Increasing speed of processing through action video games

Daphne Bavelier

Department of Brain and Cognitive Sciences

Meliora Hall-0268

University of Rochester, Rochester NY 14627-0268

Phone: (585) 275-8174

Fax: (585) 442-9216

Email: daphne@bcs.rochester.edu

Word Count: 2468 words

Increasing speed of processing with action video games

Matthew W. G. Dye, C. Shawn Green & Daphne Bavelier[1]

Department of Brain and Cognitive Sciences

University of Rochester

Rochester, NY 14627, USA

ABSTRACT – In many everyday situations, speed is of the essence. However, fast decisions typically mean more mistakes. To this day, it remains unknown whether reaction times can be reduced with appropriate training, within one individual, across a range of tasks, and without compromising accuracy. Here we review evidence that the very act of playing action video games significantly reduces reaction times without sacrificing accuracy. Critically, this increase in speed is observed across various tasks beyond game situations. Video gaming may therefore provide an efficient training regimen to induce a general speeding of perceptual reaction times without decreases in accuracy of performance.

KEYWORDS: video games, processing speed, visual attention, impulsivity, learning transfer

Playing action video games – contemporary examples include *God of War*, *Halo*, *Unreal Tournament, Grand Theft Auto* and *Call of Duty* – requires rapid processing of sensory information and prompt action, forcing players to makes decisions and execute responses at a far greater pace than is typical in everyday life. During game play, delays in processing often have severe consequences, providing large incentive for players to increase speed. Accordingly, there is anecdotal evidence that avid game players react more readily to their environment. However, it remains unknown whether any reduction in reaction time (RT) really *generalizes* to tasks beyond video game playing, and, if it does, whether it makes gamers more impulsive and prone to making errors. In short, are video game players just 'trigger happy', or does video game playing really improve RTs on a variety of tasks without a concomitant decrease in accuracy? The possibility of identifying a *single* training task that can lead to reaction time improvements across a variety of *unrelated* tasks is of great interest, but remains controversial in the field of speeded response choice tasks (where observers must choose among alternative responses/actions as rapidly as possible). On such tasks, decreases in RT are typically accompanied by decreases in accuracy. This is termed a *speed-accuracy trade-off*, with speeding up resulting in more mistakes. One exception is when individuals are trained on such speeded tasks. Performance on the trained task is then improved (faster RTs, but no speed-accuracy trade-off); however, little or at best limited transfer is observed to new tasks, limiting the benefits of training (Pashler, 1991). Interestingly, flexible or integrated training regimens – requiring constant switching of processing priorities and continual adjustments to new task demands – have been argued to lead to greater transfer (Bherer et al., 2005). Action video game playing may be an extreme case of such flexible training.

Here we consider the possibility that action video game training leads to faster RTs on tasks unrelated to the training, and thus for the first time may offer a regimen leading to generalized speeding across tasks in young adults.

ACTION VIDEO GAMES AND SPEEDED CHOICE REACTION TIME TASKS

The possibility that playing video games affects perceptual and cognitive skills has received much interest lately. Most past studies have compared expert action gamers (VGPs) to novice players (NVGPs) using tasks that measure RTs in order to draw conclusions about cognitive performance. Although usually not the primary focus of these studies, they invariably show that the VGPs are faster overall than those who do not play such games (Bialystok, 2006; Castel et al., 2005; Clark, et al., 1987; Greenfield et al., 1994). This is perhaps unsurprising given the fast pace of games considered in these studies. There are, however, two surprising characteristics of these RT decreases: (1) the *consistency* in speed of processing advantages for VGPs across a range of tasks, and (2) the fact that there is *no speed-accuracy trade-off*. These points are illustrated by the following meta-analysis, which examines the reported RTs of avid action gamers versus those of novices across a number of studies.

