Cognitive enhancement in video game training: two separate routes of transfer?

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**COGNITIVE ENHANCEMENT IN VIDEO GAME TRAINING:
TWO SEPARATE ROUTES OF TRANSFER?**

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ABSTRACT

There has been considerable interest in the last decade on action video games' effects on human perception and cognition, with many studies showing a positive effect of video game play on a variety of cognitive and perceptual measures. However, the mechanisms of transfer have not been well characterized. Here, review of existing evidence suggests that improvements shown in transfer tasks are limited to the same skills that are frequently demanded in the trained video game, namely lower level perceptual and attentional skills. Hence, frequent practice of these skills in the video game lead to improvements in these same skills that are demanded in the transfer task. In three studies, this theory is tested. In study 1, different video games with different cognitive demands were compared. Following 20 hours of training on one of several games, participants' improvement on various cognitive tasks matched the demands of the game that they trained in respectively. Specifically, those trained in a hidden-object game and spatial working memory game improved in visual search efficiency and spatial working memory. Search efficiency was also improved in those that played a match-3 puzzle game. By comparison, those trained in an action game improved in the attentional blink, a filter task and a multiple-object tracking task. In study 2, participants trained in a variety of shooter games with different demands. Following 20 hours of training, participants that played a fast-paced first person shooter improved in the attentional blink and multiple-object tracking, while a slower paced third person shooter training also resulted in attentional blink improvements, but to a smaller extent. Again, the improvements were limited to skills common to the trained video game and transfer task. In contrast, no transfer occurred from other action video games that did not contain demands to switch attention rapidly and track multiple objects to tasks that measured these skills. Finally, in Study 3, to test the hypothesis of a general transfer to measures of executive control, participants were

trained to play games with different executive demands for 20 hours. The games included a first-person shooter, an arcade game, a real-time strategy game and a physics puzzle game that demanded complex problem solving, planning and reframing. Only the latter game improved all executive control as measured by task switching, inhibition, and stimulus-response interference. The results of all three studies and other studies reviewed taken together suggest two possible routes of transfer in video game training. On one hand, transfer of lower-level information-processing skills such as visual perception and attention may depend on a close match in demands between the transfer task and trained game. Conversely, transfer of higher-order executive control skills and mental flexibility may depend upon the training in more general demands such as high-level planning, strategizing, complex problem solving and reframing.

CHAPTER 1: GENERAL INTRODUCTION AND LITERATURE REVIEW

In contrast to the consensus several decades ago that the human brain and cognitive abilities are immutable beyond a critical or sensitive period (see Jäncke, 2009), emerging research suggests that the adult brain and cognitive abilities retain sufficient plasticity for changes to occur with training throughout the lifespan. There is now a large body of evidence indicating that participation in variety of activities could lead to improvements in a number of cognitive and perceptual skills. These studies mainly take three different forms. First is a cross-sectional comparison of performance and neurological differences between experts and non-experts in a particular activity. Second is a pre and post comparison between a control group and experimental group that undergoes a short bout of a particular intervention or training of interest. Finally, a third involves comparisons of the aforementioned groups following a long-term (often years) intervention or training regime (Jäncke, 2009).

Research using the above methodologies has yielded some interesting findings that suggest that our cognitive and perceptual abilities change as a result of experience. For instance, musical training has been associated with enhanced verbal and visual memory, attention as well as various executive functions (Chan, Ho, & Cheung, 1998; Ho, Cheung, & Chan, 2003; Moreno et al., 2011; Rodrigues, Loureiro, & Caramelli, 2010). Additionally, short and long-term meditation practice has been shown to enhance performance in a number of attention tasks (Slagter, Lutz, Greischar, & Francis, 2007; Tang et al., 2010; van den Hurk, Giommi, Gielen, Speckens, & Barendregt, 2009; Zeidan, Johnson, Diamond, David, & Goolkasian, 2010). Furthermore, aerobic and athletic training do not only improve physical health but were also shown to enhance cognitive performance, especially executive functions across the lifespan from young children to the elderly, even among the elderly with neurodegenerative diseases (see Hillman, Erickson, & Kramer, 2008).

A growing number of studies have also investigated whether human cognition can be improved directly by means of “mental or brain exercise”. These activities take the form of traditional laboratory-based cognitive tasks adapted into computerized working memory training and “brain training” games. However, results are currently mixed as to whether these types of training are truly beneficial as claimed. While some reported cognitive gains following working memory and “brain” training (e.g., in working memory and fluid intelligence; Jaeggi, Buschkuhl, Jonides, & Perrig, 2008; Salminen, Strobach, & Schubert, 2012), others failed to find such effects (Chooi & Thompson, 2012; Harrison et al., 2013b; Owen et al., 2010; Redick et al., 2013; Thompson et al., 2013).

As opposed to repeatedly training using computerized cognitive tasks or “brain training” games, there is increasing interest over the last decade on training cognition via commercial video games. This has arguably stemmed from the pioneering work of Green and Bavelier (2003) who demonstrated a causal effect of “action” video game play on different visual-perceptual and attentional measures. Although interest and debate over the benefits of video game play have intensified over the last decade, research into this area goes back further to the 1990s with the work of Greenfield and colleagues (Greenfield, DeWinstanley, Kilpatrick, & Kaye, 1994; Subrahmanyam & Greenfield, 1994).

With a few exceptions (e.g., Boot, Kramer, Simons, Fabiani, & Gratton, 2008; Irons, Remington, & McLean, 2011) results from independent laboratories have shown evidence of experienced video game players outperforming non-players in a variety of cognitive and perceptual tasks (e.g., Colzato, van Leeuwen, van den Wildenberg, & Hommel, 2010; Green & Bavelier, 2003; Vallett, Lamb, & Annetta, 2013).

Although cross-sectional comparisons may be suggestive of a video game advantage, they actually have little bearing on causality. Primary problems include issues of directionality (i.e., it is unclear whether people develop superior cognitive skill because of

gaming or whether people with superior skill become gamers) and expectancy effects (people recruited for their gaming expertise are more motivated and expect to perform better) (Boot, Blakely, & Simons, 2011; Kristjánsson, 2013).

While differences in abilities between regular video game players and non-players do not equate causality of video game playing, stronger inferences of causality are found in studies documenting enhancements of various abilities following a short bout of video game playing in non-video game players (Green & Bavelier, 2003; Okagaki & Frensch, 1994; Wu & Spence, 2013). What is so intriguing about these types of studies is that the games that were used were not specifically designed with the goal of training human cognition and perception (cf., Anguera et al., 2013; Jaeggi, Buschkuhl, Jonides, & Shah, 2011; Klingberg et al., 2005). Rather, they are commercially available games designed for entertainment. Hence, the learning as a result of playing these games is incidental rather than intentional.

One possibility why video games make good training tools is that they are enjoyable and increases arousal, reward and motivation (Fleming & Rick Wood, 2001; Hébert, Béland, Dionne-Fournelle, Crête, & Lupien, 2005; Przybylski, Ryan, & Rigby, 2009). Therefore, people are more likely to comply with a video game training regime (Boot, Champion, et al., 2013). In contrast, participants in traditional learning activities rarely demonstrate high levels of effort and motivation required for effective learning, and often, additional motivators such as grades are required to maintain interest and effort (Tennyson & Jorczak, 2008). As an added benefit for learning, in many games, players are often allowed to start off at easy levels before tackling more challenging ones as the game progresses (Ahissar & Hochstein, 1997). This “scaffolding” of learning allows a novice to gradually acquire expertise, mastering increasingly difficult levels along the way (Tennyson & Jorczak, 2008).

There are many genres of video games available commercially today that appeal to a wide range of people. These genres include action, role-playing, adventure, strategy, sports

and puzzle games (Laird & Van Lent, 2001; Spence & Feng, 2010). However, these distinctions are arbitrary and many of today's games contain elements that overlap several genres. For example, in many adventure games today, a player commonly takes on a role to embark on a quest, killing off enemies but will encounter some puzzles he/she would have to solve along the way. Therefore, it is difficult to pigeonhole some games into distinct categories or genres (Spence & Feng, 2010).

Repeatedly playing a game is most likely to result in improvement only in the game itself. However, in the context of learning, the primary desired outcome is not simply an improvement in gameplay but rather a transfer of skills learnt to other non-game or altered environments (Munro, 2008; Schmidt & Bjork, 1992). Hence, to demonstrate the effectiveness of any video game training regime, transfer of skills must be demonstrated outside of the trained game.

Purpose of the Current Dissertation

The purpose of this dissertation is to characterize the different transfer effects arising from video game studies. As mentioned previously and to be reviewed more in depth later, the transfer effects as a result of video game training mainly range from visuo-perceptual to different attentional skills (Green & Bavelier, 2003; Okagaki & Frensch, 1994; Wu & Spence, 2013). However, the mechanisms of transfer as a result of video game training are not well understood. One proposal is the cognitive and perceptual enhancements stem from general improvement in the ability to interpret and gather statistical information to predict future actions (Green & Bavelier, 2012; Green, Pouget, & Bavelier, 2010). However, it is unclear whether this mechanism only applies to action video games or also to non-action games. Furthermore, although enhanced statistical learning has been shown in action video game play (Green, Pouget, et al., 2010), it has not been established empirically that this is

indeed the causal mechanism for enhancements seen across many laboratory tasks after video game play.

In contrast, I argue that the transfer from video game play is made possible because of the close match in processing demands between the training game and transfer task (cf. Thorndike & Woodworth, 1901). Therefore, repeated training in games with such demands transfers to transfer tasks with similar demands. Hence, an original contribution from this dissertation is to demonstrate empirically that transfer effects, at least to lower level perception and cognition, are specific to abilities that are common to the transfer task and game. I investigated this in Studies 1 and 2 by comparing different video games (action and non-action) that have different demands and testing their transfer effects in several cognitive tasks that have demands in common with the trained video games. In doing so, another contribution is the extension of previous works to show that aside from action video games; non-action game training also leads to transfer effects. I should acknowledge however, that it is non-trivial to arrive at a clear taxonomy of exact demands that are utilized while playing different games. A main problem is that in most, if not all cases, the games used in the reviewed studies are commercially available video games not designed with cognitive training in mind. These are unlike computerized working memory training or brain training games that often are designed to mimic cognitive tasks and hence the demands can be mapped clearly to transfer tasks. Although some (J. E. Cohen, Green, & Bavelier, 2007; Spence & Feng, 2010) have attempted to detail the specific factors and demands within video games that could lead to transfer, an objective metric of remains elusive.

Another purpose and contribution of this dissertation is to distinguish whether transfer to higher order executive functions are specific or general. On one hand, if predicted by the common-demands theory (cf. Thorndike & Woodworth, 1901) that the game and task must share common demands, training in games that have specific executive function demands

should transfer to tasks that demands the same executive skill. However, on the other hand, given that different executive functions are highly related (Miyake et al., 2000), it is plausible that improvement in one executive skill might also generalize to other executive skills. Yet, another possibility related to general transfer is that training in video games that emphasizes higher-order planning, strategizing and problem solving skills might transfer broadly to different executive function skills. These possibilities are investigated in Study 3, where 20 hours of training in a physics-based puzzle game that required changing strategies and demands from level to level, enhanced different executive functions. To my knowledge, aside from Boot and colleagues (Basak, Boot, Voss, & Kramer, 2008; Boot et al., 2008) that utilized a real-time strategy game for training, no studies have yet investigated the transfer effects of training in a video game that emphasizes complex problem solving with changing strategies between levels. Hence, this is another original contribution this study makes.

Outline and Scope of the Review

This review is aimed at providing a general introduction to the current video game literature and should provide the reader with a broad overview on the following: 1) what cognitive and perceptual abilities are improved (or not) with video game play and 2) what video game types are particularly effective in changing human cognition. Importantly, from the review, it should be apparent that the evidence shows that video game related enhancements are limited to skills common to both the transfer task and trained video game. I reviewed primarily two kinds of investigations - cross-sectional comparisons between experienced video gamers and novices as well as longitudinal-type training studies. I limit the focus of the review to commercial video games as opposed to games designed solely for perceptual and cognitive training. Furthermore, as video game training has been studied across the lifespan from young children (Subrahmanyam & Greenfield, 1994; Yuji, 1996) to older adults (Basak et al., 2008; Boot, Champion, et al., 2013), a comprehensive review of

these studies would be beyond the scope of this dissertation. Hence, I limit the scope of this review to young adults, which make up the majority of the samples used in the video game literature.

The reader should note that because of the interest generated by the groundbreaking work that emerged from the Bavelier lab (Green & Bavelier, 2003), the majority of investigations over the last decade has been focused mainly on action video games. Hence, inevitably a large portion of the review will document cognitive and perceptual enhancements via action video game play. However, where available, evidence of cognitive and perceptual enhancements using non-action video games is included as well. First, I review studies that investigated video game effects on lower-level, bottom-up visual-perceptual enhancements. This is then followed by a review on video games' effects on different attentional processes, and finally, the focus shifts to studies that investigated video game effects on higher-level executive control and memory processes.

The review is then followed by a discussion of the controversies and issues one must consider when evaluating the current cross-sectional and training-type studies. Following that, a preliminary conclusion is made before I describe the studies in this dissertation.

What Is (and is not) Improved with Video Games?

Vision

Video games today represent a rich but very demanding visual experience. In many games, a basic requirement is intense concentration as well as the ability to react to quick changes. This is even more so in games that are fast paced and have multiple objects to keep track of and acted upon. These features appear frequently in action video games especially in first and third person shooters. Although there are no definitive rules on what constitutes an action video game, there are several characteristics that are typical. These include unpredictability, intense speed, high perceptual, cognitive and motor load, the selection

between multiple action plans and an emphasis on peripheral processing (Green, Li, & Bavelier, 2010; Hubert-Wallander, Green, Sugarman, & Bavelier, 2011). More specifically, in these games, a great premium is placed on spotting and responding to sudden onset stimuli. Moreover, as stimuli appear rapidly one after another or simultaneously, there is great emphasis on rapid attentional switches from one target to another. At many points throughout the game, there can also be demands to attend to several items simultaneously as well as resist distraction by salient task irrelevant stimuli. Because of these special properties, one can imagine that a strong premium is placed on optimal visual attention and perceptual skills. Thus, hours of gameplay allow one to hone these visuo-perceptual and attentional skills.

Contrast Sensitivity. An important aspect of visual perception that is enhanced by action video game playing is the ability to detect differences in luminance, also known as contrast sensitivity (Campbell, 1983). Li, Polat, Makous, and Bavelier (2009) found that habitual action video game had enhanced contrast sensitivity functions compared to non-gamers.

To show causality of action video game play, participants who reported little action video game play (less than 1 hour of action video game play) were trained using one of two genres of video games, action (*Unreal Tournament* or *Call of Duty 2*), and an agent-based simulation (*The Sims*), for 50 hours. Comparisons of pre and post-training contrast sensitivity functions showed that the former had greater improvements than the control group.

Useful field of view. Useful Field of View (UFOV) is the total area of the visual field where useful information is captured at a glance without eye or head movements (Ball, Beard, Roenker, Miller, & Griggs, 1988; Sanders, 1970). UFOV captures essentially the “effective” or “working” visual field that is needed for specific visual tasks. Thus, this measure can be much smaller than the area of visual sensitivity that is measured in clinical tests (Ball & Owsley, 1993). Assessment of this is usually accomplished by requiring

participants to detect a briefly flashed target at various eccentricities in the periphery whilst maintaining central fixation. The ability to spot a target decreases as eccentricity increases from fixation (Ball & Owsley, 1993).

Theoretically, action video games make good candidates in training peripheral vision because of their heavy emphasis on detecting targets across different central and peripheral areas. For example, in many shooter games, enemies often appear at far areas of the periphery and a premium is placed on spotting and dispatching them early. It is therefore likely that hours spent on action video game play would serve to enhance sensitivity to targets in the periphery.

Comparisons between regular action video game players and non-players using the UFOV task have shown that the former exhibit superior ability to detect targets at peripheral areas of vision (10° , 20° , or 30° eccentricity) (Green & Bavelier, 2003). The finding of enhanced accuracy as far as 30° in video game players is important, as it demonstrates a far transfer effect to regions that is not typically viewed on screen during video game play.

In their training study, Green and Bavelier (2003) compared non-gamers trained on a first person shooter, *Medal of Honor*, and *Tetris* for 1 hour a day over 10 consecutive days. Again, an advantage with action video game training was seen at 10° , 20° and even 30° eccentricity that as mentioned, was beyond the range typically encountered in video games. These results were generally consistent with a replication by Feng, Spence, and Pratt (2007) following a 10-hour training study comparing an action video game and a 3D puzzle game.

Adding demanding secondary tasks and task-irrelevant distractors exerts deleterious effects on one's effective field of view (Ikeda & Takeuchi, 1975; Williams, 1982). Despite the more demanding conditions, Green and Bavelier (2006a) showed that action video game experts still outperformed their non-action video game counterparts at all eccentricities measured (10° , 20° and even 30°). The results were also consistent following a 30-hour

training study (Green & Bavelier, 2006a) where non-gamers trained in *Medal of Honor* improving more than a control group trained in *Tetris* in peripheral target detection with and without distractors and a secondary task. These results thus provide converging evidence of a causal effect of action video game play on UFOV.

Unlike previous works (Green & Bavelier, 2003, 2006a), Boot et al. (2008) failed to find that action video game experts had a larger functional field of view compared to non game players despite using a similar paradigm. They found that target detection at three eccentricities (10°, 20° and 30°) were largely statistically equivalent between experts and non-players. Furthermore, 20 hours of action video game training (*Medal of Honor*) also did not result in significantly greater improvement compared to other groups (*Tetris*, real-time strategy game and a passive control group¹).

As Boot et al. (2008) is often cited in the literature and accounts for the majority of null findings in the literature, it is important to highlight some limitations of the research here that may account for the null findings. This is done so that the reader can bear these caveats in mind when this study is contrasted to in later sections. First, for the differences in cross-sectional findings, the sample of video game players in Boot et al is highly heterogeneous. Specifically, their video game players comprised of not only regular action video game players but players that played a wide variety of games. This is in contrast to numerous other studies (e.g., Green & Bavelier, 2003, 2006a) that used more homogenous samples of habitual action video game players. If expanded UFOV depended upon regular action video game play, it is thus plausible that combining regular action gamers and those that play other games may minimize the differences in UFOV between video game players and non-video game players in Boot et al's study.

¹ Passive or no-contact control groups are generally not recommended as comparisons because they potentially introduce several confounds such as “demand characteristics” (Shipstead, Redick, & Engle, 2012).

Additionally, a very large set of transfer tasks (12) was administered in Boot et al. (2008). While the administering of such a large set of tests allows for a comprehensive assessment for transfer effects, this could have resulted in test fatigue. Furthermore, it is notable that participants in all the groups were required to perform the transfer tasks three times; prior to, midway and after training. Hence, it is conceivable that test-retest and practice effects would have masked any specific improvements that arose as a result of video game training.

Visual field sensitivity. As the UFOV represented only an effective or functional field of view relevant to a particular visual task, a recent study has extended the aforementioned studies on UFOV by using clinical measures of central and peripheral visual fields. Buckley, Codina, Bhardwaj, and Pascalis (2010) argued that previous findings (Green & Bavelier, 2003, 2006a) where video game advantage extended to 30° eccentricity from fixation represented only the outer edges of central vision. Hence, they tested regular action video game players and non-players on the Goldman Kinetic perimetry, a standard clinical measure of visual field sensitivity to determine if action video game players really had an advantage in peripheral vision. The test required participants to detect moving lights at various locations in central (30° eccentricity from fixation) and peripheral (60° eccentricity from fixation) visual fields. Their results extended previous findings (Green & Bavelier, 2003, 2006a) by showing enhanced central visual fields. Crucially, the action video game players also had, on average, a larger peripheral visual field.

Visual Attention

Distribution of spatial attention. Evidence has shown that our attentional focus can be divided between two (Bichot, Cave, & Pashler, 1999) or more locations/items (Pylyshyn & Storm, 1988). Given the nature of many fast paced action video games, the ability to divide

attention to several items and shift rapidly from one target to another confers a great advantage when playing these games.

One task used to test for shifting of visual attention is the Posner cueing task (Posner, Snyder, & Davidson, 1980). In this task, participants are asked to fixate on a central stimulus and a cue was given to indicate where a target would appear. There were three probabilities of the target appearing where the cue indicated - 80% (high probability), 50% (neutral) or 20% (low). The speed of target detection was fastest in the high probability condition, and slowest in the low probability condition (Posner et al., 1980).

In one of the first studies that explored visual attention shifting advantage in video game players, Greenfield, DeWinstanley, et al. (1994) showed, using the Posner cueing task, that expert players of the game *Robot Battle*, were faster in target detection in the high and low probability conditions compared to non-gamers. Furthermore, the experts did not show an increased response time in the low probability relative to the neutral condition (Greenfield, DeWinstanley, et al., 1994).

Demonstrating a causal effect, those trained to play a video game, *Robotron* for 5 hours, where a player would have to fend off robot attacks from many directions, showed greater improvement at the low probability condition whereas non-players showed no improvement. These results thus provided early and preliminary evidence of action video game-related advantage in shifting visual attention across multiple locations in space, a demand common to many fast-paced action video games.

Multiple object tracking. The ability to divide attention has also been examined using the multiple-object tracking (MOT) task (Pylyshyn & Storm, 1988). This task requires attention to be split to track multiple moving items simultaneously. Evidence suggests that each to-be-tracked is individually indexed, indicating an actual allocation of attention to individual items during tracking (Sears & Pylyshyn, 2000).

Green and Bavelier (2006b) found that experienced action video game players were able to track on average 2 items more than non-video game players. Following up with a training study, they assigned a group of video game novices to play an action video game, *Unreal Tournament*, while another group played *Tetris*, for 30 hours each. Comparison of pre and post-training performance revealed that only the action video game trainees improved in MOT, especially in conditions with more than 4 items. In contrast, performance for the group trained in *Tetris* remained unchanged regardless of the number of targets shown.

The transfer to MOT again appears confined to a fast-paced first-person shooter. In contrast, training in other kinds of action video games with a much slower pace or a fast paced sports game showed no such improvement (J. E. Cohen et al., 2007). Specifically, participants trained for 12 hours in one of three action video games - a fast paced first person-shooter (*Unreal Tournament*), a slower paced first person shooter (*America's Army*) and a fast paced non-shooter game (*Harry Potter: Quidditch World Cup*). Other groups trained in *Tetris*, card games and Rhythmicity training in which participants performed a set of simple physical movements in synch with beats. Only the *Unreal Tournament* group showed improvement in tracking more than 4 items compared to baseline.

Unlike previous works (J. E. Cohen et al., 2007; Green & Bavelier, 2006b) that focused on tracking accuracy, Boot et al. (2008) showed that action video game experts were able to track on average, at much higher speeds than did non-gamers. Participants were allowed to vary the speed in which the objects were moving with the aim of maintaining 100% accuracy of tracking objects amidst distractors.

Evidence for the enhanced ability of action video game players to attend to several items has also been corroborated using an enumeration task. This requires participants to report the number of briefly flashed items on a display. When there are between 1-4 items on screen, RT for determining the number of items is generally fast, effortless and accurate.

However, when the number of items exceeds 4, RT increases sharply while accuracy decreases (Trick & Pylyshyn, 1993, 1994). The former automatic and effortless process is termed subitizing, whereas the latter more effortful and slower process is attributed to counting (Trick & Pylyshyn, 1994).

Using an enumeration task, Green and Bavelier (2006b) showed that experienced action gamers were generally more accurate in enumerating in trials with large numbers of items presented. Furthermore, on average, experienced action gamers were able to enumerate about two items more than non-action gamers.

Again, to establish causality, Green and Bavelier (2006b) compared non-gaming participants trained in an action video game, *Medal of Honor*, and a control group that played *Tetris*. At post-training, only the action game trained group showed an increase in accuracy rate for 4 and more items.

The enhancement of the ability to shift and distribute attention towards multiple targets or locations makes sense with action video game play. This is considering how an action game demands a player to allocate attention to several items in the visual field in parallel (e.g., enemies, items to collect, distractors, etc.). Moreover, enemies are often fast moving and penalties are incurred when the player loses track of them (e.g., being killed). Prolonged demanding action gameplay thus might have enhanced this skill.

Despite the converging evidence above, contrasting evidence has also been found that has shown no action video game advantage in the ability to attend to several items simultaneously. Although Boot et al. (2008) provided evidence of enhanced ability to track moving objects at high speed in expert action video game players, they found no evidence that a 21.5-hour training in an action video game improves this ability relative to other games (real time strategy, *Tetris* and no-game control). Similarly, they found no evidence that expert action gamers or those trained were able to enumerate more items (Boot et al., 2008).

Visual Search

Visual search activities are highly familiar in many games. An example of this is computer based hidden-object games that require players to search for various items embedded in a picture. In theory, such games are good candidates to directly train visual search skills. However, to my knowledge, no such studies have tested this possibility. In contrast, action video games have been the primary candidate in investigating visual search enhancements.

It has been argued that first person shooter games are highly similar to visual search paradigms because such games often require a player to search for targets amidst a distracting background, such as an enemy in hiding (Wu & Spence, 2013). Indeed, converging evidence indicates that action video game players exhibited much faster search speeds overall without sacrificing accuracy (Castel, Pratt, & Drummond, 2005) as well as greater search efficiency (Hubert-Wallander et al., 2011). Moreover, action video game players displayed superiority in demanding search conditions such as conjunction searches and dual-search tasks involving searches in central and peripheral vision (Wu & Spence, 2013). Finally, habitual action video game players were able to search more accurately when distracting objects are in close proximity to the target (Green & Bavelier, 2007), a condition known as crowding (Intriligator & Cavanagh, 2001; Toet & Levi, 1992). These findings were generally consistent following a short bout of action video game training. Specifically, following 30 hours of action video game (*Unreal Tournament*) training, participants were able to detect targets at closer target-distractor distances compared to the non-action trained group (*Tetris*) at 0°, 10° and 25° eccentricity. Furthermore, those trained in a first-person shooter for 10 hours improved overall search speed and accuracy for feature and conjunction searches to a greater extent than the control group (3D puzzle game, *Ballance*) (Wu & Spence, 2013).

