of attention during social interaction. Lastly, in Experiment 3, we identified that the N2 amplitude at the frontal regions showed an alexithymic reduction in eye-contact effect of angry faces that mirrors the behavioural tendency of the high alexithymia individuals. These findings converge to show that alexithymia affects the evaluation of self-relevance during social threat processing, and we provide evidence for the potential behavioural and neural mechanism for the deficit.

	Major findings
Survey	1.1. Singapore university students (majority sampled in NTU) has an alexithymia rate of 24%

	1.2. Alexithymia is related to both the deficit in social processing and emotional processing
Exp 1	2.1. Alexithymia is related to the reduced evaluation of self-relevance, indexed by the magnitude of eye-contact effect, during social threat (angry face) perception
Exp 2	3.1. Alexithymic eye avoidance is most prominent in upright angry faces in comparison with other upright faces
Exp 3	4.1. Alexithymia is linked to a reduced overall eye-contact effect at the frontal N1
	4.2. Alexithymia is linked to an increased eye-contact effect of happy faces at the frontal VPP
	4.3. Alexithymia is linked to a reduced eye-contact effect of angry faces at the midline frontal N2

Table 6.1. Summary of findings

6.1. Prevalence of Alexithymia in Singapore and its Implications

Our survey study showed that around 24% of the sample fall under the "high alexithymia" category. This means that alexithymia affects approximately 1 in 4 in our sample of Singapore university students. This prevalence rate was higher than the prevalence rates reported in the western countries (10% to 19%; Franz et al., 2008; Mason, Tyson, Jones, & Potts, 2005; Parker, Taylor, & Bagby, 1989; Salminen, Saarijärvi, Äärelä, Toikka, & Kauhanen, 1999). The finding may be attributed to the cultural differences in alexithymia (Dere et al., 2012; Dion, 1996; Lo, 2014). However, the difference in alexithymia level may also be because of the demographic differences of our sample in compared to other studies, i.e., we recruited university students while most of the other studies recruited general population (Franz et al., 2008; McGillivray et al., 2017; Parker et al., 1989; Salminen et al., 1999).

Alexithymia not only affects socio-emotional processing at the individual level, but may also have critical societal impacts. One of the major governing directions of Singapore is to build a caring and cohesive society (Ministry of Finance, 2019; Tan, 2019). A caring and cohesive society depends on effective interpersonal communication and active understanding of others' feeling at a societal level. However, the high prevalence rate of alexithymia, which is associated with the impairment in socio-emotional processing, may imply that there is also a higher tendency for university students to have interpersonal problems such as appearing cold and avoidant during social interaction (Vanheule et al., 2007), and having a reduced tendency for social interaction and collaboration (Nicolò et al., 2011). Considering the high prevalence rate of alexithymia, these personal struggles may be very common and have far-reaching effects, resulting in overall poorer social communication among Singapore population, especially in the younger generation. As such, there is an urgent need for a systematic investigation on how alexithymia affects socio-emotional processing as a good understanding of the underlying mechanism of alexithymia is needed for the formulation of intervention strategies.

6.2. Revisiting alexithymia and socio-emotional processing

Experiments 1 to 3 in this thesis converge to show that alexithymia affects gaze processing during emotional face perception. The perception of others' gaze direction is important for successful social interaction. One social function of gaze direction is to identify the communicator's focus of attention and indicate if the social signal from the communicator is relevant to oneself or not (Emery, 2000; Hoehl et al., 2009; Langton et al., 2000). Although there are other models that describe the integration of facial emotion and gaze information during socio-emotional processing (Johnson et al., 2015; Senju & Johnson, 2009), these models primarily concern the topography of the processing (i.e., where in the brain is responsible for this process?) with minimum information related to the temporal trajectory of the processing. In contrast, Hoehl and colleagues' (2009) directed attention model clearly arranges the sequence of the processing, from the extraction of information independently, to the interaction among information, and finally to the social decision making. Since our thesis focuses on the effect of alexithymia on each stage of the socio-emotional processing, we will base our discussion on Hoehl and colleagues' (2009) model. Nevertheless, since the discussion on the possible neural correlates that are affected by alexithymia is inevitable, we would make reference to the topographic models of socio-emotional processing when suitable (Johnson et al., 2015; Senju & Johnson, 2009).