-- FIGURE 1 HERE –

Figure 1 shows a *Brinley plot* comparing the RTs of VGPs and NVGPs on a range of speeded choice RT tasks. A Brinley plot is a type of *scatter plot*, with each data point reflecting the performance of two different groups *on the same experimental condition* – the performance of one group can be read off on the X-axis and the other group off of the Y-axis. The data points included in Figure 1 come from seven studies containing a total of nine experiments each including various experimental conditions. For each experimental condition, an average RT score for VGPs and for NVGPs was extracted producing a total of 89 data points. These data points are extracted from tasks as markedly dissimilar as detection of a flashed stimulus, looking for a letter in a field of other letters, and indicating the direction of an arrow while ignoring arrows pointing in the other direction. Accordingly, the magnitudes of the measured RTs cover a wide range – from a few hundred milliseconds to nearly two seconds. There are several points of interest to note. Firstly, VGPs were found to be *consistently faster* than NVGPs (with Cohen's d effect sizes ranging from 0.48–1.47 depending upon the task, suggesting moderate-to-large effects). Secondly, there was *no difference in accuracy* (92.76% vs. 92.75% across all conditions), suggesting that the VGPs were not sacrificing accuracy in order to respond faster. Thirdly, and perhaps most importantly, the magnitude of this effect is well described by a *straight line* relating VGP and NVGP RTs, which suggests a single common underlying change in VGPs that results in faster processing across tasks and conditions. Furthermore, a straight line indicates a *multiplicative advantage* in VGPs with *no additive component*. This implies a mechanism whereby the reduction in RT is proportional to the total time necessary to complete the task. Explanations that refer to additive components of a task such as speeding up motor execution once response selection has occurred are inconsistent with the data.

Importantly, a few studies (Clark et al., 1987; Green, 2008) have indicated that these faster RTs can be trained by action video game play, therefore establishing *causality* (as opposed to strictly correlative studies where population bias is a significant concern). RTs in NVGP individuals were assessed before and after action video game training, and these results were then compared to NVGP individuals trained on control non-action video games. The control video games were chosen to be as engrossing as the experimental game, minimizing differences in motivation across groups and thus controlling for both test-retest and Hawthorne-like effects, where individuals who receive more attention from the researcher tend to fulfill the researcher's expectations. Furthermore, by evaluating subject behavior a few days before and a few days after the end of training (rather than immediately prior to and after training), these training studies attempt to exclude short-term effects that gaming may have on behavior, such as changes in arousal state or frame of mind.

Figure 2 shows a Brinley plot displaying data from two training studies conducted recently in our laboratory In these training studies, twenty-five NVGPs were randomly assigned to either an action game (*Unreal Tournament*, *Call of Duty 2*) or a control game (*The Sims*), which they played for 50 hours over 8-9 weeks between pre and post-testing. Across the four tasks tested before and after the training, action game trainees demonstrated decreases in RT (a 13% decrease) – double that of control game trainees (a 6% decrease). Again, the RT speeding was well fitted to a simple linear function with zero intercept, accounting for 97% of the pre-post test variation in both action and control game trainees. No differences in accuracy were observed (the action game group showed a 0.3% increase in accuracy - posttest accuracy = 0.997 * pretest accuracy, R^2 = 0.96, and the control group showed a 0.6% increase, with posttest accuracy = 0.994 * pretest accuracy, R^2 = 0.95)..

-- FIGURE 2 HERE –

Thus, unlike the majority of the literature on the training of speeded responses, the learning that occurs during action video game experience generalizes well beyond the act of playing games itself.

ACTION VIDEO GAMES AND IMPULSIVITY

The increased speed of processing noted in VGPs is often viewed as a 'trigger-happy' behavior, where VGPs respond faster but make more *anticipatory errors* (responding incorrectly because they do not wait for enough information to become available). Available research suggests this is not the case. First, the meta-analysis above reveals that VGPs have equivalent accuracy to NVGPs in the face of an 11% decrease in RTs. Second, a more direct evaluation of impulsivity using the *Test of Variables of Attention* (T.O.V.A.) indicates equivalent performance in VGPs and NVGPs. Briefly, this test requires subjects to look at a computer monitor and make a timed response to shapes appearing at one location (targets), while ignoring the same shapes if they appear at another location (non-targets). In different parts of the experiment, the target can appear either often or very rarely (see Figure 3A). The T.O.V.A. therefore offers a measure of both *impulsivity* (is the observer able to withhold a response to a non-target when most of the stimuli are targets?) and a measure of *sustained attention* (is the observer able to stay 'on task' and respond quickly to a target when most of the stimuli are non-targets?).