Interestingly, Wu and Spence (2013) included a group that was trained in a racing game (*Need for Speed*). Results indicate that playing this game resulted in equivalent visual search enhancements as the first-person shooter group. Although on the surface, one would not expect visual search to be a skill practiced in the racing game, Wu and Spence (2013) argued that for this particular racing game, the player is expected to also locate and identify several targets. Therefore, the gains by playing this racing game should be comparable to the first-person shooter.

These results obtained using different visual search paradigms taken together suggest that action video game play may have a beneficial impact on visual search skills. One possible mechanism for visual search improvements may be the hours spent playing action video games led to a sharpening of the distinction of targets and distractors even in crowded visual displays. This in turn may improve biasing of top-down search to target and filtering of distractors (Desimone & Duncan, 1995). If so, this reasoning is consistent with evidence showing superior capabilities in action video game players in attentional filtering (Bavelier, Achtman, Mani, & Föcker, 2012; Chisholm, Hickey, Theeuwes, & Kingstone, 2010; Chisholm & Kingstone, 2012).

Change Detection

A classic finding in human visual attention is that we often miss highly salient visual anomalies when our attention is occupied elsewhere. This phenomenon, referred to as inattention blindness, was first described by Mack and Rock (see Mack & Rock, 1998) and popularized subsequently by Simons and Chabris (1999). Arguably, a fundamental requirement in any fast paced action video game is the need to respond quickly to a sudden onset stimulus. The sudden onset stimulus could be a visual anomaly such as an enemy that appears when the player is preoccupied by something else in the visual field.

Given this requirement for successful gameplay, it is plausible that expert action video game players exhibit superior ability to detect visual anomalies when they are focused on other features in their visual field. However, this was not the case as Murphy and Spencer (2009) showed that action video game players were not more likely to detect a sudden onset visual anomaly whilst performing a counting task.

Recently, Vallett et al. (2013) compared regular and non-action video game players on the inattention blindness task popularized by Simons and Chabris (1999). In this task, a participant counted the number of passes made by people in a video. Unknown to them, a person dressed in a gorilla suit would appear and walk across the room in the video. Simons and Chabris (1999) demonstrated that people often miss the gorilla when they were preoccupied with the counting task. In contrast to Murphy and Spencer (2009), Vallett et al. showed that action video game players have a significantly greater likelihood of detecting the gorilla than non-gamers. The differences in findings between these two studies are not clear, but one speculation may be that the visual anomaly (gorilla) may be more salient and captures attention more than the stimulus (colored cross) in Murphy and Spencer's task, which may be subtler.

The Attentional Blink

The attentional blink refers to a bottleneck in information processing whereby a second target (T2) is missed when it is presented close in time (between 200–500ms) after a successfully detected first target (T1) (Raymond & Shapiro, 1992; Shapiro & Raymond, 1997). The intervals between T1 and T2 are known as lags. Hence, lag 1 would refer to T2 appearing 100ms after T1 and lag 2 referring to 200ms after T1 and so on. Usually, observers would miss T2 when it appears within 200-500ms (lags 2-5) after successful T1 detection (Raymond & Shapiro, 1992; Shapiro & Raymond, 1997).

In their seminal work, Green and Bavelier (2003) showed that action video game players are less affected by the attentional blink, showing higher detection accuracy rates for T2 in lags 2-5 relative to non-action video game players. Furthermore, relative to a control group that played *Tetris*, those trained on an action video game (*Medal of Honor*) for 10 hours improved target detection in the lags susceptible to the attentional blink (Green & Bavelier, 2003).

Crucially, attentional blink improvements are only seen following a training in a fast-paced first-person shooter, but not to other slower paced ones, third-person shooters and sports games (J. E. Cohen et al., 2007). This likely highlights that fast-paced first-person shooters contain exclusive properties that lead to such specific improvements. J. E. Cohen et al. (2007) further argued that the improvement in recovery from the attentional blink following action video game play is due to the frequency of demands placed on attending to rapidly appearing stimuli within a fast-paced first-person shooter.

Despite the positive effects of action video game training shown in the attentional blink (J. E. Cohen et al., 2007; Green & Bavelier, 2006a), there have been a few notable failures to replicate those findings. For instance, Boot et al. (2008) found equivalent susceptibility to the attentional blink between action video game experts and non-gamers. Furthermore, they failed to find a greater improvement from action video game training relative to a passive control group and other video game training groups (strategy game and Tetris) in any lags on the attentional blink task following 20 hours of video game training. These results are consistent with a later attempt to replicate Green and Bavelier (2003) showing that experienced action video game players did not perform better than non-players in lags susceptible to the blink (Murphy & Spencer, 2009). Again, the issues raised earlier on Boot et al.'s study would also apply here and could account for the inconsistent findings. For Murphy and Spencer (2009), limited conclusions can be drawn regarding the causal effects of video

game play because no training studies were conducted. Perhaps there could be sample differences uncontrolled for that could have led to inconsistent findings.

Mental Rotation

Mental rotation, part of a broad array of spatial skills, can briefly be defined as skills required for mentally visualizing and manipulating objects in space (Spence & Feng, 2010). Action video games, especially those with a first-person perspective, are presumably good training tools for spatial skills because of the number of skills trained that are required for mental rotation such as visuomotor coordination, spatial selective attention and speed (Sanchez, 2012; Spence & Feng, 2010). Furthermore, playing action video games in 3-D space involves an unrestricted field of view. Such environments are thus more realistic and fit better with our visual perception system, in turn enhancing sensory processing (Spence & Feng, 2010). Current evidence lends some support the assertion that playing action video games improves mental rotation skills. In support for of the above, enhanced 3-D mental rotation (Feng et al., 2007; Sanchez, 2012) was found only in trainees trained in 3-D first-person shooters but not in other games (e.g., 3-D puzzle game, *Ballance* and *Word Whump*, respectively). Furthermore, the enhancement to spatial ability is specific to only mental rotation of 3-D shapes but not to other spatial abilities like paper folding (Sanchez, 2012).

Evidence for mental rotation advantages has also been found in experienced *Tetris* players and those trained (Boot et al., 2008; Okagaki & Frensch, 1994; Sims & Mayer, 2002). Notably, these advantages are highly specific to spatial ability tests akin to *Tetris*. For example, video game novices trained on *Tetris* showed greater improvement in mental rotation of *Tetris*-like shapes compared to the other training groups (Boot et al., 2008). Also, Sims and Mayer (2002) showed that skilled *Tetris* players were faster in mental rotation of shapes that are similar or identical to shapes in *Tetris* than low skilled players. However, no advantage was seen in the skilled players in the mental rotation tests that did not involve

Tetris-like shapes. Furthermore, although 12 hours of *Tetris* training did not result in transfer to spatial ability tests in general, examinations of the mental rotation strategies showed that *Tetris* trainees were more likely to use an alternative type of mental rotation (clockwise rotation up to 225°) for *Tetris* shapes (Sims & Mayer, 2002).

Thus, taken together, these results suggest that training in games that had demands on mental rotation, of which *Tetris* is a good exemplar, enhances mental rotation. Two lines of evidence further support the hypothesis of a specificity of transfer. One is from first-person shooters where transfer is only seen following games that 3-D demands navigation (Sanchez, 2012; Spence & Feng, 2010). Another is from *Tetris* training where transfer is seen specifically only to rotation of *Tetris*-like shapes (Boot et al., 2008; Sims & Mayer, 2002).

Executive Control

Executive control represents a complex range of cognitive functions that are important for responding in an adaptive manner to novel situations as well as for organizing thoughts and actions in service of a goal (Friedman et al., 2006; Fuster, 2008; Lezak, Howieson, & Loring, 2004). These complex cognitive functions consist of a family of top-down processes ranging from updating working memory, monitoring conflict and control (selective attention and stimulus-response interference), behavioral inhibition, and mental flexibility (also called shifting or task switching) (Braver & Ruge, 2006; Diamond, 2013; Miyake et al., 2000; Shallice & Burgess, 1993). These functions are in turn critical for controlling intentional behavior, planning, translating plans into action, and the monitoring of one's performance (Lezak et al., 2004).

Video game related enhancements to higher-order executive processes have also been reported. However, results are currently inconclusive with support that action video games can improve some but not all aspects of executive function.

Task switching. Task switching is a measure of mental flexibility that involves switching between two or more tasks rapidly (Monsell, 2003). Performing each task requires a mental representation or a ‘task-set’ appropriate to the current task and inhibition of the requirements of the other task (Monsell, 2003). Often, a ‘switch cost’ is incurred in terms of response time (RT) or accuracy on a switch trial relative to performing the same task in succession (Monsell, Sumner, & Waters, 2003; Rogers & Monsell, 1995). Switching of tasks can follow a predictable or unpredictable manner. In the former, a task-switch takes place after a pre-determined number of trials (alternate-runs format). In this instance, switching is less demanding and typically yield smaller switch costs (Monsell, 2003). In contrast, in the latter condition, switches are random, thus switching between tasks is unpredictable. Therefore, the lack of opportunity for preparation of a switch results in greater conflicts, which in turn results in a larger switch cost (Monsell, 2003; Rogers & Monsell, 1995).

Smaller switch costs in RT and accuracy has been demonstrated in regular action video game players compared to non-players in alternate-runs and more demanding random task switches (Andrews & Murphy, 2006; Boot et al., 2008; Cain, Landau, & Shimamura, 2012; Colzato et al., 2010; Green, Sugarman, Medford, Klobusicky, & Bavelier, 2012; Strobach, Frensch, & Schubert, 2012). Furthermore, greater switch-cost reductions in alternate-runs task switching has been shown following 15 (Strobach et al., 2012) and 50 hours (Green et al., 2012) of action video game training compared to controls that played non-action games (e.g., *Tetris* and *The Sims*).

Although the findings of task switching superiority in experienced action video game players are consistent, training studies to test for causal effects of transfer to task switching remains equivocal. In contrast to Green et al. (2012) and Strobach et al. (2012), Boot et al. (2008) failed to find similar transfer effects following 21.5 hours of action video game training relative to other control groups (*Tetris*, real time strategy and passive control).

One possibility for these conflicting findings may be due to different task-switching paradigms used in each study. Unlike Strobach et al. (2012) and Green et al. (2012) who utilized an alternate-runs switch task, Boot et al. (2008) employed a random switch task.

There are several possibilities that may account for the lack of transfer to random task switching. First, action video game training may not improve mental flexibility per se as measured by random task switching paradigms because random or “pure” task switching employs a different neural mechanism than predictable task switching (Pereg, Shahar, & Meiran, 2013). For alternate-runs task switches, there is a requirement to constantly update working memory for how many trials have been completed in the current task and to count down for the upcoming switch or task repetition. In contrast, updating of working memory is not required in random task switches as the identity of the current trial is independent of the previous one. As opposed to updating, the working memory requirement here is to hold the identity of the cue online that signifies a switch or repeat.

Several studies support the hypothesized relationship between alternate-runs task switch and working memory updating. For instance, working memory updating training improves alternate-runs task switching (Salminen et al., 2012). Furthermore, articulatory suppression selectively disrupts performance in alternate-runs task switches but not random task switch performance (Baddeley, Chincotta, & Adlam, 2001; Bryck & Mayr, 2005). Plausibly, the articulatory suppression disrupted sub-vocal verbalizations important in helping to endogenously maintain and update the trial order in working memory (Bryck & Mayr, 2005). Further supporting separate mechanisms, a recent study showed that training in an alternate-runs switch paradigm did not result in transfer to an untrained random switch paradigm (Pereg et al., 2013).

In light of this evidence, it is possible that one route by which action video game training transfers to alternate-runs task switching paradigms is via an enhancement to

working memory updating by more efficiently using articulatory rehearsal. Hypothetically, working memory updating could be important in action video games as players are required to update their working memory in terms of the mission objectives, items collected, etc. Therefore, it is plausible that working memory updating is improved in action video game training but not mental flexibility per se, which is needed for sudden and unexpected switching of task sets. Unfortunately, this hypothesis has not been sufficiently tested.

To date, only one cross-sectional study and one longitudinal study have explored the relationship between working memory updating and action video game playing, and both used n-back tasks which may recruit several working memory processes (J. D. Cohen et al., 1997), making conclusions difficult. For the cross-sectional study, an action video game advantage in accuracy and response time for a verbal n-back task has been found (Colzato, van den Wildenberg, Zmigrod, & Hommel, 2013). Conversely, Boot et al. (2008) failed to find a transfer to a spatial n-back task after action video game training. Storage of different types of information during tasks in these studies (verbal and spatial) could have contributed to the inconsistencies in findings. In addition, tasks that focus on whether there are changes in specific working memory processes are needed. Thus, further work on evaluating this link between working memory updating and task switching in video game training studies is warranted.

Finally, in line with the argument of a different neural and cognitive mechanism subserving random and alternate-runs task switches, it is also possible that action video game training enhances learning of the task statistics in the latter such that it enables trainees to better predict upcoming task switches and make corresponding preparations to switch (Bavelier, Green, Pouget, & Schrater, 2012). In contrast, learning of task statistics is unlikely to be helpful in random task switches.

Multi-tasking. With the findings of enhanced attentional capacity and divided attention in action video game players (Green & Bavelier, 2003; Greenfield, Brannon, & Lohr, 1994) and the finding that action gamers perform better at a dual search task (Wu & Spence, 2013), it is tempting to conclude that they are better than others at multitasking. However, evidence shows that action video game players and non-players were equally impaired when performing separate driving, multiple object tracking and visual search tasks while concurrently answering trivia questions. (Donohue, Woldorff, & Mitroff, 2010). Hence, although action video game may be associated with superior attentional capacity and divided attention, there is no evidence that they can multitask more effectively than non-players.

Distractor suppression. Evidence shows that action video game players are less susceptible to attentional capture by task-irrelevant stimuli. Tasks that assessed this ability required participants to ignore distractors and focus on a predetermined target. Chisholm et al. (2010) showed that experienced action video gamers were less affected by the presence of distractors and demonstrated overall faster RT in making line judgments than non-gamers.

The reduction in attentional capture has been shown to stem from improved top-down suppression of attentional capture rather than from recovery from capture (Chisholm & Kingstone, 2012). Specifically, Chisholm and Kingstone (2012) tracked participants' eye movements during a target-detection task with distractors and found that experienced action video gamers made fewer initial saccades to the abrupt onset distractors. Importantly, the action video game players and non-players were equivalent in the time taken to disengage from attentional capture by the abrupt onset distractor.

Differences in neural responses to distractors between action gamers and non-gamers also support the above assertion. Relative to non-gamers, action gamers showed increased suppression of steady state evoked potential (SSVEP) amplitudes to unattended peripheral stimuli compared to non-gamers (Mishra, Zinni, Bavelier, & Hillyard, 2011). An fMRI study

also indicated that action gamers showed reduced blood-oxygenated level dependent (BOLD) response in visual motion-sensitive regions (MT/MST) to moving distractors compared to non-gamers (Bavelier, Achtman, et al., 2012). Furthermore, 10 hours of action video game training (*Medal of Honor*), relative to non-action game trained controls (*Ballance*) has been shown to increase P2 and P3 waves (positive electric potential of 200 and 300ms after stimulus onset) at occipital and occipito-parietal sites (Wu et al., 2012). Previous research indicates that increases in P2 and P3 amplitudes may reflect adaptations to task demands on attentional control in attentional selection as well as inhibition of processing of task-irrelevant stimuli (Bledowski, Prvulovic, Goebel, Zanella, & Linden, 2004; Fritzsche, Stahl, & Gibbons, 2011; Potts, Patel, & Azzam, 2004; Sawaki & Luck, 2010). Taken together, these findings suggest that experienced action video game players are superior at applying top-down control to suppress attentional capture.

Stimulus-response interference. The above tasks on selective attention contain distractors that are clearly distinguishable from the target. In this case, the response mapping is clear and there is a one-to-one correspondence between target and response. However, there are instances whereby conflicts arise because the distractor is a target in another trial. The presence of the distractor would thus prime responses associated with that target but is not appropriate for the current trial. Therefore, one is required to suppress the response code associated with the distractor and activate the response code associated with the current target (Eriksen & Eriksen, 1974). Failure to do so results in interference. One such task that produces interference at this level is the flanker task. The requirements of a standard flanker task are to quickly identify a central target (e.g., left or right pointing arrow) and to ignore flanking distractors. The flanking distractors could be congruent (arrows pointing in the same direction), incongruent (arrows pointing in opposite directions) or neutral (e.g., dashes). When flanking distractors are congruent with the response mapping for the central target,

response time is faster than when the flankers are neutral or incongruent. Conversely, RT is slower when the flanking distractors are incongruent with the response mapping for the central target (Eriksen & Eriksen, 1974). The difference in RT between the incongruent and congruent condition yields a flanker compatibility effect (FCE) (Eriksen & Eriksen, 1974). One possibility for this is that delayed response in incongruent trials reflects the unsuccessful suppression of distracting flankers leading to the activation of multiple response codes. This forces the respondent to choose the appropriate response between these codes and stimulus-response interference results (Chapman, Gavrilescu, Kean, Egan, & Castiello, 2005).

Green and Bavelier (2003) used a variant of the flanker task (from Lavie & Cox, 1997) to test the effects of action video game play. Unlike a standard flanker task where the target appears in one fixed position (in between left and right flankers), they presented the target in one of six rings, arranged in a circle. The task was to determine whether the target was present in one of the rings. A distractor was also positioned outside of the ring that either matched the target (congruent), or not (incongruent). Furthermore, they varied the perceptual load by either leaving the other five rings empty (low load) or filling the rings with shapes (high load). Action video game players were found to have greater FCE in the high-perceptual load condition compared to their non-action gamer counterparts, while no difference between the two groups was seen in the low load condition. One interpretation of these results is that action video game playing is detrimental the ability to suppress distracting flankers. An alternate interpretation is that in the high-perceptual load condition, action video game players had greater attentional capacities than non-players allowing 'left-over' attentional resources to process the distracting flanker, leading to the greater compatibility effect in that condition (Green & Bavelier, 2003). In contrast, non-gamers were not distracted by the flanker because their lower attentional capacities did not allow

processing of distracting flankers, having spent all of their attention resources searching through the rings for the target (Green & Bavelier, 2003).

Using an identical flanker task from Green and Bavelier (2003), Irons et al. (2011) found that action video game players compared to non-players had a lower compatibility effect in the high perceptual load condition. This contradicted Green and Bavelier (2003). The reason for the differences in findings despite using identical paradigms is unclear. Perhaps, individual variation unaccounted for between the samples used in both studies may have led to different findings. Nevertheless, these conflicting results therefore call into question whether real differences exist between experienced action video gamers and non-gamers' performance in flanker tasks. Further work is necessary to investigate the differences.

Unlike the modified flanker task in Green and Bavelier (2003), there were no reliable differences found between action video game players and non-players in standard flanker tasks (Cain et al., 2012). In the standard flanker task, there is no need to actively search for the target since the target and distractors are always located at the same position. As a result of the conflicts in findings using different flanker tasks, more studies are therefore needed to determine if flanker effects are indeed different between action and non-action video game players. Notably, none of the aforementioned studies included a video game training regime in testing transfer to the flanker task. Hence, in addition to the conflicting findings, it is yet to be established that the effects of video game playing on the flanker task is causal.

Corroborating evidence for the lack of video game advantage in tasks involving resolution of conflicts in stimulus-response interference has been found using the Simon task. In the Simon task, participants perform a shape or color judgment task, with the responses assigned to left or right hand key presses. The stimuli however, can appear on the left or right side of a fixation (Lu & Proctor, 1995). The Simon effect refers to the phenomenon whereby

responses are faster when the stimulus location is congruent to the location of the assigned response (e.g., stimulus appears on the left and correct response is a manual response of the left key). In contrast, a slowed response is evident when the correct key is on the opposite side of the stimulus (Lu & Proctor, 1995). Previous research has shown that “conflict tasks” like the Simon and flanker tasks share similar underlying processing demands generally involving the anterior cingulate cortex and the dorsolateral prefrontal cortex (Fan, Flombaum, McCandliss, Thomas, & Posner, 2003).

Bialystok (2006) tested whether regular players of “speeded” video games show an advantage in two versions of the Simon task. The first was a standard Simon task where the stimuli consisted of colored squares presented on the right or left side of fixation. The second however contained arrows pointing to the left and right that appeared in either the left or right sides of fixation. Overall, video game players responded faster in both versions of the Simon task than non-players. This was especially so in consecutive trials where no switch in response or stimulus position occurred. However, when there was a switch in stimulus location or response required (hence a demand for conflict resolution), the speed advantage in video game players disappeared. Bialystok concluded that players who play fast paced games have an advantage in activities that are more akin to speeded video games, which is more fluent interpretation of stimuli and more rapid motor response. However, the advantage did not extend to resolving of perceptual and processing conflicts that are inherent in Simon tasks.

From the above studies, it appears that action video game players tend to perform better in target detection tasks where responses for target and distractors are clearly distinct. This advantage could stem from enhancements in top-down biasing of attention towards targets and away from distractors (cf. Desimone & Duncan, 1995). However, when there are perceptual and decisional conflicts especially between multiple response codes, action video

game players are no better at resolving these decisional conflicts than novice video game players. This makes sense especially when one considers action video game play where players are expected to make split second decisions to engage highly distinguishable targets (enemies) but not distractors (non-enemies). Hence, a frequently utilized ability within an action video game may be the top-down biasing of highly salient task-relevant targets (enemies) and filtering out of irrelevant ones. In this case, the action required is clear - a highly practiced quick motor response to engage the enemy. On the other hand, response conflicts are rarely (if ever) encountered and thus less well practiced.

A response-related conflict may also occur when one is required to cease responding when a signal is given. This is made especially difficult when responses required are fast and automatic. Hence, top-down inhibitory control is necessary to “inhibit” or override a strong internal disposition to respond (Diamond, 2013; Miyake et al., 2000). There have been concerns and evidence suggesting that excessive video game play is detrimental to inhibitory control (Barlett, Anderson, & Swing, 2009; Gentile, Swing, Lim, & Khoo, 2012).

Colzato et al. (2013) compared inhibitory control between habitual action video game players and non-players using a stop signal task, in which participants were required to cease speeded responses when a signal occurred. There were no discernible differences between habitual action gamers and non-gamers. Hence, action video game players were not better at inhibiting unwanted responses nor were they more impulsive than their non-gaming counterparts.

Working Memory

Although there is evidence to support the impact of video game training on various aspects of visual attention, its benefits on human memory are less well investigated. In one of the few investigations on video game effects on memory, Boot et al. (2008) compared regular video game players and non-players on a variety of memory tasks that included a spatial 2-

back task, a Corsi-block tapping task and an operation span task. The spatial 2-back task is a measure of spatial working memory updating. This involved participants judging whether a currently presented letter was located in the same location as a letter presented 2 trials ago. For the Corsi-block tapping task, participants had to replicate a pattern of blocks changing color in the exact sequence. The operation span task is a measure of working memory capacity and involved participants remembering sets of words presented while performing a math operation. No differences were found between action gamers and non-gamers in performance on all memory measures. Additionally, following 21.5 hours of video game training either in an action video game, *Medal of Honor*, *Tetris*, or a strategy game, *Rise of Nations*, there were no differential improvements in any of the memory tasks between the different games trained.

In contrast to Boot et al. (2008), a recent investigation provided evidence of superior working memory updating in experienced action video game players. Colzato et al. (2013) compared regular action video game players and non-players on an n-back task (1-back and 2-back) that required participants to determine if a currently presented letter matched one presented 1 or 2 trials ago. The results show that in both 1 and 2 back conditions, regular action video game players responded faster, were more accurate, made more correct hits and rejections as well as committed fewer false alarms than their non-gaming counterparts. However, again bearing in mind the cross-sectional approach of this study, limited inferences on causality can be made.

Controversies and Criticisms of Video game Studies

Before we consider the merits of video game experience and training based on the literature reviewed in the earlier sections, there are several issues and controversies that need to be addressed so that the research findings can be placed in the relevant context. Although cross-sectional studies have limited inference on the causality of video game play on

perception and cognition (Boot et al., 2011; Kristjánsson, 2013), a brief mention of the controversies using such a design is necessary, as a large proportion of studies utilized such cross-sectional comparisons. While many of these criticisms are mainly directed towards action video game studies, I believe that they apply to any study on other video game genres as well.

Lack of covert recruitment. A critical issue with cross-sectional studies is that many of them fail to report how participants were recruited and many investigators openly recruit video game players and non-players without masking the intention of the study (Boot et al., 2011). This leads to the problem of differential expectations about how these groups perform in laboratory cognitive tasks. Increasing media and blog reports of video game playing benefits further exacerbates this problem (Boot et al., 2011). Therefore, habitual gamers recruited might expect that the a video game study is intended to assess their superior abilities (Beyko, Stothart, & Boot, 2012) and be more motivated to perform better. As a result, better performance by habitual gamers may not be the result of video game experience but rather because of extra motivation and demand characteristics. However, although this is a potential issue, it must be noted that the impact of prior expectancies affecting performance in video game studies has not been demonstrated empirically (Schubert & Strobach, 2012).

