Psychological Research (2013) 77:234–239
DOI 10.1007/s00426-012-0415-2

ORIGINAL ARTICLE

Action video gaming and cognitive control: playing first person shooter games is associated with improvement in working memory but not action inhibition

Lorenza S. Colzato · Wery P. M. van den Wildenberg · Sharon Zmigrod · Bernhard Hommel

Received: 28 November 2011 / Accepted: 10 January 2012 / Published online: 22 January 2012

Abstract The interest in the influence of videogame experience in our daily life is constantly growing. "First Person Shooter" (FPS) games require players to develop a flexible mindset to rapidly react and monitor fast moving visual and auditory stimuli, and to inhibit erroneous actions. This study investigated whether and to which degree experience with such videogames generalizes to other cognitive control tasks. Experienced video game players (VGPs) and individuals with little to no videogame experience (NVGPs) performed on a N-back task and a stop-signal paradigm that provide a relatively well-established diagnostic measure of the monitoring and updating of working memory (WM) and response inhibition (an index of behavioral impulsivity), respectively. VGPs were faster and more accurate in the monitoring and updating of WM than NVGPs, which were faster in reacting to go signals, but showed comparable stopping performance. Our findings support the idea that playing FPS games is associated with enhanced flexible updating of task-relevant information without affecting impulsivity.

L. S. Colzato · S. Zmigrod · B. Hommel
Cognitive Psychology Unit, Leiden Institute for Brain and Cognition, Leiden University, Leiden, The Netherlands

L. S. Colzato (✉)
Department of Psychology, Cognitive Psychology Unit, Leiden University, Wassenaarseweg 52, 2333 AK Leiden, The Netherlands
e-mail: colzato@fsw.leidenuniv.nl

W. P. M. van den Wildenberg
Psychology Department, Amsterdam Center for the Study of Adaptive Control in Brain and Behaviour (Acacia), University of Amsterdam, Amsterdam, The Netherlands

Introduction

The video game industry has seen a rapid growth over the recent years, as has the interest in the influence of videogame experience on people's daily life. Game developers and designers keep reinventing the world of videogames by introducing new types of game play and new methods to enhance the gaming experience. Violent video games have often been a hot topic of debate in our society, mainly surrounding the topic of whether aggressive content in such games stimulates aggressive behavior in the players.

Recently, there has been an increasing interest in the possible cognitive benefits that playing video games may have on players. Green and Bavelier (2003) conducted a series of experiments on the effects of video game playing on visual attention comparing video game players (VGPs) and non-video game players (NVGPs) on a flanker compatibility task, an enumeration task, and a useful field of view task. The results suggested that video game playing experience enhances the capacity of the players' visual attentional system.

Consistent with this idea, VGPs have been reported to show better performance in both easy and difficult visual search tasks (Castel, Pratt, & Drummond, 2005) and a more efficient distribution of visuo-spatial attention capacity (Green & Bavelier, 2006b), to exhibit a general increase of visual acuity across all eccentricities tested (Green & Bavelier, 2007), and to show an increment in the number of objects that can be apprehended (Green & Bavelier, 2006a).

Surprisingly, however, so far only few studies have investigated whether and to which degree experience with videogames generalizes to cognitive control, that is, to people's capacity to control their thoughts and goal-directed behavior. In one recent study, VGPs and NVGPs [all playing first person shooter (FPS) games] performed on a task switching paradigm that provides a relatively well-established diagnostic measure of cognitive flexibility (Colzato, van Leeuwen, van den Wildenberg, & Hommel, 2010). VGPs showed smaller switching costs (i.e., greater cognitive flexibility) than NVGPs supporting the idea that playing FPS games is associated with increased cognitive flexibility. In line with these results, Karle, Water and Shedden (2010) and Boot, Kramer, Simons, Fabiani and Gratton (2008), using different paradigms, found VGPS to switch faster between tasks. However, the ability to shift between tasks and mental sets represents just one of a larger set of control functions. In particular, Miyake et al., (2000) have suggested the existence of three major, separable control functions: the "shifting" between tasks and mental sets (also called "flexibility"), the "inhibition" of unwanted responses, and the "updating" (and monitoring of) working memory (WM) representations.