In their model, Hoehl and colleagues (2009) proposed that there are four stages of social processing: 1) Detection of faces and gaze directions; 2) Encoding of facial information; 3) Evaluation of the self-relevance of the social cues; and 4) Attention allocation and intention encoding. This thesis focuses on how alexithymia affects Stage 1 and Stage 3 of Hoehl and colleagues' (2009) model. We will also discuss how our findings may be used to demonstrate the alexithymic influences on other stages of the model in the following sections.

6.2.1. Stage 1: Detection of faces and gaze directions

Cook, Brewer, Shah, and Bird (2013) showed that alexithymic individuals have an intact facial feature differentiation ability. Furthermore, Grynberg, Vermeulen, and Luminet (2014) demonstrated that alexithymia does not affect the detection of upright faces among a stream of inverted faces. These two studies suggest that the facial feature detection at Stage 1 is not affected by alexithymia. Nonetheless, there are plenty of studies showing that alexithymia is related to impairment in the early detection of emotion. It has been repeatedly shown that the accuracy of emotional face categorization is reduced in the high alexithymia individuals when the presentation of the emotional faces is suboptimal, i.e., when it is brief (Ihme et al., 2014b; Parker et al., 2005; Prkachin et al., 2009), blurry or noisy (Brewer et al., 2015a; Kätsyri et al., 2008), and emotionally ambiguous (Cook et al., 2013; Starita et al., 2018). The high alexithymia individuals therefore are less able to detect facial emotions.

Although the alexithymic impairment in early facial emotion detection is not evident in our data, we found that the early detection of gaze direction at Stage 1 is affected by alexithymia. In Experiment 2, using a one-back task in which processing of facial emotion is unnecessary, we showed that alexithymia is marked by more prominent eye avoidance in upright angry faces. The result indicates that high alexithymia individuals pay less attention to the eyes than low alexithymia individuals especially when facing a potential social threat. This replicates and extended the previous findings on the alexithymic eye avoidance during passive viewing task in a suggestion that the avoidance is related to the alexithymic aversion to eyes (Bird et al., 2011). Some recent studies which implemented an explicit emotion recognition task however reported negative results in the alexithymic eye avoidance (Fujiwara et al., 2017; Stephenson et al., 2019). Besides the substantial differences in the participant backgrounds and the experimental designs, one possible explanation to the inconsistent results is that the high alexithymia individuals may avoid eye information only when the processing of eye information is unnecessary. In other words, they understand the social meaning of eye information and they can attend to the information if it is important for the on-going task (e.g., emotion recognition task). Otherwise, the high alexithymia individuals will pay less attention to the eyes because they are overacting to the potential social threat implicated by direct gaze (Emery, 2000; Skuse, 2004). Although this explanation has yet been tested explicitly, it fits with the social characteristic of alexithymia: avoiding social situation and interpersonal relationship (Lane et al., 1997; Nicolò et al., 2011; Vanheule et al., 2007). Both properties of alexithymic eye avoidance, threat enhancement and task modulation, agree with the hyperarousal account of alexithymia which proposed that the high alexithymia population are overly reacting against social threat (de Timary, Roy, Luminet, Fillée, & Mikolajczak, 2008; Karlsson et al., 2008), and they thus may have a greater tendency to avoid the feeling of threat (for review on the autistic literature, see Cuve, Gao, & Fuse, 2018).

The reduced attention to the eye information in alexithymia also fits with our findings in Experiment 3 in which the high alexithymia individuals were found to have an impaired frontal N1 differentiation for gaze direction. Since the frontal N1 peaks at the very early stage of neural processing, its activation is very likely to reflect the feedforward signals to the frontal regions from the subcortical structures (Cremers et al., 2010; Kim et al., 2011; Sato et al., 2017). The diminished frontal N1 differentiation for gaze direction thus supports the hypothesis that alexithymia is related to the impairment in subcortical pathway (Donges & Suslow, 2017). Given that gaze information can be processed through both subcortical and cortical pathways (Johnson et al., 2015; Senju & Johnson, 2009), the impaired subcortical pathway of the high alexithymia individuals may lead them to rely on the cortical route for gaze processing, which is reflected in the intact temporal N170 (which has been sourced from the FFA and the STS in the face perception literature (Gao, Conte, Richards, Xie, & Hanayik, 2019; Nguyen & Cunnington, 2014)) differentiation for gaze direction in alexithymia. Nonetheless, the non-automaticity implies that processing gaze information may be effortful and require attentional resources in alexithymia (see Schneider & Chein, 2003).