Variability in classification of video game players. In cross-sectional studies, the criteria of being classified as an action video game player vary between studies. Action video game players in these studies range from participants who play action video games as little as 3-4 hours per week over the last 6 months (Buckley et al., 2010; Chisholm et al., 2010; Green & Bavelier, 2003, 2006a) to 7 hours per week over the last 2 years (Boot et al., 2008) or even as much as 20 hours per week (Irons et al., 2011). These differences in video game experience may lead to different level of expertise in the video game players from study to study. Furthermore, even within the same study, there is variation in the number of hours of

video game play by their habitual video game players. For example, in Irons et al. (2011), their sample of video game players reported playing between 4 – 20 hours of video games per week. Another characteristic of video game players uncontrolled for is expertise. While in some studies the criteria of being labeled a video game player depends on frequency of game play (Colzato et al., 2013; Green & Bavelier, 2003, 2006a), in others, the classification is dependent also upon self-rated expertise (Bialystok, 2006; Boot et al., 2008; Cain et al., 2012). Video game experience does not equate to video game expertise. Even amongst regular video game players, there is arguably much variability in expertise. Hence, the differences in so-called “video game experience” or “expertise” within and between studies may have led to inconsistent findings between studies as experts in one study may be quite different from experts in another study.

Another issue often overlooked in action video game studies is that playing of other games in the action video game group is not controlled for. Arguably, it is inconceivable that an avid video game player plays only one game genre exclusively. For instance, a player may play 3-4 hours per week of action video game, but spend a larger portion of time playing other game types. Examples of this potential confound can be found in studies (Boot et al., 2008; Murphy & Spencer, 2009) who reported that their action video game players also play other genres such as sports, role-playing and strategy games extensively. Hence, these participants may not strictly be defined as action video game players. Grouping such heterogeneous participants in the same group may result in masking any effects or advantages seen in “true” action gamers. It is thus also plausible that heterogeneity in action video game groups across different studies may have led to inconsistent findings.

To add to the complexity of grouping action video gamers is that “action video games” may mean quite different games to different investigators. As mentioned previously, short of a hard and fast definition, it has generally been agreed in the video games literature that

action video games are games that are characterized by their unpredictability, intense speed, high perceptual, cognitive and motor load, the selection between multiple action plans and an emphasis on peripheral processing (Green, Li, et al., 2010). Although many studies have mainly focused on first-person shooters, players that play other types of games have also been classified as action video gamers. For example in Green and Bavelier (2003), participants who played non first person shooters like *Grand Theft Auto*, racing (e.g., *Mario Cart*) and arcade fighting games (*Marvel vs. Capcom*) were also classified as action video gamers. There could also be variations amongst shooter games. This could be in the form of perspective - first or third person, the speed of the game and the demands on strategy use. Hence, given the lack of consistency in classifying action video game players, it makes efforts to replicate previous works difficult.

Aside from grouping action video game players, grouping of non-video game players is also problematic. In many cross-sectional studies, investigators have typically placed a minimum of the number of hours of gameplay a week for participants to be classified as action video game players (e.g., minimum of 4 hour per week) (Green & Bavelier, 2003) with those that do not meet the criterion classified as non-players or controls. In reality, however, their control group are not entirely made up of “true” non-players, but rather, some report casual playing of various genres of non-action video games (Chisholm et al., 2010; Green & Bavelier, 2003, 2006a, 2006b; Vallett et al., 2013). In some studies, casual gamers of non-action game have been grouped together with “true” non-gamers in a single control group. For example, in Vallet et al. (2013), regular action video game players were compared to a control group comprised of non-gamers and non-action gamers. Hence, there is confusion about the comparison group whether it is a group of non-action gamers or non-gamers. Drawing conclusions on the superiority of action video games based on such selection criteria is problematic because in the control group, effects of playing non-action games may have

been masked by the inclusion of “true” non-gamers. Grouping casual game players of different genres within the same control group poses another problem. Assuming that playing different genres of non-action video games train different abilities, it is possible that the effects of different non-action games may cancel each other out. One possible way to circumvent this problem would be to directly compare performances between experienced and casual players of specific game genres in a single study, although this could be operationally difficult because gamers, casual or not, tend not to play a single genre of game exclusively.

Transfer tasks are highly similar to trained game of interest. A common methodology in most if not all action video game training studies involves comparing a treatment group playing an action video game and a control group playing a non-action video game (e.g., *Tetris*) (Green & Bavelier, 2003, 2007). The methods that have been used in these previous studies may have favored the treatment group. Specifically, many action video game training studies have utilized transfer tasks that mimic the demands of action video games, thus possibly maximizing transfer effects (e.g., attentional blink, multiple object tracking). Therefore, by including only transfer tasks that share common demands with action video games, the transfer effects might be only limited to action video games but not to control games that do not share common demands. Thus, it is plausible that positive transfer effects resulting from non-action games may also be evident by having a more balanced selection of transfer tasks that included tasks that share common elements with these games.

Another potential problem with only including transfer tasks that closely mimicked the treatment game is that participants may see the similarities between the game and transfer cognitive task. Participants trained in the treatment game may therefore expect to perform better than participants trained in the control game that do not see such similarities. This latter group may therefore be less motivated to perform, as they might not expect such

improvements. For instance, in a recent preliminary study, participants were less likely to believe *Tetris* training would improve a UFOV task compared to an action video game (Beyko et al., 2012). Such differential expectations may therefore account for differences in transfer rather than due to the training itself.

Summary and Preliminary Conclusions

Over the last ten years since the seminal work of Green and Bavelier (2003), the focus of video game training has been directed towards a particular genre – action video games. The earlier review of cross-sectional and longitudinal type studies suggest that action video games confer advantage in several attentional and perceptual skills (Feng et al., 2007; Green & Bavelier, 2003, 2006b, 2007; Wu et al., 2012). In contrast, evidence for action video game related enhancement to executive function is equivocal (Bialystok, 2006; Boot et al., 2008).

In contrast to action video games, there is insufficient evidence to suggest that other game types improve cognition and visual perception. One notable exception is improvements in spatial cognition by playing games that tap heavily on spatial abilities such as *Tetris* (Boot et al., 2008; Sims & Mayer, 2002). However, the extant evidence suggests that improvements to mental rotation are also quite specific, with improvements in mental rotation limited to shapes encountered within *Tetris* (Boot et al., 2008; Sims & Mayer, 2002).

In light of these findings, a working hypothesis I put forth from the review of the literature on video game training is that the improvements in various aspects of attentional and perceptual processes reflect more specific rather than general forms of learning. This is evident from action video games where transfer is mainly limited to skills that are demanded during gameplay. This is also evident from the limited evidence gathered from non-action gameplay like *Tetris*. In contrast, skills not practiced in such games are not improved (e.g., task switching). These specific forms of transfer are consistent with the proposal that transfer of learning is more likely to occur if two tasks (i.e. learning and transfer task) share similar

elements or features and processing/cognitive demands (Thorndike & Woodworth, 1901). In line with this, Dahlin, Neely, Larsson, Bäckman, and Nyberg (2008) showed that training related transfer is more likely if the training and transfer task engaged similar processing components and brain regions. Hence, the amount of transfer may depend on the amount of elements or cognitive demands the two tasks have in common with each other. Interestingly, this theory has support from the working memory training literature. Specifically, working memory training has been shown to improve performance on working memory measures but not to measures of fluid intelligence (Harrison et al., 2013b; Melby-Lervåg & Hulme, 2013; Redick et al., 2013). Hence, although working memory and videogame play are different activities, they seem share a common underlying principle in relation to transfer of cognitive skill in that transfer is specific to what is practiced within the training regime. In contrast, little or no transfer can be expected for skills not explicitly practiced.

Nevertheless, to further demonstrate this empirically, studies 1 and 2 in this dissertation involved training video game novices in different action and non-action games and testing for transfer across several cognitive tasks that have demands common to the trained video games. As discussed earlier, evidence for transfer of video game training to tasks of executive functioning remains equivocal. One possibility argued was that the trained video game does not contain executive demands as measured by the transfer tasks. Therefore, study 3 tested whether training in games that contained executive demands common to the transfer tasks would lead to transfer as predicted by the common demands theory.

CHAPTER 2:

STUDY 1 - ENHANCING COGNITION WITH VIDEO GAMES: A MULTIPLE GAME TRAINING STUDY²

As seen in the review, a large body of evidence suggests that action video games may be superior to other genres in improving a number of cognitive and perceptual abilities (e.g., Chisholm et al., 2010; Green & Bavelier, 2003). Based on the earlier review, a proposal was made that transfer is possible because of shared demands between the video game and transfer task. Therefore, this suggestion opens up the possibility that different cognitive abilities can be augmented by non-action games in addition to action ones.

Currently, with the focus largely on action video games, little is known about the cognitive benefits of non-action video games. To date, there has been a paucity of published studies that compared transfer effects of different genres of games within the same study. A comparison of multiple genres is therefore important because it is possible that different game types will improve different aspects of cognition and perception. Furthermore, there is also the possibility that skills not improved by action video game play can be improved by other game types.

As discussed earlier, several issues with study design in longitudinal studies may have unfairly skewed results in favor of action video games. In most longitudinal studies, researchers have compared a control group playing a non-action video game (e.g., Tetris) to an experimental group playing an action video game (Green & Bavelier, 2003, 2006a, 2006b). One potential problem raised earlier is that the chosen transfer tasks that have been used in these previous studies may have favored action games. Specifically, many action video game training studies have utilized transfer tasks that mimic the demands of action video games, thus possibly maximizing transfer effects. In contrast the transfer tasks have

² This study is published in Oei, A.C. and Patterson, M.D. (2013). Enhancing cognition with video games: A multiple game training study. *PLOS One*, 8(3), e58546

little in common with the control game(s). Hence, assuming that transfer is more likely when the game and transfer task share common demands (Thorndike & Woodworth, 1901), choosing of only transfer tasks that share common elements with action video games may result in transfer that is specific to action video game training but not to the other forms of training.

In light of these concerns, there is a need to compare the effects of training in a variety of video games on different transfer tasks. These tasks should not only share common elements with the video game of interest (action video game), but also with the other trained games.

Study 1 is therefore designed with two main aims in mind. First is to address the aforementioned limitations of previous training studies by choosing transfer tasks that share common elements with other games aside from just the game of interest (action video game). This allows the realization of the main aim, which is to test the theory that transfer is more likely after training in games that share common elements with the transfer tasks. By incorporating a multi-game study rather than having one other game compare to an action video game, study 1 also allowed the extension of previous action video game training studies to test whether non-action game training also transfers to other cognitive domains.

There are also practical benefits for comparing multiple genres of video games. Despite the well-documented benefits of action video games, they may not be suitable for everyone. Many action video games contain violent themes, making their suitability for young children questionable (cf. C. A. Anderson & Dill, 2000). Furthermore, another target population for cognitive enhancements, the elderly generally, do not prefer to play games that are fast paced and violent and thus may not comply with an action video game training regime (Boot, Champion, et al., 2013; McKay & Maki, 2010). Moreover, it remains questionable whether action video games are equally as beneficial in older populations (Belchior et al., 2013).

Hence, there is a practical need to investigate whether non-action games benefit cognitive and perceptual abilities.

Study 1 Predictions

This study sought to extend previous findings of cognitive improvements seen in action video games by including a wider range of video game genres. That is, in addition to an action game (Modern Combat), games were purposefully chosen that differ in cognitive demands like visual matching and search (e.g., match-3 and hidden-object game) as well as games that specifically train spatial working memory (e.g., memory matrix). An agent-based life simulation game (The Sims) was also included that did not initially appear to contain any of the aforementioned cognitive demands as a control.

Briefly, the action game (Modern Combat) is a first-person shooter game in a war zone. Each level presents with different objectives and whilst achieving them, the player has to navigate in 3D space and dispatch enemies that appear suddenly. Doing so requires rapid actions as well as to attend to several items simultaneously. The Match-3 game, Bejeweled is a popular game that requires matching of three or more items with the same color. The more matches made earns a player higher points. As the level progresses, searching of available matches becomes more difficult. Memory matrix is an adaptation of the Corsi-tapping task but arranged in a grid. Players are required to follow and replicate the order in which blocks light up. The Hidden object game presents items hidden or camouflaged in a scene where a player is required to search for them. Finally, the Sims is an agent-based life simulation game where the player's avatar interacts with others in a community and is able to perform actions related to real-life (e.g., eat, sleep find a job, etc).

Consistent with the claim that transfer of learning depends on the similarities between the learning and transfer task (Thorndike & Woodworth, 1901), we propose that transfer will be more likely to occur in behavioral tasks that share similar demands with the trained video

games. Hence, frequent training of skills within the games briefly mentioned above should lead to improvements when the same skills are used in the behavioral tasks. Note that this proposal contrasts with far-transfer proposals that suggest training on one task will improve performance on multiple tasks. Far transfer claims include enhanced attentional control and speeded learning of new tasks after action video game training (Green & Bavelier, 2012). The near and far transfer proposals make different predictions. The former predicts that training on one cognitive task will only lead to improvements in a similar cognitive task, but the latter proposal predicts improvements in several or all tasks.

To test for these transfer effects, a wide range of cognitive paradigms was included whose demands closely mimic the demands of the video game training. This allowed the determination of the limits of how cognitive abilities can be affected by video game playing. Thus, measures were included that have previously shown improvement after action video game training (i.e., selective attention, apprehension of multiple objects and attentional blink) as well as two tasks that contain features similar to both action and non-action video games used in the current study, but have not been tested in relation to action video game training (i.e., spatial working memory and visual search).

When a visual search and spatial working memory task were administered concurrently, performance in both declined compared to performance on each task separately (Oh & Kim, 2004; Woodman & Luck, 2004). Hence, the inclusion of this dual task allows the evaluation of whether training in video games that place demands on either search skills or spatial working memory separately reduces interference between the two tasks. Finally, a task was included to assess verbal working memory span to determine if spatial working memory training can lead to far transfer effects from a visual to verbal modality.

The apparent similarity between the demands in the training games and the behavioral tasks used as pre- and post-measures allowed specific predictions to be made regarding

transfer effects. First, the action game makes strong demands on flexible, rapid and multiple target detection but at the same time requires filtering out of distracting stimuli. Training should therefore transfer to attentional blink, multiple object tracking and selective attention respectively. On the other hand, we predict that the action game would not transfer to visual search because of the lack of search demands in the game. The action game used here have little search demands because enemies tend to “pop out” and engage the player rather than require the player to search for them.

In contrast to the action game where enemies are salient and require selective attention, the match-3 game demands tracking the location of multiple static items across a large area, effortful and deliberate searching for items that can be moved to make matches, and strategic planning to produce cascades of matches. To find matches requires conjunctive search of both the item color and the pattern in which it is arranged. Although at the earliest levels, the number of possible matches is plentiful so a match can be found by searching a small area of the game display, as the levels progress, the number of possible matches decreases, requiring the player to examine a larger area to find a match. There is little demand to filter out simple visual information such as color alone since matches may be made using any color at any location of the screen. Any filtering of information would be at a higher level of pattern analysis. There is a demand to keep track of multiple, separate colored groups of objects so that possible areas where matches can occur are remembered. Thus, playing match-3 should lead to improvements in visual search and the tracking of multiple static objects.

Third, the hidden-object game places demands upon visual search and thus is expected to lead to improvement in search, allowing more resources to be used for a dual task of visual search and spatial working memory. However, it does not demand fast tracking of multiple objects and thus should not improve attentional blink, cognitive control, and multiple-object tracking.

Fourth, the demands in memory matrix game are specific since only spatial working memory is trained. Although there are some memory demands in action video games to keep track of multiple items, they contain many other demands. It is thus possible that transfer will be more effective in the memory-matrix game since it has no competing demands and therefore offers the most training in spatial memory compared to other games. In addition, assuming far transfer, there remains a possibility of memory matrix game training leading to improvements in verbal working memory. This assumes that the memory matrix task trains general memory processes that are not modality specific.

Finally, for the agent-based life simulation game, there is no expectation of improvements in any behavioral tasks in this study since it does not appear to have similar demands to the behavioral tasks. Although it does have some memory demands to keep track of the goals of each agent, there is no incentive or need to do so as goals and objectives are available on demand in the game menu.

Methods

Participants

Participants were recruited via an online portal targeted at undergraduates at Nanyang Technological University (NTU). 75 (28 males; $M_{age} = 21.07$, $SD = 2.12$) participants completed the study for course credits and S\$50. Participants were randomly assigned to each training group. However, five participants dropped out during the study – two each from memory matrix and match-3 groups, and one from the hidden-object group. The final numbers for each group are as follows: hidden-object ($n = 15$), memory matrix ($n = 14$), match-3 ($n = 14$), action ($n = 16$) and The Sims ($n = 16$). A no-contact, passive control group was not included in this study because of the potential confounds such groups introduce (Shipstead et al., 2012). For instance, having a no-contact control group has the potential to introduce “Hawthorne effects”, whereby the groups assigned to a non-training regime expect

no improvements and hence show no improvements. Therefore, training effects are confounded by treatment and control groups being treated differently. One possible alternative as suggested by Shipstead et al. (2012) is to include a nonadaptive control group (i.e. gameplay difficulty is the same throughout). Inclusion of The Sims here could be such an alternative as gameplay is the same throughout (without increasing levels of difficulty) and yet keeping trainees engaged, thus circumventing potential the aforementioned confounds associated with no-contact groups.

All participants were not regular video game players based on self-report (defined as fewer than 1 hour of video game play of any kind per week in the preceding year). Written informed consent was sought from all participants prior to participation.

Transfer Tasks

All the experimental tasks were displayed using E-Prime 2.0 (Release candidate: 2.08.90; Psychology Software Tools, Inc., Pittsburgh, PA, www.pstnet.com). The experimental stimuli were presented to participants via a 19-inch LCD monitor from a distance of approximately 60cm. Participants responded to experimental stimuli via a standard computer keyboard.

Attentional blink. As per previous studies (Green & Bavelier, 2003), the attentional blink task was used as a proxy for measuring the temporal dynamics of visual attention. In each trial, participants saw a series of black letters presented sequentially in the center of the screen subtending 0.48° of visual angle on a grey background. Between the 7th and 15th letter presented, a white letter (B, G or S) appeared. Each letter was presented for 15ms with 85ms inter-stimulus interval (ISI). Participants were instructed to monitor the stream of letters presented in each trial and identify the white letter (T1). Additionally, they were instructed to decide whether a letter “X” (T2) was present in the stream of letters after T1. T2 appeared immediately after T1 (Lag 1), up to 7 letters after T1 (Lag 8) or not at all (see figure

2.1). T2 did not appear in 50% of the trials. Participants practiced the task for 12 trials followed by 128 test trials presented in random order. At the end of each trial, participants were instructed to indicate the target letter (T1) shown as well as whether they detected T2.

Previous studies have shown that observers often failed to detect a highly salient T2 appearing approximately 200-500ms (Lags 2-4) after T1 was detected. This phenomenon is known as attentional blink (Raymond & Shapiro, 1992).

The DV of interest here is the accuracy of detecting T2 after T1 was correctly identified. Correct T2 detections were not included when T1 was not correctly identified. Lags 2, 3 and 4 are the lags of interest given that these lags were susceptible to the attentional blink effect.

Figure 2.1. Sample of a single trial of the attentional blink task. T1 is the white letter B. In this trial, the “X” (T2) appeared in Lag 2.

Filter task. Participants were presented with an array of targets (red rectangles) and distractors (blue rectangles) in different orientations against a white background. The rectangles were presented within an imaginary square subtending about 9.5° of visual angle. Targets and distractors appeared in 10 different conditions of different quantities. These conditions varied from 2 to 8 targets as well as 2 to 6 distractors with the constraint of a

maximum of 8 items in each array. Each array was displayed for 100ms followed by a retention interval of 900ms during which a fixation cross was displayed. In the subsequent display, one of the targets changed orientation in 50% of the trials. Participants responded by pressing one of two keys to indicate an orientation change or not. Participants performed 10 practice trials followed by 200 test trials.

This task was similar to that used in Ophir, Nass, and Wagner (2009) adapted originally from Vogel, McCollough, and Machizawa (2005). The difference between the current and previous studies was that stimuli were not manipulated so that they would appear in different hemifields and thus no hemifield cue was needed.

The focus is on two conditions in particular: the ability to filter out multiple distractors (2 targets 6 distractors condition; figure 2.2a) and the ability to detect changes amidst a high number of targets (8 targets 0 distractor condition; figure 2.2b). For the 2 targets 6 distractors condition, the assumption is made that due to the high number of distractors to filter out, it measured cognitive control. The ability to filter out distractors can vary between individuals (Vogel et al., 2005). Conversely, in the latter 8 targets 0 distractor condition, cognitive control to filter out distractors should not have been involved due to the absence of distractors. However, owing to the high number of targets, and the requirement to allocate attention towards multiple items simultaneously, this condition demanded multiple-object tracking.

Figures 2.2a and 2.2b. Filter task. Samples from the 2 targets 6 distractors (2a) and 8 targets 0 distractors conditions (2b). Both samples include changed orientation of a single target.

Visual search/spatial memory. This task was adapted from Woodman and Luck (2004). The task included three measures – a visual search task, a spatial working task as well as a dual task of visual search and spatial working memory. For the visual search task performed alone, participants saw a search array of 4, 8 or 12 squares (set sizes) each with a gap on one side of each square. Similar to Woodman and Luck (2004), the squares (0.45° by 0.45°) were presented within a 6.1° by 6.1° region. On each trial, only one square was a target while the rest were distractors. Targets had a gap on either the top or bottom of the square. Distractors had gaps on the right or left sides. Participants were instructed to respond as quickly and accurately as possible with a key press when they spotted a target. Each target was mapped to a different response key. The positions of the squares depended upon the set size. For set size 4, the squares occupied the top right corner of the screen followed by four additional squares per corner in a clockwise fashion for set sizes 8 and 12 respectively. As per the original task, the presentation time for the array was for 4000ms followed by 1000ms

ISI. There were 12 trials for each set size for a total of 36 trials for the search alone condition. Participants practiced on the task for 6 trials prior to starting the experiment.

For the spatial working memory task, participants were shown a central fixation and two dots appeared sequentially, one at a time at different locations. The presentation time for each stimulus was 500ms with an ISI (blank screen) of 500ms. Next, a blank screen was displayed during a 5000ms retention interval. Then a test array appeared consisting of a central fixation cross surrounded by two dots. Participants were given up to 2000ms to indicate using a button press whether the location of the dots matched the locations of the two dots shown previously. Half the trials included squares in the matching locations. Participants were instructed to focus on accuracy instead of speed. There was a 1000ms inter-trial interval. In the memory-alone condition, participants practiced 6 trials before 36 experimental trials. Similar to Woodman and Luck (2004), dot size is 0.13° by 0.13° and each dot was presented within a 1.625° by 1.625° region at the center of the display.

For the dual-task condition, participants were instructed to perform both tasks concurrently. First, two dots were displayed sequentially for 500ms each (separated by a 500ms ISI). During the retention interval, the participants performed the search task described above with 4, 8, or 12 squares with gaps. Next, they were shown the array with a central fixation and two squares as described above for the spatial working memory task. There were 72 trials for the dual-task condition randomly presented for each visual search set size (see figure 2.3).

Figure 2.3. Visual search/spatial working memory task. Sample trial for dual task condition. Note that figure is in reverse contrast.

Complex span. This task is the same described elsewhere (Barrouillet, Bernardin, & Camos, 2004). Participants were requested to recall one to six sequentially presented letters while performing an arithmetic task. Every trial contained a series of letters presented sequentially and interspersed first by a base number in blue (e.g., 5) and subsequent sign-operand pairs (e.g., +2) in black. Letter and numbers were presented within a 1.91° by 1.91° imaginary square at the center of the display. There was a minimum of one sign-operand pair and a maximum of three. The task followed a predetermined order of an increasing quantity of letters to be recalled. Within this order, the number of sign-operands pairs between each letter presented increased from one to three. A red sign-operand pair signified the end of an operation. Participants were asked to remember each letter and to compute numerical operations simultaneously. At the end of each trial, participants were instructed to enter an answer for the results of the last operation together with the letters they remembered in order (see figure 2.4 for an example of a trial). The total number of trials was 18 based on one to six letters to be remembered in order and one to three operations to be performed at each

letter load. To limit the stress and difficulty of the operations, the sign-operand pairs were limited to either ± 1 or 2 .

Although participants were asked to key in the final operation, the response was analyzed only to confirm that the participants were following directions correctly. To ensure that participants were following instructions to perform the operations, participants that did not achieve at least 70% accuracy for the final operation for either the pre or post-training task were excluded from the analyses (see results section). One point was awarded for each letter correctly recalled in each trial. Hence, the DV was the total of all correctly recalled letters across all trials.

Figure 2.4. Complex span task. Sample trial for a complex span task with a two-letter load and two operations. Participants were asked to recall all the letters in order while performing the operations. In this case, one operation would be “ $5+221 = 6$ ” and the last operation would be “ $6+122 = 5$ ”. Hence, the correct answer in this trial is GC5.

Training Games

All participants utilized their personal iPhone or iPod Touch (Apple Inc) to play the games assigned to them. Interaction with the game was done using a touch-screen measured

at 3.5 inches diagonally. Participants downloaded their assigned game onto their mobile devices via the iTunes App store (Apple Inc). Participants were instructed to play the games for an hour per day for 5 days each week. They were given the option to split up the hour into two half-hour playing sessions. The total duration of training was 4 weeks (20 hours in total). Previous studies that showed successful transfer have utilized training durations for as short as 10 hours (Feng et al., 2007; Green & Bavelier, 2003) to as long as 50 hours (Green et al., 2012). Hence, 20 hours of training here is expected to be a reasonable amount of time for training-related transfer to take place without incurring too much time demands on the participants.

To keep track of their game playing, participants were instructed to input their daily playing time in an online database. Based on participants' input, all adhered to the gameplay duration as instructed.

