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Differential development of visual attention skills in school-age children

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ABSTRACT

Children aged 7–17 years and adults aged 18–22 years were tested on three aspects of visual attention: the ability to distribute visual attention across the field to search for a target, the time required for attention to recover from being directed towards a target, and the number of objects to which attention can be simultaneously allocated. The data suggested different developmental trajectories for these components of visual attention within the same set of participants. This suggests that, to some extent, spatial, temporal and object-based attentional processes are subserved by different neural resources which develop at different rate. In addition, participants who played action games showed enhanced performance on all aspects of attention tested as compared to non-gamers. These findings reveal a potential facilitation of development of attentional skills in children who are avid players of action video games. As these games are predominantly drawing a male audience, young girls are at risk of under-performing on such tests, calling for a careful control of video game usage when assessing gender differences in attentional tasks.

1. Introduction

The ability of children to pay attention is quite limited early in development; with increasing age, attentional skills improve, allowing better on-task focus and improved performance (Plude, Enns, & Brodeur, 1994). Little is known, however, about the factors that promote this development and its exact time line. This field of inquiry is complicated by the fact that attention is far from being a homogeneous concept, but rather encompasses several different skills which may or may not mature at the same rate or under the same conditions (Goldberg, Maurer, & Lewis, 2001). In this study we contrast three specific attentional skills – the ability to distribute visual attention spatially, deploy attention over time, and allocate attention to visual objects. Using a cross-sectional design, we compare the rate of development of these skills as well as their sensitivity to an environmental factor: action video game usage.

The rate of maturation of the spatial deployment of attention was tested using an adaptation of the Useful Field of View paradigm (UFOV) in which participants are asked to locate a simple target shape amongst a field of distractors (Ball & Sekuler, 1982). The developmental literature is rich in studies documenting the maturation of such visual search skills. Peak performance is noted as early as 6 years of age for simple feature search paradigms (Hommel, Li, & Li, 2004; Lobaugh, Cole, & Rovet, 1998; Ruskin & Kaye, 1990), but performance is seen to improve during school years when using complex search tasks. For example, reduced response latencies from early childhood to adolescence have been reported in conjunction searches (Hommel et al., 2004; Lobaugh et al., 1998; Ruskin & Kaye, 1990; Trick & Enns, 1998). Similarly, there is some evidence that very young children – aged between 6 and 8 years – are susceptible to the influence of distractors during conjunction searches but not during simple feature search (Hommel et al., 2004). This difference between complex and simple search tasks may reflect a rather rapid maturation of the ability to distribute attention over space, but a slower development of the mechanism that mediates feature binding (Trick & Enns, 1998). As our study focuses on a relatively simple search task, a fast development with peak performance reached by 6 to 7 years of age was expected. The children tested in this study are aged between 7 and 17 years of age, alongside 18–22 year old adults. Thus we anticipated that this paradigm would allow us to assess the impact of action video gaming on an attentional skill that was expected to be mature and stable across the age range tested.

The effect of age on the temporal dynamics of visual attention was studied using the attentional blink (AB) task, which measures how attention recovers over time once it has been allocated to an item (Raymond, Shapiro, & Arnell, 1992). In contrast to visual selective attention across space, the only developmental study available using this task suggests a protracted period of development with improvement still noted during adolescence (Shapiro & Garrad-Cole, 2003). Therefore, attention was expected to recover faster in older than in younger children, allowing older children to process a stream of rapidly presented stimuli more accurately. Developmental studies of the temporal deployment of attention

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typically focus on sustained attention or the ability to maintain attention over a range of minutes, rather than the fast recovery of attention over a few hundreds of milliseconds as measured by the attentional blink. These sustained attention studies report improvement during the primary school ages (Levy, 1980; Lin, Hsiao, & Chen, 1999). It is unknown whether these tests measure similar or distinct aspects of the dynamics of attention. Performance on sustained attention tests and the attentional blink have been shown to correlate, at least in some clinical populations such as people with schizophrenia (Li et al., 2002), suggesting these attentional skills may be under the control of some common dynamical constraints. However the extent to which they overlap remains unknown.

Finally, we used a multiple object tracking (MOT) task to assess the developmental time line of the number of objects to which attention can be simultaneously deployed. The number of objects that can be tracked has been shown to improve across the school-age years. In addition, children who were action gamers displayed increased capacity in the number of objects they could track (Trick, Jaspers-Fayer, & Sethi, 2005). While we employ a different paradigm to that of Trick and colleagues, the present study will provide not only a conceptual replication of the MOT benefit, but will also confirm that the amount and quality of action video game playing behavior in our sample is sufficient to induce observable effects.

By administering all of these tasks to the same sample of juvenile and adult participants, this study aims to establish whether different components of visual attention share the same developmental profile. If they mature at similar rates, this suggests that they share substantial underlying neural circuitry. On the other hand, differential rates of development would indicate that, at least to some extent, these visual attention processes rely upon differing neural mechanisms that are maturing at different times during the course of development. An important additional feature of this study is that children and adults who play action video games were considered separately from those that do not. Recently, it has been demonstrated that playing action video games changes several aspects of visual selective attention in adults (Green & Bavelier, 2003, 2006a, 2006b), and in particular the three attentional skills tested in this study – the efficiency of attentional allocation over space, over time and to objects. Performance of gamers was better than that of non-gamers on the UFOV search task, the AB task and the MOT task in adults (Green & Bavelier, 2003, 2006b). Importantly, the causal effect of gaming has been established through training studies. Non-gamers trained on a first-person point-of-view action video game showed significant improvement from their pre-training scores on these three measures of attention – UFOV, AB and MOT – indicating that as little as ten hours of video game playing can alter these fundamental aspects of visual attention in young adults (Green & Bavelier, 2003, 2006b).