Donges and Suslow (2017) argued for a hypo-aroused subcortical pathway in alexithymia, and our findings of the diminished differentiation for gaze direction at the frontal N1 also aligns with their argument. However, our results from Experiment 2 which showed that the alexithymic eye avoidance is most prominent in angry faces argues otherwise and suggests that the high alexithymia individuals are hyper-aroused towards eye contact. Such discrepancy in the behavioral data and the neural data can be resolved when we consider the commonly observed alexithymic impairment in interoceptive awareness (Brewer et al., 2016; Shah et al., 2016) and emotion awareness (Eastabrook et al., 2013; Pollatos et al., 2011). Typically, the high alexithymia individuals tend to report hyper-aroused stress level, but obtain a hypo-aroused or normal physiological responses through objective measurements (Decoupling hypothesis; Eastabrook et al., 2013; Pollatos et al., 2011). Therefore, their eye avoidance tendency may be due to their subjective hyper-aroused experience rather than their hypo-aroused physiological responses.

In sum, while the literature suggests that alexithymia is affecting early facial emotion detection, our results in general showed that alexithymia might have an impaired early attention to gaze direction. We associate the impairment with the alexithymic deficit in the subcortico-frontal pathway during face processing.

6.2.2. Stage 2: Encoding of facial information

In this thesis, we focus on the encoding of facial emotion, rather than facial identity. As we have reviewed in the literature review (Chapter 1), the literature is inconclusive in whether there is alexithymic impairment in the perceptual encoding of facial emotion. Similarly, in our data from Experiment 1, alexithymia was not related to the recognition accuracies nor the emotional intensity ratings of any emotional faces. Furthermore, at the neural level, our EEG data also showed that alexithymia does not affect neural processing of facial emotion at the temporal P200 and the frontal N2. Early EEG studies that investigated the neural differences in emotional face processing showed controversial results. In one study

(Vermeulen et al., 2008), the latency of the posterior N250 component was shown to be delayed when the subjects discriminated faces from different emotional categories. However, in another study (Campanella et al., 2012), the high alexithymia individuals showed earlier posterior N250 peak when identifying fearful faces. In Experiment 3 of our study, the posterior N250 peak amplitudes and the peak latencies did not respond to emotional categories across alexithymia groups, indicating that this component may not be a major candidate for emotional face perception. Equally contradicting findings have been reported in the fMRI literature. In one study, the temporal regions (e.g., the FFA and the STS) of the high alexithymia individuals were less activated than those with low alexithymia trait during optimal emotional face perception (Jongen et al., 2014), whereas in another study the same temporal regions were hyper-aroused (Ihme et al., 2014a)

In sum, the behavioural literature and the neural literature provide inconclusive evidence for alexithymic impairment in encoding of facial emotion. Therefore, the cortical processing of emotional faces may be intact in alexithymia.

6.2.3. Stage 3: Evaluation of the self-relevance of the social cues

While the first two stages of social processing have been widely tested in alexithymia, no studies have attempted to investigate whether the evaluation of self-relevance of social cues is affected by alexithymia. We for the first time demonstrated that the high alexithymia individuals may have difficulty in differentiating social threat that is relevant to them from those that are not. The behavioural reflection of the difficulty is that they tend to feel equally threatened by angry faces that are looking away from them (self-irrelevant) as those that are looking at them (self-relevant). Interestingly, this alexithymic impairment in the evaluation of self-relevance was only observed in angry faces. This agrees with Hoehl and colleagues (2009) who suggested that from this stage onwards, facial expression and gaze direction should be integrated as an indicator of social threat. There are two potential causes for this alexithymic impairment in the evaluation of self-relevance: 1) high alexithymia individuals pay less attention to the eye information and thus do not have sufficient information to infer others' focus of attention; and/or 2) they are impaired in a high-level cognitive processing that is associated with the evaluation of self-relevance.

In Experiment 2, we found that the alexithymic eye avoidance is most prominent in angry faces, and it is coherent with the reduced eye-contact effect of angry faces in alexithymia shown in Experiment 1. Furthermore, in Experiment 3, we also found that the reduced eye-contact effect of angry face at the frontal N2 component in alexithymia can be explained by the diminished gaze difference at the frontal N1 component. This relationship suggests that the early gaze differentiation is related to the subsequent evaluation of self-relevance during social threat processing. Therefore, one possible mechanism for the alexithymic deficit in the evaluation of self-relevance is that it is a carry-over effect from reduced attention to eye information at the earlier stage (i.e., Stage 1). Nevertheless, this mechanism cannot fully explain all of our results. In Experiment 1, we also found that the high alexithymia individuals are able to use the gaze information to inform their decisions in other tasks that do not require the evaluation of self-relevance (e.g., reporting how other feels towards the angry faces with different gaze directions). On top of that, despite the drastic difference in the experimental design and the subject backgrounds, recent studies implementing explicit emotional task could not find alexithymic eye avoidance (Fujiwara et al., 2017; Stephenson et al., 2019). Together, these two pieces of evidence suggest that we should not ignore the possibility that the alexithymic impairment in the evaluation of self-relevance is a result of the deficit in a high-level cognitive processing, such that the impairment would remain even if gaze direction is accurately perceived by the high alexithymia individuals.