Hidden-object game (Hidden Expedition-Everest; Big Fish Games). The objective of this game is to find hidden objects in a complex visual scene. The hidden objects are often camouflaged among other objects to reduce saliency and prevent pop-out effects. Players were instructed to touch the object on the screen when they located it. Finding objects advanced the game's storyline.

Memory matrix 1.0 (Tvishi Technologies). For this game, players were shown a 3 X 3 matrix in which tiles lit up in sequence. Players were then instructed to reproduce the sequence by touching the location of each tile sequentially in the matrix. Correct reproduction of the sequence increased the sequence length and matrix size. Conversely, failure to reproduce the sequence correctly resulted in decreased sequence length and matrix size. Hence, difficulty level was adjusted based on the player's performance.

Match-3 (Bejewelled 2, PopCap Games). For this game, participants were presented with different shapes (e.g., polygons, diamonds, squares, triangles and circles) of different

colors in an 8 X 8 matrix. They were instructed to line up at least three similar colors either horizontally or diagonally by switching the positions of adjacent squares. Players earned bonus points if they achieved a cascade of matches or more than a 3-item match.

Action game (Modern Combat: Sandstorm, Gameloft®). Similar to previous studies (Green & Bavelier, 2003, 2006a, 2006b), the action video game was a first-person shooter. In this game, players controlled an in-game avatar as part of a special operations team in a war zone. The objective was to navigate in hostile enemy territory and to achieve predetermined objectives such as deactivating enemy equipment. Throughout the game, multiple enemies would appear in quick succession to engage the player. Therefore, to ensure survival in the game, players had to shoot at enemies as they appeared. Players controlled the game via virtual joysticks on screen and fired their weapons by touching a designated area on the screen. There were 10 levels in total and each level saw an increase in difficulty level. Each level was unlocked when a player completed a preceding level.

Agent-based life simulation game (The Sims 3, Electronic Arts). In this game, players controlled an in-game avatar to accomplish tasks that mimicked real-life activities. These included making friends, finding a job, sleeping, bathing, etc. The players were allowed to follow or ignore in-game objectives. Accomplishing in-game objectives required no pre-determined order.

General Procedure

Participants performed all the tasks in a computer lab. The maximum number of participants tested in a single session was seven. Participants were first briefed about the requirements of the study. No information pertaining to their assigned training games were given during this briefing.

Following the briefing, participants performed all computerized tasks in a randomized order. The time taken to complete all experimental tasks was approximately 1.5 hours. After

completing the tasks, participants were instructed to download their assigned game and play that game for the prescribed duration. Participants were explicitly instructed to play only the game assigned to them and refrain from playing other kinds of video games during the training phase. Also, they were asked to play only the prescribed number of hours (one hour per day / 5 days a week). Another reason as to why only non-video game players are chosen for the study is so that since they do not play games regularly, they are unlikely to play games other than instructed in the training phase.

After the training phase, they returned for the same set of computerized tasks. Participants only returned after at least 24-hours after their gameplay cessation. This washout period was to control for arousal effects arising from their last session of gameplay which might in turn affect their performance at the post-test as their arousal from playing the game may induce strategy changes in the transfer tasks (cf. Nelson & Strachan, 2009). The post-training sessions were conducted in the same manner again with randomization of the transfer tasks. Finally, a debriefing was done at the end of the study.

At the post-training session, participants' handsets were also checked to ascertain that they downloaded the game and played it. They were not informed beforehand that their devices would be checked. It was verified that all participants downloaded and played the game. Furthermore, all participants made some progress within the game they were assigned. These, taken together with their on-line self-report of daily playing time is indicative of their fidelity to the prescribed training regime.

Results

Attentional blink. Since a goal of the study was to determine whether video game training could reduce attentional blink, the analysis was limited to T2 detection accuracy only to lags affected by attentional blink (lags 2-4). The effects of gender were also analyzed for due to previous reports of possible gender differences in training effects (Feng et al., 2007).

A 2 (time: pre and post training) X 3 (AB lags) X 5 (training groups) X 2 (Gender) ANOVA was conducted to determine if training resulted in improvements for any of these lags. There was a significant main effect of time, Wilks $\lambda = .74$, $F(1, 64) = 22.11$, $p < .001$, indicating that participants improved from pretest to posttest. This was however, qualified by a training group x time interaction, Wilks $\lambda = .80$, $F(4, 64) = 4.04$, $p = .006$. All other interactions and between subjects effects were not statistically significant (all $ps > .30$).

To determine which groups benefited from training, separate ANOVAs and follow-up paired t-tests were computed for each training group following a main effect or interaction. There was a significant main effect of time for the action game group, $F(1, 15) = 35.80$, $MSE = .07$, $p < .001$. Time X Lag interaction failed to reach statistical significance, $F(2, 30) = .195$, $MSE = .02$, $p = .159$. Follow-up paired t-test conducted on the action game group indicated that the improvements in accuracies for lag 2 [$t(15) = 5.80$, $p < .001$, Cohen's $d = 2.19$], lag 3 [$t(15) = 5.42$, $p < .001$, Cohen's $d = 2.26$], and lag 4 [$t(15) = 3.55$, $p = .003$, Cohen's $d = 1.53$] were statistically significant (see figure 2.5a). Furthermore, unlike the other groups, the action video game group no longer showed an attentional blink since they were at equivalent levels of accuracy for all lags (all pairwise comparisons for lags 1-7 were not statistically significant, corrected for multiple comparisons using Bonferroni correction; see figure 2.5b). Repeated measures ANOVA for all other training groups failed to achieve a significant main effect of time or time X lag interaction (all $ps > .15$).

Figure 2.5a and 2.5b. Attentional blink performance. (A) Depicts changes in T2 detection accuracy from pre to post training for each training group. (B) T2 detection accuracy during post training for each training group. Asterisks represent statistically significant ($\alpha \leq .01$) pre to post-training improvements. Error bars denote 95% confidence interval (Loftus & Masson, 1994).

Filter task. The dependent variables (DV) in this task were calculated as a sensitivity index, d' (Tanner & Swets, 1954) for the two conditions of interest. Hit and false alarm rates of 0 or 1 were adjusted using the convention adopted in Stanislaw and Todorov (1999).

A 2 (time) X 2 (filter task conditions) X 5 (training groups) X 2 (Gender) mixed ANOVA was conducted to determine if video game training improved performance in either filter task conditions. The analysis showed a main effect of time, Wilks $\lambda = .91$, $F(1, 65) = 6.72$, $p = .012$, indicating that participants' performance changed from pre to post training. However, this was qualified by a significant time X training group interaction, Wilks $\lambda = .87$, $F(4, 65) = 2.49$, $p = .05$. There was also a main effect of condition, Wilks $\lambda = .24$, $F(4, 65) = 208.61$, $p < .001$. All other interactions and between subjects effects were not statistically significant (all $ps > .08$).

To follow-up the significant interactions, a separate 2 (time) X 2 (condition) repeated measures ANOVA was conducted for each training group. For the hidden-object group, the main effect of time failed to achieve statistical significance, Wilks $\lambda = .97$, $F(1, 14) = .38$, p

=.546. However, there was a main effect of condition, Wilks $\lambda = .22$, $F(1, 14) = 51.24$, $p < .001$ and a significant time X condition interaction, Wilks $\lambda = .70$, $F(1, 14) = 5.93$, $p = .029$.

For the memory-matrix group, there was a main effect of condition, Wilks $\lambda = .11$, $F(1, 13) = 103.20$, $p < .001$. However, main effect of time and interaction between time and condition failed to reach statistical significance (both $ps > .20$).

For the match-3 group, there was a significant condition main effect, Wilks $\lambda = .20$, $F(1, 13) = 52.06$, $p < .001$. But this was qualified by a time X condition interaction, Wilks $\lambda = .70$, $F(1, 13) = 5.65$, $p = .033$. Conversely, time main effect failed to achieve significance, Wilks $\lambda = .97$, $F(1, 13) = .47$, $p = .50$.

The analyses for the action game group revealed significant time, Wilks $\lambda = .38$, $F(1, 15) = 24.58$, $p < .001$ and condition, Wilks $\lambda = .38$, $F(1, 15) = 24.63$, $p < .001$, main effects with no significant interactions between the two, Wilks $\lambda = .88$, $F(1, 15) = 2.02$, $p = .176$.

Finally, for The Sims group, only condition yielded a significant main effect, Wilks $\lambda = .21$, $F(1, 15) = 6.23$, $p < .001$, with time main effect and time X condition interaction failing to reach statistical significance (both $ps > .64$).

Separate paired t-tests were conducted for each group that showed a significant time main effect or time X condition interactions to evaluate if performance changed from pre to post-training in the 2 target 6 distractor and 8 targets 0 distractor conditions. Only the action group showed a statistically significant improvement on the 2 targets 6 distractor [$t(15) = 4.11$, $p = .001$, Cohen's $d = 1.71$] and the 8 targets 0 distractor conditions [$t(15) = 2.78$, $p = .014$, Cohen's $d = 1.02$] (see figure 2.6a and 2.6b).

Figure 2.6a and 2.6b. Filter task performance. (A) Depicts pre and post-training performance for each training group in 2 target 6 distractor condition for cognitive control. (B) Depicts pre and post-training performance for each training group in the 8 target 0 distractor condition for multiple-object tracking. Asterisks represent statistically significant ($p \leq .05$) pre to post-training improvements. Error bars denote 95% CI.

Visual search accuracy. For the visual search task, RT for correct detections and accuracy rates were the DVs. A 2 (time) X 2 (condition: single vs dual task) X 3 (set size) X 5 (training groups) X 2 (Gender) mixed ANOVA was conducted to determine if there were any differences in improvement in accuracy for the visual search task. Overall, there were significant main effects of time, Wilks $\lambda = .72$, $F(1, 63) = 24.51$, $p < .001$, condition, Wilks $\lambda = .88$, $F(1, 63) = 8.78$, $p = .004$ and set size, Wilks $\lambda = .78$, $F(2, 62) = 8.68$, $p < .001$. These results were qualified by significant interactions of time X condition, Wilks $\lambda = .87$, $F(1, 63) = 9.53$, $p = .003$, time X set size, Wilks $\lambda = .88$, $F(2, 62) = 4.36$, $p = .017$, as well as three way interactions of time X condition X training group, Wilks $\lambda = .85$, $F(4, 63) = 2.83$, $p = .032$. There was also a significant 4 way interaction between time, condition, set size and training group, Wilks $\lambda = .72$, $F(8, 126) = 2.83$, $p = .006$. All other interactions and between subject effects were not statistically significant, (all $ps = .12$).

Separate mixed-ANOVAs were analyzed for each training group to determine whether each group improved from pre to post-training. With the exception of a significant time main effect, Wilks $\lambda = .61$, $F(1, 13) = 8.42$, $p = .012$ and time X condition interaction, Wilks $\lambda = .67$, $F(1, 13) = 6.40$, $p = .025$ in the match-3 group, all main effects of time, time X condition, time X set size as well as 3-way interactions were not statistically significant for all other training groups. Follow-up paired samples t-tests for the match-3 group were conducted. The t-tests revealed that the improvement from pre to post training in the dual task condition for the match-3 training group was significant for set-size 4 [$t(13) = 2.43$, $p = .03$, Cohen's $d = 1.32$], set size 8 [$t(13) = 2.81$, $p = .015$, Cohen's $d = 2.4$] and set size 12 [$t(13) = 2.80$, $p = .015$, Cohen's $d = 1.35$; see figure 2.7]. Improvements for single task conditions were not statistically significant.

Figure 2.7. Visual search accuracy for dual-task set sizes from pre to post training for each group. Asterisks represent statistically significant ($p \leq .05$) pre to post-training improvements. Error bars denote 95% CI.

Visual search RT. A 2 (time) X 2 (condition: single vs dual task) X 3 (set size) X 5 (training groups) X 2 (Gender) mixed ANOVA was conducted to determine if there were any differences in improvement for the visual search task in RT. Overall, there were significant main effects of time, Wilks $\lambda = .80$, $F(1, 63) = 15.73$, $p < .001$, condition, Wilks $\lambda = .33$, $F(1,$

63) = 128.26, $p < .001$ and set size, Wilks $\lambda = .05$, $F(2, 62) = 627.89$, $p < .001$. These results were qualified by significant interactions of time X condition X training group, Wilks $\lambda = .86$, $F(4, 63) = 4.70$, $p = .042$, and condition X set size, Wilks $\lambda = .83$, $F(2, 62) = 6.49$, $p = .003$. All other interactions and between subject effects failed to reach statistical significance. To follow up the significant time X condition X training group interaction, separate ANOVAs were analyzed for each training group to determine whether there were any pre-post training reductions in RT. For the hidden-object group, there were significant main effects of time, Wilks $\lambda = .36$, $F(1, 14) = 24.41$, $p < .001$ as well as an interaction between time and condition, Wilks $\lambda = .45$, $F(1, 14) = 17.33$, $p = .001$. Significant time main effects were also seen in the memory matrix group, Wilks $\lambda = .36$, $F(1, 13) = 22.97$, $p < .001$, but there were no significant interactions. There was also a significant main effect of time for the match-3 group, Wilks $\lambda = .53$, $F(1, 13) = 11.70$, $p = .005$ as well as significant time X condition X set size interaction, Wilks $\lambda = .41$, $F(2, 12) = 8.73$, $p = .005$. All other main effects or interactions with time were not significant.

Planned paired t-tests were conducted on the hidden-object, memory matrix, and match-3 groups to examine pre to post training improvements in search time. The hidden-object game group had a significant reduction in RT for all set sizes in both single and dual task conditions [search-only condition of set size 4, $t(14) = 3.95$, $p = .001$, Cohen's $d = 1.54$, set size 8, $t(14) = 2.50$, $p = .025$, Cohen's $d = 0.91$ and set size 12, $t(14) = 2.33$, $p = .035$, Cohen's $d = 0.85$; dual-task condition of set size 4, $t(14) = 6.38$, $p < .001$, $d = 2.49$; set size 8, $t(14) = 4.92$, $p = .001$, Cohen's $d = 1.81$; set size 12, $t(14) = 4.40$, $p = .001$, Cohen's $d = 1.91$].

The memory matrix training group had a reduction in RT in set size 4 [$t(13) = 2.38$, $p = .034$, Cohen's $d = 1.23$] and set size 8 [$t(13) = 3.19$, $p = .007$, Cohen's $d = 1.21$], for the search-only conditions. There was a significant reduction in RT for all set sizes in the dual

task condition [set size 4, $t(13) = 2.78$, $p = .016$, Cohen's $d = 1.16$; set size 8, $t(13) = 4.00$, $p = .002$, Cohen's $d = 1.67$ and set size 12, $t(13) = 2.64$, $p = .02$, Cohen's $d = 1.09$].

For the match-3 training group, there were significant RT improvements seen in search-only set size 8 [$t(13) = 3.16$, $p = .008$, Cohen's $d = 1.21$], and set size 12 [$t(13) = 2.71$, $p = .018$, Cohen's $d = 1.02$]. For the dual-task condition, there was a reduction in RT for set size 4 [$t(13) = 3.04$, $p = .009$, Cohen's $d = 1.34$] (see figure 2.8).

Figure 2.8. Visual search RT in milliseconds (ms). Pre and post training search RT for each training group. Asterisks represent statistically significant ($p \leq .05$) pre to post-training improvements. Error bars denote 95% CI.

Spatial memory task accuracy. For the sake of simplicity, rather than include task condition (single vs dual task), the memory alone condition was coded as set-size 0 in the analysis, thus eliminating one factor. The resulting analysis was a mixed 2 (time) X 4 (set sizes 0 = memory alone; 1-3 = dual task conditions) X 5 (training groups) X 2 (Gender). The results of the ANOVA indicated a significant main effect of time, Wilks $\lambda = .72$, $F(1,64) = 24.42$, $p < .001$. There was also a main effect of set-size, Wilks $\lambda = .38$, $F(3,62) = 34.26$, $p < .001$. These main effects were qualified by a significant time X set size interaction, Wilks $\lambda = .80$, $F(3,62) = 6.38$, $p = .003$. All other interactions failed to achieve statistical significance (all $ps \geq .11$). Training group and gender effects was also not statistically significant (all $ps > .43$)

Planned separate 2(time) X 4(Set size) ANOVAs were analyzed for each training group to determine whether there were any pre-post training improvements in accuracy for the spatial memory task. For the hidden-object group, there was a significant time main effect, Wilks $\lambda = .72$, $F(1,14) = 5.34$, $p = .037$ as well as a significant time X set size interaction, Wilks $\lambda = .33$, $F(3,12) = 8.11$, $p = .003$. Separate paired t-tests indicated that the hidden-object group improved in the dual-task condition, set sizes 8 [$t(14) = -3.13$, $p = .007$, Cohen's $d = 1.19$] as well as set size 12 [$t(14) = -3.29$, $p = .005$, Cohen's $d = 1.21$] (see figure 2.9a).

For the memory matrix training group, there was a significant main effect of time, Wilks $\lambda = .64$, $F(1,13) = 7.22$, $p = .019$ but a non-significant time X set size interaction, Wilks $\lambda = .66$, $F(3, 11) = 1.93$, $p = .183$. Planned paired t-tests indicated that only dual-task spatial memory accuracy set-size 8 had a significant improvement [$t(13) = -2.28$, $p = .04$, Cohen's $d = .90$] while dual task set size 12 was marginally non-significant [$t(13) = -1.91$, $p = .078$, Cohen's $d = .79$] (see figure 2.9b). All other main effects and interactions for other training groups not mentioned here failed to achieve statistical significance.

Figure 2.9. Spatial working memory accuracy from pre to post training for all training groups. Asterisk represent statistically significant ($p \leq .05$) pre to post-training improvements. Error bars denote 95% CI.

Complex span. To ensure that the participants gave adequate attention to both arithmetic and verbal memory tasks, the analysis was limited to only participants that achieved 70% accuracy for the final operations. In all, 20 participants were excluded from subsequent analyses that did not make this cut-off. Four participants each from the hidden-object, match-3 and action game groups were excluded while three and five participants were excluded from the memory matrix and The Sims groups respectively. The average percent correct for the last operations for each of the remaining groups for pre and post-training was at least 85%.

As each letter load consists of one to three operations, a repeated-measures ANOVA at each level of the time factor compared the scores of the three operations to determine if performance differed. The results indicated that performance did not differ across the three operations for pre-training, $F(2, 108) = .17$, $MSE = 14.33$, $p = .85$ and post-training, $F(2, 108) = .15$, $MSE = 13.89$, $p = .86$. As a result, the scores obtained from each of the operations for each letter load in the subsequent analyses were combined.

The dependent variable is the total score calculated from all 18 trials. A 2 (time) X 5 (training group) X 2 (Gender) mixed ANOVA was first conducted to test for performance changes and if changes differed between groups and gender. The analysis showed a significant time main effect, Wilks $\lambda = .84$, $F(1, 65) = 12.32$, $p = .001$. However, this was qualified by a time X training group interaction, Wilks $\lambda = .84$, $F(4, 65) = 3.18$, $p = .02$. Three way interactions and all between subject effects were not significant ($ps > .54$).

To follow up the significant interaction, paired t -tests were conducted to determine if each training group improved performance from pre to post-training. The paired t -tests revealed that the match-3 [$t(9) = 3.36$, $p = .008$, Cohen's $d = 1.51$], action [$t(11) = 3.24$, $p = .008$, Cohen's $d = 1.78$] and The Sims group [$t(10) = -2.63$, $p = .025$, Cohen's $d = 1.13$] improved significantly (see figure 2.10). All other paired t -test revealed no significant

improvements in span performance for the memory matrix group and the hidden-object groups (all $ps \geq .74$).

Figure 2.10. Complex verbal span performance from pre to post training. Asterisks represent statistically significant pre to post training improvements ($p \leq .05$). Error bars denote 95% CI.

Summary of key findings

Due to the large number of results and analyses, a summary of the key findings is presented here for clarity. First, action video game (Modern Combat) training resulted in reduction of the attentional blink, as well as enhancements of selective attention and multiple object tracking. Second, Match-3 training improved visual search skills while Memory matrix and Hidden object game training improved both visual search and spatial working memory. Finally, complex span performance was improved following training in Match-3, Modern Combat and the Sims. These results are discussed more in depth in the following section.

Discussion

This study was designed with two aims in mind. The first was to address the aforementioned concerns of only including transfer tasks that have demands common to action video games. This was addressed by including a wide variety of transfer tasks that have demands common not only to action video games, but also to the other trained games

here. A second and more important aim was to test the theory that transfer is more likely after training in games that share common elements with transfer task (cf. Thorndike & Woodworth, 1901). I reasoned that if this is indeed a putative mechanism of transfer, transfer effects should also be realized by training in other non-action games, provided these games have common demands/elements with the transfer task. The hypothesis that transfer would take place when game demands closely matched behavioral task demands was confirmed. It was also demonstrated that cognitive improvements following video game playing were not limited to action video games alone. Additionally, it was shown that that video game-related enhancements to cognition occurred despite using mobile devices (3.5 inches diagonally) for training, which had much smaller screen sizes than desktop or laptop computer screens used in other studies (~ 17 to 20 inch monitors; e.g., Boot et al., 2008; Green et al., 2012). Performance on each task will be discussed separately before examining the improvements from a larger vista.

Attentional blink. Only the action game group showed post-training improvement in detecting T2 during the period normally affected by attentional blink. These results supported the hypothesis that transfer is more likely when the game and task share common elements or demands, and corroborated previous work showing that action video game training can improve recovery from attentional blink (J. E. Cohen et al., 2007; Green & Bavelier, 2003). In fact, playing the action game appeared to eliminate the attentional blink effect altogether, at least within the limits of how it was measured in the current study. The complete elimination of the attentional blink is surprising since the training regime used in this study was not better controlled nor was it a more intensive training regimen than previous studies. On the contrary, compared to previous studies, the current study was designed to allow more freedom to participants to play games in their own time at the location of their choosing. Hence, it is unclear whether complete elimination of attentional blink could be expected in

future studies using an identical paradigm. Nevertheless, the results of action game training-related reductions in attentional blink are consistent with previous investigations (J. E. Cohen et al., 2007; Green & Bavelier, 2003).

How might playing an action video game improve detection of temporally close targets without a reduction in accuracy? One possible mechanism is an improvement in the speed and control of switching attention between targets (Enns, Visser, Kawahara, & Di Lollo, 2001; Kawahara, Zuvic, Enns, & Di Lollo, 2003). Note that the need to switch attention rapidly amongst targets is a highly practiced skill in an action game because the player must frequently respond to enemies that appear in quick succession. In contrast, the other training games do not demand such rapid switches of attention. Thus, this frequent practice and the increasing demand to switch between temporally close stimuli as the action video game progresses may have resulted in a reduction of the attentional blink effect via an improvement in attention switching. This suggestion is further supported by results showing that experienced action video gamers and those trained in action video games were better able to rapidly switch between stimuli compared to controls (Colzato et al., 2010; Green et al., 2012).

Multiple object tracking. Matching the transfer hypothesis of common elements between the game and task, the action game group improved in multiple-object tracking. This finding is consistent with previous work that showed regular action game players and those trained using action games were better at apprehending multiple objects simultaneously compared to non-gamers or those trained using non-action video games (J. E. Cohen et al., 2007; Green & Bavelier, 2003, 2004, 2006b). Importantly, the training regime in the current study used a much smaller touch-screen as a display compared to previous studies. Hence, the fact that the behavioral task used a screen a magnitude larger than the training indicates that the training improved performance in parts of the visual field that had not been explicitly

trained. This finding corroborates earlier work that showed that useful field of view was improved by action gaming that extended to the regions in the periphery that were not trained in typical action game play (Green & Bavelier, 2003).

In the action video game used for training in this study, players had to keep track of and respond quickly to multiple objects in their focus of attention (e.g., multiple enemies, goals, paths, items to be retrieved). Hence, as a result of regular action game play, it is plausible that the participants became more efficient in their ability to track multiple fast moving objects in parallel, an ability that transferred to tracking static objects in the transfer task.

In contrast, there was no evidence for transfer from the match-3 training. This could possibly be due to the match-3 differing from the action game in two important ways. First, for match-3, the number of objects to track did not progressively increase. There were always 64 objects on view. Although there was an increasing speed pressure as the game progressed, the number of items to track remained constant. Second, the objects only changed position due to the player's actions, and were predictable and mostly static. Thus, the failure to find evidence of a transfer in the match-3 group compared to the action video game may be due to the fact that only tracking moving objects was demanding enough to lead to increased capacity, or that there was no progressive increase allowing players to master tracking at an easier level before moving on to a more difficult level. Further experiments are necessary to decide between these possibilities.

We also failed to find evidence for transfer from memory matrix training to keeping track of multiple objects. This is somewhat surprising since on the surface, memory matrix should match well with the multiple-object tracking task. The number of items to remember is progressively increased as the participant improves in the memory game. However, the training was different from the behavioral task in that a) it required memory for a sequence of items each individually, rather than the necessity to keep track of multiple objects

simultaneously; b) it is repetitive without any changes to the presentation and context of the stimuli. Hence it is possible that the repetitiveness of the game led to specificity in learning that made improvement only possible within the game itself or an extremely similar task to the game (cf. Fahle & Morgan, 1996). In addition, the participants may have developed strategies that work for encoding each item individually, but not for encoding multiple items quickly as demanded by the behavioral task.

Selective attention. Consistent with our hypothesis, only action video game training resulted in improvements in selective attention. This corroborated previous evidence of improvements in visual selective attention as a result of action video game play using different experimental paradigms to measure selective attention (Chisholm et al., 2010; Chisholm & Kingstone, 2012; Green & Bavelier, 2003).