The present study asks whether children who play action video games exhibit similar enhancement of performance on these tests as that observed in adults. Children were classified as gamers or non-gamers after selection for inclusion and prior to data analysis. Those who reported playing first/third-person ‘shooter’ games in the 12 months prior to testing were classified as action gamers. Other children, although classified as non-gamers, still played video games. However, these games were not action-based, did not have a first-/third-person point-of-view, and were not as fast-paced. We acknowledge that any differences observed between gamers and non-gamers may reflect pre-existing population differences, i.e. children who have better attentional skills initially may tend to be better at action-based video games, and thus more likely to play them. Although this is certainly a concern, research has shown that training using action video games leads to enhanced performance on the skills tested in adults who have not played such games in the past (Green & Bavelier, 2003, 2006a, 2006b).

Our aim was to first determine the impact of normal maturation upon the development of the ability to deploy attention over space, time and objects. To this effect, a large sample of school-aged children, aged 7–17 years, and 18–22 year old adults were tested on child-friendly versions of the UFOV, AB and MOT tasks. Once the variation due to age had been accounted for, we then assessed the difference between those who played and those who did not play action video games. We predicted that little improvement would be observed on the UFOV task (a simple search task) in non-gamers after the age of 7 years, but that those who played action video games would be able to detect peripheral targets in a field of distractors more easily than those who did not play such games. For the AB task, we predicted that the time needed to recover attentional resources would show a decrease in non-gamers as age increased from 7 to 22 years. We further predicted that resources would recover more rapidly in gamers than in non-gamers. Finally, for the MOT task, we predicted increases in performance across the age range tested in non-gamers, with an additional improvement in the number of objects that could be tracked resulting from action video game experience.

2. Methods

2.1. General method

2.1.1. Participants

One hundred and fourteen school children were recruited from a suburban school district in Rochester, NY. In addition, 47 adults were recruited at the University of Rochester, Rochester, NY. Recruitment and testing took place between January 2003 and April 2007. Participants were aged between 7 and 22 years, and divided into four age groups according to the level of schooling they were receiving at the time of testing: elementary/primary school (7–10 years), middle school (11–13 years), high school (14–17 years) and university (18–22 years). While seemingly arbitrary, these *a priori* age divisions reflect transitions within the US educational system, with concomitant changes in expectations of a child’s maturation and ability to attend to their school environment.

After testing, participants were interviewed about their video game playing habits. The interview aimed to establish the frequency of action video game usage in the 12 months prior to testing. For each video game the participants reported playing, they were asked how often they played that game in the previous 12 months and for how long they played it during a typical session. This approach was motivated by that used in surveys to elicit information that can be hard for interviewees to accurately recall; for example, the method is similar to that used in the UK’s General Household Survey to acquire information on alcohol consumption (Office for National Statistics, 2004, chap. 9).Those who reported playing first- or third-person perspective ‘shooter’ games were classified post-hoc as ‘gamers’ (VGPs; $N = 58$). Others were designated as ‘non-gamers’ (NVGPs; $N = 103$). Sample size, gender, and age data for the subjects are reported in Table 1 and lists of which games were reported and how they were classified is reported in an Appendix. It should be noted that because males are more likely to play action video games our sample reflects that bias with the gamer group predominantly made of males and the non-gamer group predominantly female. We will return to this issue in the General Discussion.

2.1.2. Apparatus

Stimuli were presented to participants using Matlab version 5.2.1 software and the Psychophysics Toolbox running on an Apple G4 PowerBook computer. The laptop was connected to a 23 in. Apple Cinema Display via an Apple ADC-DVI adaptor, running with a refresh rate of 60 Hz. The display was adapted to function as a

Table 1
Age, gaming status and gender of participants.

	7–10 year olds		11–13 year olds		14–17 year olds		18–22 year olds	
	NVGP	VGP	NVGP	VGP	NVGP	VGP	NVGP	VGP
N	46	6	16	16	15	15	26	21
# Males	17	5	5	15	1	14	3	13
Mean age (months)	107	116	146	154	188	180	246	241
SD age (months)	14	16	11	8	13	8	15	20

touchscreen, using pressure sensitive resistive (PSR-1®) technology supplied and fitted by Troll Touch Touchscreens (Valencia, CA). For all tasks, the viewing distance was set to 40 cm and checked using a length of string attached to the base of the touch screen. This was checked periodically by the experimenter.

3. Experiment 1 – Useful Field of View

3.1. Method

3.1.1. Design and procedure

The UFOV task proceeded in two stages. The first training stage was designed to familiarize participants with the requirements of the main UFOV task and to ensure they could complete the task requirements successfully. The second part was the main UFOV task itself.