The goal of the present study was to test the hypothesis that FPS gaming is associated with a general and generalizable enhancement of cognitive control. Given Colzato et al.'s (2010) demonstration that FPS players were associated with greater cognitive flexibility, which covers the first cognitive control factor considered by Miyake et al. (2000), we tested whether playing FPS is also linked with increased levels of efficiency regarding response inhibition and WM updating—the other two cognitive control functions.

Indeed, the new generations of FPS (compared to strategic) games are not just about pressing a button at the right moment but require the players to develop an adaptive mindset to rapidly react and monitor fast moving visual and auditory stimuli, and to inhibit erroneous actions as shooting team mates instead of enemies. If so, more extensive experience with video games could be associated with better performance on a task that requires the monitoring and updating of WM, such as the N-back task (Kane, Conway, Miura, & Colflesh, 2007, for a recent review), and on a task that requires behavioral inhibition, such as the stop-signal task (Logan & Cowan, 1984). In the N-back task, participants are to decide whether each stimulus in a sequence matches the one that appeared *n* items ago, which requires the on-line monitoring, updating, and manipulation of remembered information. In the stop-signal task, participants are first presented with a stimulus (i.e., a go signal) prompting them to execute a particular manual response, and this stimulus may or may not be followed by a stop signal calling for the immediate abortion of that response. Based on the mathematical considerations formulated by Logan and Cowan (1984), the stop-signal paradigm provides a direct behavioral assessment of the individual ability to stop a planned or ongoing motor response in a voluntary fashion and a quantitative estimate of the duration of the covert response-inhibition process (i.e., stop-signal reaction time or SSRT). If playing FPS games would indeed be associated with more efficient monitoring and updating of WM and higher inhibitory efficiency, VGPs should be more accurate in the N-back task and should show shorter SSRTs in the stop-signal task than NVGPs.

Methods

Participants

Fifty-two young healthy adults (48 men and 4 women) were compensated for their participation. They constituted the two groups of 26 VGPs and 26 individuals with little to no video game experience (NVGPs). The sample was drawn from 100 adults, who volunteered to participate in behavioral studies. Following Clark, Fleck and Mitroff (2011), participants filled in a video game questionnaire, as part of a large test battery, that assessed their familiarity with several video game genres (e.g., FPS, role-playing, puzzle) over several time frames. Their responses were used to classify them as VGPs, NVGPs, or "neither" (participants who did not fully qualify as either VGP or NVGP were not included in this study). According to Boot, Blakely and Simons (2011), such covert recruitment strategy is ideal to avoid the possibility that expectations and motivation drive VGPs/NVGPs differences in cognitive tasks. VGPs met the following criteria: play action video games at least 5 h a week for a minimum period of 1 year. Subjects playing web-based puzzle and role-playing games were excluded. VGPs played on multiple platforms (PC, Xbox, Playstation and Nintendo). VGP's participating in the study played only FPS games, such as Call of Duty: Modern Warfare, Unreal Tournament, Half-Life 2, Battlefield, and Grand Theft Auto IV. All of these games are situated in a 3D environment and require frequent updating between multiple tasks and stimuli. Participants with no action video game experience and little to no experience with other video games were classified as NVGPs.

A week after the completion of the test battery, based on the results of the questionnaire, the participants classified as VGPs and NVGPs, but not "neither" ($n = 28$), were invited to take part in the testing session, without revealing them why they were being recruited. Demographic statistics are provided in Table 1. Written informed consent was obtained from all participants after the nature of the study was explained to them. The protocol and the remuneration arrangements of 6.5 Euro were approved by the institutional review board (Leiden University, Institute for Psychological Research).

Apparatus and stimuli

The experiment was controlled by a PC attached to a 17-inch monitor (96 dpi with a refresh rate of 120 Hz). Participants were seated approximately 0.5 m from the screen.