Through examining the its neural correlates, we can infer which cognitive processing is potentially related to the impaired the evaluation of self-relevance in alexithymia. Of all ERP components examined (occipital P100, temporal N170, temporal P200, parietal P3b, frontal N1, frontal VPP, frontal N2, and frontal P3a), only the frontal N2 demonstrated a similar pattern as the behavioural index of the alexithymic impairment in the evaluation of self-relevance. At the frontal N2, while the low alexithymia individuals demonstrated weaker amplitude towards the angry faces with direct gaze than those with averted gaze as has been documented in previous studies (Conty, Dezecache, Hugueville, & Grezes, 2012[1]; Li et al., 2017), the high alexithymia individuals did not show such amplitude differentiation. The source of the frontal N2 has been consistently localized at the frontal regions, including the ACC and the mPFC (for review, see Bocquillon et al., 2014), which are part of the self-referential processing network (Conway et al., 2016; Jenkins et al., 2008; Moeller & Goldstein, 2014; Northoff et al., 2006; Schmitz & Johnson, 2007). This is also coherent with Hoehl and colleagues' (2009) proposal that the neural correlates related to Stage 3 is the mPFC, as well as with Johnson and colleagues' (2015) topographic model which suggests that the mPFC receives direct signals from the subcortical structures for processing intentionality (it is noteworthy that in Johnson and colleagues's (2015) model, the evaluation of self-relevance and intention encoding (Stage 3 and Stage 4 of Hoehl and colleagues' (2009) model) have been combined as intentionality processing at the mPFC and the STS).

Conty, George, and Hietanen (2016) proposed that eye-contact effect is the result of the activation of self-referential processing. One of the supporting evidence is the report showing that eye contact can enhance one's self-awareness, which is part of self-referential

[1] In their study, Conty and colleagues (2012) claimed that they used the frontal P200 as the indicator. However, based on their graphs, there was a negative deflect within the time window they used to extract the ERP signal. Furthermore, their time-window hugely overlaps with the one we use to identify the frontal N2. Therefore, it is possible that the effect they observed was partially due to the frontal N2 activation.

processing (Baltazar et al., 2014). However, the fact that such self-awareness is commonly found to be impaired in the high alexithymia individuals indicates that the activation of self-referential processing may be impaired in alexithymia (Eastabrook et al., 2013; Pollatos et al., 2011; Shah et al., 2016). For example, the high alexithymia individuals are less accurate in reporting their own heart beat rates (Shah et al., 2016). Their self-report stress levels also do not correspond totheir objectively measured physiological responses (Eastabrook et al., 2013; Pollatos et al., 2011). These pieces of evidence point to the possibility that the high alexithymia individuals are less efficient in allocating attention to self. Although whether the alexithymic impairment in self-awareness can be improved by eye contact remains an uninvestigated question, we believe that even if there is an improvement, the improved self-awareness in alexithymia may not be as strong as the individuals with low alexithymia trait. As a result, the impaired self-referential processing may cause the high alexithymia individuals not able to differentiate the self-relevant social threats from those that are self-irrelevant.

In this thesis, we observed evidence for both possible mechanisms (i.e., carry-over effect from the deficit in eye gaze detection vs. local deficit in high-level cognitive processing) that may lead to the impaired evaluation of self-relevance during social threat processing in alexithymia. Further investigations therefore are required to directly test whether the impaired evaluation of self-relevance during social threat processing is an effect carried over from the reduced attention to eye information (i.e., subcortical deficit, see Section 6.2.1), and/or that it is a local deficit at the high-level cognitive processing that is related to self-referential processing (i.e., frontal deficit). Of note, the two mechanisms are not mutually exclusive, so we do not exclude the possibility that the alexithymic impairment in the evaluation of self-relevance is a result from the combination of the two mechanisms. Nevertheless, regardless of which mechanism is true, our data clearly shows that alexithymia is closely related to the impairment in the subcortico-frontal pathway of socio-emotional processing (Nemiah, 1977; Van der Velde et al., 2013). This will provide basis for future investigation on alexithymia.

