

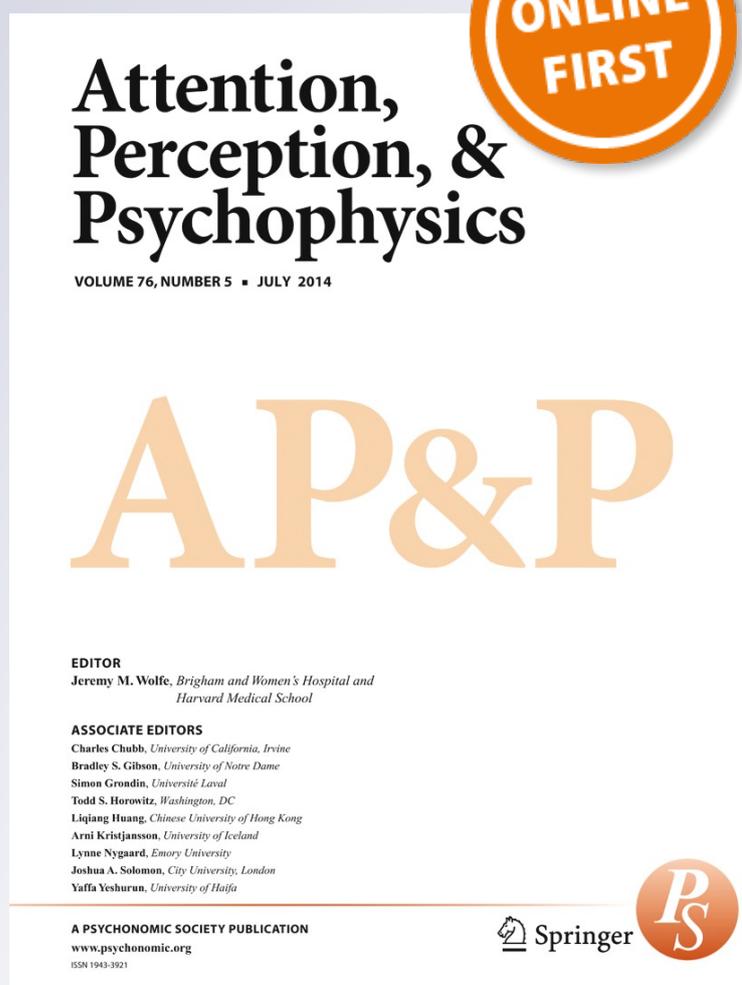
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Stimulus- and goal-driven control of eye movements: Action videogame players are faster but not better

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Abstract Action videogame players (AVGPs) have been shown to outperform nongamers (NVGPs) in covert visual attention tasks. These advantages have been attributed to improved top-down control in this population. The time course of visual selection, which permits researchers to highlight when top-down strategies start to control performance, has rarely been investigated in AVGPs. Here, we addressed specifically this issue through an oculomotor additional-singleton paradigm. Participants were instructed to make a saccadic eye movement to a unique orientation singleton. The target was presented among homogeneous nontargets and one additional orientation singleton that was more, equally, or less salient than the target. Saliency was manipulated in the color dimension. Our results showed similar patterns of performance for both AVGPs and NVGPs: Fast-initiated saccades were saliency-driven, whereas later-initiated saccades were more goal-driven. However, although AVGPs were faster than NVGPs, they were also less accurate. Importantly, a multinomial model applied to the data revealed comparable underlying saliency-driven and goal-driven functions for the two groups. Taken together, the observed differences in performance are compatible with the presence of a lower decision bound for releasing saccades in AVGPs than in NVGPs, in the context of comparable temporal interplay between the

underlying attentional mechanisms. In sum, the present findings show that in both AVGPs and NVGPs, the implementation of top-down control in visual selection takes time to come about, and they argue against the idea of a general enhancement of top-down control in AVGPs.