Table 1 Demographic characteristics, mean stop-signal RT (SSRT) and mean RTs on go trials in milliseconds for the stop-signal task and means responses latencies (ms), accuracy, hits, correct rejections, false alarms and misses (in percent) for the N-back task for VGPs and NVGPs

Variables (SE)	VGPs	NVGPs
N (M:F)	26 (24:2)	26 (24:2)
Age	22.6 (4.5)	23.6 (3.2)
Fluid intelligence	110 (3.8)	108 (4.2)
Stop-signal task		
Mean stop-signal RT (SSRT)	209 (7.5)	206 (7.5)
Mean RTs on go trials*	389 (10.7)	421 (10.7)
N-back (WMmonitoring/updating)		
1-back		
Reaction times* (ms)	432 (10.4)	477 (10.4)
Accuracy* (%)	94 (1.2)	88 (1.2)
Hits (%)	37.6 (0.5)	36.2 (0.5)
Correct rejections* (%)	57.0 (1.1)	53.7 (1.1)
False alarms* (%)	3.0 (1.0)	6.3 (1.1)
Misses (%)	3.4 (0.5)	4.8 (0.5)
2-back		
Reaction times* (ms)	475 (10.5)	518 (10.5)
Accuracy* (%)	89 (1.6)	80 (1.6)
Hits* (%)	35.1 (1.0)	31.3 (1.1)
Correct rejections* (%)	54.7 (1.0)	51.0 (1.1)
False alarms* (%)	5.5 (1.0)	9.5 (1.0)
Misses* (%)	6.0 (1.1)	9.8 (1.1)

Standard errors of the mean are presented in parentheses

Significant group difference; * $p < 0.05$

Procedure

All participants were tested individually. Participants performed the stop-signal task (30 min), the N-back task (15 min) and completed the SPM (Standard Progressive Matrices; Raven, 1988). Participants were allowed to take a short break (maximal 5 min) between tasks.

Stop-signal task (inhibitory control)

The experimental session took about 30 min, in which participants completed a version of the stop-signal task adopted from Colzato, van den Wildenberg and Hommel (2007). Each trial began with the presentation of an arrow pointing to the left or right (with a probability of 50% each). Arrows were presented pseudorandomly, with the constraint that they often signaled left- and right-hand responses equally. Arrow presentation was response-terminated. Intervals between subsequent go signals varied randomly but equiprobably, from 1,250 to 1,750 ms in steps of 125 ms. During these interstimulus intervals, a white fixation point (3 mm in diameter) was presented. The green arrow changed to red on 30% of the trials, upon which the choice response had to be aborted (stop trials). A staircase-tracking procedure dynamically adjusted the delay between the onset of the go signal and the onset of the stop signal to control inhibition probability (Levitt, 1971). After a successfully inhibited stop trial, stop-signal delay in the next stop trial increased by 50 ms, whereas the stop-signal delay decreased by 50 ms in the next stop trial when the participant was unable to stop. This algorithm ensured that motor actions were successfully inhibited in about half of the stop trials, which yielded accurate estimates of SSRT and compensates for differences in choice RT between participants (Band, van der Molen, & Logan, 2003).[1] SSRT was computed according to the integration method described by Logan and Cowan (1984). The parameters of our task version, such as the number of trials and the percentage of stop-signals, were chosen to yield a reliable estimate of stop-signal RT according to the computer simulations of Band et al. (2003). The stop task consisted of five blocks of 104 trials each, the first of which served as a practice block to obtain stable performance.

N-back task (WM monitoring)

Participants performed two N-back tasks adopted from Colzato, Huizinga and Hommel (2009a) consisting of the sequential visual presentation (stimulus onset asynchrony 2,000 ms; duration of presentation 1,000 ms) of single letters (B, C, D, G, P, T, F, N, L). Participants responded to targets (presented in 33% of the trials) and to non-targets. Half of the participants pressed the left shift-key in response to a target and the right shift-key in response to a non-target, while the other half of the participants received the opposite mapping. Target definition differed with respect to the experimental condition. In the 1-back condition, targets were defined as stimuli within the sequence that were identical to the immediately preceding one. In the 2-back condition, participants had to respond if the presented letter matched the one that was presented two trials before. The 1-back and 2-back tasks differ in their amount of memory load and demands on executive control for the processing of information within working memory. RTs were analyzed for correct responses only. Each block consisted of four cycles of the same task; each cycle comprised of 32 stimuli.