VGPs were selected based on self-reports of playing five hours per week (or more) of action video games in the previous year, and compared to NVGPs who reported little-or-no video gaming (and no action gaming for several years). VGPs responded more quickly than did NVGPs on both task components (Figure 3B), confirming increased processing speed in this group. Crucially, accuracy did not differ for the two groups, this being the case for both the impulsivity and the sustained attention measures (Figure 3C). VGPs were therefore faster but not more impulsive than NVGPs and equally capable of sustaining their attention. Thus, in contrast to the 'trigger-happy' hypothesis, VGPs did not compensate for their faster RTs by making more anticipatory errors than NVGPs.

-- FIGURE 3 HERE –

ACTION VIDEO GAMES AND ACCURACY MEASURES

Although earlier studies typically used speeded RT tasks, more recent studies of action video game players have focused on accuracy measures. This choice was motivated by the difficulty of making fair comparisons regarding cognitive processes across populations that have large differences in how quickly they make their responses. This problem is well acknowledged in the aging literature and we refer the reader to Madden et al. (1996) for a comprehensive discussion of the issue.

One area that has received considerable attention is the effect of action video games on *visual cognition*. Video game players have been reported to show improved hand-eye coordination, increased visual processing in the periphery, enhanced mental rotation skills, greater divided attention, and enhanced visuo-spatial memory. A series of published accuracy studies have established that playing action video games enhances performance on tasks thought to measure different aspects of *visual attention*, including the ability to (i) distribute attention across space, (ii) efficiently perform dual tasks, (iii) track several moving objects at once, and (iv) process streams of briefly presented visual stimuli (Green and Bavelier, 2003, 2007). One such study focusing on visuo-spatial skills has suggested that action game playing may provide a reliable training regimen to reduce gender differences in visuo-spatial cognition (Feng et al., 2007). In each of these instances, a causative role for action video games was demonstrated by conducting training studies with college students who did not play video games.

While these results in accuracy based tasks have been previously interpreted as an increase in attentional resources in action video game players and/or an enhancement in the ability to allocate those resources across space and time, the Brinley plot in Figure 1 suggests an alternative hypothesis that parsimoniously explains the entire pattern of previous data, both reaction time and accuracy based. The consistent multiplicative VGP advantage in reaction time observed in the Brinley plot suggests a clear difference in the speed with which visual information is processed between the groups. In tasks where reaction time is the primary dependent measure, this difference will be manifested as predictably faster RTs in VGPs than NVGPs. However, such a difference in the speed of processing also predicts higher accuracy in VGPs in accuracy-based tasks where the stimulus is typically quickly flashed or moving. This prediction was confirmed by Li et al. (in press) showing that VGPs acquire visual information more rapidly than NVGPs. In fact, such a hypothesis predicts VGP advantages on virtually any task where speeded visual processing is at the root of performance. To some extent this hypothesis can be thought of as the converse of the generalized slowing hypothesis for cognitive aging, where it has been suggested that the observed decrements on a wide range of tasks in the elderly can be explained by one underlying mechanism, i.e. decreases in the speed of information processing.

IMPLICATIONS AND FUTURE DIRECTIONS

A training regimen that efficiently increases processing speed is of great potential interest, as faster RTs are reported to correlate with higher performance on tests of high-level cognition (Conway et al., 2002) and to be responsible for many of the observed changes in cognitive performance across the lifespan (Kail & Salthouse, 1994). For example, age-related declines in visual search, memory and spatial reasoning tasks appear largely due to task-independent slowing of processing speed in elderly subjects. Action video game training may therefore prove to be a helpful training regimen for providing a marked increase in speed of information processing to individuals with slower-than-normal speed of processing, such as the elderly or victims of brain trauma (Clark et al., 1987; Drew & Waters, 1986).

While the evidence reviewed here shows that these improvements generalize to a wide range of perceptual and attentional tasks, the extent of this generalization remains unknown. Because available work has focused on visual tasks, there is no information about generalization to other modalities, such as audition or touch. Similarly, because the focus has been so far on relatively fast tasks requiring decisions between just two alternatives (with RTs less than 2000ms), it remains unknown whether more cognitive tasks would benefit in any way.