Keywords Attention modeling · Action videogame players · Cognitive control · Automaticity · Eye movements · Visual attention

Action videogames are a form of entertainment with the potential to trigger substantial modifications in our brain and behavior (for a review, see Bavelier, Green, Pouget, & Schrater, 2012). In the last decade a growing body of data showed that action videogame players (AVGPs) outperform nongamers (NVGPs) in a wide variety of visual attention tasks, including selective-attention tasks (Hubert-Wallander, Green, Sugarman, & Bavelier, 2011) and sustained-attention and divided-attention tasks (Green & Bavelier, 2003, 2006)—tasks that require skills that go well beyond the abilities directly trained within the game environment. Moreover, the same patterns of results have been observed in naïve participants who were trained for a short period of time with action videogames, demonstrating a direct causal role of action videogame playing in these improvements in visual attention (Green & Bavelier, 2003, 2006; but see Kristjánsson, 2013). Until now, the explanation for this superior performance is that AVGPs show enhanced top-down control relative to NVGPs. This is generally expressed through a more efficient suppression of irrelevant information in AVGPs relative to NVGPs (Bavelier, Achtman, Mani, & Föcker, 2012; Green, Sugarman, Medford, Klobusicky, & Bavelier, 2012; Hubert-Wallander et al., 2011; Mishra, Zinni, Bavelier, & Hillyard, 2011). However, specifically how and when in time this

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enhanced top-down control is established during performance has not been systematically investigated.

Notably, recent evidence from overt visual selection paradigms suggests that voluntary and intentional goal-driven strategies generally take time to be implemented, such that early in time visual selection is driven primarily by stimulus-salience and only later in time by goal-driven behavior (van Zoest & Donk, 2005, 2008; van Zoest, Donk, & Theeuwes, 2004; van Zoest, Hunt, & Kingstone, 2010). The aim of the present study was to investigate the time course of overt visual selection in AVGPs as compared to NVGPs. More specifically the goal was to examine possible differences in the temporal dynamics of stimulus-driven and goal-directed contributions to performance in the two populations. In fact, it is still unclear whether the better suppression of irrelevant information reported in AVGPs than in NVGPs depends from a decreased contribution of saliency-driven processes or from an increased contribution of goal-driven control to performance in the former population as compared to the latter. Importantly, the potential new insights on the characteristics of AVGPs performance would also permit to further contribute to the debate within the visual selection literature regarding the properties and constraints concerning the efficient implementation of goal-driven strategies.

The majority of results on the effects of intensive action videogame playing on performance have been collected in covert orienting tasks measuring manual responses and involving restricted eye movements. When eye movements were permitted, they were not recorded. These works consistently reported that AVGPs-related improvements involve top-down (endogenous) mechanisms of attention (Castel, Pratt, & Drummond, 2005; Green & Bavelier, 2003; Hubert-Wallander, Green, & Bavelier, 2010; West, Stevens, Pun, & Pratt, 2008), whereas stimulus-driven (exogenous) processing tends to be comparable between groups (Castel et al., 2005; Dye, Green, & Bavelier, 2009a; Hubert-Wallander et al., 2011; but see West et al., 2008). Importantly, the lack of exogenous-related changes in AVGPs has been corroborated also by studies that directly compare the role of these two attentional mechanisms within the same paradigm (Chisholm, Hickey, Theeuwes, & Kingstone, 2010; Chisholm & Kingstone, 2012; West, Al-Aidroos, & Pratt, 2013). For example, Chisholm and colleagues (2010) used an attentional capture paradigm, in which AVGPs and NVGPs were instructed to search for a unique target shape presented among a number of homogeneous nontargets. Participants were required to respond to the orientation of the line inside the target element, while maintaining fixation. In half of the trials one of the irrelevant nontargets was a unique colored singleton. Participants were told to ignore any color information and to concentrate only on the orientation of the line inside the target—the unique shape element. Response times revealed that AVGPs were overall faster to respond than NVGPs.

Moreover, AVGPs were also less affected in their search rate by the presence of the colored distractor. It was concluded that videogame players have enhanced top-down attentional control, which, in turn, modulates the interference from stimulus-driven attentional capture.

Two recent studies have investigated the interplay between stimulus and goal-driven control in overt visual selection (thus recording eye movements and not manual responses) confirming the results above coming from covert attention studies. Chisholm and Kingstone (2012) tested AVGPs and NVGPs with an oculomotor version of the attentional capture task. In each trial six uniformly colored circles appeared arranged in a hexagonal display. One of these circles randomly changed color and the task of the participants was to make an eye movement (saccade) as fast and as accurate as possible toward the unique color singleton. In half of the trials, concurrent with the color change, an additional circle in the same color as the distractors was added to the display. The results showed that AVGPs were faster than NVGPs at searching and finding the target in the trials when an onset distractor was presented. However, AVGPs and NVGPs showed comparable initial saccade latencies as well as comparable fixation durations on the distractor, when they made an incorrect saccade toward this location instead of a correct saccade toward the location of the target. Nonetheless, fewer overall saccades toward distractors were found in AVGPs than in NVGPs. The authors conclude that the enhanced top-down control in AVGPs is the result of more efficient suppression of task-irrelevant information and that this reflects a general principle of human cognition such that the top-down modulation of capture can be realized before selection is determined (e.g., Bacon & Egeth, 1994; Folk, Remington, & Johnston, 1992). In addition, these results suggest that overt and covert attentional mechanisms are modified in a similar way by avid action videogame playing.