Fluid intelligence

Individual fluid intelligence was estimated by means of a 30-min reasoning-based intelligence test (Raven Standard

[1] Note that the staircase method that we used allowed separating SSRT from the general RT level, which ensures that the former cannot be explained on the basis of the latter.

Progressive Matrices: SPM). The SPM assesses the individual's ability to create perceptual relations and to reason by analogy independent of language and formal schooling; it is a standard, widely used test to measure Spearman's g factor as well as fluid intelligence (Raven, 1988). Participants completed the SPM and subsequently performed on the behavioral tasks measuring inhibitory control and WM updating.

Statistical analysis

First, independent samples *t* tests were performed to compare age and fluid intelligence across the two groups. Second, individual SSRTs for stop-signal trials were calculated to index response inhibition for all participants. SSRTs were analyzed separately by means of univariate ANOVAs with Group (VGPs vs. NVGPs) as between-subject factor. Third, differences between groups on N-back task performance (RT on correct trials as well as accuracy, hits, correct rejections, false alarms, and misses in percent) were analyzed using repeated measures ANOVA with Load as within-subject factor and Group (VGPs vs. NVGPs) as between-subject factor. In the N-back task, two participants of the control group were excluded from the analyses because their accuracy was below 55% in relevant conditions. A significance level of $p < 0.05$ was adopted for all statistical tests.

Results

Participants

No significant group differences were obtained for age, $t(50) = 1.01$, $p = 0.318$, and intelligence, $t(50) = 0.98$, $p = 0.346$.

Stop-signal task

Analyses of mean RT to go signals showed that VGPs (421 ms) responded significantly faster than NVGPs (489 ms), $F(1,50) = 4.49$, $p < 0.05$, MSE = 2,983.065, $\eta^2 p = 0.08$, and this effect remained reliable when age and IQ were entered as covariates, $F(3,48) = 2.90$, $p < 0.05$, MSE = 28,866.191, $\eta^2 p = 0.154$. The percentage of choice errors to go signals was low and did not discriminate between NVGPs (1.6%) and VGPs (1.4%), $F < 1$. SSRTs were computed for each participant and for each group separately. All participants were able to stop their responses on stop-signal trials successfully in about half of the time a stop signal instructed them to do so (52.3% in NVGPs and 53.6% in VGPs), indicating that the dynamic tracking algorithm worked well in both groups. SSRTs were comparable for NVGPs (206 ms) and VGPs (209 ms); $F < 1$ also after correcting for age and IQ (Table 1).

N-back task

As the overview in Table 1 suggests, all dependent measures were reliably affected by group and load but there was no interaction (all *F*s < 1). With regard to the effect of group, VGPs were not only faster than NVGPs (467 vs. 528 ms), $F(1,48) = 11.52$, $p < 0.01$, MSE = 8,271.63, $\eta^2 p = 0.19$ and more accurate (91.2 vs. 85.3%), $F(1,48) = 13.68$, $p < 0.01$, MSE = 0.006, $\eta^2 p = 0.22$, they also showed more hits (36.3 vs. 33.8%), $F(1,48) = 8.35$, $p < 0.01$, MSE = 0.002, $\eta^2 p = 0.15$, and correct rejections (55.8 vs. 52.3%), $F(1,48) = 9.23$, $p < 0.01$, MSE = 0.003, $\eta^2 p = 0.16$, but fewer false alarms (4.3 vs. 7.9%), $F(1,48) = 10.07$, $p < 0.01$, MSE = 0.003, $\eta^2 p = 0.17$, and misses than NVGPs (4.7 vs. 7.3%), $F(1,48) = 8.07$, $p < 0.01$, MSE = 0.002, $\eta^2 p = 0.14$. The same pattern of results was obtained in ANOVAs with age and IQ as covariates: RT level, $F(1,46) = 8.87$, $p < 0.01$, MSE = 8,386.35, $\eta^2 p = 0.16$, accuracy, $F(1,46) = 10.65$, $p < 0.01$, MSE = 0.007, $\eta^2 p = 0.18$, the level of hits, $F(1,46) = 7.21$, $p < 0.01$, MSE = 0.002, $\eta^2 p = 0.14$, of correct rejections, $F(1,46) = 6.94$, $p < 0.05$, MSE = 0.003, $\eta^2 p = 0.13$, of false alarm, $F(1,46) = 7.63$, $p < 0.01$, MSE = 0.003, $\eta^2 p = 0.14$, and of misses, $F(1,46) = 6.96$, $p < 0.05$, MSE = 0.002, $\eta^2 p = 0.13$.