While the mechanism of this generalization remains unknown, the need to maximize the number of actions per unit of time to achieve the greatest reward when playing action video games may well be a key factor. This will certainly be a promising avenue of research for future studies. A second important topic for future work concerns a clearer understanding of the characteristics of the action video game play experience that favors performance enhancement. Much of what is currently known is descriptive (for instance that fast-paced and visually complex games promote greater levels of learning than slower, more visually benign games – see Cohen et al., 2007) – there is a clear need to move towards more explanatory accounts. Hand-in-hand with such an account, it will be important to isolate the characteristics of action video games that cause the observed changes and relate those characteristics to the mechanisms by which performance is altered. Finally, most of the games found to enhance performance are unsuitable for children in terms of their content, and difficult for elderly gamers in terms of the dexterity of response and visual acuity required. Identifying which aspects of the games are relevant will allow the development of games that have a wide range of suitability and accessibility that can be used in clinical as well as educational applications. As with any research endeavor, a combination of basic theoretical research combined with evidence-led practical applications is the most likely to produce tangible results.

ENDNOTES

[1] Address correspondence to: Daphne Bavelier, Department of Brain and Cognitive Sciences, Meliora Hall-0268, University of Rochester, Rochester NY 14627-0268; email: daphne@bcs.rochester.edu.

ACKNOWLEDGEMENTS

This work was supported by grants from the National Institute of Health (EY- O16880) and the Office of Naval Research (MURI Program) to DB.

REFERENCES

Bherer, L., Kramer, A.F., Peterson, M.S., Colcombe, S., Erickson, K. & Becic, E. (2005). Training effects on dual-task performance: Are there age-related differences in plasticity of attentional control? *Psychology and Aging*, *20*, 695-709.

Bialystok, E. (2006). Effect of bilingualism and computer video game experience on the Simon task. *Canadian Journal of Experimental Psychology*, *60*, 68-79.

Cameron, E. L., Tai, J.C., Eckstein, M.P., & Carrasco, M. (2004). Signal detection theory applied to three visual search tasks – identification, yes/no detection and localization. *Spatial Vision*, *17*(4-5), 295-325.

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, J.E., Lanphear, A. K. & Riddick, C.C. (1987). The effects of videogame playing on the response selection processing of elderly adults. *Journal of Gerontology*, *42*, 82-85.

Cohen, J.E., Green, C.S. & Bavelier, D. (2007). Training visual attention with video games: Not all games are created equal. In Harry O'Neil & Ray Perez (Eds), *Computer games and adult learning.* Oxford, England: Elsevier Group Inc.

Conway, A.R.A., Cowan, N., Bunting, M.F., Therriault, D.J. & Minkoff, S.R.B. (2002). A latent variable analysis of working memory capacity, short-term memory capacity, processing speed, and general fluid intelligence. *Intelligence*, *30*, 163-183.

Drew, D. & Waters, J. (1986). Video games: Utilization of a novel strategy to improve perceptual motor skills and cognitive functioning in the non-institutionalized elderly. *Cognitive Rehabilitation*, *4*, 26-31.

Dye, M.W.G., Green, C.S. & Bavelier, D. (in press). The development of attention skills in action video game players. *Neuropsychologia*. doi:10.1016/j.neuropsychologia.2009.02.002.

Feng, J., Spence, I. & Pratt, J. (2007). Playing action video games reduces or eliminates gender differences in spatial cognition. *Psychological Science*, *18*, 850-855.

Green, C.S. (2008). *The effects of action video game experience on perceptual decision making*. Ph.D. Dissertation, University of Rochester, Rochester, NY.

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

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

Greenfield, P. M., deWinstanley, P., Kilpatrick, H. & Kaye, D. (1994). Action video games and informal education: Effects on strategies for dividing visual attention. Journal of Applied Developmental Psychology, 15, 105-123

Kail, R. & Salthouse, T.A. (1994). Processing speed as a mental capacity. *Acta Psychologica*, *86*, 199-225.

Li, R., Polat, U., Makous, W. & Bavelier, D. (in press). Enhancing the contrast sensitivity function through action video game training. Nature Neuroscience. doi:10.1038/nn.2296.

Madden, D. J., Pierce, T. W. & Allen, P. A. (1996). Adult age differences in the use of distractor homogeneity during visual search. *Psychology and Aging*, *11*, 454-474.

Monsell, S., Sumner, P., & Waters, H. (2003). Task-set reconfiguration with predictable and unpredictable task switches. *Memory and Cognition*, *31*(3), 327-342.

Palmer, J., Huk, A., & Shadlen, M. (2005). The effect of stimulus strength on the speed and accuracy of a perceptual decision. *Journal of Vision*, *55*(5), 376-404.