3.1.1.1. Training tasks. During the training stage, subjects were first asked to discriminate an isolated central target by reporting verbally whether a centrally presented cartoon-face had long or short hair (Fig. 1A). The central target subtended 2° of visual angle. The initial stimulus duration was 11 frames, followed by a 'white noise' mask that occupied the entire screen in a uniform field. The display duration was adjusted following a 3-up/1-down adaptive staircase procedure (step-size fixed at 1 screen refresh or 16.7 ms) to determine the 79.3% threshold. Testing stopped either after eight reversals, or seventy-two total trials or ten trials at a stimulus duration of 1 frame, whichever occurred first. Subjects then performed the peripheral target localization training task. In this task, the central target was accompanied by a solitary "sheriff's badge" shape presented randomly at one of the eight cardinal or inter-cardinal locations at 20° of visual angle from the center of the screen (Fig. 1B). The peripheral target subtended 2° of visual angle. The subject was required to verbally state whether the central target had long or short hair, and then touch the line on the screen corresponding to the location of the peripherally presented target. The central and peripheral targets appeared at the same time for the same duration, and were followed by a 'white noise' mask that occupied the whole screen in a uniform field. All aspects of the procedure were otherwise identical to that described for the central training task, utilizing the same 3-up/1-down staircase. Subjects then proceeded to the main UFOV task.

3.1.1.2. UFOV main task. The UFOV task consisted of the peripheral target localization task using distractors (white squares) presented at 6.7°, 13.3° and 20° of visual angle along each of the directions along which the peripheral target could appear (Fig. 1C). The distractors subtended the same degree of visual angle as the peripheral target. Apart from the introduction of these distractor shapes, the procedure was the same as for the peripheral target localization training task, and a threshold measure was collected for each subject.

3.1.2. Results

3.1.2.1. Treatment of outliers. Five NVGPs were excluded because they were outliers on the main UFOV task – two 7–10 year olds, one 11–13 year old, one 14–17 year old and one 18–22 year old – having thresholds more than 2 SD worse than their NVGP peers. A further four VGPs were also excluded as they were outliers on the main UFOV task – two 7–10 year olds, one 14–17 year old and one 18–22 year old. The VGP outliers all performed more than 2 SD worse than their VGP peers.

3.1.2.2. Training task performance. Age group and game playing had no effect on training task performance. The training task thresholds were entered into a MANOVA with age group (7–10 years, 11–13 years, 14–17 years, 18–22 years) and game playing (VGP, NVGP) as between-subjects factors and the center discrimination and peripheral localization thresholds from the training tasks as dependent measures. This revealed that the effects of age group and game playing were not statistically significant: Wilk's λ (age group) = 0.93, $p = .190$, partial $\eta^2 = .04$; Wilk's λ (game playing) = 0.99, $p = .615$, partial $\eta^2 = .01$. The lack of any effect reflected the success of the training regimen, with subjects in all groups achieving asymptotic performance on both the center discrimination and peripheral localization tasks.

3.1.2.3. UFOV main task. The main UFOV thresholds from NVGPs were entered into a one-way ANOVA with age group (7–10 years, 10–13 years, 14–17 years, 18–22 years) as a between-subjects factor. As predicted, there was no significant effect of age group (*F* (3,

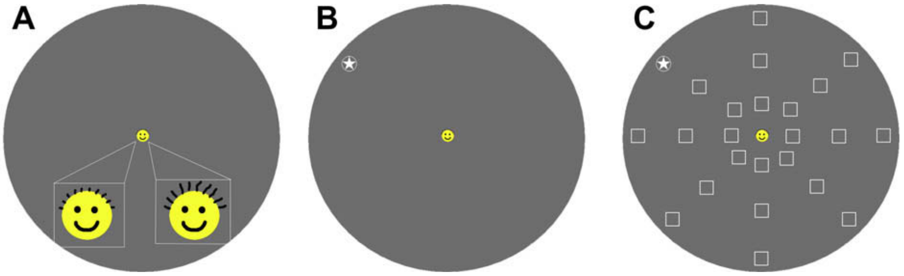

Fig. 1. (A) The first training task required subjects to discriminate a briefly presented face in the center of the display – the cutaways show detail of the 'short hair' and 'long hair' faces. (B) In the second training task, subjects made the central discrimination and then indicated the location of a peripheral target (a five-pointed star in a circle). (C) In the main UFOV task, subjects made the central discrimination and localized the peripheral target, but they did so in the presence of distractor items (23 white squares).

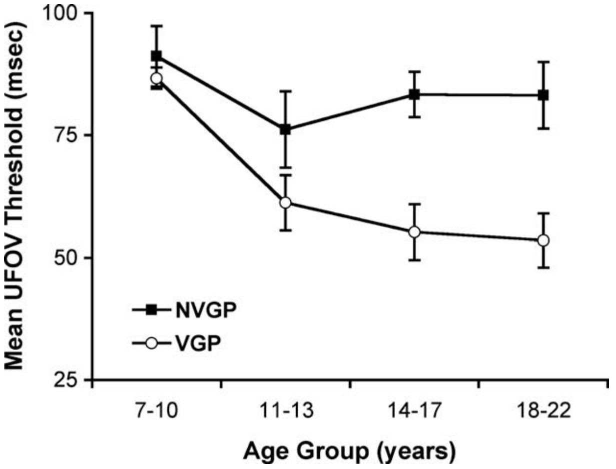

Fig. 2. Participants were asked to locate a peripheral stimulus among distractors. Display duration was shortened until participants performed at threshold (~79.3% accuracy). VGPs (○) required the display to be presented for less time than NVGPs (□) in order to achieve the same level of accuracy. Error bars indicate the standard error of the mean.