Recently, West and colleagues (2013) directly investigated the interplay between stimulus and goal-directed contributions to performance in AVGPs using a saccadic trajectory deviation task; to our knowledge, they were the first to take into account the role of time (i.e., saccadic latencies) to explain AVGPs performance. In this task the dynamics between stimulus-driven and top-down mechanisms was inferred from the trajectories of saccadic eye movements. In each trial, participants had to make a speeded saccade to a target appearing either above or below the fixation point while ignoring a concomitant distractor presented in proximity of the target. Performance in this paradigm typically shows that early-initiated saccades tend to curve toward the distractor, thus being captured by irrelevant information, whereas later-initiated saccades tend to curve away from the distractor. The latter oculomotor behavior is considered a consequence of the inhibition of the irrelevant distractor and an index of top-down control acquisition (McSorley,

Haggard, & Walker, 2006; Walker, McSorley, & Haggard, 2006). West and colleagues (2013) showed that saccadic trajectories of early-initiated saccades were equally affected by distractors in the two groups, whereas the curvature of later initiated saccades differed between AVGPs and NVGPs. Indeed when participants initiated their saccades later in time, AVGPs were better able than NVGPs to ignore distractors (i.e., less saccades were directed incorrectly to the distractor). However this result emerged only for the second part of the experiment, once the trials were divided in two parts to better account for training related effects within individual performances. Overall, and beside this latter training effect, these findings demonstrate the benefit of tracing the time course of the acquisition of control in performance. At the same time, the results further suggest that the beneficial effects of avid action videogame playing as measured via overt saccadic responses are not substantially different from the benefits measured in performance via covert manual responses: In both overt and covert selection, enhanced top-down strategies of the AVGPs make them better able to ignore the irrelevant information, whereas exogenous, stimulus-driven processes seem to be unaltered.

It should be highlighted, though, that saccade trajectory deviations reflect very subtle variation in saccade programming. In these paradigms, eye movements are ultimately goal-driven as the saccades almost always end-up at the target location. In the present study, we aim at tracing the time course of stimulus-driven and of goal-driven strategies in AVGPs in a visual selection task that typically reveals dramatic errors in course of oculomotor programming. This task provides direct insight in the impact on performance of exogenous information (i.e., stimulus saliency) over time and provides also a measure of when in time top-down strategies are able to control overt selection. The approach proposed is similar to previous works by van Zoest and Donk (2005, 2008), who used a search task in which participants searched for a target while competing powerful—but irrelevant for the task—salient information was presented (van Zoest & Donk, 2005). For example, van Zoest and Donk (2005) presented participants with search displays always composed of a target and a distractor (i.e., two tilted lines) embedded in a homogeneous set of nontargets (i.e., vertical lines). The relative saliency of the target and distractor was manipulated in the color dimension: On one third of trials the target was colored, and it was the most salient stimulus in the display; on one third of trials the distractor was colored, and it was the most salient stimulus in the display; and on the remaining third of trials, neither the target nor the distractor was colored (no unique color). Van Zoest and Donk (2005) found that early-in-time eye movements were strongly driven by stimulus saliency. Saccades were directed to the most salient element, independently of the task instructions. Later in time saccades were no longer

affected by irrelevant salience but were directed in line with the task instructions. This study suggested that it takes about 250 ms before goal-driven strategies are available to guide selection (see also van Zoest & Donk, 2008; van Zoest, Donk, & Theeuwes, 2004).

In the present study, performance in an oculomotor additional-singleton paradigm of a group of AVGPs was compared to that of a group of NVGPs. Importantly, to further investigate possible differences between AVGPs and NVGPs in the evolution over time of stimulus-driven and goal-driven processes, we constructed a model allowing us to separately estimate the underlying evolutions over time of both types of processes, while taking into account possible differences in speeds of responding between groups. If, as suggested by Chisholm and Kingstone (2012), AVGPs are better able than NVGPs to suppress stimulus-driven information already before the appearance of a display, we would expect the influence of stimulus-driven processes to be smaller in AVGPs than in NVGPs. In particular, the enhanced ability to suppress irrelevant salient information should reduce or be less probably, or even completely eliminate the contribution of stimulus-driven processes to performance.