Separate comparisons confirmed that the group effect was reliable for all variables under both load conditions except for hits and misses in the 1-back condition (see Table 1), but even here the numerical effects went into the same direction and the *p* values approached significance, $F(1,48) = 3.30$, $p = 0.076$, MSE = 0.001, $\eta^2 p = 0.064$.

Load also affected all variables, showing that higher load increased RT, $F(1,48) = 86.66$, $p < 0.001$, MSE = 1,742.70, $\eta^2 p = 0.64$, and reduced accuracy, $F(1,48) = 22.57$, $p < 0.001$, MSE = 0.005, $\eta^2 p = 0.32$. Higher load also produced fewer hits, $F(1,48) = 23.08$, $p < 0.001$, MSE = 0.002, $\eta^2 p = 0.32$, and correct rejections, $F(1,48) = 6.70$, $p < 0.01$, MSE = 0.002, $\eta^2 p = 0.12$, but more false alarm, $F(1,48) = 9.20$, $p < 0.01$, MSE = 0.002, $\eta^2 p = 0.16$, and misses, $F(1,48) = 22.76$, $p < 0.001$, MSE = 0.002, $\eta^2 p = 0.32$, than the lower load did.

Discussion

This study tested, for the first time, whether playing FPS games is associated with cognitive control skills in monitoring and updating WM and inhibiting unwanted responses. VGPs showed, compared to NVGPs, more accurate performance in both load conditions of the N-back task, faster reactions to go signals, but comparable stopping efficiency. No significant group differences were found for age or estimated fluid intelligence and all group-related effects stayed reliable when age and IQ were used as covariates, suggesting that we can rule out an account of the observed group effects in these terms.

The observation that playing FPS games predicts performance on a relatively well-established diagnostic index of monitoring and updating of WM (Kane et al., 2007) provides support for the idea that video game experience is linked with enhancement in the monitoring and updating of task relevant information in general. In particular, it makes sense to assume that, on average, VPGs have a larger capacity than NVGPs in removing old, no longer relevant items from WM—thereby reducing possible competition and freeing capacity for new items.

From a broader perspective, the finding that VGPs show comparable performance to NVGPs with respect to stopping performance is particularly intriguing[1]. After the horrific shooting sprees at Columbine High School in 1999 and Virginia Tech in 2007, players of FPS games have often been accused in the media of being impulsive, antisocial, or aggressive (but see Ferguson, 2011, for challenging this idea), which would seem to suggest that they show worse performance than non-players in a task that has been shown to assess behavioral impulsivity (Logan, Schachar, & Tannock, 1997; Colzato et al., 2010a; van den Wildenberg & Christoffels, 2010). Our findings do not seem to provide a scientific basis for such accusations. Moreover, our observation is in line with the results by Dye, Green and Bavelier (2009), who measured a similar sort of impulsivity by means of the test of variables of attention. In this task participants react to shapes appearing at one location (target stimuli), while ignoring the same shapes if they appear in a different location. Like in our study, VGPs and NVGP showed equivalent performance.

However, it is important to consider that this possible conclusion rests on a null result and relies on the validity of SSRT as an index of impulsivity. Regarding the first issue, the 3-ms difference in SSRT between VGPs (209 ms) and NVGPs (206 ms) was far from significance. Given that the number of participants was rather large for this kind of task ($n = 26$ per group) and in view of the fact that the task was sensitive enough to pick up the 32-ms difference in Go RT between the two groups, there is no obvious reason to doubt that it was well-suited to pick up possible group differences in SSRT as well. Regarding validity, we have successfully used the same stop-task design to identify significant group differences in SSRT related to drug use and other impulsivity-related issues (Colzato et al., 2007; Colzato, van den Wildenberg, van Wouwe, Pannebakker, & Hommel, 2009b; Colzato et al., 2010a, b), suggesting that SSRT is a valid marker of impulsivity.