87) = 0.82, p = .486, partial η^2=.03). In short, non-gamers' performance was stable on this task across the age groups tested.

In order to assess the effect of video game playing on selective visual attention, both age group and game playing (NVGP, VGP) were used as between-subjects factors. This ANOVA revealed no significant effect of age group (F (3, 131) = 1.91, p = .131, partial η^2 = .05), and no interaction between age group and game playing (F < 1, p = .495, partial η^2 = .01). As predicted, however, a significant main effect of video game playing was present (F (1, 131) = 9.65, p = .002, partial η^2 = .07). Action video game playing resulted in improved selective visual attention as evidenced by reduced thresholds in the main UFOV task (see Fig. 2 and Table 2).

To demonstrate that this was due to enhanced spatial attention across the visual field, it is important to show that VGPs did not direct their attention to the periphery at the expense of attention to the center of the screen. Center task accuracy for the main UFOV task was entered into an ANOVA with age group and gaming as between-subjects factors. This revealed that, while age group had a significant effect on central discrimination in the main UFOV task (F (3, 131) = 3.78, p = .012, partial η^2 = .06), video game playing did not (F (1, 131) = 3.02, p = .085, partial η^2 = .02) nor did video game playing interact with age group (F (3, 131) = 1.33, p = .268, partial η^2 = .03). Thus, better attention to the periphery was not at the cost of inattention to the center of the screen in VGPs, validating the interpretation that children and adults who play action video games exhibit enhanced spatial attention compared to their non-gamer peers (Green & Bavelier, 2003, 2006a).

4. Experiment 2 – attentional blink

4.1. Method

4.1.1. Subjects

Some participants did not complete the AB task. Of the 103 NVGPs in the sample, four 7–10 year olds did not complete the task. Of the 58 VGPs, data were not collected from three subjects – two 11–13 year olds and one 18–22 year old.

4.1.2. Design and procedure

The AB procedure was modeled after that employed by Shapiro and Garrad-Cole (2003). Each of 56 trials on the AB task consisted of a rapid serial visual presentation (RSVP) of colored shapes (Fig. 3B) occupying a 10° by 10° area in the center of the screen. On each trial, a series of these shapes was presented one at a time in the center of the screen. Embedded within the stream of shapes were two targets (T1 and T2): a red isosceles triangle and a blue isosceles triangle. For half of the subjects, T1 was a red isosceles triangle pointing either left or right, and T2 was a blue isosceles triangle pointing either up or down. For the remaining subjects, the order was switched. Between one and seven shapes could appear before T1, and from three to six shapes could appear following T2. The number of shapes between T1 and T2 (the T1–T2 lag) was manipulated systematically as 1, 2, 4, 6, 8, 10 or 12 shapes, with each lag occurring a total of eight times. At the end of each trial the subject was required to identify the direction of T1 and T2 by touching corresponding isosceles triangles presented on the touchscreen. A baseline procedure was also run, where the subject saw only one target shape, corresponding to the T2 shape in the main body of trials (Fig. 3A). This baseline task was presented before and after the main task, with 16 trials in each block. In the baseline task, only T2 was presented in the RSVP of shapes, providing a measure of how well subjects could determine the identity of T2 in the absence of a blink-inducing T1.

The attentional return lag (ARL) was computed as the T1–T2 lag at which task performance had recovered to 80% of their maximum level of performance. First, each subject's 'maximum' level of performance was calculated by averaging the percentage of trials where T1 and T2 were correctly identified at T1–T2 lags of 8, 10 and 12 items, corrected for performance on the T2-only baseline task. For example, if a subject averaged 85% across lags 8, 10 and 12 on the T1–T2 task and scored 95% on the baseline T2-only task, then their maximum level of performance was computed as 85/95% × 100%, or 89% of baseline. Then the attentional return lag (ARL) was computed as the T1–T2 lag at which task performance had recovered to 80% of this 'maximum'. This hypothetical subject's ARL was therefore computed as the T1–T2 lag at which performance had returned to 89% × 0.8%, or 72%. This baseline correction controls for differences in the ability to discriminate a single target independent of the size of an attentional blink.

4.1.3. Results

4.1.3.1. Treatment of outliers. Fifteen subjects were outliers on the AB task, performing more than 2 SD units worse than their peers – four 7–10 year old NVGPs, eight 18–22 year old NVGPs and three 18–22 year old VGPs.

4.1.3.2. T2-only performance (baseline task). The percentage of correct trials on the T2-only baseline task was entered into a two-way ANOVA with age group (7–10 years, 11–13 years, 14–17 years, 18–22 years) and gaming (NVGP, VGP) as between-subjects factors. This revealed a main effect of age group (F (3, 139) = 4.58, p = .004, partial η^2 = .10) but no main effect of gaming (F < 1,

Table 2
Means (and SDs) of UFOV thresholds and concurrent center task accuracies.