If, instead, stimulus-driven processes are unaltered, and only goal-driven processes are enhanced in AVGPs relative to NVGPs, as West and colleagues (2013) have proposed, we would expect to see no difference between the two groups in the contributions of stimulus-driven processes, but AVGPs should show only a stronger contribution of goal-driven processes relative to NVGPs.

Method

Participants

A total of 22 AVGPs (mean age = 21.7 years, $SD = 2.9$; all males) and 16 NVGPs (mean age = 22.9 years, $SD = 2.5$; all males) took part to the experiment. NVGP and AVGP participants were recruited separately. NVGP participants were recruited only if they declared having played very little, if at all, on any videogame in the last year. AVGP participants were recruited on the basis of the self-identification of being an action videogame player; before starting the experiment, these participants completed a questionnaire on their videogames habits, in which they were asked (a) to list up to six games they had played mostly during the last year; (b) to identify the game genre for each of these listed games; (c) to specify how many times per month they would usually play each of the listed games and (d) for how long each session typically lasted; and (e) to specify the console they used. AVGPs were included in the experiment only if they reported having played action videogames on average for more than 5 h per week in the last year (Li, Polat, Scalzo, & Bavelier, 2010; mean

number of hours played per week by our AVGP sample = 19.5).

All participants were recruited at the University of Trento, and they all had normal or corrected-to normal vision. The Ethics Committee of the University of Trento approved the experiment. Each participant was given written instructions about the task, was informed of the general purpose of the study, was asked to sign a consent form, and received credits or a payoff of €7 for participating in the study.

Apparatus

A Dell PC controlled the timing of the events and generated the stimuli. Eye movements were recorded through an EyeLink tracker (EyeLink 1000 Desktop Remote, SR Research) with 1000-Hz temporal resolution and 0.05° spatial resolution. The system uses an infrared video-based tracking technology to compute the pupil center and pupil size of both eyes. The display was a 19-in. SVGA color monitor, with 1,024 × 768 pixels resolution and a 75-Hz refresh rate. All participants were tested in a dimly lit room with their heads resting on a chinrest. The monitor was located at eye level, 60 cm from the chinrest.

Stimuli

Participants performed a visual search task in which they were instructed to make a speeded saccade as quickly as possible to a target. The target was defined in the orientation dimension (e.g., a line oriented 45° to the right). The displays consisted of one target, a series of vertical oriented nontargets, and one distractor tilted in the opposite direction from the target (e.g., a line oriented 45° to the left). Saliency was manipulated by means of color. The vertical nontargets were always white. On one-third of trials, the target was colored red, and the distractor was white (*colored-target singleton*), thus making the target the most salient singleton in the display. On another third of trials, the distractor was colored green and the target was white (*colored-distractor singleton*), thus making the distractor singleton the most salient stimulus in the display. On the remaining third of trials, both the target and distractor were white (*no-colored singleton*), and thus no unique color singleton was in the display. Elements were presented on a dark gray background, arranged in a 15 × 11 square matrix with a raster width of 30.7° × 25° of visual angle. Targets and distractors could appear at six different locations. These six potential locations were placed at the vertex of an imaginary hexagon in such a way that, embedded in the matrix of nontargets, the targets and distractors were always presented at equal eccentricities from fixation (12.4° of visual angle). When a target and a distractor were presented, the angular distance between the two elements was always 120° (see Fig. 1). The elements had an

approximate height of 0.9° of visual angle and an approximate width of 0.3° of visual angle.

Design and procedure

Each participant performed 24 practice trials, followed by 432 experimental trials. The three conditions manipulating target and distractor saliency (no colored singleton, target colored singleton, distractor colored singleton) were mixed. The target and distractor orientations (i.e., right-tilted target with a left-tilted distractor, and vice versa) were counterbalanced among participants.