Our observations fit with previous reports of beneficial effects associated with video gaming on cognitive flexibility (Colzato et al., 2010; Karle et al., 2010; Boot et al., 2008) and cognitive skills and abilities, such as needed for visual search (Castel et al., 2005) and other visual tasks (Green & Bavelier, 2007). However, it is important to note that a causal relation between our observations and video game experience may not be straightforward. Indeed, we cannot exclude that preexisting neuro-developmental factors and/or a particular pre-gaming learning experience may play mediating roles. For instance, individuals with a genetic predisposition that favors executive control functions, or with some gaming-unrelated learning experience that strengthened such functions, might be drawn to video games more strongly, so that what looks like an effect of practice might actually represent a kind of self-selection. Nevertheless, several studies in which NVGPs were trained for several months on action video game have shown strongly improved performance in tasks requiring good spatial resolution in vision and the efficient distribution of visual attention (Green & Bavelier, 2003, 2006a, b, 2007). Remarkably, Spence, Feng, and colleagues (2007) found that after only 10 h of training in such video games participants significantly improved in spatial attention and mental rotation, and in learning spatial skills, with women benefiting more than men (Feng, Spence, & Pratt, 2007; Spence, Yu, Feng, & Marshman, 2009).

Future research needs also to take into account individual differences. There is ample evidence suggesting a considerable role of individual differences with respect to the efficiency of cognitive control processes and the neurotransmitter systems driving them (Cools, 2006). It makes sense to assume that these preexisting neuro-developmental factors (such as genetic variability related to levels of the neurotransmitter systems) affect the degree to which individuals can benefit from video game training, especially because many of them are arguably tapping into cognitive control processes. Indeed, very recently, we showed that in an elderly population, BDNF Val/Val homozygotes (i.e., individuals with a genetic predisposition that benefits attentional processes) showed larger beneficial transfer effects in attentional processes, as measured the useful field of view task, than Met/-carriers (i.e., individuals associated with a less favorable genetic predisposition). These findings, however, with a limited sample size, support the idea that genetic predisposition modulates transfer effects (Colzato, van Muijden, Band, & Hommel, 2011).

Acknowledgments We thank Pim Bakker, Iris Doorgeest, Miralda Fesselet, Yara Tiggelhoven, Paulien Brower, Leonie van Wijk and Liesbeth Crezee for their enthusiasm and invaluable assistance in recruiting the participants of this study. The research of LSC, WvdW, and BH is supported by NWO (Netherlands Organization for Scientific Research).

Conflict of interest The authors have declared that no competing interests exist.

References

Band, G. P. H., van der Molen, M. W., & Logan, G. D. (2003). Horse-race model simulations of the stop-signal procedure. *Acta Psychologica, 112*, 105–142.

Boot, W. R., Blakely, D. P., & Simons, D. J. (2011). Do action video games improve perception and cognition? *Frontiers in Psychology, 2*, 226. doi:10.3389/fpsyg.2011.00226.

Boot, W. R., Kramer, A. F., Simons, D. J., Fabiani, M., & Gratton, G. (2008). The effects of video game playing on attention, memory, and executive control. *Acta Psychologica, 129*(3), 387–398.

Castel, A. D., Pratt, J., & Drummond, E. (2005). The effects of action video game experience on the time course of inhibition of return and the efficiency of visual search. *Acta Psychologica, 119*, 217–230.

Clark, K., Fleck, M. S., & Mitroff, S. R. (2011). Enhanced change detection performance reveals improved strategy use in avid action video game players. *Acta Psychologica, 136*, 67–72.

Colzato, L. S., Hertsig, G., van den Wildenberg, W., & Hommel, B. (2010a). Estrogen modulates inhibitory control in healthy human females: Evidence from the stop-signal paradigm. *Neuroscience, 167*, 709–715.

Colzato, L. S., van den Wildenberg W.P.M., & Hommel, B. (2007). Impaired inhibitory control in recreational users of cocaine. *PLoS ONE*, *2*, e1143. http://www.plosone.org/doi/pone.0001143.