		7–10 years	11–13 years	14–17 years	18–22 years
NVGP	UFOV Threshold (msec)	91 (39)	76 (30)	83 (17)	83 (29)
	Center Task Accuracy (%)	89.8 (6.4)	94.1 (5.6)	94.3 (5.9)	98.0 (2.6)
VGP	UFOV Threshold (msec)	87 (4)	61 (22)	55 (21)	53 (17)
	Center Task Accuracy (%)	91.5 (6.2)	92.9 (4.4)	89.9 (5.6)	94.0 (4.2)

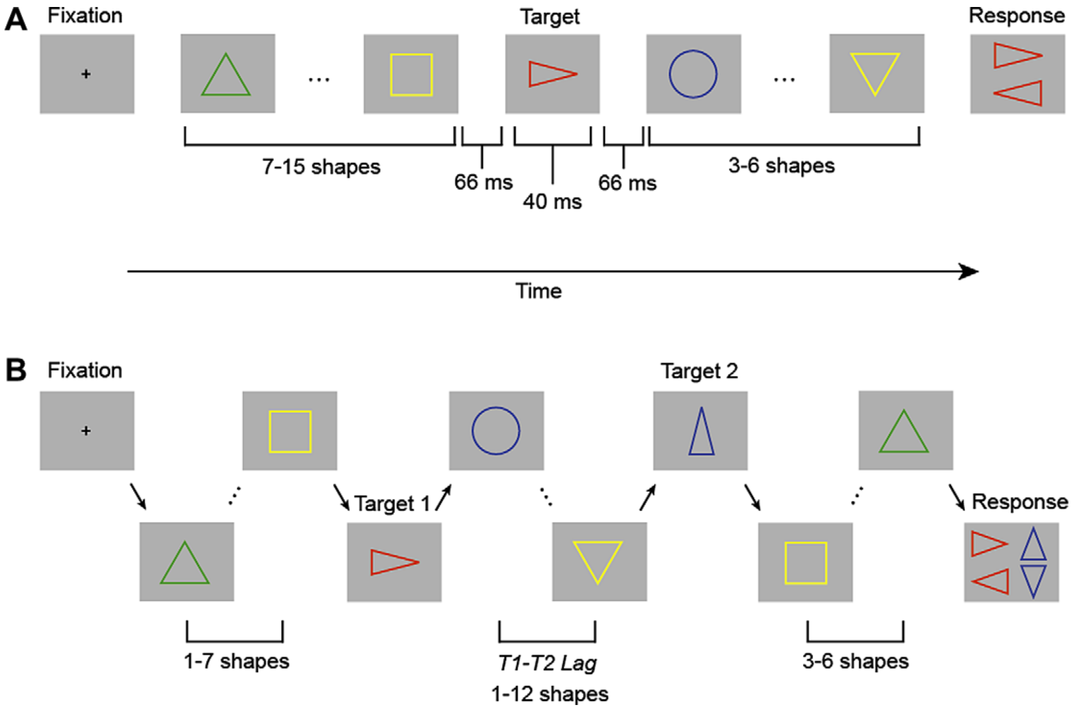

Fig. 3. Subjects were presented with a rapid, serial visual presentation of colored shapes in the center of the display. (A) In a baseline task, only one target (an isosceles triangle) had to be identified. (B) In the main attentional blink task, they were instructed to detect two target shapes (isosceles triangles – T1 and T2) and indicate the direction in which they pointed. The blue isosceles triangle could point either up or down, and the red isosceles triangle either left or right. The assignment of the blue and red triangle to T1 or T2 was done randomly for each subject, but kept constant across trials. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

$p = .489$, partial $\eta^2 < .01$) nor any interaction between age group and gaming ($F < 1$, $p = .736$, partial $\eta^2 = .01$). Thus, while 7–10 year olds ($M_{7-10} = 97.8\%$) were less accurate at identifying a single target in an RSVP stream than older subjects ($M_{11-13} = 99.5\%$, $M_{14-17} = 99.4\%$, $M_{18-22} = 100.0\%$), VGPs ($M = 99.5\%$) and NVGPs ($M = 98.8\%$) performed equally well on this task.

4.1.3.3. Attentional recovery. Using data from the main AB task, the T1–T2 lag at which performance had returned to 80% of maximum (attentional return lag – ARL) was calculated for NVGPs, and entered into an ANOVA with age group (7–10 years, 11–13 years, 14–17 years, 18–22 years) as a between-subjects factor. Contrary to what was predicted, the main effect of age group was not significant for NVGPs ($F(3, 87) = 1.67$, $p = .180$, partial $\eta^2 = .06$). Thus the time required to recover attentional resources to 80% of baseline appears equivalent across the ages tested in NVGPs. However, inspection of the mean ARLs in Fig. 4 suggests that 7–13 year olds have slower recovery times than 14–22 year olds, as predicted. Post-hoc repeated contrasts revealed that this difference was statistically significant ($t(83) = 2.02$, $p = .046$), with 14–22 year olds ($M = 354$ ms) having faster recovery rates than 7–13 year olds ($M = 446$ ms).

The same data from NVGPs and VGPs were then entered into an ANOVA with age group (7–10 years, 11–13 years, 14–17 years, 18–22 years) and game playing (NVGP, VGP) as between-subjects factors. As predicted, VGPs exhibited faster attentional recovery times than NVGPs ($F(1, 139) = 7.80$, $p = .006$, partial $\eta^2 = .06$). The mean ARL for VGPs was 298 ms, with 412 ms required for NVGPs to recover to the same criterion (Fig. 4, Table 3). As reported above, no main effect of age group was observed ($F < 1$, $p = .534$, partial $\eta^2 = .02$), nor was there any interaction between age group and gaming ($F < 1$, $p = .531$, partial $\eta^2 = .02$).