Pashler, H. & Baylis, G. (1991). Procedural learning: I. Locus of practice effects in speeded choice tasks. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *17*, 20-32.

RECOMMENDED READINGS

- Green and Bavelier (2003). (See References). The first study reporting changes in visual attention as a result of action video game playing incorporating a training study designed to establish causality.
- Green, C. S. & Bavelier, D. (2006). The cognitive neuroscience of video games. In P. Messaris & L. Humphreys (Eds), *Digital Media: Transformations in Human Communication*. New York, NY, Peter Lang. A review of existing studies on the effects of action video game on perception and cognition as well as brain organization.
- Kail and Salthouse (1994). (See References). A discussion of the role of processing speed in cognition.

FIGURE CAPTIONS

Figure 1. A Brinley plot documents the reaction time (RT) of NVGPs on the X-axis versus that of VGPs on the Y-axis for 89 different experimental conditions taken from the 8 studies listed below. These studies contained multiple experiments with multiple experimental conditions comparing VGPs and NVGPs. For each experimental condition, the RTs of VGPs and NVGPs were retrieved and plotted as one separate data point. A simple linear function ($y = mx$) was used to describe the relationship between VGP and NVGP RTs (dashed line). Fitting the data with a linear function of the form $y = mx + c$ failed to account for significantly more of the relationship between the RTs of the two groups. VGPs responded 11% faster than NVGPs across a wide range of RTs. This multiplicative relationship argues against an account expressed simply in terms of faster motor execution in VGPs, as a motor explanation predicts an additive difference. Moreover, similar accuracy was observed across groups, ruling out an explanation in terms of simple speed-accuracy tradeoff (VGP accuracy = 0.99 * NVGP accuracy, $R^2 = 0.92$). a. Greenfield et al. (1994) b. Castel et al. (2005) c. Bialystok (2006) d. Dye et al. (in press) e. Green and Bavelier (2003) f. Green and Bavelier (unpublished data) g. Bailey and Bavelier (unpublished data)

Figure 2. Separate Brinley plots comparing pretest and posttest reaction times (RTs) for action game trainees (A) and control game trainees (B) for four tasks: motion discrimination (based upon Palmer et al., 2005), task switching (based upon Monsell et al., 2003), visual search for letters (based upon Castel et al., 2005) and visual search for Gabor patches (based upon Cameron et al., 2004). For both action and control game trainees (N=25 NVGPs, 7males and 7 females in the action group and 7 females and 4 males in the control group), training consisted of

playing randomly assigned videogames for 50 total hours over a period of 8-9 weeks. The members of the control group played the game The Sims^{TM} 2 (2004, Electronic Arts Inc.). Members of the experimental group played the game Unreal® Tournament 2004 (Epic Games) followed by the game Call of Duty® 2 (ActiVision). Again, a linear function taking the form y=mx provided the most parsimonious fit to the data (from Green, 2008; Green and Bavelier, unpublished data). The action trained group demonstrated a 13% decrease in their RTs, whereas the control trained group exhibited only a 6% decrease.

Figure 3. A. The Test of Variables of Attention (T.O.V.A.) was used to assess differences in impulsivity and sustained attention between NVGPs and VGPs, using both reaction time and accuracy measures. B. VGPs were faster at responding than NVGPs on both the impulsivity and sustained attention measures. (impulsivity trials – high target frequency: M_{NVGP}=292 msec, M_{VGP}=258 msec, Cohen's d=1.03; sustained attention trials – low target frequency: M_{NVGP}=354 msec, M_{VGP}=297 msec; Cohen's d=1.19) C. The groups differed little on the accuracy measure, (impulsivity trials – high target frequency: d'_{NVGP}=5.10, d'_{VGP}=5.06, Cohen's d=0.15; sustained attention trials – low target frequency: d'_{NVGP}=3.89, d'_{VGP}=3.74; Cohen's d=0.33), suggesting that the faster responses of VGPs were not due to impulsive responses to the stimuli, and that they did not have greater problems sustaining their attention.