In sum, alexithymia is associated with impaired evaluation of self-relevance during social threat perception at Stage 3. This impairment may relate to the reduced attention to eye information in alexithymia. Another possible mechanism as suggested by the neural evidence is that the high alexithymia individual may have a mal-functional self-referential processing.

6.2.4. Stage 4: Attention allocation and intention encoding

Whether alexithymia is impaired in intention encoding remains an open question. Although Moriguchi and colleagues (2009) reported an alexithymic deficit in theory of mind, subsequent investigation however suggested that the ability for theory of mind is spared in alexithymia (Bernhardt et al., 2014; Lane et al., 2015; Pluta et al., 2018). In our results in Experiment 1, we also showed that the high alexithymia individuals can successfully identify that an imaginary person should feel more threatened by an angry face looking at him/her in compared to an angry face looking away from him/her. Therefore, based on the limited evidence, we lean towards to the possibility that the high alexithymia individuals have intact intention encoding. In terms of attention allocation, no evidence has yet shown that alexithymia is associated with the performance of the task related to emotional spatial attention allocation (emotional dot probe task) (see Hornung, Kogler, Wolpert, Freiherr, & Derntl, 2017). In Experiment 3, we also showed that alexithymia does not affect the parietal P3b activation, which indicates conscious attention allocation during emotional face perception (Schupp, Flaisch, Stockburger, & Junghöfer, 2006; Sergent, Baillet, & Dehaene, 2005; Zhang, Liu, Wang, Ai, & Luo, 2017). In sum, the available evidence does not suggest that alexithymia is associated with attention allocation and intention encoding during social processing.

6.2.5. Summary of the relationship between alexithymia and the directed attention model of social cognition

Summarizing the above evidence, it appears that alexithymia might be more severely impaired in detecting gaze direction at Stage 1 and in the evaluation of self-relevance at Stage 3 in Hoehl and colleagues' (2009) socio-emotional processing model. The alexithymic impairments at the two stages are related but the relationship cannot fully explain the alexithymic impairment in the evaluation of self-relevance. This leads us to believe that on top of the impairment at the subcortical pathway (Donges & Suslow, 2017), alexithymia also has a major deficit at the frontal regions (Lane et al., 1997; Larsen et al., 2003; Wingbermühle et al., 2012), which are part of the self-referential processing network for the evaluation of self-relevance (Conway et al., 2016; Northoff et al., 2006; Schmitz & Johnson, 2007). Therefore, the core deficit of alexithymia might be related to the subcortico-frontal network. Similar ideas have also been put forward by other scholars (Nemiah, 1977; Van der Velde et al., 2013). Yet, the causal relationship between the impairments of the two neural substrates (i.e., the subcortical regions and the frontal regions) remains unknown in the field. More specifically, whether the impairment at the subcortical structures causes that at the frontal regions, or vice versa. The answer to this question is vital for the prevention and therapeutic development of alexithymic symptoms because it reveals the root cause of the condition. To address this question, future research should investigate the developmental trajectory of alexithymia, i.e., whether the onset of the symptoms related to the high-level cognitive emotional processing starts earlier or later than those related to the early and automatic processing of emotional information, and how the relationship between the two changes along the development stages.

6.3. Alexithymia trait and autistic traits

Unexpectedly, we did not consistently observe the close relationship between alexithymia trait and autistic traits that has been repeatedly reported in the literature (low correlation between AQ score and TAS-20 score in Experiment 2). Although TAS-20 was not correlated with the total score of AQ, it was correlated with one of the subscales of AQ, Imagination ($r = .33$, $p = .048$), and there was an insignificant trend of positive correlation of TAS-20 with another subscale of AQ, Communication ($r = .24$, $p = .164$). This suggests that there are multiple facets of autistic traits and alexithymia may not relate to all of them. In their review which proposed the "alexithymia hypothesis of autism", Bird and Cook (2013) suggested that there are four subpopulations: pure alexithymic population, pure autistic population, population with both alexithymia and autism, and population with neither alexithymia nor autism. They argued that the pure autistic population should have impaired social cognition (e.g., cognitively and explicitly evaluate other's intention) and cognitive control, whereas the pure alexithymic population is related to the deficits in processing emotional information. Having deficits in one of the aspects (e.g., autistic deficits) might make one more vulnerable to deficits in the other aspect. However, the relationship between the two phenotypes however is not absolute. In fact, very recently, there is another study showed that TAS-20 was negatively correlated with the AQ subscale Details and Patterns (Bothe, Palermo, Rhodes, Burton, & Jeffery, 2019). Since the AQ subscale Imagination is associated with empathy (Svedholm-Häkkinen, Halme, & Lindeman, 2018), autistic traits and alexithymia may overlap in predicting the impairment in empathy. There may be certain protective mechanisms that can modulate the interaction between the two phenotypes. For example, Milosavljevic and colleagues (2016) showed that autistic adolescents with alexithymia tend to score lower on the verbal IQ than those without alexithymia. Therefore, the ability to reason and verbalize might protect individuals with autism from alexithymia.