While the ARL measure provides a measure more comparable to the thresholds used in the UFOV (see above) and MOT (see below) tasks, interested readers are referred to Supplementary Results for line charts reporting performance for each experimental group as a function of T1–T2 lag.

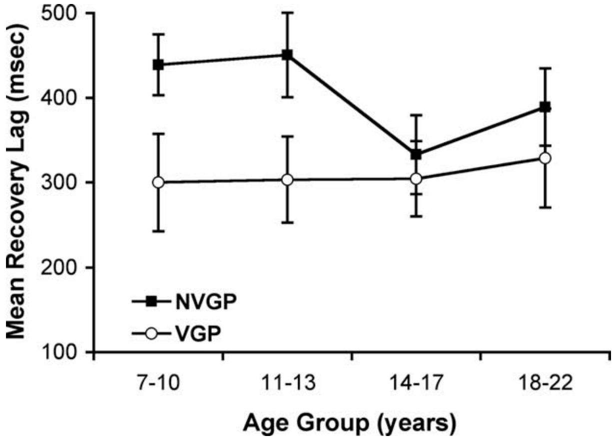

Fig. 4. For the attentional blink task, the attentional return lag was defined as the lag of time elapsed between T1 and T2 at which performance on T2 (given T1 was correctly discriminated) had recovered to 80% of maximum. VGPs (○) recovered more quickly than NVGPs (□); this effect was especially marked in young gamers. Error bars indicate the standard error of the mean.

5. Experiment 3 – multiple object tracking

5.1. Method

5.1.1. Subjects

Some participants did not complete the MOT task. Of the 103 NVGPs in the sample, eight did not complete the task – one 11–13 year old and seven 18–22 year olds. Of the 58 VGPs, data were not collected from two subjects – both 18–22 year olds.

Table 3
Means (and SDs) of attentional recovery lags in the attentional blink task.

	7–10 years	11–13 years	14–17 years	18–22 years
NVGP	443 (215)	451 (199)	318 (179)	389 (193)
VGP	300 (141)	303 (190)	304 (174)	287 (171)

5.1.2. Design and procedure

Using a task based upon that reported by Pylyshyn and Storm (1988), the number of moving objects that subjects could track simultaneously was assessed. Sixteen cartoon faces (each subtending 0.4° of visual angle) were presented inside a gray circle on the screen that subtended 10° of visual angle from its center. All these faces were yellow circles with black lines depicting a 'happy face', except for a variable number of faces (1–8), which were designated as target faces to be tracked. These target faces were blue circles with black lines depicting a 'sad' face. When the subject was ready, the experimenter initiated trials. Each trial consisted of all the cartoon faces moving within the gray circle at a speed of 5 deg/s with direction of movement determined stochastically. The faces never overlapped or touched, and were programmed to 'bounce' off each other and the walls of the gray circle. After 2 s, the blue target faces changed to match the yellow, happy distractor faces. After 5 further seconds of movement, the faces were halted and a white circle containing a question mark replaced one of the faces. The question mark had a 50% chance of appearing over a target face. Subjects were required to indicate whether or not the indicated face was a blue target face from the onset of the trial. The content of the next trial was determined using an adaptive staircase procedure. If a subject achieved three correct trials in a row, another blue target face was added (with a maximum of 8 target faces), whereas one incorrect trial resulted in one less blue target face on the next trial (with a minimum of 1 blue target face). The procedure was stopped when either eight 'reversals' had occurred or after 72 trials, whichever came sooner. The subject's 79.3% threshold was approximated as the average number of blue target faces in the last 10 correct trials. Note that this task probes only one face per trial rather than asking for full report of all the initially blue faces as Trick et al. (2005) used in their developmental study. This design was chosen to limit response interference in task performance.

5.1.3. Results

5.1.3.1. Treatment of outliers. Data from five NVGPs were excluded due to thresholds greater than 2 SD from the mean for their group – two 7–10 year olds, one 14–17 year old and two 18–22 year olds. Data from one 11–13 year old VGP, one 14–17 year old VGP and two 18–22 year old VGPs were excluded as outliers with tracking thresholds greater than 2 SD from the mean for their group.

5.1.3.2. MOT performance. Non-gamers demonstrated improvements in object tracking performance with increasing age. The MOT thresholds from NVGPs were entered into an ANOVA with age group (7–10 years, 10–13 years, 14–17 years, 18–22 years) as a between-subjects factor. A significant effect of age group was found ($F(3, 90) = 5.16$, $p = .003$, $\eta^2 = .15$). Older NVGPs had a greater tracking ability than younger NVGPs as indicated by the linear trend in Fig. 5 (see also Table 4).

In order to assess the effect of video game playing on object tracking, both age group and game playing (NVGP, VGP) were used as between-subjects factors. This ANOVA revealed a significant effect of age group ($F(3, 142) = 8.07$, $p < .001$, partial $\eta^2 = .15$), and no interaction between age group and game playing ($F < 1$, $p = .535$, partial $\eta^2 = .02$). As predicted, however, a significant main effect of video game playing was present ($F(1, 142) = 5.15$, $p = .025$, partial $\eta^2 = .04$). Action video game playing in children resulted in improved object tracking abilities as evidenced by enhanced MOT thresholds in VGPs compared to NVGPs (see Fig. 5, Table 4).