FIGURES

Figure 1

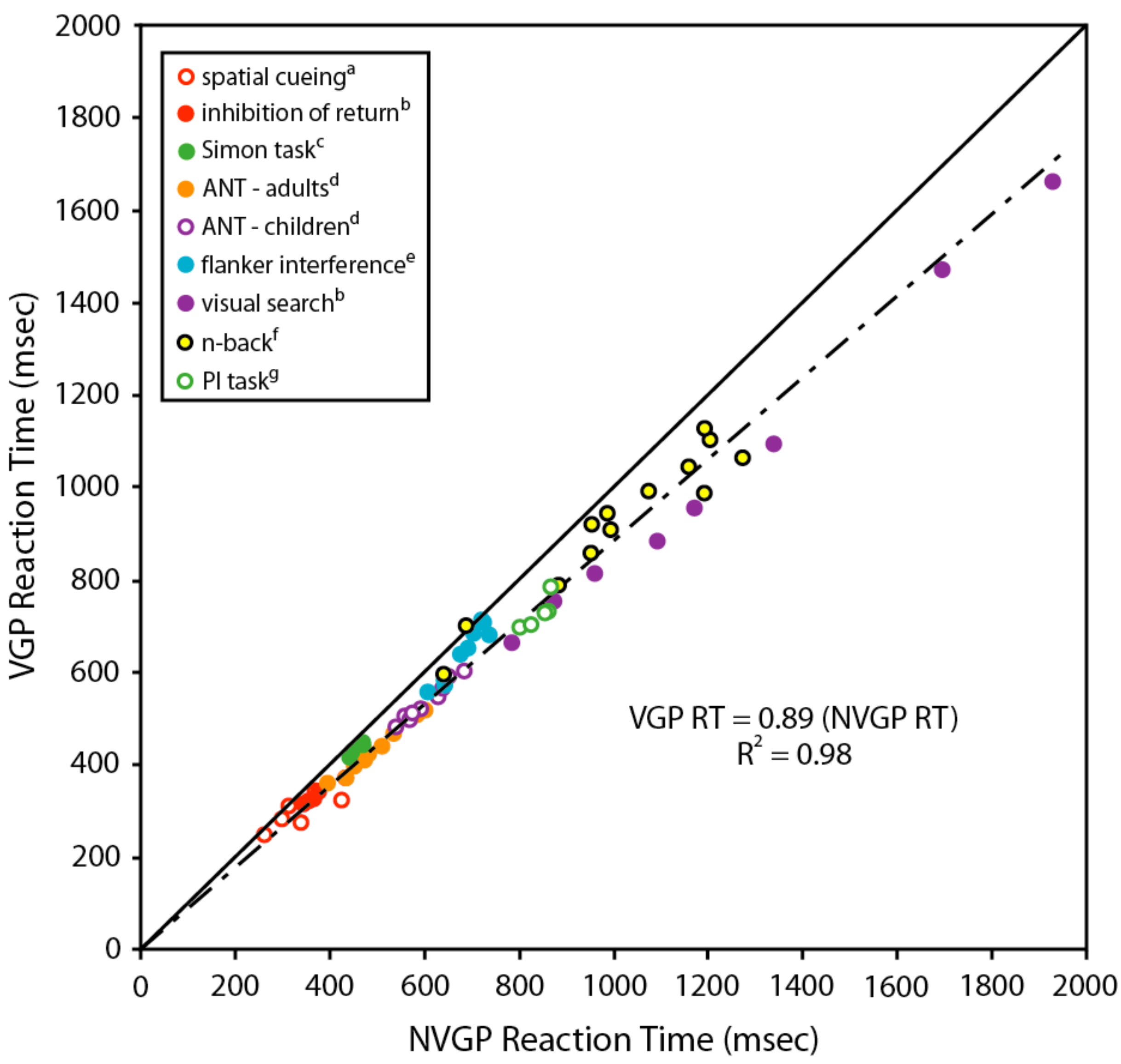


Figure 2