To start a trial, participants pressed the space bar, then the fixation point was presented for 1,000 ms, followed by the stimulus matrix for 1,500 ms. Participants were instructed to maintain fixation until the search display appeared and then to make a speeded saccade to the target as quickly as possible, ignoring the distractor. They were also told that sometimes the target or the distractor would be colored but that this information would not be informative, and therefore they were instructed to ignore color information. All participants received written instructions. Feedback on the initial saccade mean latencies was provided every 27 trials. The experiment was divided into 16 blocks, and the participants were free to take a break between experimental blocks. Prior to the recording and after every four blocks, participants viewed a calibration display consisting of nine points in a square array, fixated sequentially.

Results

Two of the AVGPs were discarded due to problems during data acquisition. Four participants initially recruited as potential AVGPs were later excluded from the sample because, although they played with action videogames, they reported playing less than our criterion for inclusion (i.e., less than 5 h per week). In our remaining samples, we excluded all trials in which the initial saccade latencies were below 80 ms (anticipation errors; for NVGPs, 1 % of trials; for AVGPs, also 1 % of trials) or above 600 ms (for NVGPs, 4 % of trials; for AVGPs, 2 % of trials), as well as trials that started when the eyes of the participants were more than 2.5° of visual angle away from fixation (for NVGPs, 5 %; for AVGPs, 4 %) and trials on which the initial saccade missed the location of either the target or the distractor (NVGPs, 9 %; AVGPs, 8 %). Independent-groups *t* tests on each set of the discarded trials revealed no difference between groups with regard to the percentage of discarded trials in any of the to-be-discarded conditions (all *p* values > .13). We therefore proceeded with analyses that included only those trials in which the initial saccades ended 6° of visual angle around either the target or

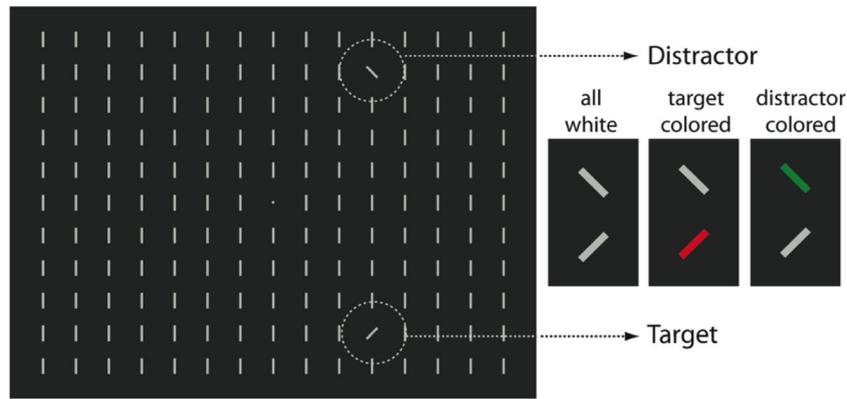


Fig. 1 Example of a stimulus display. In each trial, the target and distractor could both be white, the target could be colored red, or the distractor could be colored green

the distractor. On the basis of the trimmed data, one AVGP was discarded because his mean initial saccade latencies (346.22 ms) fell more than two standard deviations above the AVGP group mean (237.14 ms). All subsequent analyses were conducted on 16 NVGPs and 15 AVGPs (see Table 1 for the overall mean saccadic latencies and the overall mean proportions of correct saccades to the target, reported separately for each group and only for the included participants; i.e., NVGPs = 16, AVGPs = 15).

Saccadic latencies

In order to look at the temporal dynamics of selection performance (van Zoest & Donk, 2005, 2008; van Zoest et al., 2004), for each participant and each of the three saliency conditions, we divided the overall distribution of the initial saccade latencies into quintiles. For each quintile, we calculated the proportion of correct saccades to the target. Then we separately averaged together the saccadic latencies and proportions of correct saccades to the target for all participants in each quintile (see Table 2).

On data organized in this way, we conducted a mixed, repeated measures analysis of variance (ANOVA) on the mean saccadic latencies, with Saliency Condition (colored target, colored distractor, no colored singleton) and Quintile (1–5) as within-subjects factors, and Group (NVGPs, AVGPs)

Table 1 Mean saccadic latencies (SRTs), with standard errors (SEs), and mean proportions of correct saccades to the target (*p*Corr), with SEs, for the 16 non-videogame players (NVGPs) and the 15 action videogame players (AVGPs) included in all the following analyses