As discussed earlier in the review, action video game-related enhancement in selective attention might stem from enhanced top-down control to filter out distractors rather than a recovery from attentional capture (Bavelier, Achtman, et al., 2012; Chisholm & Kingstone, 2012; Mishra et al., 2011; Wu et al., 2012). Again, this is a highly practiced skill in many action video games, including the one in this study. For instance, to perform successfully within the game, the player must apply top-down control to filter out large amounts of irrelevant stimuli (e.g., friendly forces, other non-enemy moving items) and focus on multiple targets on the screen. Failure to filter out these distractors may result in an inability to progress within the game. Therefore, playing this and other action video games for prolonged periods of time could have enhanced the ability to suppress task-irrelevant distractors. Hence, the common demands hypothesis suggesting a limited transfer effect is valid to explain the action game related transfer effects on selective attention, specifically on the ability to inhibit distractors. Plausibly, these common elements are at a cognitive stage of processing rather than a perceptual or motor stage. Thus, it is expected that the enhancements in performance

will transfer to many tasks that can vary widely on perceptual and response demands as long as they retain the same underlying cognitive demands.

Visual search/spatial WM. Previous research showed that performing a visual search task concurrently with a spatial working memory task adversely impacted performance in both tasks compared to performing each task separately (Oh & Kim, 2004; Woodman & Luck, 2004). The results here replicated previous findings by showing reduced accuracy for the spatial working memory task and increased RT for visual search as participants performed the dual task compared to performing each task separately. This may reflect dual-task interference within a limited-capacity mechanism that is shared between visual search and visual working memory (D. E. Anderson, Vogel, & Awh, 2013; Awh, Jonides, & Reuter-Lorenz, 1998; Klein, 1988; Mayer et al., 2007; Woodman & Luck, 2004).

In the current study, hidden-object and memory matrix training significantly improved both visual search and spatial working memory while match-3 training improved visual search, supporting the earlier predictions. For the hidden-object game training, although there was no significant improvement in search accuracy in any of the set-sizes, search performance was enhanced as shown by significant search time improvement. As accuracy was very high (at least 90%) in all but the dual task set size 12 condition, it is plausible that a ceiling effect limited the possibility of finding of an improvement.

The search time improvement in the hidden-object game group was surprising because the game did not require speeded search. Yet, training resulted in improved search efficiency. It is important to note that the search for targets in the hidden-object game was arguably more difficult than the visual search behavioral task as the items-to-be-found in the game were not predictable and the visual scene was far more complex and varied. Furthermore, the hidden objects were often camouflaged within the colored background unlike the visual search task. Hence, frequent search for varied and novel targets in the hidden-object game may have led

to improved efficiency in top-down biasing of search (Baluch & Itti, 2010; Desimone & Duncan, 1995).

Training in the hidden-object game led to improved spatial working memory accuracy. Crucially, the improvements were seen only in the dual-task conditions. Nevertheless, taken together with improvements in search efficiency, these results suggest that the hidden-object training led to improved search so that additional cognitive resources in the aforementioned hypothesized limited-capacity mechanism were available to perform the spatial working memory task.

As expected, the memory matrix group also showed improvements in the spatial working memory tasks. Specifically, while memory matrix training did not improve accuracy rate for every condition in the spatial working memory task, there were accuracy improvements for the dual-task set size 8 condition. Additionally, for the visual search task, the memory matrix group decreased search times for search-only set-sizes 4 and 8. Importantly, there were also significant reductions in RT for *all* set-sizes in the dual task condition when both visual search and spatial working memory were required.

How would memory matrix training improve spatial working memory and visual search? One fundamental difference between the memory matrix game and the other games in this study is the heavy reliance of spatial working memory to successfully play the game. Hence, assuming that the shared capacity-limited resource is visual working memory as suggested (D. E. Anderson et al., 2013; Awh et al., 1998; Klein, 1988; Mayer et al., 2007; Woodman & Luck, 2004), memory matrix training may have enhanced visual-spatial working memory so that both location change detection and visual search performance were improved. This game was unique in the sense that visual-spatial working memory was the only skill that was explicitly trained in the game itself, unlike the other games that had multiple demands.

As expected, the match-3 game training group also showed improvements in visual search accuracy and search time as a result of training. These improvements in accuracy were seen in all set sizes in the dual-task condition while search time decreases were seen in search-only set size 8 and 12 as well as dual-task set size 4 conditions. It was hypothesized that improvements in search and visual working memory would occur due to characteristics of the match-3 game, Bejeweled 2. Within the game, players were expected to search the entire visual scene to locate jewels that matched in color and in shape. Hence, it is likely that general visual search skills were also actively engaged and trained during playing. Another important factor that might contribute to learning and transfer in the game is the increasing difficulty in searching within the game. As a player advanced to higher levels, the number of possible matches within the 8x8 matrix decreased which led to a lower chance of finding a match within any one area of the matrix. This gradual increase in search difficulty is important as learning and transfer is more likely when the task is optimally challenging to the learner (Ahissar & Hochstein, 1997). Thus, other variants of match-3 (e.g., Bejeweled Blitz) that do not change in difficulty, may not lead to improvements in visual search.

Complex span. The complex span task was administered to determine whether training in any of these games would transfer to complex verbal working memory tasks (Turner & Engle, 1989). It was predicted that memory matrix, the only task that focused on memory alone, would be most likely to transfer if the improvement was for a modality-free process of memory. Contrary to this hypothesis, no significant improvements were seen in the memory matrix group. Unexpectedly, improvements in the complex span task occurred in the match-3, action video game and The Sims training groups.

The reasons for improvements by these groups are unclear and remain speculative. One possibility is that the improvement is accounted simply by a test-retest effect. Given that three out of the five training groups improved, one could argue that the improvements are

unrelated to training. However, one could also argue that if test-retest effects were to account for the improvements, the other two groups (hidden object game and memory matrix training) should also show performance gains.

Another possibility is that playing these games (match-3, action video game and *The Sims*) led to improvements in higher-order executive processes, which are crucial for performing complex span tasks. Unlike simple working memory span tasks that emphasize only storage and retrieval, complex span tasks are dual-tasks that recruit additional cognitive processes, such as executive control of attention to allow for efficient switching between tasks and to increase focus on current tasks in the presence of distractors (Conway, Kane, & Engle, 2003; Faraco et al., 2011). Previous neuroimaging research indicates that performance in complex span tasks such as the one used here actively recruits the left dorsolateral prefrontal cortex, an area linked with executive processes, but not when either the span or arithmetic tasks were performed in isolation (Smith et al., 2001). Hence, these games may have recruited and trained higher-order executive function, including switching between tasks and strategic planning. First, for the action game, players switched between concurrent tasks like engaging sudden onset enemies while accomplishing several mini-objectives within the game, which in turn required holding the objectives in working memory. Similarly, performance on the match-3 game also required keeping track of matching items in working memory while formulating movement plans. These plans may occur several moves in advance. Also, playing *The Sims* may invoke some planning and strategizing demands. For instance, players were required to hold active representations of future plans in working memory while performing other tasks. Hence, training using these games may have led to improvements in executive processing, which translated to improvements in the cognitively demanding complex span task. Interestingly, a study supported this possibility by reporting that 50 hours training in the game *The Sims* improved alternate-runs task switching (Green et

al., 2012). Again, I emphasize that these suggestions are speculative and further investigations are necessary to determine on the transferability of executive improvement from training to novel tasks, especially given that evidence for transfer to executive functions by video game training remains inconclusive.

In contrast to the match-3 and action video game training, I argue that memory matrix training had negligible demands in higher order executive functions. In memory matrix, there was always only one fixed order of presentation. Furthermore, memory matrix training appears more similar to a simple span, rather than a complex span task. This may explain why no improvements were found for the memory matrix group in the complex span task.

Limitations of the Current Study

There were a number of limitations in the current study. First, unlike previous investigations that required participants to perform the training tasks in a laboratory (e.g., Green & Bavelier, 2003, 2006a, 2006b), participants in the current study were allowed to train on the games at their own leisure. Although participants entered daily logs of their gameplay, it was not possible to ensure actual fidelity to the prescribed training regimen. However, allowing participants to train during their own free time had the advantage of being more applicable to how the games were played normally. Furthermore, as mentioned above, participants' mobile devices were checked despite not being told previously and all participants made substantial progress within their assigned games. These taken together suggest fidelity to the training regime. In addition, the results using action games replicated results of lab-controlled studies.

Second, some of the games may have drawn more interest from the players than others leading to non-specific factors such as motivational differences rather than the properties of the game accounting for behavioral change (Green, Strobach, & Schubert, 2013). It is known that action video games are highly motivating and arousing (Przybylski et al., 2009; Wang &

Perry, 2006). In contrast, games like memory matrix were repetitive. Moreover, there may also be possible gender differences in motivation and arousal levels for playing different games. However, differences in arousal and motivation are unlikely to have affected the results here. This is mainly because improvements are seen across different groups and not just those that are more arousing (e.g., action video game). Additionally, even games that were repetitive showed transfer to cognitive tasks, confirming that strong interest and variability in gameplay alone were not vital for transfer to occur. There were also no gender differences found in the amount of improvements from video game training here.

Although this was mentioned previously, it should be acknowledged again that because the games used in this study was not designed specifically for cognitive and perceptual training in mind, it is difficult to objectively “measure” the specific demands that is needed for gameplay. The approach taken here is to describe subjectively what the possible demands are, similar to that elsewhere (J. E. Cohen et al., 2007; Spence & Feng, 2010). Objective characterization of actual game demands necessary for successful transfer remains a difficulty within the field of video game training.

Conclusion

The results from the current study corroborated the increasing body of evidence indicating that action video game play enhances several cognitive and perceptual abilities. However, it also extends previous works by showing non-action game related transfer. Importantly, it demonstrated empirically the theory proposed earlier that transfer of cognitive skill is more likely when the transfer task matched the demands of the trained video game – a specific transfer.

Although previous studies had found only limited evidence of transfer after playing non-action video games, most of these studies only included transfer tasks that closely mimicked the demands in action video games. In the current study, however, by including

transfer tasks that matched the demands of the non-action games, the results demonstrate empirically that transfer occurs also with non-action games. Notably, the transfer of skill is limited to that which is highly practiced in the video game. Thus, this is consistent with the theory that transfer effects are maximized when the transfer task contains elements that are similar to the training game (cf. Thorndike & Woodworth, 1901). Hence, transfer is not only limited to the action video game as seen in previous investigations. Rather, training-related transfers by the other non-action games were also seen in tasks that shared similar demands.

In closing, the results here are consistent with many previous studies that showed that action video games lead to the most varied transfer. These transfer effects possibly highlight the uniqueness of action video games in that they contain many of the demands shared in laboratory attentional and perceptual tasks. Some unique features that set action video games apart from others is its unpredictability, the need to allocate attention across multiple locations and items simultaneously, with pace of the game an especially important determinant of learning (Achtman, Green, & Bavelier, 2008). However, it is important to qualify that different action video games contain varying demands and the intensity of those demands. Hence, it is unlikely that all action video games lead to identical transfer effects. To further demonstrate the specificity of transfer effects that depends on the similarities between the game and transfer task and the aforementioned demands suggested by Achtman et al. (2008), a follow-up study comparing transfer effects of different types of action video games with varying demands is warranted. This is addressed in study 2 by comparing action games with different demands.

CHAPTER 3

STUDY 2: DIFFERENTIAL TRANSFER EFFECTS WITH ACTION VIDEO GAME TRAINING: NOT ALL ACTION VIDEO GAMES ARE CREATED EQUAL

Thus far, action video games represent the most studied and demonstrated the most varied transfer to perceptual and attentional laboratory tasks. As argued previously, transfer from video game training to laboratory-based task measuring perceptual and cognitive skills may be attributed to the similarities in demands between the game and the task (Thorndike & Woodworth, 1901). Take for instance action video games where the advantages in trained and habitual players are demonstrated in laboratory tasks that have highly similar demands to that experienced within the game such as multiple object tracking (Green & Bavelier, 2003, 2004, 2006b, 2008), peripheral target detection (Feng et al., 2007; Green & Bavelier, 2003) and rapid attentional switching (J. E. Cohen et al., 2007; Green & Bavelier, 2003). Study 1 further corroborated previous findings by showing specific action game related transfer to these abilities. Importantly, non-action game related transfer to tasks that share common demands further supports this theory.

Although action games have thus far showed the most varied transfer, it is unclear what elements of action video games are important. Achtman et al. (2008) suggested that key ingredients of action video games that promote transfer include speed, unpredictability, attentional switch, selective attention and the need to allocate attention across multiple locations/items. Arguably, action video games represent an arbitrarily defined category that contains many games with quite varying demands and intensities of those demands. Therefore, if transfer depends on shared demands between the game and transfer task, it is likely that different action games with varying demands will lead to different transfer effects. The current study is therefore designed with two goals in mind: first is to provide a conceptual replication of the results in study 1 to further determine whether differences in

demands are likely to lead to different transfer effects in different tasks. Second and most importantly, is whether the ingredients mentioned above are indeed important to transfer according to Achtman et al. (2008).

Here, participants were asked to play one of four action video games for 20 hours that varied in the above demands. One is a fast-paced first-person shooter identical to that chosen in Study 1 (Modern Combat). This was chosen as it has common demands to our laboratory tasks and was previously shown to transfer specifically to the attentional blink, multiple-object tracking and selective attention tasks. Two third-person shooters, MGS Touch and Super Sniper were also chosen to have varying demands in speed and the need to switch attention rapidly, but did not have demands to attend to multiple objects. In MGS Touch the player's avatar adopts a fixed position and the goal is to fire at enemies appearing at various locations. However, unlike Modern Combat, the game has a much slower pace and the player is allowed a much longer time to respond to appearing enemies. Super Sniper involves the player moving in a helicopter and engaging enemies in buildings. Players also do not have to shoot at enemies immediately and the pace of the game is not as fast as Modern Combat and MGS Touch. Finally, the last game, *Deer Hunter* was chosen specifically for its slow speed, and the lack of the aforementioned components. The only similarity is that it is a shooter game that adopted a first-person view (see table 2 for a comparison of these demands).

The inclusion of these action games with varying demands therefore allowed the testing of the hypothesis that (1) not all action games bring about similar transfer effects and (2) most importantly, transfer depends on common demands between the transfer task and the trained game. Given the game demands, I expect that like in study 1, Modern Combat training should improve attentional blink, selective attention and multiple object tracking. Although MGS Touch has some demands to switch attention rapidly between targets, these demands are not as intense as Modern Combat. Specifically, while there is a need to switch

between targets, players have more time to do so as the enemies do not engage the players immediately upon appearing. Additionally, as there are few scenarios whereby a player is expected to track multiple objects within the game. Therefore, in light of these decreased demands compared to Modern Combat, it is interesting to determine whether a transfer is seen in attentional blink, selective attention and multiple object tracking. Finally, as the other two games, Super Sniper and Deer Hunter do not contain the aforementioned demands; there would be no expectations on improvements in these three areas.

In addition to tasks assessing these skills, I also included a visual search task and an auditory detection task. Study 1 failed to replicate the finding of previous investigations showing superiority in action gamers' visual search skills (Hubert-Wallander et al., 2011; Wu & Spence, 2013). There are two possibilities for this. One is that the action video game lacked the demand for visual search. Again, in the action video game used in this investigation, enemies tend to "pop-out" and engage the player. Hence, there is little need for the player to search for the enemy. Another possibility may be that the presence of the working memory task within the visual search task in Study 1 masked any transfer effect. Hence, a single-task visual search task was included here to determine if transfer could occur even though the action video games lacked an intensive visual search demand.

In Study 1, an enhancement in visual detection skills was demonstrated following action video game training. However, it is unclear if the improvement as a result of action video game training represented a general attentional improvement or due to a specific improvement to visual attention. Here, an auditory detection task was included to further test the specificity of transfer. If transfer following training were specific to visual skills, there would be no transfer to auditory detection. On the contrary, if improvements were a general attentional enhancement, regardless of modality, there would be training-related

improvements to auditory detection as well. Hence, the inclusion of the auditory detection task further allowed for the testing of training-transfer specificity.

Methods

Participants

55 (29 males) undergraduates ($M_{\text{age}} = 21.78$, $SD = 1.76$) were recruited via an online advertisement. Participants were randomly assigned to each training group. However, five participants failed to return for the post-training session (one each from Modern Combat, MGS Touch and Super Sniper groups and two from Deer Hunter group). The final n-size in each group that were used for the data-analysis was: Modern Combat ($n = 14$), MGS Touch ($n = 14$), Super Sniper ($n = 14$), Deer Hunter ($n = 13$). All participants were self-reported to be non-video game players based on the criteria that they play video games less than one hour per week over the past 1 year on average. All participants were reimbursed S\$50 for their participation and completion of the study. This study was conducted in approval and accordance to the ethical guidelines prescribed by the Nanyang Technological University, Institutional Review Board (IRB).

Materials

All games were played via participants' personal iPhone/iPod Touch (Apple Inc.). Interaction with the game was via a touch-sensitive interface.

Training Games

Modern Combat: Sandstorm (Gameloft®). This is identical to that used in Study 1.

Metal Gear Solid (MGS) Touch. This is a third person shooter where the game character controlled by the player remained stationary with only the ability to move left, right or duck under a cover. The objective of the game is to rapidly fire at appearing enemies at various locations. However, unlike Modern Combat, the enemies appear sequentially. These enemies stay visible for 5000ms before they fire at the player and then disappear. Hence, a

there is less demand to allocate attention across several targets at once and engage an enemy immediately after shooting at another enemy. There is however, “lures” that the player must avoid shooting at which if engaged, incurs a penalty.

Super Sniper. In this game, players undertake the role of a sniper and look for enemies to shoot at by pointing their scope at them. Enemies are located at various locations and are easily spotted. Enemies do not fire at the player unless the player points their scope at the enemy.

Deer Hunter. For this game, participants play as a hunter and search for animals to fire at. Unlike the other games here, there is little speed demand. A player is required to aim a scope at an animal and fire at the animal. Points are awarded for a successful kill. If the player misses, the animal would run away and the player would have to look for another animal. There is also very little need to filter out distractors because the player only has to engage animals. Also, there is no need to attend to several items at once.

Differences between the training games. As mentioned previously, the games chosen for training here vary in demands on speed, selective attention, multiple object tracking and visual search (see table 2.1 for a summary). As these differences are arbitrarily defined, it is difficult to provide objective metrics of the differences. However, some distinct differences can be stated. I make some comparisons based on gameplay at the lowest level of each game (level 1).

Differences in speed. The reaction time to engage the targets in Modern Combat is of utmost importance because the enemies engage the player immediately upon onset. This is unlike MGS Touch, where the target does not fire at the player until 5000ms after onset. For Super Sniper, the enemy will engage the player only after the player engages it. For Deer Hunter, the target will not engage the player. Hence, only Modern Combat has an intense speed requirement.

Differences in multiple object tracking. For Modern Combat, in terms of tracking multiple objects, in level 1, as many as 4 enemies engage the player at once. In contrast, in MGS Touch, enemies appear one at a time with the player having up to 5000ms to aim and fire at the enemy. If the player chooses to ignore the enemy that appears, it disappears after firing at the player. For Super Sniper, the player engages one enemy at a time and unlike Modern Combat and MGS Touch, the enemy does not appear until the player scrolls to where the enemy is. For Deer Hunter, there is only one target per screen and the target is largely stationary unless the player fires at it and misses.

Differences in attentional switch. Because of many targets appearing at once or in quick succession, Modern Combat has the highest demands to switch attention rapidly. The other games either allow more time to switch attention (MGS Touch), or time-negligible (Super Sniper) or only contains one target (Deer Hunter).

Differences in selective attention. For Modern Combat, a team of fellow soldiers, which must be filtered out, surrounds the main character played. Attention must be directed towards only enemies firing at the player. Furthermore, the environment contains several items that can be shot at which further act as sources of distraction. In contrast, the other games do not contain distractors with the possible exception of MGS Touch, which occasionally has a highly distinguishable distractor (a duck), which make distractor suppression easy. The demands for selective attention in Super Sniper are likely very low because although a player is required to locate an enemy within a building, the enemy stands out as there are no other salient stimuli within each screen. This is similar for Deer Hunter whereby each scene has one target and no other stimulus competes for the player's attention.

Differences in visual search. Only Super Sniper and MGS Touch contain some search requirements. For instance, in Super Sniper, a player has to search a building for targets. However, locating a target is untimed and there are no distractors interfering with search. In

MGS Touch, the player has to locate sudden onset but salient targets, but is allowed up to 5000ms after onset to locate enemy. In contrast, the other games do not have a search component.

It is important to note however, that the differences between the games are not limited to these demands only, but is likely to differ in several other demands and characteristics. However, for parsimony, these demands were studied, as they are similar to the transfer tasks that chosen here and hence it is possible to determine if differences in these demands can lead to differential transfer effects. Furthermore the demands are suggested to be important for action video game related transfer (Achtman et al., 2008). Hence, including of games with these demands allow for testing whether these are indeed important for transfer.

Table 2.1
Demands of the video games and cognitive tasks used.

Training game	Hypothesized game demands				
	Speed	Attentional switch	Multiple-object tracking	Selective attention	Visual search
Modern Combat	High	High	High	High	None
MGS Touch	Moderate	Moderate	Low	Moderate	Low
Super Sniper	Moderate	None	None	Low	Moderate
Deer Hunter	None	None	None	Low	Low

Transfer Tasks

Attentional blink. The attentional blink task is identical to study.

Filter task. This is identical to Study 1.

Visual search. This task was adapted from Woodman and Luck (2004). Therefore, the visual search stimuli are identical. However, unlike Study 1 and in Woodman and Luck, the spatial working memory task was omitted and the visual search set size was increased to 8, 16 and 24 (see figure 3.1). Depending on set size, the squares (0.45° by 0.45°) were presented within an imaginary box of 7.6° by 7.6° (set size 8), 11.31° by 11.31° (set size 16) or 12.68°

by 12.68° (set size 24). There were 12 trials for each set size for a total of 36 trials.

Participants practiced on the task for 6 trials prior to starting the task.

Figure 3.1. Sample trials for visual search set sizes 8, 16 and 24.

Auditory detection task. The auditory detection task is a measure of auditory attention. The task requires participants to detect whether a 300Hz beep (signal) is present in a stream of white noise. The duration of the white noise is 2000ms while the beep occurred for 500ms. In all trials, the auditory stimuli (white noise and signal) are played on either the left or right sides of participants' headphones. A total of 180 trials were presented with 120 signal-present and 60 signal-absent trials. Half the trials were played on the left and half were played to the right ear. Participants were instructed to make a speeded response by pressing the "z" key if no signal accompanied the white noise. When the signal occurred, participants were to press the "n" or "m" key to indicate the detection of the sound played on the left or right ears respectively.

General Procedure

Participants performed all the tasks in a computer lab. Participants were first briefed about the requirements of the study and information pertaining to their assigned training games was not divulged.

Following briefing, participants performed all computerized tasks in a randomized order. The time taken to complete all experimental tasks was approximately 1 hour. After completing the tasks, participants were instructed to download their assigned game and play that game for the prescribed duration (i.e. they were asked to play only the prescribed number

of hours - one hour per day / 5 days a week, and refrain from playing more). Additionally, they were instructed to enter their daily gameplay duration in an online spreadsheet. Participants were also explicitly told to play only the game assigned to them and refrain from playing other kinds of video games during the training phase.

After the training, they returned for the same set of computerized tasks. Participants only returned after at least 24 hours after their gameplay cessation. This washout period was to control for arousal effects arising from their last session of gameplay which might in turn affect their performance at the post-test as their arousal from playing the game may induce strategy changes in the transfer tasks (cf. Nelson & Strachan, 2009). The post-training sessions were conducted in the same manner again with randomization of the transfer tasks.

At the post-training session, participants' handsets were also checked to ascertain that they downloaded the game and played it. A debrief would then follow.

Participants were not informed beforehand that their devices would be checked. It was verified that all participants downloaded and played the game. Furthermore, all participants made some progress within the game they were assigned. These, taken together with their on-line self-report of daily playing time is indicative of their fidelity to the prescribed training regime.

Results

Attentional blink. First, a within subjects ANOVA was conducted to determine if the attentional blink task yielded the classic attentional blink effect. There was a significant effect of lag, Wilks $\lambda = .39$, $F(6, 46) = 4.99$, $p = .001$. Follow-up paired t-tests indicate that overall, accuracy at lag 2 was significantly lower than accuracy rates at all other lags (all $ps < .019$) with the exception of lag 3 ($p = .091$). Accuracy at lag 3 was also lower than all other lags (all $ps < .012$) with the exception of lags 2 and 6 ($p = .18$). These findings are indicative

of the attentional blink effect. There was also no significant lag X group interaction, Wilks $\lambda = .65$, $F(18, 130.59) = 1.19$, $p = .28$.

To ensure that each group started out having similar AB performance prior to training, a 4 (training group) X 4 (AB Lags 2-5) mixed ANOVA was conducted for the lags of interest (Lags 2-5). Aside from a main effect of lag, Wilks $\lambda = .75$, $F(3, 49) = 5.58$, $p = .002$, no interactions between lag and group was found, nor were there any between subjects effects ($ps > .35$). These results indicate that the groups had equivalent performance prior to training.

For the analyses to determine if there were improvements from training, only the lags of interest are included in the mixed ANOVA. A 4 (AB lags 2 - 5) X 2 (time: pre and post-training) X 4 (training groups) X 2 (Gender) mixed ANOVA was conducted to determine if pretest scores differed among the training groups. Gender was included in the analyses due to previous studies suggesting that males and females may show different gains following training (Feng et al., 2007). The within subjects factors are lags 2 to 5 and time while the between subjects factor was the training group and gender with four and two levels respectively. There was a significant main effect of lag, Wilks $\lambda = .66$, $F(3, 45) = 7.90$, $p < .001$ and time Wilks $\lambda = .58$, $F(1, 47) = 34.33$, $p < .001$. This was qualified by a group X time interaction, Wilks $\lambda = .85$, $F(3, 47) = 2.87$, $p = .046$. All other main effects and interactions failed to reach statistical significance.