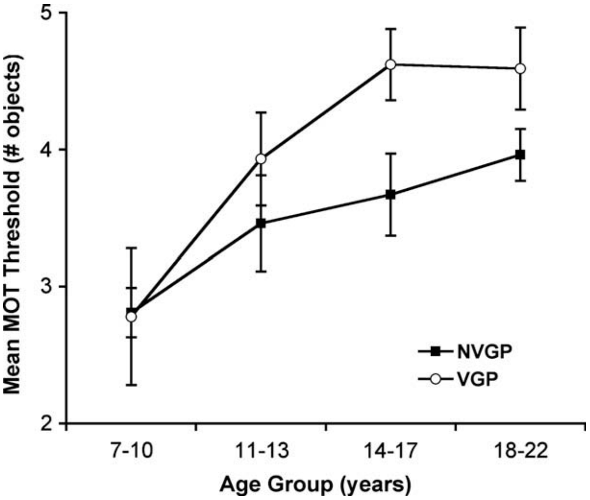

Fig. 5. The multiple object tracking threshold measures how many objects can be apprehended at the same time with 79.3% accuracy. Video game players (❍) had larger tracking thresholds than non-video game players (❑), suggesting video game players can allocate attention to more objects at the same time.

Table 4
Mean (and SD) of multiple object tracking thresholds.

	7–10 years	11–13 years	14–17 years	18–22 years
NVGP	2.81 (1.19)	3.46 (1.37)	3.67 (1.12)	3.96 (0.78)
VGP	2.78 (1.22)	3.93 (1.31)	4.62 (0.97)	4.59 (1.23)

6. General discussion

Spatial, temporal and object-based aspects of visual selective attention were assessed using child-friendly versions of the Useful Field of View, attentional blink and multiple object tracking tasks administered to subjects ranging in age from 7 to 22 years. On the UFOV task, no improvement with age was observed in those subjects who did not play action video games (NVGPs), suggesting that the development of the visual search skills required for this task have stabilized by the time children enter elementary school. In the attentional blink task, the amount of time necessary to recover from the attentional blink diminished slightly with age in NVGPs, with performance asymptoting around the end of the middle school years. As subjects got older, they were better at detecting single targets in an RSVP stream, and the time required for attentional resources to recover after being directed towards the identification of a first target decreased also. On the multiple object tracking task, older participants were able to track more objects than the younger ones, with the span increasing by about one object from 7 to 22 years of age (an increase from 2–3 items to 3–4 items). This suggests that object-based attention continues to develop post-adolescence, at least into early adulthood.

One important aspect of the current study is that measures of different aspects of visual attention were administered to the same group of children and adults. The observation that the different paradigms revealed different rates of development, with performance peaking at different ages, supports the proposal that these different aspects of visual attention rely upon different neural resources. Indeed, the bivariate correlations between the three experimental measures obtained from NVGPs were remarkably low (UFOV.MOT $r = -0.12$, MOT.AB $r = 0.10$, AB.UFOV $r = 0.07$). This leads to a consideration of whether they also differ in their susceptibility to the effects of environmental factors such as action video game playing.

Comparing non-video game players (NVGPs) with action video game players (VGPs), we found that gamers had significantly lower thresholds than NVGPs on the spatial attention task, faster recovery on the temporal attention task, and greater object tracking capacity. In other words, on the UFOV task, VGPs required the stimulus to be available for less time than NVGPs in order to achieve the same level of accuracy in localizing a peripheral target embedded in a field of distractors. In addition, improved peripheral performance in VGPs was not at the cost of poorer central task performance, indicating an overall increase in the efficiency of visual selective attention over space. On the attentional blink task, attention was found to recover faster in VGPs than in NVGPs, allowing gamers to process a stream of rapidly presented stimuli more accurately. Finally, VGPs could track more objects in the multiple object tracking task than NVGPs. These findings in children mirror those observed in adult gamers (Green & Bavelier, 2003, 2006a, 2006b). Thus, action video gaming does not only enhance attentional skills that are still developing in young children such as those tapped by the attentional blink and multiple object tracking paradigm; it also has an impact upon attentional skills that are relatively stable early in development, such as those measured using the Useful Field of View paradigm. Examination of the bivariate correlations between the three measures for VGPs revealed much higher correlations than observed for NVGPs (UFOV.MOT $r = -0.21$, MOT.AB $r = -0.35$, AB.UFOV $r = 0.34$) pointing to a common source for these effects.

This study shows that children who play action games exhibit performance levels that are only reached at a much later age, or not at all, in non-gamers. This is not to say that societal concerns over playing video games need be ignored. Suggestions that extensive playing of action-based games may lead to increased aggressiveness and/or poorer academic performance (Anderson & Dill, 2000) certainly warrant caution about video game exposure in children. What the present study shows is that when it comes to basic attentional skills such as visual selective attention across both space and time and attention to objects, children who are exposed to action-based games show better performance, above and beyond that expected on the basis of maturational processes.