The actual mechanism underlying the relationship between autistic traits and alexithymia trait remain uncertain. Future studies are urged for a more systematic investigation.

Interestingly, in all of reported results, autistic traits were not a significant predictor for any gaze direction-related behaviors during angry face processing. This may be because processing social threat involves more the emotional domain than the social cognition domain. It has been suggested that alexithymia is associated to the impairment in the emotional domain whereas autism tend to impair the social cognition domain (Bird & Cook, 2013). Therefore, the previously reported facial expression - gaze direction interaction impairment in autistic children might be due to their alexithymia trait which was not measured (Akechi et al., 2009, 2010). Another possibility is that the highly functional adults with high autistic traits might have developed strategies to compensate for their impairments in emotion processing (Livingston & Happé, 2017). Autistic compensation can be supported by our finding in Experiment 3 that only when controlled for alexithymia, autistic traits were strongly correlated with eye contact effect of angry faces at the N2 activity, such that the higher autistic trait one has, the stronger the eye contact effect was. The pattern was the opposite from that observed in the alexithymic population. This indicates that a highly autistic individual might over-compensate through making a greater distinction between different eye gaze directions during social threat processing. Similar findings were reported in previous studies investigating autistic impairment in Theory of Mind task (ToM). It was found that although younger adults with autism tended to have difficulty in performing ToM, there was not such autistic difference in the older adults (age > 50) (Lever & Geurts, 2016). Furthermore, in the autistic population that perform the ToM task similar to the typically developed population, atypical eye movement and hyper-aroused frontal activations were observed (Senju et al., 2009; White et al., 2014), suggesting that they are either using different strategies to complete the task or that the task was more effortful to them than the typically developed individuals.

6.4. Open questions and future directions

While our work has demonstrated the alexithymic impairment in the evaluation of self-relevance during social threat perception, it has also raised further questions that require systematic investigation with future studies. First, although we provided evidence showing that the impairment in the evaluation of self-relevance in alexithymia may be sourced from the frontal regions using EEG measurement, we are unable to accurately locate which regions of the frontal cortex are involved in the impairment. Furthermore, we have suggested that the alexithymic inability in evaluating the degree of self-relevance of social threat is related to the impairment of the subcortico-frontal network. The alexithymic impairment therefore may be reflected in the connectivity among these regions (see Liemburg et al., 2012; Mériau et al., 2006). While we have provided the temporal trajectory of the alexithymic impairment in the evaluation of self-relevance, future studies are encouraged to investigate the topographic trajectory of this alexithymic impairment.

Secondly, in this study we argue that the impairment in the evaluation of self-relevance during social threat perception in alexithymia is at least partially related to the deficit in self-referential processing. This proposal would be further supported if alexithymia is also predicting other measures that are related to the self-referential processing, such as self-face perception (e.g., Kircher et al., 2001; Sugiura et al., 2012; Sui & Han, 2007) and encoding self-related traits (e.g., Benoit, Gilbert, Volle, & Burgess, 2010; Kelley et al., 2002; Schmitz, Kawahara-Baccus, & Johnson, 2004). No experiment has yet investigated how these effects are affected by alexithymia. There is however some literature showed behavioural and neural differences in autism and schizophrenia when processing self-face and self-name

(Cygan, Tacikowski, Ostaszewski, Chojnicka, & Nowicka, 2014; Kircher, Seiferth, Plewnia, Baar, & Schwabe, 2007; Morita et al., 2012; Yun et al., 2014). Since alexithymia is a common comorbidity of autism and schizophrenia, it is possible that the reduced self-face perception in the autistic individuals and the schizophrenic individuals can be explained by alexithymia.