Paired t-tests were conducted to follow-up the significant interactions above and to determine which group improved in the AB lags of interest following training. The paired t-tests revealed that the improvement by the Modern Combat group in accuracies for Lag 2 [$t(13) = 3.70$, $p = .003$, Cohen's $d = 1.61$], lag 3 [$t(13) = 3.61$, $p = .003$, Cohen's $d = 1.43$], lag 4 [$t(13) = 2.43$, $p = .03$, Cohen's $d = 0.95$] and lag 5 [$t(13) = 2.43$, $p = .03$, Cohen's $d = 1.00$] were statistically significant.

By comparison, for the MGS Touch group, there were statistically significant improvements in lag 3 [$t(13) = 2.75, p = .016$, Cohen's $d = 1.46$], lag 4 [$t(13) = 3.79, p = .002$, Cohen's $d = 1.76$] and lag 5 [$t(13) = 2.75, p = .017$, Cohen's $d = 1.22$]. In contrast, improvements in accuracy rate for lag 2 failed to reach statistical significance ($p = .20$). Paired samples t-test conducted for the four lags for the other training groups revealed that aside from the Super Sniper group's improvement in lag 5 reaching statistical significance, ($p = .027$), no other improvements were seen. This indicated that both groups did not show any improvement as a result of training in attentional blink (figure 3.2).

Figure 3.2. Changes (Δ) in T2 detection accuracy rate for each training group during post-training. Asterisks denote statistical significance at $p < .05$. Error bars denote 95% CI.

Filter task. The DVs in the task were calculated as a sensitivity index, d' for each of the 10 conditions. This is derived from correct change detections and false alarms. The formula used to derive the d' statistic is based on Tanner and Swets (1954) and was analyzed in a similar manner to Study 1.

Two conditions in the filter task were of interest here – the 2 target 6 distractors condition and the 8 target 0 distractor condition. First, the sensitivity score (d') was entered into a within subjects ANOVA to determine if scores differed between the groups prior to training. The mixed ANOVA showed no group X condition interaction, Wilks $\lambda = .87, F(3,$

51) = 2.47, $p = .07$. Additionally, there was no between subjects difference overall in d' prior to training, $F(3, 51) = .29$, $p = .83$. These results indicate that prior to testing, detection sensitivity (d') was equivalent between the groups.

A 2 (time) X 2 (filter task conditions) X 4 (training groups) X 2 (Gender) mixed ANOVA was conducted. There was a main effect of time, Wilks $\lambda = .92$, $F(1, 47) = 4.17$, $p = .047$. This was qualified by a time X group interaction, Wilks $\lambda = .76$, $F(3, 47) = 4.91$, $p = .005$. There was also a condition main effect, Wilks $\lambda = .21$, $F(1, 47) = 173.01$, $p < .001$ and a significant three-way interaction between condition X time X training group, Wilks $\lambda = .84$, $F(3, 47) = 2.92$, $p = .04$. All other main effects and interactions were not statistically significant. Paired t-tests were conducted for each group to determine if performance improved as a result of training.

For the Modern Combat group, the improvement in d' from pre ($M = 2.70$ $SD = .56$) to post training ($M = 3.02$ $SD = .28$) for the 2 target 6 distractor condition approached significance, $t(13) = 2.08$, $p = .058$, Cohen's $d = .84$. Conversely, there was a significant improvement in the 8 target 0 distractor condition, $t(13) = 2.61$, $p = .022$, Cohen's $d = 0.99$. All other groups did not show improvements in either condition (all $ps > .05$). Interestingly but unexpectedly, the Super Sniper group's detection sensitivity decreased following training ($M_{pre} = 1.49$ $SD = .50$) to post-training, ($M_{post} = .91$ $SD = .82$) in the 8 target 0 distractors condition, $t(13) = -3.18$, $p = .007$. These results indicate that only the Modern Combat group improved in the ability to apprehend multiple objects simultaneously (see figure 3.3).

Figure 3.3. Detection sensitivity (d') for 8 target 0 distractor condition from pre to post-training for each training group. Asterisk denote statistical significant change at $p < .05$. Error bars denote 95% CI.

Visual search accuracy. For visual search, RT for correct detections and accuracy rates are the DVs. First, a 4 (training group) X 3 (set size) mixed ANOVA was conducted on visual search accuracy to determine if there were pre-existing differences between the groups. The ANOVA revealed a significant set size main effect, Wilks $\lambda = .26$, $F(2, 49) = 68.43$, $p < .001$, but failed to find significant training group effects and set-size and training group interactions ($ps > .37$). These results indicate that there were no pre-existing differences in search accuracy prior to training.

A 2 (time: pre and post training) X 3 (set size) X 4 (training groups) X 2 (Gender) ANOVA was then conducted to determine if training resulted in accuracy improvements for any of the set sizes. There was a significant main effect of time, Wilks $\lambda = .62$, $F(1, 46) = 28.82$, $p < .001$, and set size, Wilks $\lambda = .22$, $F(2, 45) = 78.38$, $p < .001$. This was qualified by a time X set size interaction, Wilks $\lambda = .67$, $F(2, 45) = 11.09$, $p < .001$. All other interactions and main effects failed to reach statistical significance. This suggests that the groups and gender did not differ in the magnitude of improvements in visual search accuracy.

Visual search RT. Similarly, preexisting differences between groups was evaluated. A 4 (training group) X 3 (set size) mixed ANOVA revealed significant set size main effects,

Wilks $\lambda = .10$, $F(2, 49) = 220.80$, $p < .001$, but again failed to find significant group main effects or interactions ($ps > .39$). These results suggest that the groups had equivalent search RTs prior to training.

A 2 (time: pre and post training) X 3 (set size) X 4 (training groups) X 2 (Gender) ANOVA was conducted to determine if there were differences in performance gains between the groups following training. There was a significant time main effect, Wilks $\lambda = .60$, $F(1, 46) = 26.31$, $p < .001$. There was also a significant main effect of set size, Wilks $\lambda = .05$, $F(2, 45) = 396.96$, $p < .001$. All interactions failed to reach statistical significance. These results indicate that improvement did not differ between groups or gender.

Auditory detection task detection accuracy. A 4 (training group) X 2 (ear: left vs. right) mixed ANOVA was computed to determine if the training groups differed in auditory detection prior to training. The analysis showed no significant main effects of ear, group or any interaction effects. These results indicate that the groups had equivalent performance in auditory detection prior to training.

A 2 (time) X 2 (ear: left vs. right) X 4 (training group) X 2 (Gender) repeated-measures ANOVA was conducted to determine if there were any improvements in auditory signal detection accuracy from pre to post training. The ANOVA revealed a significant time effect, Wilks $\lambda = .91$, $F(1, 46) = 4.44$, $p = .04$. However, all other main effects and interactions failed to reach statistical significance (all $ps > .11$). These results suggest that the improvements from pre to post-training were equivalent between the training groups.

Auditory detection task RT. A 4 (training group) X 2 (ear: left vs. right) mixed ANOVA was computed to determine if the training groups differed in performance prior to training. The analysis revealed no significant main effects of ear, group as well as ear X group interactions. Overall, these results indicate that the groups did not differ in performance (RT) in the auditory detection task prior to training.

A repeated-measures ANOVA was conducted to determine if there were any improvements in auditory signal RT from pre to post training. There was a significant time effect, Wilks $\lambda = .67$, $F(1, 46) = 23.21$, $p < .001$. However, all other main effects and interactions did not reach statistical significance (all $ps > .31$). These results suggest that the improvements from pre to post-training were equivalent between the training groups.

Summary of key findings

Due to the large number of results and analyses, a summary of the key findings is presented here for clarity. First, similar to study 1, Modern Combat training for 20 hours led to reductions in the attentional blink effect and multiple object tracking. However, improvements in selective attention failed to reach statistical significance. Improvements in later lags (lags 3-5) of the attentional blink were also observed following training in MGS Touch. No other pre-post gains were seen in the other training groups. These results are discussed more in depth in the next section

Discussion

One goal of this study was to add to Study 1 to show that variations in demands in different action video games bring about different transfer effects. Another motivation for this study was to determine whether elements such as speed, attentional switch and tracking of multiple items are necessary for action video game related transfer as proposed by Achtman et al. (2008).

Attentional Blink. Similar to Study 1, it was predicted that playing Modern Combat would improve attentional blink performance. As attentional blink requires rapid recovery from detecting T1 to detect T2, it was reasoned that playing Modern Combat, like most fast-paced first-person shooters that place intense demands on the temporal aspect of attention, would improve the attentional blink. This hypothesis was supported and corroborated the results in study 1. Specifically, the Modern Combat group improved detection of T2 in lags

most commonly affected by the attentional blink (2 to 5). Furthermore, the unique improvement in T2 detection in lag 2 by the Modern Combat group is important because lag 2 is most affected by the attentional blink. Hence, it suggests that only a game that had the requirement to switch attention between targets at intense speeds lead to this improvement.

Interestingly, the MGS Touch group also showed improved recovery from an attentional blink (in lags 3 to 5). However, unlike Modern Combat, there was no evidence of transfer to the lag most susceptible to the attentional blink effect, lag 2, which is consistent with the suggested difference between attentional switching demands between Modern Combat and MGS Touch. For instance, in Modern Combat, enemies appear rapidly in succession and sometimes even concurrently and fire at the player. On the other hand, in MGS Touch, although the enemies appear rapidly in succession, they do not engage the player immediately. Therefore, players are allowed some time to recover from attentional capture and engage an enemy before the enemy fires back at the player. Nevertheless, there is possibly still the need to switch attention from one enemy to another rapidly, albeit to a lesser degree. Hence, this lesser demand may explain that the attentional blink improvements are seen in the latter lags as opposed to lag 2 that is shown to be most susceptible to the blink effect.

In contrast, no evidence of transfer was seen in T2 detection by playing Deer Hunter and only improvements seen in the latest lag that is susceptible to the blink by the Super Sniper group. These games contain little to no demands to switch attention rapidly from one target to another. Hence, this is consistent with the argument that attentional blink improvements are only achieved by playing games that have the need to switch attention rapidly from one target to another.

Multiple object tracking. It was also predicted that playing Modern Combat would improve tracking of multiple objects. This hypothesis was supported. Again, the similarities

in demands between the Modern Combat game and the task may explain the transfer effect. For the task, participants are required to attend to multiple items at once for a brief moment to detect any changes in orientation took place. For the Modern Combat game, there are heavy demands to keep track of multiple enemies simultaneously. As mentioned, previous work has shown that playing a fast-paced first-person shooter improves multiple object tracking for moving objects (Green & Bavelier, 2006b). Here, the finding of an improved ability to attend to multiple static objects further corroborated study 1 and extended previous works.

In contrast, the other games tested here that did not have demands to attend to multiple items failed to result in a transfer to multiple object tracking. This further lends weight to the assertion that intense practice of a skill within a game is necessary for transfer to a task that shares common demands.

Selective attention. It was predicted that playing Modern Combat would improve the selective attention (2 target 6 distractor) condition relative to the other groups. The improvement for the Modern Combat group approached but failed to reach statistical significance ($p = .058$). Hence, this hypothesis was not supported. However, many previous works have shown an improvement in selective attention using a first-person shooter (Green & Bavelier, 2003). The lack of a positive transfer effect is unclear but I speculate that differences in baseline characteristics between the participants here and in Study 1 may have contributed to the differences in findings. For example, participants in the Modern Combat group here ($M_d' = 2.70$, $SD = .56$) performed significantly better in this particular condition compared to their counterparts in Study 1 [$(M_d' = 2.07$, $SD = 1.00)$, $t(28) = 2.09$, $p = .046$]. Hence, it is plausible that the lack of a transfer is due to the participants in study 2 having a greater pre-existing ability in selective attention, which in turn limited the gains from action video game play.

Visual search. The results in the visual search task show no differential transfer by any of the different training groups. This is consistent with Study 1 that showed that training in a fast paced first person shooter does not transfer to visual search skills. On the other hand, this is inconsistent with previous works that showed a transfer to visual search skills (Wu & Spence, 2013). A key difference in the games used in Wu and Spence and that used here may account for the different findings. Wu and Spence argued that the racing and first person shooter game used in their study contained high search demands. However, the games used here have relatively few requirements for the need to search a scene. Rather, targets often pop out and engaged the player (Modern Combat) or move among a static background (Deer Hunter). Hence, there is little opportunity to practice search skills. Earlier, in Study 1, it was showed that training in a game with high search demands (Hidden Expedition) led to improvements in visual search. Hence, further replications involving an action game with high search demands to confirm the present results may be necessary.

Auditory detection. There was also no differential transfer to auditory detection in any of the trained games. This shows that there was no cross-modality transfer to auditory attention even in the fast-paced first person shooter, Modern Combat. This suggests that action video games, especially fast paced first person shooters may bring about visual-based attentional capacities (Green & Bavelier, 2003) but not transfer across modalities. Again, this shows the specificity of transfer that is limited to that which is trained within the game.

Limitations

Again, it should be acknowledged that because the games used in this study were not designed specifically for cognitive and perceptual training in mind, it is difficult to objectively “measure” the specific demands needed for gameplay. As the focus was on action video games, the approach taken here more explicitly describes and contrasts the different demands in these games. However, the comparisons and descriptions remain subjective,

similar to that elsewhere (J. E. Cohen et al., 2007; Spence & Feng, 2010). Objective characterization of actual game demands necessary for gameplay and successful transfer remains a difficulty within the field of video game training.

Conclusion

In this study, it was demonstrated that not all action video games are similar in bringing about cognitive and perceptual changes. This highlights the fact that different action games require varying cognitive demands even though on the surface, they may seem highly similar (e.g., fast paced first-person perspective). It was again showed here that transfer to a cognitive task is more likely if a similar underlying skill is highly practiced in a video game. This further corroborates the findings in Study 1 and is overall consistent with the theory proposed earlier that transfer is more likely if the game and task shared common demands (Thorndike & Woodworth, 1901). Additionally, the finding here that MGS Touch, relative to Modern Combat, transferred to later lags of the attentional blink but not to lag 2, further suggest that transfer of cognitive skill is highly specific. Importantly, the study here provided empirical evidence that several key ingredients are important to promote transfer in action video games. Consistent with Achtman et al. (2008), the results here indicate that to promote learning, action video games should be fast paced, place heavy demands on the visual and attention system to track multiple items simultaneously and switch attention while ignoring distractors.

CHAPTER 4

STUDY 3: A GENERAL TRANSFER OF VIDEO GAME TRAINING TO EXECUTIVE FUNCTIONS³

The results in studies 1 and 2 are consistent with previous investigations that show enhanced lower-level perceptual and attentional capabilities following a short bout of action video game training. Thus far, as argued in the literature review earlier and demonstrated empirically in studies 1 and 2, the transfer of skills from action video game training is likely a result of the common demands shared by the game and transfer task such that these demands are repeatedly trained in the video game. This mechanism of transfer accounts for action as well as non-action video game related transfer.

While the current evidence supports enhancement and plasticity of these lower level perceptual and cognitive skills, the current evidence for executive function enhancement in experienced action video game players and following video game training is inconclusive. While some studies providing evidence for enhancement (Colzato et al., 2010; Green et al., 2012; Strobach et al., 2012), others do not (Bialystok, 2006; Boot et al., 2008; Irons et al., 2011).

There are several possibilities that may explain the equivocal evidence of video game related transfer to executive functioning. First, if transfer of executive skill depends similarly on shared demands between the game and executive transfer task, it could be that executive demands are lacking or not sufficient in the trained video games. This may seem counterintuitive given the nature of action video games where target switching and top-down distractor suppression seemed to be common feature. However, it is important to bear in mind that these activities in most action video games do not involve perceptual and response conflict. For instance, switching attention between targets is straightforward and involves

³ This study is published in Oei, A.C. and Patterson, M.D. (2014). Playing a puzzle video game with changing requirements improves executive functions. *Computers in Human Behavior*, 37, 216-228

engaging one enemy followed by another. Distractor suppression is also straightforward where target and distractor engagement has distinct responses – to engage or not. Consistent with this view, evidence of transfer to executive functioning tasks like task switching is limited to sequential variants (Green et al., 2012; Strobach et al., 2012), which has little conflict as a participant can plan for an upcoming task switch. In contrast, action video game training has little impact on random and unpredictable task switching tasks (Boot et al., 2008) that involve greater response conflicts, as participants have no prior knowledge of an upcoming switch to guide behavior. Additionally, predictable, alternate-runs task switching may not be a true representation of mental flexibility per se as compared to random task switching (Pereg et al., 2013). Moreover, aside from task switching, action video game players also show equivalent performance compared to non-video game players in other executive tasks that involve conflicts such as the flanker (Cain et al., 2012; Irons et al., 2011), Simon (Bialystok, 2006) and inhibition tasks (Colzato et al., 2013). Nevertheless, given that only Boot et al have tested random task switching in a training study, it is important to further replicate those results.

Yet another possibility for the lack of action video game related transfer to executive function tasks that involve conflict is that unlike transfer to lower level information processing skills, the transfer of higher-order executive skill depends on a different mechanism. Unlike the transfer of low-level attentional and perceptual skill, training of specific shared demands between game and executive transfer task may not be sufficient to result in transfer or enhancement in executive functioning.

Executive functions underpin higher order planning, reasoning, strategizing and problem solving skills (Diamond, 2013; Gilhooly & Fioratou, 2009; Shallice, 1982). Furthermore, neuroimaging studies demonstrate overlapping brain regions that support these abilities (Bunge, Dudukovic, Thomason, Vaidya, & Gabrieli, 2002). Hence, one possibility

may be that frequent demands in planning, strategizing, reframing and problem solving in a video game could in turn train different executive functioning skills. This is a novel approach that to my knowledge is yet to be attempted in the video game training field. Interestingly, a recent research outside the video game literature suggest the viability of such an approach. Specifically, a school-based strategy and reasoning training program was found to improve the executive function of inhibition (Motes et al., 2014). Hence, it would be interesting to determine if training in a video game that emphasizes planning, problem solving and strategizing would transfer to different executive functions.

Purpose and Overview of the Current Study

The study here is designed to test whether consistent with the earlier proposed common elements theory; transfer of executive skill also depends on similar demands between the transfer task and trained game. That is, whether transfer is more likely when the game contains similar executive demands as the laboratory transfer task – a specific transfer.

Also as discussed earlier, unlike visual perceptual and attention skills, evidence of transfer of top-down executive function skills is currently equivocal. Hence, a possibility is that transfer of executive skill may depend on a separate mechanism. Therefore, a possibility tested here is whether general top-down executive control skills can be trained with a puzzle game that require high level planning, problem solving and strategizing skills. Furthermore, given the close relations between different executive functions (Miyake et al., 2000), another possibility would be training in one executive function could also result in improvements to other executive functions - a general transfer. Hence, the conduct of this study allowed the testing of whether such transfer effects of training in games with different executive demands lead to a specific or a general transfer.

The current study utilized a multiple game comparison comprising of action, puzzle, arcade and strategy games. It is important to compare multiple games with multiple demands

because different games can train different cognitive abilities (see study 1). The action video game - Modern Combat, similar to those in studies 1 and 2, is a fast-paced first person shooter that involves deployment of attention across several objects simultaneously and cognitive control to filter out distractors. However as mentioned previously, these processes presumably do not entail monitoring and resolution of perceptual and response conflicts. The inclusion of this game is to add to the literature and further test whether transfer to executive tasks that involve conflict occurs with action video game training. Second, similar to Boot et al. (2008), a real time strategy game - Starfront Collision, was included, which necessitated the player to amass and manage resources in order to expand the territory under their control. In this game, it is expected that players would make quick decisions and depending on the game situation, make quick readjustments. Boot et al argued that such games might train executive functions due to the need for strategizing in the game. Additionally, it was shown that older adults improved task switching after playing a real-time strategy game, *Rise of Nations* for 23.5 hours (Basak et al., 2008). A third, arcade-style game - Fruit Ninja was included that involves quick reflexes to slash fruits that appeared in quick succession. It is expected that this game would have the fewest high-level executive demands such as planning, and strategizing. However, it does entail inhibition of slashing distractor “bombs” amidst the quick responses. Finally, a physics puzzle game - Cut The Rope, was included which requires formulating and revising action plans, mental imagery, and trial and error while learning from past errors. In contrast to the other games in this study, this game is slower paced and allows the player time to formulate plans during gameplay.

Although previous investigations have utilized puzzle games as part of a multiple game comparison (Boot et al., 2008; Green & Bavelier, 2003; Strobach et al., 2012), the puzzle games used were limited in their demands. Specifically, a frequently used puzzle game in these studies is Tetris. Arguably, the main cognitive demand in this game is centered mostly

on mental rotation and spatial visualization. Furthermore, in each level, the strategy used and gameplay is very similar. It has been demonstrated that transfer as a result of Tetris training is specific to mental rotation tests (Okagaki & Frensch, 1994; Sims & Mayer, 2002). Hence, Tetris may not represent a good candidate in training high-level executive function skills.

In contrast, the puzzle game included here (Cut the Rope) demands high-level planning, problem solving and reframing. Moreover, unlike many puzzle games, the puzzle game here is highly varied and requires a new strategy from level to level. Often, a player would be required to discard a previously successful strategy and reframe the problem set to come up with new ways to tackle the level. Additionally, at times, there can be more than one way to solve an existing puzzle. Currently, there remains a paucity of studies (but see Boot et al., 2008 for a possible exception) that investigated the transfer effects of such games that demanded deliberate higher-order problem solving skills. Hence, an original contribution this study makes is to investigate whether games that require complex planning, strategizing and reframing improve executive functioning.

Three tasks measuring distinct executive functions were given prior to and after 20 hours of video game training. Two of these measures are similar to tasks used in previous video game studies: task switching (Colzato et al., 2010; Green et al., 2012; Strobach et al., 2012) and a standard flanker task for selective attention and resolution of stimulus-response interference (Cain et al., 2012; Irons et al., 2011). A third executive function measure, the Go/No-go task of behavioral inhibition measured the ability to withhold or override a strong prepotent response to a lure (Diamond, 2013; MacLeod, 2007).

While previous studies have shown a link between action video game training and task switching (Green et al., 2012; Strobach et al., 2012), they utilized a sequential and predictable task-switching paradigm. Here, instead, an attempt is made to replicate Boot et al. (2008) by

utilizing a random task switching paradigm to determine if transfer occurs with action or other video game training.

The inclusion of tasks that measured these abilities allowed the testing of both specific and general transfer effects since there are varying degrees of similarity between the tasks and games. For specific transfer, it is hypothesized that transfer would take place in instances where the executive functions utilized by the transfer task were also frequently practiced in the game assigned (cf Thorndike & Woodworth, 1901). In contrast, for general transfer, broad improvements in multiple aspects of executive functions rather than specifically trained aspects would occur.

Specific Transfer Predictions

For specific transfer, several training-specific improvements may occur. First, action video game training could improve task switching because the game requires continuous switching between targets. Hence, frequent training in switching within Modern Combat may lead to improvements in the ability and speed to flexibly switch between responding to different targets or tasks. With regards to the flanker task, as mentioned, previous action game studies had failed to find an action video game advantage (Cain et al., 2012; Irons et al., 2011). Hence, it is not expected that an improvement in reducing the flanker compatibility effect would occur by playing Modern Combat.

Second, the arcade game, Fruit Ninja requires both fast responses to task relevant stimuli, and inhibition of responses to distractors. Hence, transfer could be seen in the Go/No go task for those trained in the arcade game. Although at first glance, Fruit Ninja has similarities to the flanker task since both require selective attention to targets amidst distractors, there are fundamental differences between them. Specifically, in the flanker task, there is a need to inhibit attention to the flanking stimulus and focus on the central target. This is especially so when the flankers are incongruent to the target. Conversely, for Fruit

Ninja, the player must not lose sight of the distractors but instead, rapidly (but carefully) avoid slashing at the distractors. This involves deliberate movements around distractors that are flying into the screen from several locations. Hence, it is important that the player attends closely to the distractors and actively avoids slashing them. As a result, an improvement in filtering out task-irrelevant distractors following training in Fruit Ninja is not expected.

Third, since the real-time strategy game, Starfront Collision requires rapid switching of tasks such as building bases and quickly switching to attack enemies, transfer to only task switching may be seen. In other words, if a specific transfer occurred with training in the real-time strategy game, a reduction in only switch cost should be evident.

General Transfer Predictions

For general transfer, improvements to tasks are not dependent on how similar they are to the training game. Rather, it is expected that playing games that require higher order cognition like planning and strategizing as well as keeping multiple items in working memory (such as the steps to take and to monitor errors) would enhance a general learning mechanism or a higher order executive control system (Green & Bavelier, 2012). Given the relationships between executive functions and higher order planning, reasoning and problem solving both behaviorally and neurologically (Bunge et al., 2002; Diamond, 2013; Shallice, 1982), it is hypothesized that training in games that required complex planning, problem solving and strategizing would modify the general neural network that supported executive functions and complex planning. If this is indeed the case, it is expected that broad improvements would occur to all three executive control tasks with Cut the Rope and Starfront Collision training – two games that contained both planning and strategizing requirements. Furthermore, Starfront Collision is most similar to the game leading to executive improvements in seniors (Basak et al., 2008). On the other hand, it is unlikely that general transfer would occur to all executive functions with Modern Combat and Fruit Ninja

training because they require more reflexive actions rather than deliberate planning, strategizing and problem solving. Therefore, as hypothesized above, the transfer, by playing these games should be narrower and be limited to specific aspects trained like switching of tasks and inhibition.

Methods

Participants

Participants were recruited via an online portal targeted at undergraduates. Participants were not told what games were being tested in the online advertisement. Furthermore, participants were addressed individually on the games they would be playing and the games that other participants trained in were not divulged.