Colzato, L. S., Huizinga, M., & Hommel, B. (2009a). Recreational polydrug use of cocaine impairs cognitive flexibility but not working memory. *Psychopharmacology, 207*, 225–234.

Colzato, L. S., van den Wildenberg, W. P. M., van der Does, W. A. J., & Hommel, B. (2010b). Genetic markers of striatal dopamine predict individual differences in dysfunctional, but not functional impulsivity. *Neuroscience, 170*, 782–788.

Colzato, L. S., van den Wildenberg, W. P. M., van Wouwe, N. C., Pannebakker, M. M., & Hommel, B. (2009b). Dopamine and inhibitory action control: evidence from spontaneous eye blink rates. *Experimental Brain Research, 196*, 467–474.

Colzato, L. S., van Leeuwen, P. J. A., van den Wildenberg, W. P. M., & Hommel, B. (2010c). DOOM'd to switch: Superior cognitive flexibility in players of first person shooter games. *Frontiers in Psychology, 1*, 8. doi:10.3389/fpsyg.2010.00008.

Cools, R. (2006). Dopaminergic modulation of cognitive function: implication for L-DOPA therapy in Parkinson's disease. *Neuroscience Biobehavioral Review, 30*, 1–34.

Dye, M. W. G., Green, S. C., & Bavelier, D. (2009). Increasing speed of processing with action video games. *Current Directions in Psychological Science, 18*, 321–326.

Feng, J., Spence, I., & Pratt, J. (2007). Playing an action video game reduces gender differences in spatial cognition. *Psychological Science, 18*, 850–855.

Ferguson, C. J. (2011). Video games and youth violence: a prospective analysis in adolescents. *Journal of Youth and Adolescence, 40*, 377–391.

Green, C. S., & Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature, 423*, 534–537.

Green, C. S., & Bavelier, D. (2006a). Enumeration versus multiple object tracking: the case of action video game players. *Cognition, 101*, 217–245.

Green, C. S., & Bavelier, D. (2006b). Effect of action video games on the spatial distribution of visuospatial attention. *Journal of Experimental Psychology: Human Perception and Performance, 32*, 1465–1468.

Green, C. S., & Bavelier, D. (2007). Action-video-game experience alters the spatial resolution of attention. *Psychological Science, 18*, 88–94.

Kane, M. J., Conway, A. R. A., Miura, T. K., & Colflesh, G. J. H. (2007). Working memory, attention control, and the N-back task: A question of construct validity. *Journal of Experimental Psychology Learning, Memory, and Cognition, 33*, 615–622.

Karle, J. W., Watter, S., & Shedden, J. M. (2010). Task switching in video game players: Benefits of selective attention but not resistance to proactive interference. *Acta Psychologica, 134*(1), 70–78.

Levitt, H. J. (1971). Transformed up-down methods in psychoacoustics. *Journal of the Acoustical Society of America, 49*, 467–477.

Logan, G. D., & Cowan, W. B. (1984). On the ability to inhibit thought and action: A theory of an act of control. *Psychological Review, 91*, 295–327.

Logan, G. D., Schachar, R. J., & Tannock, R. (1997). Impulsivity and inhibitory control. *Psychological Science, 8*, 60–64.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "Frontal Lobe" tasks: a latent variable analysis. *Cognitive Psychology, 41*, 49–100.

Raven, J. (1998). *Manual for Raven's progressive matrices and vocabulary scales*. Oxford: Oxford Psychologists.

Spence, I., Yu, J. J. J., Feng, J., & Marshman, J. (2009). Women match men when learning a spatial skill. *Journal of Experimental Psychology Learning, Memory, and Cognition, 35*, 1097–1103.

van Colzato, L. S., Muiden, J., Band, G., & Hommel, B. (2011). Genetic modulation of training and transfer in older adults: BDNF Val66Met polymorphism is associated with wider useful field of view. *Frontiers in Cognition,*. doi:10.3389/fpsyg.2011.00199.

van den Wildenberg, W. P. M., & Christoffels, I. K. (2010). STOP TALKING! Inhibition of speech is affected by word frequency and dysfunctional impulsivity. *Frontiers in Psychology, 1*, 145. doi:10.3389/fpsyg.2010.00145.