It remains unclear at this point whether the effect of video games on the development of these various aspects of visual attention is purely causal or rather, children who possess better-than-average visual attention skills may be drawn towards playing action-based video games, thus placing themselves within an environment that leads to further enhancement of those visual skills (see Dickens & Flynn, 2001 for a similar discussion). Training studies in adults demonstrate that the dynamic visual environment provided by action video gaming can have an effect upon the visual skills of those who do not demonstrate a natural aptitude for such an activity (Cohen, Green, & Bavelier, 2008; Green & Bavelier, 2003, 2006a, 2006b). Although there is little reason to believe that this would not also be the case for children, only a training study can unambiguously settle the issue. However, performing such a training study is at present ethically questionable – the games found to have an effect all belong to the action game category, and therefore have a significant amount of violent content (often accompanied by an M for Mature rating from the Entertainment Software Rating Board). Age-appropriate video games may exist that may modify visual attention as they require attention to multiple, fast-moving objects spread across the visual field (e.g. Ratchet: Deadlocked, Super Mario Kart, Harry Potter: Quidditch World Cup). However, using one such game in an adult training study, we were not able to induce the same observable changes in attentional skills that are brought about by action games (Cohen et al., 2008). A pilot study using the game Ratchet: Deadlocked with children also failed to show significant effects. The identification of a suitable training game for children is certainly a high priority, but at present we have not identified a game that has had consistent and replicable effects on the attentional skills measured in juvenile populations.

The constitution of our sample reflects the common observation that action games are predominantly drawing a male audience, not only during adolescence but also at younger ages. It is therefore important to ask whether our results may document a gender difference in visual attention skills rather than an effect of video game playing. Apart from a well-documented gender difference on 3D mental rotation of blocks (Casey, Nuttall, Pezaris, & Persson Benbow, 1995), studies looking for gender differences in visual processing have provided a mixed picture (Valian, 1999). There is much debate on whether gender differences exist in spatial abilities in general (Voyer, Voyer, & Bryden, 1995), and there is little evidence for gender differences in the type of attentional skills measured here. There is one notable exception, however, in the literature. Feng, Spence, and Pratt (2007) recently reported that adult NVGP males outperformed adult NVGP females on the UFOV.

In order to address this issue, we focused upon data from NVGPs. In this sub-set of our sample, there are data from both males and females to allow an initial assessment of the effect of gender. Fig. 6 shows scatter plots of task performance as a function of age and gender for each of the three measures employed in this study.

These data suggest negligible differences on task performance between male and female early in development, but a possible widening gap by adulthood, at least for the UFOV and the MOT. Although the trend in older subjects is far from conclusive in this study, it mirrors the effect reported in the Feng et al.'s study. It is possible that differences in video game exposure earlier in life may account for part of the gender effect seen by adulthood. Indeed, NVGPs are typically selected based on their action video game play in the past few years with little information about exposure earlier in life. The demonstration that training on action video games enhances performance across a range of visual attention skills, calls for caution in the future interpretation of gender effects

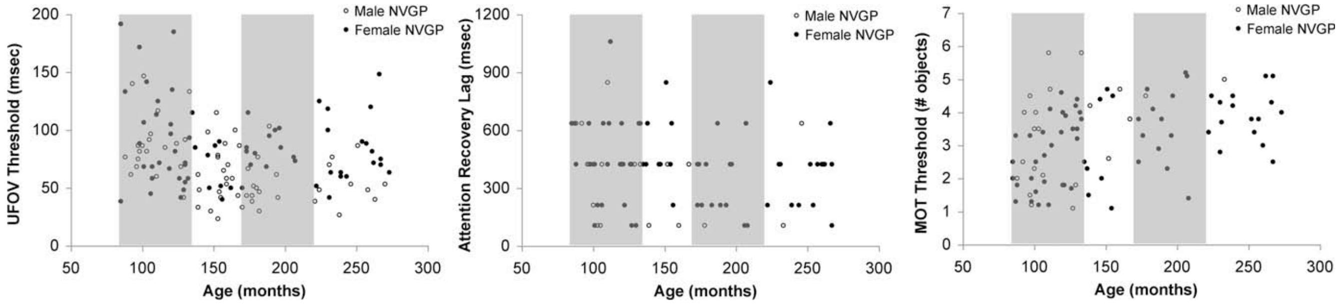

Fig. 6. Scatterplots of NVGP performance on the UFOV, AB and MOT tasks as a function of age and gender.

on these kind of tasks. Indeed, as these games are dominantly drawing a male audience at all ages, young and older girls alike are at risk of under-performing on such tests. With gaming becoming more and more widespread, new reports of gender differences in visual selective attention are likely to emerge, unless very careful control of past and present video game usage becomes routine practice.

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Appendix A. Action Video Games

007 Agent Under Fire; 007 Everything or Nothing; 007 Nightfire; America's Army; Battlefield 1942; Counter Strike; Doom; Grand Theft Auto 3; Grand Theft Auto: Vice City; Halo 2; Halo; Hitman 2; Max Payne; Medal of Honor: Allied Assault; Perfect Dark; Ratchet & Clank; Return to Castle Wolfenstein; Tom Clancy's Ghost Recon; Tom Clancy's Rainbow Six; Tom Clancy's Splinter Cell; Unreal Tournament 2003; Viet Cong.

Appendix B. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.visres.2009.10.010.

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