Lastly, little is known about the development of alexithymia in the field (for review, see Karukivi, 2014). One important question that can be addressed by the investigation of the developmental trajectory of alexithymia is that which symptoms of alexithymia have the earliest onset. This would allow us to pinpoint the root cause of alexithymia and thus benefit the development of preventive and therapeutic programmes against alexithymic symptoms. Another developmental problem that has to be resolved concerns the relationship between the alexithymia trait and the autistic traits. It remains unknown whether the two traits co-occur during the developmental trajectory, or whether one trait causes the other. Also, what are the factors that contribute to the development of the two traits? Some studies have shown that childhood trauma (Güleç et al., 2013; Schimmenti et al., 2017), over parental protection (Karukivi et al., 2011; Thorberg, Young, Sullivan, & Lyvers, 2011), and early language ability (Karukivi et al., 2012; Kokkonen et al., 2003) predict alexithymia in adolescents and adulthood. Do these factors mediate the relationship between autistic traits and alexithymia trait in the children population and the adolescent population during their developmental stage? The answer to this question may allow us to identify the precursors of alexithymia and autism, such that we can provide effective preventive measures for individuals at high risk.

6.5. Conclusion

All in all, the four experiments conducted in this thesis showed that 1) the Singapore university students (majority sampled in NTU) showed a high alexithymia rate of 24%; 2) alexithymia is closely associated with both social processing and emotional processing; 3) alexithymia reduces the eye-contact effect of angry face perception; 4) alexithymic eye avoidance is most prominent in angry face perception among the tested emotions (i.e., angry, happy, and neutral); and 5) the alexithymic reduction in eye-contact effect of angry face is reflected at the frontal N2 activity. Summarizing the evidence, we concluded that the evaluation of self-relevance during social threat processing is affected by alexithymia. The impairment may be related to the subcortico-frontal pathway of social processing, which is associated with the self-referential processing. Our findings support the subcortical account (Donges & Suslow, 2017) and the frontal account of alexithymia (Lane et al., 1997; Larsen et al., 2003; Wingbermühle et al., 2012).

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Appendix I – Correlations among socio-emotional constructs in Survey Study

n = 202	1	2	3	4	5	6	7	8	9	10
1. AQ		-.12	.05	.14	-.36***	-.10	.31***	.35***	.34***	.49***
2. BEQ			-.08	-.10	.25***	.12	.20**	.06	.03	-.17*
3. HI				.24***	-.08	.12	.08	-.01	.07	-.08
4. VI					-.18**	-.01	.13*	.12	.13	.17*
5. HC						.48***	-.08	-.15*	-.21**	-.23***
6. VC							-.08	-.18*	-.19**	-.18*
7. Stress								.73***	.68***	.42***
8. Anxiety									.65***	.46***
9. Depression										.47***
10. TAS										

Appendix II – Details on the Behavioral Results of Experiment 3

"Angry Face?" probe	*F*	*p*	*Post-hoc* pairwise comparisons (Holms-Bonferroni-corrected)
TAS Group	0.42	.522	
Emotion	1017.70	<.001	An (80.91%) > Ne (5.91%) ($p < .001$) An (80.91%) > Ha (2.21%) ($p < .001$) Ne (5.91%) > Ha (2.21%) ($p < .01$)
Emotion × *TAS Group*	0.06	.864	
Gaze Direction	1.28	.266	
Gaze Direction × *TAS Group*	0.23	.637	
Emotion × *Gaze Direction*	3.31	.042	Direct: Ne (5.27%) = Ha (2.56%) (p =.052) Averted: Ne (6.55%) > Ha (1.85%) ($p < .001$)
Emotion × *Gaze Direction* × *TAS Group*	0.58	.563	
Note. Percentage in brackets indicates the average chance for the subjects to choose "Yes" as their responses.			

“Happy Face?” probe	*F*	*p*	*Post-hoc* pairwise comparisons (Holms-Bonferroni-corrected)
TAS Group	0.02	.899	
Emotion	3346.20	<.001	Ha (92.38%) > Ne (2.78%) (*p* < .001) Ha (92.38%) > An (1.92%) (*p* < .001) Ne (2.78%) = An (1.92%) (*p* = .110)
Emotion × *TAS Group*	0.07	.834	
Gaze Direction	10.06	.003	Direct (33.76%) > Averted (30.96%) (*p* = .003)
Gaze Direction × *TAS Group*	0.06	.810	
Emotion × *Gaze Direction*	5.64	.012	Ha: Direct (95.16%) > Averted (89.60%) (*p* = .009) An: Direct (2.99%) > Averted (0.85%) (*p* = .010) Ne: Direct (3.13%) = Averted (2.42%) (*p* = .453)
Emotion × *Gaze Direction* × *TAS Group*	0.98	.356	
Note. Percentage in brackets indicates the average chance for the subjects to choose “Yes” as their responses.			