In total, 55 undergraduates signed up for course credits and S\$50 reimbursement. However, 3 participants that were assigned to Modern Combat training failed to return for the post-training testing session. 52 (29 males) completed the study. Participants were randomly assigned to each training group as follows: Modern Combat ($n = 10$), Cut the Rope ($n = 14$), Starfront Collision ($n = 14$) and Fruit Ninja ($n = 14$). The age of the participants ranged from 19 to 24 years ($M_{\text{age}} = 21.06$, $SD = 1.36$). All participants were not regular video game players (less than one hour per week for the last year) based on self-report. All participants provided written consent prior to their participation. The study was approved and conducted in strict compliance to the guidelines prescribed by the Nanyang Technological University Institutional Review Board (IRB).

Transfer tasks

Participants performed three executive control tasks (described below) via a personal computer in a lab. Experimental stimuli were presented to participants using 19-inch LCD monitors viewed from a distance of approximately 60cm. Responses were made via a standard QWERTY keyboard. The three tasks were administered randomly and each took

approximately 15 minutes to complete. All experimental tasks were written using E-prime 2.0 (Release candidate: 2.08.90; Psychology Software Tools, Inc., Pittsburgh, PA, www.pstnet.com).

Flanker task. Similar to Eriksen and Eriksen (1974), participants were asked to judge the identity of a central letter amidst three left and right flanking distractors that were congruent, incongruent or neutral. Specifically, participants were instructed to respond quickly using the “left arrow” key if the central target was “K” or “H” and the “right arrow key” if the central target was “C” or “S”. Congruent trials are trials where the central target and flanking distractors are all associated with the same response key (e.g., KKKHKKK). In contrast, incongruent trials are trials where the central target and flanking distractors are associated with a different response key (e.g., CCKKCCC). On the other hand, neutral trials are trials whereby the flanking distractors are dashes (e.g., ---C---).

Letters (subtending 0.48° of visual angle) were spaced evenly from each other by approximately 0.06° of visual angle. The targets and flankers were presented in black against a white background displayed on screen for a maximum of 5000ms (see figure 4.1).

Participants practiced for 30 trials followed by the actual task comprised of three blocks of 72 trials each (total number of trials = 216). Congruent, incongruent and neutral trials were presented with equal probabilities in the practice and actual trials. Each trial was separated by a 500ms inter-trial interval.

Figure 4.1. Example of three trials from the flanker task. Trials 1 and 2 are congruent trials while trials 3 and 4 are incongruent and neutral trials respectively.

Go/No-go task. Typical tasks of response inhibition used in clinical and non-clinical populations involve fast responses to a stimulus while withholding responses to another stimulus such as the Go/No-go task (Lustig, Hashler, & Zacks, 2007). In the current experiment, participants were shown a single colored letter (subtending about 1.91° vertically and horizontally of visual angle) on each trial and were instructed to make a speeded response on whether the letter shown was a consonant or a vowel (“m” key for consonant and “n” key for vowel). However, when a consonant or vowel was printed in a certain color, they were instructed to refrain from responding (see figure 4.2). The non-response item varied between blocks, and was indicated at the start of the block. For instance, in one block, participants were instructed to respond to vowels in any color except "green." Participants first practiced the task for 20 trials including 2 “no-go” trials. This was followed by three blocks of 240 trials each. In each block, there were 10 “no-go” trials. Each letter was presented for a maximum 2500ms with a 100ms inter-trial interval. Feedback was given for practice trials only. The number of trials was heavily weighted towards “go” trials to build up a prepotent tendency to respond and at the same time, increase the effort to inhibit responding to “no-go” stimuli (Simmonds, Pekar, & Mostofsky, 2008).

Figure 4.2. Example of four trials from the Go/no-go task. As an example, in this block, participants were instructed to not respond to red vowels. Here, participants should respond to all letters except for the red “A”.

Task switching. The task switching paradigm is a measure of cognitive flexibility and the ability to reconfigure a mental task set (Monsell, 2003). The task was adapted from Rogers and Monsell (1995). Here, a letter-number pair (subtended 1.1° vertically and

horizontally) is shown in one of four boxes of a 2 x 2 square. The size of the square subtended 4.76° of visual angle. Participants were asked to perform a vowel/consonant judgment when the letter-number pair appeared in the top row and perform an odd/even number judgment when the pair appeared in the bottom row of the 2 x 2 matrix. Both the letter and number judgment task involved the same key responses (“z” key response for odd number and consonant, “m” key for even number and vowel). Of interest is the difference in reaction time between task-switch versus task-repeat trials. There is considerable response delay when a switch is involved relative to task-repeat trials (Monsell et al., 2003; Rogers & Monsell, 1995). Rogers and Monsell presented the location of the letter-number pair in a clockwise fashion (AABB format/alternate runs paradigm) from trial to trial. Hence, it was predictable in the sense that a switch was required every alternate trial, and the cost of making a switch was reduced (Monsell et al., 2003; Rogers & Monsell, 1995). However, it was not eliminated (Dreisbach, Haider, & Kluwe, 2002; Sohn & Anderson, 2001) even with long preparation intervals (Sohn, Ursu, Anderson, Stenger, & Carter, 2000).

In the current study, switches were random and unpredictable. To begin, participants completed three blocks of practice trials. The first two practice blocks (72 trials each) involved participants performing just a consonant/vowel judgment followed by an odd/even judgment without switching. This was to allow participants to familiarize themselves with the stimulus-response key mapping. Due to the complexity of the task, participants were allowed to familiarize themselves with another 128 trials in which the switch was predictable (alternate-runs paradigm). This was followed by 128 of actual trials in which switches were random and unpredictable. Each visual stimulus was presented on screen for a maximum of 5000ms or until a speeded response was made (see figure 4.3). Inter-trial interval was set at 100ms. There were an equal number of trials requiring a letter or number judgment.

Figure 4.3. Example of four trials from the task switching task. Trials two and four are switch trials. In trial two, a switch is to be made from a letter judgment task to a number judgment. In trial 4 the switch is from a number to letter judgment.

Video game Training

The training games were played on participants' personal iPhones or iPod Touches (Apple Inc.). All the training games were downloaded onto participants' mobile devices via the iTunes App store (Apple Inc.). All participants were instructed to play the games for an hour per day for 5 days in a given week for 4 weeks (total training = 20 hours). To keep track of their game playing, participants were instructed to input their daily playing time in an online database. Based on their self-report, all participants complied with the instruction to play the game for one hour each day.

Action game – Modern Combat: Sandstorm (Gameloft®). This game is identical to studies 1 and 2.

Physics based puzzle game – Cut the Rope (Zepto Lab/Chillingo Ltd). In this game, the goal of the players was to guide a “candy” suspended by a rope to the mouth of an alien creature (“Om Nom”) in order to feed it. The player was required to cut the rope using a finger gesture. However, in addition to guiding the “candy” to the creature, the player had to ensure that the candy touched “stars” situated at various locations en route to the creature. There were three stars in each level and collecting stars unlocked further levels. Level designs varied and new contraptions are introduced as the player progressed. Each level featured a different contraption that altered game play. Within each set, as the player

progressed, the levels became more difficult and convoluted. For some levels, there were also timing requirements, so speed and fast movement were sometimes, but not usually important. There were 14 stages in total in this game and within each stage there were 25 levels. In each level, participants could collect three stars. Collection of sufficient stars unlocked a new stage. At the point where this study was conducted, participants were only able to play five stages. The game developers added additional stages subsequently with game updates.

Real time strategy game – Starfront Collision© (Gameloft). In this game, the player took on the role of a commander in a virtual environment. The objective of the game was to expand and defend territories as well as manage resources. Resources included materials and manpower to construct buildings. The game screen was highly complex with multiple controls for each resource and action. Different actions included sending reinforcements to nearby bases under attack or rebuilding damaged bases as well as retrieving raw materials. In addition to managing resources and fending off enemy attacks, the player also performed other tasks such as monitoring the state of his buildings and resources. There were 20 missions in this game and completing each one unlocked a higher level.

Arcade game – Fruit Ninja© (Halfbrick Studios). The game featured a variety of fruits flying in from several directions. The aim of the game is for the player to make quick finger swipes mimicking a slashing gesture on the fruits before they dropped to the bottom of the screen. Failure to do so for three times resulted in the game ending. Bombs also appeared which the player had to avoid slashing. If the player slashed a bomb, the game ended instantly. Points were awarded for each fruit slash and bonus points were given if several fruits were cut with one slashing motion. As the game progressed, the number of stimuli (fruits and bombs) as well as the speed at which they appeared increased. For this game, participants were instructed to enter their daily high scores in an online database. This served to monitor their daily gameplay and progress in the game.

Procedure

Participants performed all the executive function tasks in a computer lab. Participants were first briefed on requirements for the study. They were not briefed on the video games they were to play initially.

Following the briefing, participants performed computerized tasks. The order of the tasks was randomized to control for order effects. The time taken to complete all the experimental tasks was approximately 1 hour. After the participants completed the tasks, they were instructed to download one of the specified video games and play that game for the prescribed duration. After the training phase, they returned to repeat the same set of computerized tasks. The post-training sessions were conducted in the same order with the exception of debriefing and participant payment at the end of the study. Also, participants' portable gaming devices were checked to ensure that they indeed had downloaded and played the game assigned to them. Participants were not told beforehand that their devices would be checked.

Results

Data Analyses

Prior to data analyses, tasks that use RT as DVs were pre-screened for outliers. Specifically, in these tasks, all trials with RTs shorter than 200ms and longer than 3000ms were considered to be outliers and removed. Outliers were rare and amounted to less than 1% of data points in each task.

First, pre-training performances from all groups were compared to determine whether there were any pre-existing differences prior to training. Next, a mixed factorial ANOVA was then conducted to test for main effects and interactions. Since comparisons were planned in advance specifically to test the hypotheses stated earlier, these planned comparisons were made independent of whether significant interactions were detected in the omnibus *F*-tests.

This is consistent with that prescribed elsewhere (Howell, 1997; Tabachnick & Fidell, 2007; Wilcox, 1987). In the case of planned comparisons or where the comparisons are orthogonal, the α -value remains at .05 (Howell, 1997). However, where post-hoc comparisons are made or where the comparisons are not orthogonal, the α -value for statistical significance is adjusted for the number of comparisons made to control for Type-I error (Howell, 1997).

Flanker task. RTs from incompatible and compatible trials were first compared to determine if the flanker effect is achieved. Paired samples *t*-tests showed that participants were slower in incompatible (flanker incongruent) trials compared to compatible (flanker congruent) trials for pre, $t(51) = 4.23, p < .001$ ($M_{congruent} = 577.65\text{ms}$, $SEM = 25.87\text{ms}$; $M_{incongruent} = 618.37\text{ms}$, $SEM = 28.52\text{ms}$) and post training, $t(51) = 7.84, p < .001$ ($M_{congruent} = 496.91\text{ms}$, $SEM = 8.05\text{ms}$; $M_{incongruent} = 527.28\text{ms}$, $SEM = 8.79\text{ms}$). Separate paired sample *t*-tests by training groups revealed that this effect was consistent in all groups prior to and after training (all $ps \leq .016$)

The dependent variable of interest is the flanker compatibility effect (FCE) in RT. This was obtained by subtracting reaction times (RT) of compatible trials from incompatible trials. To ensure that different training groups had equivalent pre-training FCE, a between-subjects ANOVA was conducted. The ANOVA revealed that the groups' FCE prior to training was statistically equivalent, $F(3, 48) = .47, MSE = 2158, p = .71$.

A 2 (time: Pre and post-training) X 4 (training groups) X 2 (Gender) mixed ANOVA found no main effect of time, $F(1, 44) = 3.09, MSE = 2722.20, p = .086$, and time X group interaction, $F(3, 44) = .92, MSE = 809.02, p = .44$. Nevertheless, comparisons of compatibility effects for each group were conducted to determine if there were changes from pre to post training. The comparisons revealed no significant differences from pre to post training for the Modern Combat [$t(9) = .44, p = .669$, Cohen's $d = .18$], Fruit Ninja [$t(13) = .12, p = .904$, Cohen's $d = .04$], and Starfront Collision groups [$t(13) = .34, p = .742$, Cohen's

$d = .15$]. However, there was a significant pre-post reduction in compatibility effect in the Cut the Rope group [$t(13) = -2.23, p = .044$, Cohen's $d = 1.08$] (see figure 4.4).

In addition, pre and post training flanker compatibility effect in error rates were also conducted. This is to test whether the improvements in RT in the Cut the Rope group were achieved at the expense of an increase in errors. A 2 (time) X 4 (training groups) mixed ANOVA showed that the time main effect was not significant, Wilks $\lambda = .74, F(1, 48) = .006, p = .938$. Group X Time interactions were also not statistically significant, Wilks $\lambda = .99, F(3, 48) = .22, p = .88$. Although this is not part of the planned comparisons, we nevertheless proceeded to compare pre and post-training FCE in error rates for the sake of consistency. Paired t-tests conducted for each group indicate that none of the groups' FCE changed from pre to post-training (all $ps > .47$). Overall, this indicates that the improvements in FCE in the Cut the Rope group were not achieved at the expense of accuracy.

Figure 4.4. Pre- and post-training flanker compatibility effects for each training group. The asterisk denotes a statistically significant difference. Error bars reflect 95% CI.

Inhibition (Go/No-go task). The dependent variable of interest here is the false alarm rate (the rate of responding when a response should be withheld). We first conducted a

between subjects ANOVA to determine if the groups had equivalent performance in this task prior to training. The ANOVA revealed that the groups' false alarm rates were statistically equivalent, $F(3, 48) = .99$, $MSE = .043$, $p = .41$, prior to training.

A 2 (time) X 4 (training groups) X 2 (Gender) mixed ANOVA revealed that there was no significant time main effect, $F(1, 44) = 2.59$, $MSE = .08$, $p = .11$, or time X group interaction, $F(3, 44) = 1.43$, $p = .25$ on false alarm rate. Planned pair-wise comparisons revealed the Modern Combat [$t(9) = 1.16$, $p = .278$, Cohen's $d = .50$], Fruit Ninja [$t(13) = .27$, $p = .795$, Cohen's $d = .10$] and Starfront Collision [$t(13) = -.78$, $p = .449$, Cohen's $d = .31$] groups failed to significantly reduce false alarm rates from pre to post-training. Conversely, the Cut the Rope group had a significant reduction in false alarm rate from pre to post training [$t(13) = 3.153$, $p = .008$, Cohen's $d = 1.19$] (see figure 4.5).

A signal detection parameter C (Tanner & Swets, 1954) was also computed. This is an index for response bias and this index was compared between pre and post training for the Cut the Rope group. This was to determine if the reduction in false alarm was attributed to a change in response bias. The paired sample t -test indicated no significant change in response bias from pre to post-training, $t(13) = -.83$, $p = .422$. This suggests that the reduction in false alarms in the Cut the Rope group was not a result of a change to a more conservative response strategy.

Figure 4.5. Pre- and post-training false alarm rates for each training group. The asterisk denotes a statistically significant difference. Error bars denote 95% CI.

Task switching. The dependent variable of interest here is switch cost, which was calculated by subtracting the RT of non-switch trials from switch trials. In contrast to the alternate runs paradigm (e.g., Rogers & Monsell, 1995) where the number of switch and non-switch trials was fixed, switch and non-switch trials were intermixed randomly in this study. Hence, there was a possibility that each training group could have an unequal number of switch trials that would in turn affect performance. To check for this possibility, a 2 (time) X 4 (group) mixed ANOVA was ran which revealed no significant main effect of groups, $F(3,48) = .39$, $MSE = 39.59$, $p = .76$, or time, $F(1,48) = .45$, $MSE = 45.87$, $p = .51$. There was also no significant group X time interaction, $F(3,48) = .29$, $p = .84$. Hence, the groups did not differ in the number of switch trials, nor did the switch trials vary significantly from pre to post-training.

A paired-samples t -test revealed that participants were significantly impaired by task switching during pre-training, $t(51) = -13.01$, $p < .001$ ($M_{non-switch} = 889.18\text{ms}$, $SEM = 29.46\text{ms}$; $M_{switch} = 1181.53\text{ms}$, $SEM = 37.55\text{ms}$) and post-training, $t(51) = -12.84$, $p < .001$

($M_{non-switch} = 801.49\text{ms}$, $SEM = 19.46\text{ms}$; $M_{switch} = 1029.53\text{ms}$, $SEM = 26.05\text{ms}$). This effect of task switching was present for all groups for pre and post-training (all $ps \leq .004$).

A between-subjects ANOVA was conducted to evaluate whether switch costs differed between the groups prior to training. The ANOVA showed that switch cost before training is statistically equivalent between groups, $F(3, 48) = 1.46$, $MSE = 25578$, $p = .24$.

A 2 (time) X 4 (training groups) X 2 (Gender) mixed ANOVA was conducted to determine if training resulted in a reduction of switch cost. The analysis revealed a significant time main effect, $F(1, 44) = 12.54$, $MSE = 106771.77$, $p = .001$. There was no significant interaction found, $F(3, 44) = .23$, $p = .87$. Nevertheless, a comparison of pre and post-training switch costs between the groups was conducted, as these were planned comparisons pertaining to the study hypotheses. Comparisons for each training group revealed that the Modern Combat [$t(9) = -1.04$, $p = .324$, Cohen's $d = 0.47$], Fruit Ninja [$t(13) = -1.62$, $p = .129$, Cohen's $d = 0.47$] and Starfront Collision groups [$t(9) = -2.01$, $p = .065$, Cohen's $d = 0.77$] had no significant reduction in switch cost from pre to post-training. On the other hand, the Cut the Rope group significantly reduced switch cost as a result of training [$t(13) = -2.79$, $p = .015$, Cohen's $d = 1.31$] (see figure 4.6).

Figure 4.6. Pre- and post-training switch costs for each training group. The asterisk denotes a statistically significant difference. Error bars denote 95% CI.

To determine whether the reduction in switch cost in the Cut the Rope group was a result of making more errors in the switch condition, the switch cost in terms of error rate was entered into a 2 (Time) X 4 (Group) mixed ANOVA. The mixed ANOVA revealed no time main effect, Wilks $\lambda = .96$, $F(1, 47) = 2.21$, $p = .144$. All other main effects and interactions also failed to achieve statistical significance. Although there were no significant interactions, nor was the reduction in switch cost in error rates part of the planned comparisons, paired comparisons were nevertheless performed for each training group for the sake of consistency. Comparisons for each training group revealed that none of the groups changed in switch cost in error rates from pre to post-training (all $ps > .45$). Overall, this indicates that the reduction in switch cost in the Cut the Rope group is not achieved at the expense of making more errors or more haphazard responding.

Game Performance

Participants' game devices were checked to ensure that they had really played the game. In addition, their game progress was also recorded in the process. As these games, aside from Fruit Ninja, do not provide objective scores, we could not assess for pre vs. post gains in game performance. Furthermore, it was felt that as participants were familiarizing the game controls and objectives of the game at the start of the training, measuring performance at the start might not give a true account of their performance. Hence, we assessed participants' game proficiencies by taking their performance at the end of the study. For the Modern Combat group, players completed an average of 6.7 levels ($SD = 2.50$). For the Fruit Ninja group, as scores fluctuated from day to day, each player's last 5 five hours of training were averaged as a measure of their peak performance. Overall, players attained an average score of 221.56 ($SD = 92.10$). For the Cut the Rope group, players obtained an average of 139.79 stars ($SD = 60.88$). Finally, players that played Starfront Collision reached on average of 5.07 levels ($SD = 1.49$). The game performance was then correlated with

changes in performance from pre to post training for each of the transfer tasks to assess whether improvements depended on game performance. Overall, there were no significant correlations between game performance and performance change (all $ps > .10$).

Summary of key findings

Due to the large number of results and analyses, a summary of the key findings is presented here for clarity. Statistically significant improvements in the flanker, task-switching and Go/No-go tasks were only observed following training in Cut the Rope. All other training groups failed to show training-related improvements. These findings are discussed in depth in the following section.

Discussion

This study was designed with two questions in mind. First, the study examined if video game playing, especially with a game that demanded high level planning, strategizing and reframing could be used to improve higher-order executive functions. Second, the study determined if the executive function improvements resulted from a general or specific transfer.

To address the above questions, three executive control tasks were administered prior to and after video game training. The results consistently showed improvements in all three executive control tasks by only the group that was trained in Cut the Rope. All pre and post-test comparisons also yielded large effect sizes (J. Cohen, 1992). Below, the discussion first focuses on why specific transfer did not occur and speculate why Cut the Rope training resulted in broad improvements in all three tasks.

Specific Transfer

Behavioral tasks were chosen so that they had similar demands to the video games used for training. It was predicted that specific transfer would occur after training in Modern Combat and Starfront Collision to task switching because these games demanded rapid

switching of targets and tasks respectively. Additionally, it was predicted that training in Fruit Ninja would result in improvement in response inhibition as measured by the Go/No go task as both demanded inhibition of responses to task-irrelevant stimuli.

Task switching. No evidence of RT reduction in switch cost was found after playing Modern Combat. This is consistent with Boot et al. (2008) but contradicted previous studies showing action video game training related reductions in switch cost RTs (Colzato et al., 2010; Green et al., 2012; Strobach et al., 2012). Several possibilities may explain the failure to find evidence of transfer to random task switching from action video game training. One may be that the action video game used here was not demanding enough to train task switching. Another possibility is that the task switching paradigm was not sensitive enough to detect changes in RT after training. However, this second possibility is unlikely because the post-training changes were detected in the Cut the Rope group. Yet another possibility may be due to differences between the task switching paradigm here and the paradigm used in studies that have found action video game training benefits in task-switching (Green et al., 2012; Strobach et al., 2012). As mentioned, both previous studies used an alternate runs format for task switching. Such a format makes the switch predictable and less demanding (Monsell et al., 2003; Rogers & Monsell, 1995). Conversely, here, task switches were random, which made switches unpredictable and cognitively more demanding. This difference in task set-up may thus have contributed to the lack of action-game related transfer in switch cost. It has also been previously demonstrated that training in an action video game did not transfer to task switching paradigms that utilized random switches (Boot et al., 2008). This relates to the argument made earlier that perhaps due to the lack of demand to resolve and monitor perceptual and response conflicts in action video games, this skill is not trained. In contrast, it is possible that transfer to alternate and predictable task switching occurs with

action video game training because of the enhanced ability to predict upcoming task switches (Bavelier, Green, et al., 2012).

It was also predicted that playing a real-time strategy game that required switching between different activities in real time would lead to a reduction in switch cost. This hypothesis was not supported. The results contradicted an earlier study showing that training in a real-time strategy game improved task switching in older adults (Basak et al., 2008).

There are several possibilities to explain the failure to find evidence for transfer. First, in contrast to Basak et al. (2008), the sample here comprised of younger college-aged adults, who may have had a higher baseline than older adults. Hence, older adults starting at a lower baseline may have been more amenable to change compared to younger adults. Furthermore, we do not rule out that real-time strategy games may result in improved switch cost because the improvements in the real-time strategy game group were marginally non-significant ($p = .065$). Plausibly, a larger sample size would result in enough power to find a statistically significant improvement.

Another possibility is that like the action video game, the switch requirements between tasks in the game were not demanding enough to result in practice-related improvements. For instance, there was clear distinguishability between activities (e.g., defending one's home base and switching to sending reinforcements to another remote site and building another resource center) in the game so that switching frequently between them may not have resulted in response conflicts. Furthermore, there is ample time for the player to switch between activities within the game. This is unlike task switching where the stimuli-response mappings shared between different conditions may have resulted in response conflicts. Moreover, the switches were random and unplanned in task switching. These differences could plausibly have restricted transfer.

Go/No-go task. It was predicted that playing the arcade game, Fruit Ninja, would lead to improvements in response inhibition because within the game, there were frequent demands to inhibit responding to “bombs” amidst quick movements to slash fruits. This hypothesis was not supported. One possibility for the failure to transfer could be that the game was not as similar to the inhibition task as initially supposed. Although on the surface both draw on the ability to inhibit responding upon the onset on a cue, there were several differences between the task and game. In the game, although the time to slash at a target was limited, an instantaneous and speeded response was not required. In fact, there was added incentive to wait for the fruits that fly into the screen to line up and slash at them together, thus earning bonus points. Furthermore, the player still had to continue responding (but making a concerted effort to avoid the distractors) when distractors appear because the targets were still on-screen. Failure to respond had negative consequences within the game. This was unlike the inhibition task, where the participant had to make speeded consonant/vowel judgments, which built up response prepotency but actually had to stop when a lure appeared. Furthermore, in the arcade game, the distractors were highly distinguishable from the targets (“bombs” vs “fruits”) and were consistent throughout the game whereas in the inhibition task, the stimulus to be inhibited changed from block to block. This not only burdens working memory but conflicts also arise due to the prepotency to make a response.

Flanker task. The lack of improvement by the action video game group failed to corroborate previous studies that have shown an action video game advantage in top down distractor suppression (Chisholm et al., 2010; Chisholm & Kingstone, 2012). However, the current results corroborated findings in studies that that used a similar standard flanker paradigm (Cain et al., 2012; Irons et al., 2011).

One possibility for these contradictory findings in action video game effects on visual selective attention could be again due to the differences in experimental paradigms used.