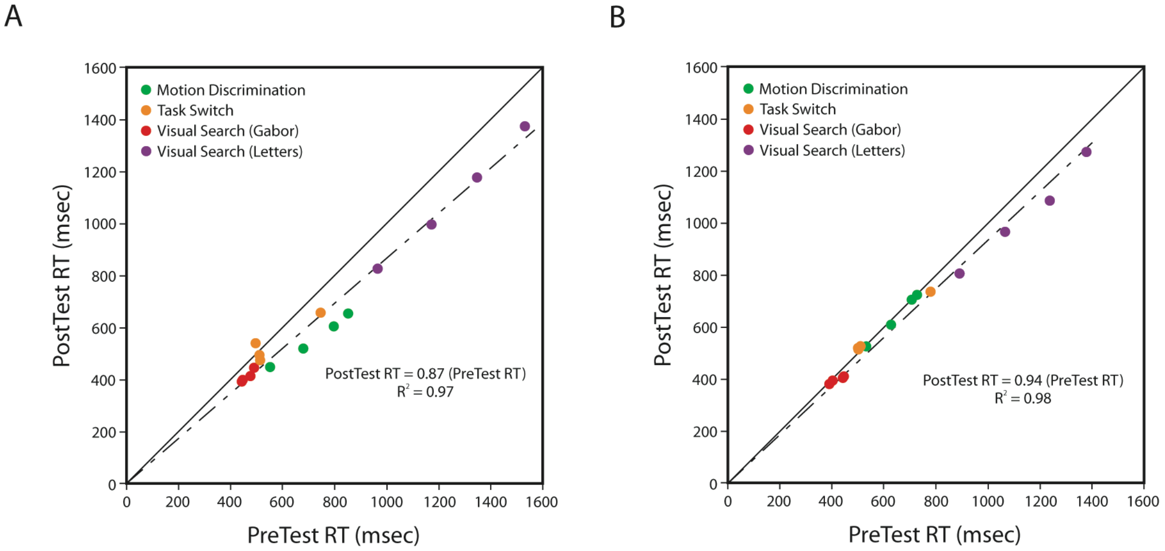
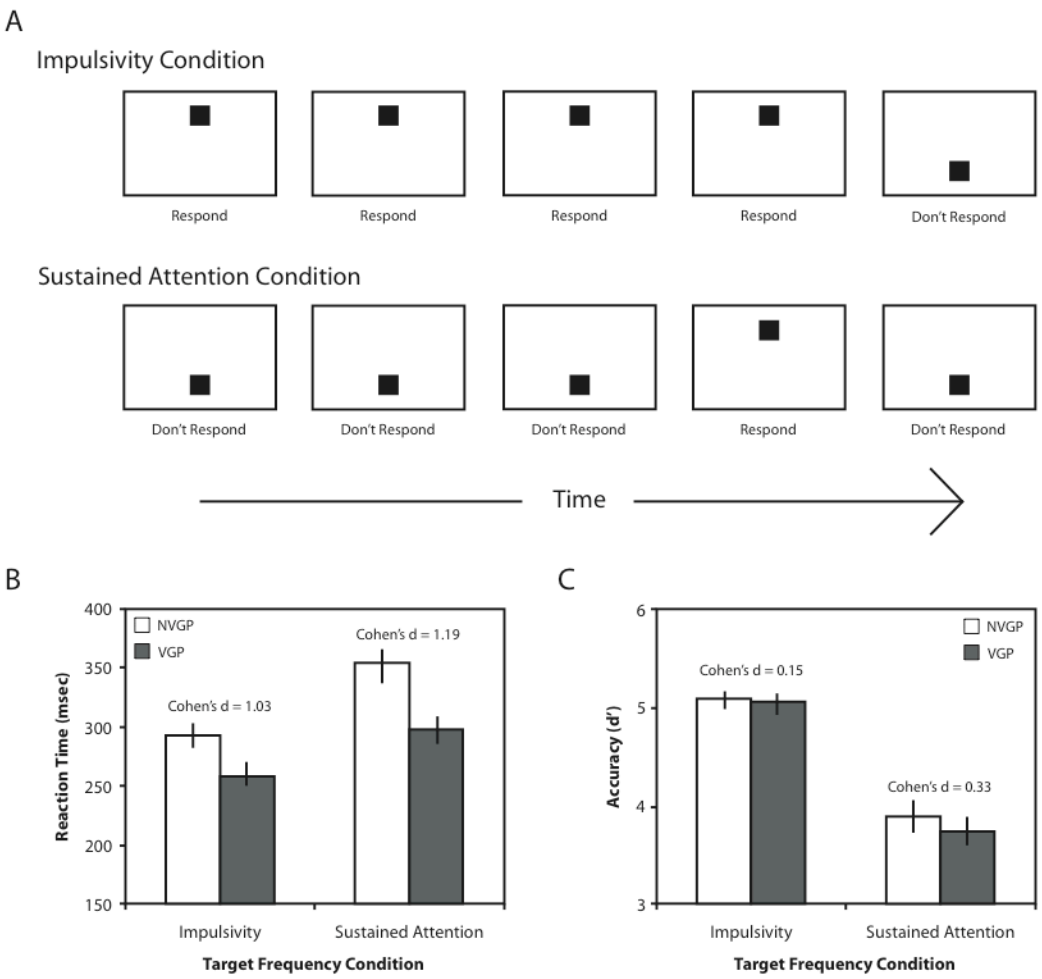