“Neutral Face?” probe	*F*	*p*	*Post-hoc* pairwise comparisons (Holms-Bonferroni-corrected)
TAS Group	1.07	.307	
Emotion	667.12	<.001	Ne (79.91%) > An (8.90%) (*p* < .001) Ne (79.91%) > Ha (4.13%) (*p* < .001) An (8.90%) > Ha (4.13%) (*p* = .002)
Emotion × *TAS Group*	0.63	.488	
Gaze Direction	49.27	<.001	Direct (35.33%) > Averted (26.64%) (*p* < .001)
Gaze Direction × *TAS Group*	0.05	.828	
Emotion × *Gaze Direction*	19.25	<.001	Ne Direct (88.60%) vs Ne Averted (71.23%) > An Direct (11.40%) vs An Averted (6.41%) (*p* < .001) Ne Direct (88.60%) vs Ne Averted (71.23%) > Ha Direct (5.98%) vs Ha Averted (2.28%) (*p* < .001) An Direct (11.40%) vs An Averted (6.41%) = Ha Direct

			(5.98%) vs Ha Averted (2.28%) (*p* = .459)
Emotion × *Gaze Direction* × *TAS Group*	2.28	.123	
Note. Percentage in brackets indicates the average chance for the subjects to choose "Yes" as their responses.			

"Central Gaze?" probe	*F*	*p*	*Post-hoc* pairwise comparisons (Holms-Bonferroni-corrected)
TAS Group	0.84	.366	
Emotion	15.47	<.001	Ne (51.64%) > An (49.22%) (*p* = .037) Ha (55.77%) > Ne (51.64%) (*p* = .001) Ha (55.77%) > An (49.22%) (*p* < .001)
Emotion × *TAS Group*	0.50	.608	
Gaze Direction	1042.45	<.001	Direct (91.93%) > Averted (12.49%) (*p* < .001)
Gaze Direction × *TAS Group*	4.17	.048	LTAS Direct (93.57%) vs Averted (8.97%) > HTAS Direct (90.37%) vs Averted (15.83%) (*p* = .048)

Emotion × *Gaze Direction*	20.65	<.001	Direct: Ne (95.30%) > An (88.89%) (*p* = .003) Direct: Ne (95.30%) > Ha (91.60%) (*p* = .031) Direct: An (88.89%) = Ha (91.60%) (*p* = .162) Averted: Ne (7.98%) = An (9.54%) (*p* = .270) Averted: Ha (19.94%) > Ne (7.98%) (*p* < .001) Averted: Ha (19.94%) = An (9.54%) (*p* < .001)
Emotion × *Gaze Direction* × *TAS Group*	0.48	.623	
Note. Percentage in brackets indicates the average chance for the subjects to choose "Yes" as their responses.			

"Left Gaze?" probe	*F*	*p*	*Post-hoc* pairwise comparisons (Holms-Bonferroni-corrected)
TAS Group	1.36	.250	
Emotion	15.00	<.001	Ne (48.22%) = An (46.58%) (*p* = .120) Ne (48.22%) > Ha (42.24%) (*p* < .001)

			An (46.58%) > Ha (42.24%) (p < .001)
Emotion × *TAS Group*	0.16	.856	
Gaze Direction	1085.95	<.001	Averted (87.18%) > Direct (4.18%) (p < .001)
Gaze Direction × *TAS Group*	3.19	.082	
Emotion × *Gaze Direction*	16.78	<.001	Direct: Ne (3.99%) = An (4.42%) (p = .711) Direct: Ne (3.99%) = Ha (4.13%) (p = .889) Direct: An (4.42%) = Ha (4.13%) (p = .815) Averted: Ne (92.45%) = An (88.75%) (p = .076) Averted: Ne (92.45%) > Ha (80.34%) (p < .001) Averted: An (88.75%) > Ha (80.34%) (p < .001)
Emotion × *Gaze Direction* × *TAS Group*	0.89	.416	
Note. Percentage in brackets indicates the average chance for the subjects to choose "Yes" as their responses.			