Specifically, previous studies that found a positive relationship between action video game play and attentional filtering have used tasks where target and distractors were highly distinguishable in terms of location (central targets vs. peripheral distractors; Mishra et al., 2011) and physical characteristics [grey target vs. blue distractors (Chisholm & Kingstone, 2012); diamond target vs. circle distractors (Chisholm et al., 2010); red rectangle targets vs. blue rectangle distractors (see study 1)]. There were also consistent target-response mappings (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). Conversely, the studies that did not find such positive transfer results used varied mapping between the distractors and the targets. For example, Cain et al. (2012) used a flanker task where the items could either be targets or distractors depending on whether they appeared in the center or the at the periphery (left and right pointing arrows) and which varied from trial to trial. These results match previous claims (A. Cohen & Magen, 2005; Johnston, McCann, & Remington, 1995; Pashler, 1991) of two separate attentional systems that deal with input and response/action selection. Specifically, the lower level system deals with perceptual selection (input) while a higher-order executive function performs actions (A. Cohen & Magen, 2005; Johnston et al., 1995). Applied here, with easily distinguishable targets and distractors, it may be relatively easy to bias early visual attention to targets and ignore distractors at the input or perceptual level. However, when the targets and distractors compete for response selection, greater executive control is required for resolution of the response-conflict output. Thus, action video game playing may influence processes that govern early perceptual selection such that when targets and distractors are easily distinguishable they can be filtered out. This is akin to fast paced action video games where stimuli that must be ignored and attended to are highly distinguishable (such as teammates, static items and enemies that must be responded to). In contrast, there is little conflict in response selection (e.g., only enemies can be fired at and the

choice is to fire or not). The games that have consistent mapping may also lead to the automated development of filtering.

General Transfer

In contrast to action and the other video games, a short 20-hour training of a physics-based puzzle game Cut the Rope consistently improved performance in all three of executive function tasks: flanker, inhibition and task-switching. It is important to note that although significant interactions were not found in the omnibus *F*-tests to suggest differences in improvements between the groups, planned comparisons nonetheless showed that improvements from pre to post-training were not equivalent across training groups. Specifically, improvements to all three executive control tasks were limited only to Cut the Rope training. Plausibly, the sample size may be insufficient to detect a significant interaction. However, it is important to emphasize that the effect sizes (Cohen's *d*) for the improvements between pre and post-training were greater than 1, which indicate large effect sizes (J. Cohen, 1992). Given that the game demands were vastly different to the demands of the flanker, task-switching and inhibition tasks, improvements constitute a general rather than a specific transfer to executive functions.

The exact reasons for the improvement are unclear and I can only speculate at this point. First, it is worth noting that Cut the Rope is vastly different from the other games tested in the current experiment in that it demands a wide variety of higher level cognitive functions in support of deliberate and effortful planning required to play the game. Unlike the other games, players had time to mentally represent the challenging puzzle, formulate action plans and evaluate between them. These tasks likely taxed the central executive component of working memory. Next, after setting the plan into action, players had to revise ineffectual plans, especially when trying to get a higher score or more stars. Revision requires reevaluation of previous plans and may also have promoted executive flexibility.

Additionally, throughout the game there is a need constantly to resolve competition between several plans or strategies. These varied demands, persistent throughout the game are all instances that bring about high levels of control (cf. Shallice & Burgess, 1993). In contrast, the other games were fast paced, requiring quick and reflexive actions from moment to moment, which thus limited the opportunities for deliberate planning. Although strategy and planning were required in *Starfront Collision* as well, which was another candidate for general transfer, the fast pace of the game may not have allowed deliberate planning and strategizing. Furthermore, although the other games varied in terms of difficulty level, game mechanics and challenges remained relatively similar from level to level, unlike *Cut the Rope* which consistently varied game mechanics to force rethinking of previous strategies.

Second, there was great variation in *Cut the Rope* from level to level in terms of both difficulty and strategic demands. Each set of levels introduced new items that the player could use without explaining how these items could be used to achieve objectives. Furthermore, using items in several different ways increased controlled processing demands (cf. Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). Therefore, the novelty of levels, strategies and goals in each level of the game likely induced high demands for cognitive and executive control. Hence, these many variations in game difficulty, strategies and stimulus-response mappings may have led to greater learning and generalization to tasks outside of the game itself (see also Schneider & Chein, 2003; Slagter, Davidson, & Lutz, 2011).

Thus, *Cut the Rope* may have led to changes in cognitive and executive control networks in the brain that support complex problem solving and higher order executive functioning (Cole & Schneider, 2007). Among the regions in the network, frontal areas like the dorsolateral prefrontal and anterior cingulate cortices have been implicated in complex cognitive planning with various studies using a variety of neuroimaging methods (Crescentini, Seyed-Allaei, Vallesi, & Shallice, 2012; Dagher, Owen, Boecker, & Brooks,

1999; Gehring & Knight, 2000; Kaller, Rahm, Spreer, Weiller, & Unterrainer, 2011; Morris, Ahmed, Syed, & Toone, 1993; Owen & Evans, 1996; Unterrainer et al., 2004). These neuroimaging studies are complemented by neuropsychological studies with patients with frontal lobe damage who showed impairments in planning and problem solving. Specifically, using the Tower of London tests, patients with frontal lobe dysfunctions showed marked difficulties in planning ahead (Owen et al., 1995), made more moves to solve problems (Carlin et al., 2000), had longer planning (Cockburn, 1995) and solution times (Carlin et al., 2000; Owen, Downes, Sahakian, Polkey, & Robbins, 1990). Although these neuropsychological and neuroimaging studies have mainly used the Tower of London as a measure of planning, similar executive functions may be involved in complex planning and problem solving. These are in turn supported by executive functions like task-switching, inhibition, conflict monitoring as well as working memory. In line with this, the prefrontal and anterior cingulate cortices, among other areas of the cognitive control network important for planning and decision-making, were shown to be important for executive functions seen in the tasks used in this study. For example, neuroimaging evidence pointed towards a link between activations in dorsolateral prefrontal and anterior cingulate cortices, among others, in executive functions tested here such as conflict resolution and suppression of task-irrelevant information in flanker-like tasks (Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999; Bunge et al., 2002; Casey et al., 2000; Van Veen & Carter, 2002; Yamaguchi, Toyoda, Xu, Kobayashi, & Henik, 2002), inhibitory processes in go/no-go tasks (Braver, Barch, Gray, Molfese, & Snyder, 2001; Bunge et al., 2002; Casey et al., 1997; Garavan, Ross, Li, & Stein, 2000; Horn, Dolan, Elliott, Deakin, & Woodruff, 2003; Liddle, Kiehl, & Smith, 2001) and task-switching (Dove, Pollmann, Schubert, Wiggins, & von Cramon, 2000; Ravizza & Carter, 2008). Thus, playing Cut the Rope, a complex cognitive planning game, may have led

to changes in overlapping areas in this network which then accounted for the improvements in various executive functions (Dahlin et al., 2008).

Another possibility regarding the consistency of improvements across all three tasks by Cut the Rope may also be attributed to the common elements between these executive function tasks (Friedman & Miyake, 2004; Miyake et al., 2000). These common elements are hypothesized to be working memory capacity or inhibitory control (Miyake et al., 2000). Accordingly, working memory constitutes control processes involved in goal maintenance, suppression and resolution of conflicts or distracting information in service of a goal (Engle, Laughlin, Tuholski, & Conway, 1999; Kane & Engle, 2002). It has also been suggested that that executive function tasks require inhibitory control processes such as ignoring irrelevant information that is no longer valid or useful and deactivating or suppressing an old mental set in task-switching (Miyake et al., 2000; Monsell, 2003). These suggestions have generally received empirical support. As an example, it has been shown that high working memory capacity individuals are better able to inhibit various forms of interference in service of a goal compared with those with low working memory capacity (Conway, Cowan, & Bunting, 2001; Conway & Engle, 1994; Kane et al., 2007; Kane & Engle, 2000; Kane & Engle, 2003). Furthermore, neuroimaging studies have implicated the anterior cingulate and dorsolateral prefrontal cortices, commonly activated in all three executive tasks used in the current study as areas important for response inhibition (Braver et al., 2001; Kopp, Rist, & Mattler, 1996) and monitoring of conflict (Carter, Braver, Barch, & Botvinick, 1998). Hence, the consistency in improvements in all these tasks could be due to the commonalities shared between all three tasks performed by participants.

Limitations of the Current Study

It is important to highlight some limitations so that the results can be placed in the proper context. First, although participants' handheld device were checked to ensure that

there was some game progress, and that participants also self-reported that they adhered to the number of hours prescribed for gameplay, there was little control over the time participants actually spent playing the game. However, we can be reasonably confident that participants spent time in playing the games as most of them showed a relatively high level of attainment in the games that is arguably hard to achieve if they had only played the games minimally. Furthermore, participants were not told beforehand that their game device would be checked. As mentioned, their devices were checked during the post-test sessions and all were verified to have installed and played the game.

Second, it is plausible that the different demands of the games may also have led to different expectations on whether or not participants would improve in the transfer tasks (Boot, Simons, Stothart, & Stutts, 2013). Although expectations were not explicitly measured, it is unlikely that the results were affected by differing expectations. The reason for this is that the only improvement was seen in Cut the Rope training. Arguably, on face value, the demands in Cut the Rope are quite different from the demands to the tasks unlike the other games. The fact that other games with closer demands with the transfer task did not result in transfer shows that differing expectations, even if they exist, would not have confounded the results. Furthermore, even if participants were cognizant of the current trends in video game research as suggested by Boot et al. (2011), they would have expected improvements as a result of action game training only. This was not evident in the current study as the action game trained group showed no improvements. Hence, it is unlikely that differing expectations or placebo effects might have accounted for the findings here.

However, it is important to acknowledge that there are some differences in how engaging the games are and this may led to some participants being more motivated during training. Hence, future studies, aside from measuring expectations, could also assess for participants' engagement with the training task (Boot et al., 2011).

Finally, as mentioned previously, an intractable problem currently within the field of video game studies is that there are no clear objective measures of the actual demands required for gameplay and transfer. Therefore, it is acknowledged that a limitation is that the study conducted here are informal and subjective descriptions of the possible demands in the games, similar to that elsewhere (J. E. Cohen et al., 2007; Spence & Feng, 2010).

Conclusions

This study demonstrated that higher-order executive function skills were improved by 20 hours of training on a physics-based puzzle game, *Cut the Rope*. The results here, taken together with others, therefore provide evidence that video games can be a potentially effective tool for training human cognition. Whereas previous studies have shown that action video games can lead to perceptual and attentional improvements, the current results expand the type of cognitive enhancements detected by demonstrating that a physics based puzzle game played on a hand-held device improves a variety of distinct executive control functions. We speculate that these executive improvements represent a generalized transfer stemming from the frequent demands to strategize, plan and reframe in a complex and varied puzzle game. However, as the other games that failed to transfer might have been more different from the laboratory executive tasks than initially thought, we do not rule out that training in games that contain more similar demands to resolve response conflict above might eventually result in transfer.

To our knowledge, this is a first attempt at showing a puzzle game that demands strategizing, reframing and planning leads to transfer of various executive control skills. Although previous studies (Boot et al., 2008; Green & Bavelier, 2003) have utilized puzzle games as comparison, these puzzle games were highly repetitive and without the need for new strategies as well as reframing (e.g., Tetris). Training using repetitive puzzle games does lead to transfer but is more limited to specific skills sets demanded by the game like mental

rotation (Boot et al., 2008; Okagaki & Frensch, 1994). Furthermore, the puzzle game used here required changing strategies every level, which is a unique feature not found in many games. This varied form of training may promote more general transfer compared to games that are more constrained in terms of variability. Such variability perhaps led to more general transfer in cognitive flexibility rather than more specific forms of transfer that is seen in other video game types that fostered more task-specific learning (cf. Schmidt & Bjork, 1992).

Beyond the laboratory, a logical application of our findings would be in groups that may face an acute need for executive functioning improvements. One such group is the elderly. Although action video games benefit many aspects of cognition and perception, older adults may be put off by the violent theme and fast reactions and optimal visual perceptual skills needed to play them (McKay & Maki, 2010; Nap, Kort, & Ijsselstein, 2009). In contrast, older adults may find puzzle-type games more appealing and thus be more motivated to comply with a puzzle game training regime (Boot, Champion, et al., 2013; Pearce, 2008). Another group that may benefit from training games such as that used here may be adolescents and children, especially those who have executive functioning deficits such as those with attention-deficit hyperactivity disorder (ADHD) (cf. Barkley, 1997). However, given the possible link between video game violence and childhood aggression (C. A. Anderson et al., 2003; C. A. Anderson & Bushman, 2001), we should exercise caution when encouraging young children and adolescents to play fast paced violent action video games. In contrast, specific types of puzzle games, like *Cut The Rope*, may be a more suitable alternative without the violent themes.

In closing, as the efforts here are a first attempt demonstration of cognitive benefits from playing a specific type of puzzle game, further replications are encouraged; especially given the vast varieties of puzzle games available. Additionally, it is also important to investigate what specific aspects are important for transfer. Furthermore, as the theory

regarding the mechanisms of transfer in this study are tentative, we encourage further endeavors to determine its validity as well as to explore alternative mechanisms underlying these transfer effects. As the end goal of such cognitive interventions is to benefit activities in the real world, there is a need to determine if such training-related improvements are generalizable beyond the laboratory. Given that executive functioning skills underpins many areas of our lives whether in occupation, social or educational settings (Diamond, 2013), future efforts aimed at improving these critical abilities are surely worthwhile.

CHAPTER 5: GENERAL DISCUSSION

What The Results Here and Elsewhere Tell Us About the Mechanism of Training-Related Transfer.

Although several lines of research suggest video game training related transfer to different perceptual and cognitive tasks, the mechanisms of transfer are not well understood. Based on the evidence reviewed, I proposed that video game related transfer is limited to skills frequently practiced within the video game itself. Hence, prolonged video game play allows the practice and honing of those skills, which in turn transfers to laboratory tasks that share common demands. This draws upon theories proposed that transfer is more likely to occur if two tasks (i.e. learning and transfer task) share similar elements and processing/cognitive demands (Graf & Ryan, 1990; Thorndike & Woodworth, 1901) or tap on common brain regions (Dahlin et al., 2008).

The purpose of this dissertation is therefore to further test the proposed common demands hypothesis. The main argument made here is that if transfer depended on the close match between trained video game and transfer task, non-action game playing should also transfer to skill(s) that are common with the transfer task.

In study 1, participants were tested on various transfer tasks after they had trained in one of four different video games that had different cognitive demands. The results showed that transfer effects of different games were limited to tasks that shared identical elements/demands with the trained game. Specifically, action video game training transferred to tasks that shared identical demands like attending to multiple objects, selective attention and the attentional blink. These results corroborated previous works. Additionally, games that trained spatial working memory and visual search improved performance in tasks that demanded these abilities respectively. In contrast, no transfer was evident where the game and transfer task did not contain similar demands. For example, there was no evidence of

action video game training transfer to spatial working memory or to visual search skills. Moreover, transfer to selective attention, multiple object tracking and attentional blink did not occur with training in games that demanded exclusively search skills or spatial working memory. Study 1 thus showed the specificity of transfer effects that depended on common demands between the trained game and transfer task. This specificity of transfer is evident in both action and non-action video games.

If transfer depends on common demands between the trained game and transfer task, we should also expect different transfer effects between action video games with varying demands. As a further validation of the common demands hypothesis, study 2 investigated transfer effects resulting from different action games that varied in the demands and the intensity of the demands. These games had different demands in terms of speed, the need to switch attention rapidly and attend to multiple objects. Specifically, training in a fast paced first-person shooter (Modern Combat) that frequently required the attending of multiple targets, selective attention and quick attentional switches enhanced performance in multiple object tracking and the attentional blink. Additionally, the results indicate that even if two games share common demands in the need to switch attention from target to target rapidly, but differ in its intensity, the transfer effects are dissimilar. Specifically, training in Modern Combat reduced the attentional blink at the earlier and most attentionally demanding lags whereas a slower paced third-person shooter that allowed more time to switch attention rapidly resulted in transfer to later less-demanding lags. As a further validation of task-specific and modality-specific transfer, no transfer was evident in visual search and auditory-based detection respectively in any of the training groups. These results further corroborate the hypothesis that game demands must closely mimic the transfer task in order for training-related transfer to occur.

The common demands hypothesis

The results from studies 1 and 2 taken together provide empirical support for the common demands hypothesis and suggest that transfer of lower level information processing and perceptual skills depend on a close match in demands between the trained video game and the transfer task (see Figure 5.1 left panel). This is especially so for transfer tasks that does not require resolving response conflicts like in the EF tasks tested in Study 3. From the review of the literature and from the results shown in studies 1 and 2, these skills include visual search, visual perceptual skills (e.g., peripheral vision), selective attention and multiple object tracking. Furthermore, the common demands hypothesis makes the claim that more intense demands should lead to greater gains compared to training regimes that contain similar but less intense demands. This was exemplified by the results in Study 2 where less intense demands in attentional switch in MGS Touch led to transfer to later lags (lags 3-5) of the attentional blink task (see long dash line in left panel of Fig. 5.1). Furthermore, Tetris training-related transfer to mental rotation (Basak et al., 2008; Sims & Mayer, 2002) further adds to the common demands hypothesis. Further validation of such transfer-specificity is that with Tetris training, improvements are not to mental rotation in general but limited only to rotation of shapes similar to those encountered in Tetris (Basak et al., 2008; Sims & Mayer, 2002).

General EF transfer

Given the specificity of training effects, it is perhaps unsurprising to find equivocal evidence with regards to enhancement of higher order information processing skills from video game training (Bialystok, 2006; Boot et al., 2008; Colzato et al., 2013). This is especially so in tasks that requires the resolving of conflicts at the response level such as random task switching or flanker tasks. In line with the hypothesis of common demands, I argue that unlike lower level perceptual and attentional skills, higher-level executive

demands to resolve conflicts are not frequently encountered in many video games that are currently studied.

To test the theory of whether frequent executive demands are sufficient to bring about executive function transfer, study 3 involved testing the transfer effects in different games with specific executive demands. The games tested included an action video game, a real-time strategy game and an arcade game. In addition to these games that had specific demands to executive functions, study 3 also included a puzzle game that included high-level problem solving, planning, strategizing and reframing demands. Although other studies have used puzzle games (Boot et al., 2008; Strobach et al., 2012), no other studies have included such a game with all of these demands as a comparison. The puzzle game used in other studies is Tetris and these studies have shown that Tetris does not transfer to executive function skills. Rather, the transfer as a result of Tetris training is more limited to mental rotation (Boot et al., 2008; Okagaki & Frensch, 1994).

The results in study 3 demonstrated that training in the puzzle game, Cut the Rope led to general and broad transfers to task-switching, stimulus-response interference and inhibition. In contrast, no transfer to any executive functions is seen from any other games. To my knowledge, this is the first investigation to show such a broad transfer to different executive functions by training in a puzzle game that had varied planning and strategizing demands.

A Dual-route of Transfer?

In light of the results here, two separate routes of transfer may account for the transfer effects to lower and higher-level information processing skills. First, transfer of more specific low-level visual perceptive and cognitive skills may depend on frequent practice in games that are more focused and specific that share similar demands with the transfer task (Figure 5.1 left panel). Conversely, transfer of top-down executive control skills involving conflict

resolution and monitoring may require training of generalized strategizing and planning skills (Figure 5.1 right panel). Training of strategizing and planning may be afforded by games that demand high level problem solving skills and that offers variability so as to prevent process or task-specific learning. This is a novel hypothesis and further replication is needed.

Interestingly however, consistent with this hypothesis, results from a recent research outside the video game literature demonstrated that strategy and reasoning training improved response inhibition (Motes et al., 2014).

Figure 5.1. A framework for the Dual Route Transfer Hypothesis. Examples given here using actual video game genres/titles (Action video game, Tetris and Puzzle game) but is not meant to be exhaustive, with other genres left out. The left and right panel depicts transfer based on common demands and general EF respectively. Dotted line denotes transfer that shown to be dependent upon intensity of the game (e.g, MGS Touch transfer to later lags of the Attentional Blink). Long dash line denotes a test for double dissociation – whether training in puzzle games transfer to tasks that assess for lower level perceptual and cognitive skills.

The differential transfer effects afforded by different games with different demands have key practical benefits in different settings. If the goal is to train specific low-level visual-perceptive or attentional skills, one could choose games/training tasks that are closely

matched in terms of its demands to the transfer setting. Conversely, training in high-level problem solving skills that is highly varied may benefit the transfer in terms of executive function skills. Hence, one could choose and tailor the training based on the area of need in different areas of occupation or education.

Concluding Remarks and Future Research

It is important to note that although the theory suggested here is consistent with the current data in video game literature, it is novel and represents only a first step in accounting for video game related transfer. Hence, further validation and refinement of this theory is warranted. Nevertheless, the common demands hypothesis suggested above provides a testable theory for future research. For instance, one could design different games with different intensities of the same demand (e.g., change detection) and compare their range of transfer to laboratory tasks with the same demands. This approach is similar to Study 2, but a key difference is that rather than have commercial games in which investigators have no control over the demands, laboratory designed games afford investigators the ability better isolate demands necessary for gameplay.

As for general transfer, additional corroborating evidence is also needed. One approach might be to test other types of puzzle games that are similar to Cut the Rope that allow for deliberate planning and problem solving to determine the range of transfer to executive functions. To further distinguish transfer from specific to general, one could also test whether training in these puzzle games transfer to lower level perceptual and attentional skills. This approach thus allows us to establish a “double-dissociation” and add further evidence to the dual-route of transfer (see long dash line in Figure 5.1).

In addition to the above, several questions remain unanswered. First at the specific-transfer level, based on common elements between game and transfer task, it remains unclear how “closely-matched” the game and transfer task ought to be to maximize transfer. One

possibility may be that the demands of the training game and transfer task must engage common neural networks (Dahlin et al., 2008). Thus far, I have argued that the games used here that show such specific transfer are qualitatively similar. In other words, quantitative metrics of how close a training game and the transfer task remains elusive and is worthy of further investigation. A quantifiable metric would be most useful especially in occupational settings where this metric can guide in the design of a training task/game to maximize transfer effects. For instance, in first-person shooters, one could compare games with varying speeds of which enemies appear or the number of enemies that appear simultaneously. These differences could then allow us to determine whether transfer effects from playing these games are equivalent. However, as mentioned earlier, this issue is non-trivial and remains an intractable problem within the field of video game training. This is unlike working memory training and “brain” training games designed specifically for training whereby demands can be adjusted to match as close as possible to transfer tasks. Hence, development of ways to objectively measure demands in a video game would be a major advance within the field.

Second, it remains plausible that not all cognitive and perceptual abilities can be enhanced with training. Currently, it remains unclear why some abilities are more resistant (e.g., multitasking) or amenable to change following training. Although it was shown here that lower-level attentional and perceptual abilities and higher-order executive functions might transfer via different routes, it is still plausible that not all cognitive and perceptual abilities can be improved via these different routes of transfer. Future research could thus identify which abilities can or cannot be trained. Further research could also elucidate why transfer does not occur with those skills.

Third, regarding general transfer to top-down executive functioning, it also remains to be seen if different games with high-level problem solving demands can also improve different aspects of executive functions and problem solving skills in tasks like the Tower of

London or even in tasks beyond the laboratory setting. With increasing computing power and artificial intelligence, one possibility may be that future games can alter gameplay and demands based on the response of the player. Hence, such games may be even more varied and demanding in problem-solving requirements, which in turn may lead to greater and more generalized transfer. Another possibility is that future games offer a hybrid of specialized low-level visual-perceptive and cognitive demands as well as high-level problem solving demands that may train several abilities at the same time. Investigations of transfer effects using such games may thus have even greater applications outside of the laboratory.

A fourth area of future research is with the retention of the transfer effects. Thus far, video game studies in the literature have not tested whether the transfer effects remained after the laboratory testes have concluded (see Li et al., 2009 for an exception). Arguably, a main goal of a training task is the retention of skills in the long term after the training had ceased (Schmidt & Bjork, 1992). Hence, as with any training, the effectiveness of video game training should also be evaluated with this criterion.

Finally, an important area that is worthy of future investigation in relation to video game training studies is with individual differences in training-related transfer. It has been argued that the capacity for “cognitive modifiability” as a result of training varies from individual to individual (Calero & Navarro, 2007). It is thus unlikely that all individuals trained with a similar video game improve similarly (e.g., Wu et al., 2012). There are many factors that can influence plasticity and how well one responds to a training regime. Briefly, some examples of individual differences shown to influence training, cognition and transfer include age and baseline cognitive ability (Bissig & Lustig, 2007; Calero & Navarro, 2007; Verhaeghen, Marcoen, & Goossens, 1992; Yesavage, Sheikh, Tanke, & Hill, 1988; Yesavage, Sheikh, Friedman, & Tanke, 1990), gender (Feng et al., 2007) as well as lifestyle factors such as cardiovascular health and exercise (Gomez-Pinilla, 2008). Thus far, video

game training studies have not examined how these individual differences affect training-related transfer. Hence, studying of individual differences is worthwhile as it can be critical for the implementation of a training regime to maximize transfer effects.

In closing, over the last decade, we have seen considerable literature documenting the potential benefits of video game training. With this increased attention and effort dedicated to this area, intense debate, skepticism and scrutiny have also resulted (Boot et al., 2011; Boot, Simons, et al., 2013; Kristjánsson, 2013). Nevertheless, such intense debate and scrutiny can only be beneficial to researchers as they strive to refine the methodology of video game training research.

Despite the growing number of works and considerable progress, I consider the field to be still in its infancy and substantial advances are still to be made. As mentioned at the start of this dissertation, there are many advantages with training via a video game. Training via video game represents a departure from traditional learning activities in that it is highly arousing and motivating and has the potential to keep the player engaged for longer periods. Although across many skills, transfer is limited to similar components shared between the game and task, some skills (e.g., spatial ability) are nonetheless important for many daily activities such as science learning (Sanchez, 2012). With progress in computing power and artificial intelligence, there are arguably major leaps that can be made in game immersion and realism. Additionally, with input from psychologists and learning theory in video game design, we can further tailor video games for learning purposes. Hence, further investments in time and money to understand, research and improve transfer from video game training to the work place, classroom and rehabilitation is surely worthwhile.

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