A
B
● Motion Discrimination
● Task Switch
● Visual Search (Gabor)
● Visual Search (Letters)
PostTest RT = 0.87 (PreTest RT)
R^2 = 0.97
PostTest RT = 0.94 (PreTest RT)
R^2 = 0.98
PostTest RT (msec)
PreTest RT (msec)
0
200
400
600
800
1000
1200
1400
1600

Figure 3


A
Impulsivity Condition
Respond
Respond
Respond
Respond
Don't Respond
Sustained Attention Condition
Don't Respond
Don't Respond
Don't Respond
Respond
Don't Respond
Time
B
400
350
300
250
200
150
Reaction Time (msec)
NVGP
VGP
Cohen's d = 1.03
Cohen's d = 1.19
Impulsivity
Sustained Attention
Target Frequency Condition
C
6
5
4
3
Accuracy (d')
NVGP
VGP
Cohen's d = 0.15
Cohen's d = 0.33
Impulsivity
Sustained Attention
Target Frequency Condition

SUPPLEMENTAL METHODS

General Training Procedure

For both action and control groups, training consisted of playing a randomly assigned videogame for 50 total hours. The subjects were allowed to play a maximum of 2 hours per day and a maximum of 10 hours per week. No minimum amount of game play per week was enforced, but subjects were required to finish the 50 hours training in no more than 9 weeks. The subjects completed the 50 hours in an average of 44 days. All training games covered the entire extent of the screen (approximately 15° height x 18° width from fixation).

The members of the control group played the game The Sims^{TM} 2 (2004, Electronic Arts Inc.). Members of the experimental group played two different action games, chosen to be similar to those played by experienced VGPs. During the first half of training, the action group played the game Unreal® Tournament 2004 (Epic Games) and during the second half of training they played the game Call of Duty® 2 (ActiVision).

This study enrolled 25 NVGPs, none of whom had taken part in previous experiments in our laboratory. In all 7 females and 7 males (mean age = 25.7 years) made up the action group, while the control group consisted of 7 females and 4 males (mean age = 24.7 years).

Motion Discrimination

The motion direction discrimination task was a replication of the protocol reported in Palmer et al. (2005). All 25 trainees completed this task before and after training.

Task Switching

Task switching data was obtained from a replication of the protocol reported by Monsell et al. (2003). All 25 trainees completed this task before and after training.

Visual Search (Letters)

The visual search (letters) task closely followed the protocol reported in Castel et al. (2005). Whereas Castel et al. used search set sizes [4, 10, 18, 26], this study used [8, 12, 16, 20]. Only 13 trainees completed this task before and after training. Of these, 6 were in the action training condition (3 males and 3 females, mean age = 26.5 years) and 7 in the control condition (5 females and 2 males, mean age = 23.7 years).

Visual Search (Gabor)

Visual search data was also obtained using Gabor patch stimuli following the protocol reported by Cameron et al. (2004). Only 12 trainees completed this task before and after training. Of these, 8 were in the action training condition (4 males and 4 females, mean age = 25.4 years) and 4 in the control condition (2 females and 2 males, mean age = 26.5 years).

Supplemental References

Cameron, E. L., Tai, J.C., Eckstein, M.P., & Carrasco, M. (2004). Signal detection theory applied to three visual search tasks – identification, yes/no detection and localization. *Spatial Vision*, *17*(4-5), 295-325.

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 Psychologia*, *119*(2), 217-230.

Monsell, S., Sumner, P., & Waters, H. (2003). Task-set reconfiguration with predictable and unpredictable task switches. *Memory and Cognition*, *31*(3), 327-342.

Palmer, J., Huk, A., & Shadlen, M. (2005). The effect of stimulus strength on the speed and accuracy of a perceptual decision. *Journal of Vision*, *55*(5), 376-404.