		NVGPs	AVGPs
SRTs (ms)	Mean	263.29	229.42
	SE	26.15	16.9
<i>p</i> Corr (%)	Mean	.59	.54
	SE	.03	.01

as a between-subjects factor. All post-hoc analyses were conducted using the Newman–Keuls test. First of all, this analysis revealed a trivial significant main effect of quintile [$F(4, 116) = 158.87, p < .00001, \eta_p^2 = .84$], due to the expected significant increase in saccadic latencies across quintiles (all *p* values $< .0001$). We also observed a significant main effect of saliency condition [$F(2, 58) = 13.61, p = .00001, \eta_p^2 = .32$], due to overall slower saccade latencies in the no-colored-singleton condition (mean = 255.40 ms, *SE* = 10.61) than in the other saliency conditions (colored target, mean = 242.53 ms, *SE* = 10.94; colored distractor, mean = 246.36 ms, *SE* = 10.51; $p < .0008$). Most importantly, we found a significant two-way interaction between quintile and group [$F(4, 116) = 2.63, p = .04, \eta_p^2 = .08$]. Post-hoc analyses revealed that AVGPs were significantly faster than NVGPs only in the last quintile, independently of saliency conditions (see Fig. 2; Quintile 5: AVGPs, mean = 320.60 ms, *SE* = 22.28; NVGPs, mean = 372.60 ms; *SE* = 21.56; $p = .0001$). No other main effects or interactions were significant (all *F* values < 2.97).

Given the fact that previous studies have repeatedly reported overall faster responses in AVGPs than in NVGPs (e.g., Chisholm et al., 2010; Green, Pouget, & Bavelier, 2010; for a review, see Dye, Green, & Bavelier, 2009b; but see Chisholm & Kingstone, 2012), we wanted to further investigate the characteristics of the underlying saccadic reaction time (SRT) distribution of AVGPs. We therefore constructed a Brinley plot (see Fig. 3) directly contrasting the SRTs reported for AVGPs and NVGPs. This graph confirms that the two populations differed only for their longest saccadic latencies.

Proportions to the target

To examine the crucial aspect of overt selection as a function of time, we conducted a similar ANOVA on mean proportions of initial saccades correctly directed to the target, again with Saliency Condition (colored target, colored distractor, no colored singleton) and Quintile (1–5) as within-subjects factors and

Table 2 Mean saccadic latencies (SRTs), with standard errors (*SE*), and mean proportions of correct saccades to the target (*p*Corr), with *SE*s, reported separately for each group of participants (NVGPs, AVGPs), each

saliency condition (target colored, no colored singleton, distractor colored), and each quintile

	Target Colored				No Colored Singleton				Distractor Colored			
	SRTs (ms)	<i>SE</i>	<i>p</i> Corr (%)	<i>SE</i>	SRTs (ms)	<i>SE</i>	<i>p</i> Corr (%)	<i>SE</i>	SRTs(ms)	<i>SE</i>	<i>p</i> Corr (%)	<i>SE</i>
NVGPs												
Quintile 1	182.73	10.59	.84	.04	196.73	11.73	.49	.03	184.12	8.90	.23	.05
Quintile 2	219.14	18.38	.80	.03	232.82	16.84	.60	.04	220.35	15.95	.32	.06
Quintile 3	247.33	21.94	.71	.04	261.85	20.33	.53	.04	251.71	21.15	.50	.06
Quintile 4	285.92	24.32	.60	.05	301.75	23.67	.62	.04	292.71	24.03	.60	.06
Quintile 5	365.26	28.44	.65	.05	380.19	26.67	.69	.04	372.34	27.91	.72	.05
AVGPs												
Quintile 1	172.09	3.82	.84	.02	178.29	4.22	.53	.03	174.60	4.09	.25	.02
Quintile 2	191.91	5.35	.78	.03	200.97	5.68	.52	.02	195.43	6.01	.29	.03
Quintile 3	209.54	7.29	.64	.04	220.29	8.12	.52	.02	214.00	8.57	.43	.04
Quintile 4	237.91	10.23	.48	.03	249.77	9.91	.49	.03	241.44	10.52	.53	.04
Quintile 5	313.49	12.74	.46	.04	331.38	13.32	.64	.02	316.93	14.03	.66	.04

Group (NVGPs, AVGPs) as a between-subjects factor. All post-hoc analyses were conducted using the Newman–Keuls test. As expected, this analysis revealed a main effect of quintile [$F(4, 116) = 9.74, p = .000001, \eta_p^2 = .25$], due to increased proportions of correct initial saccades across quintiles—namely, as saccade latencies increased—with the last quintile being the most accurate of all (mean = 64 %, *SE* = 2 %; all *p* values

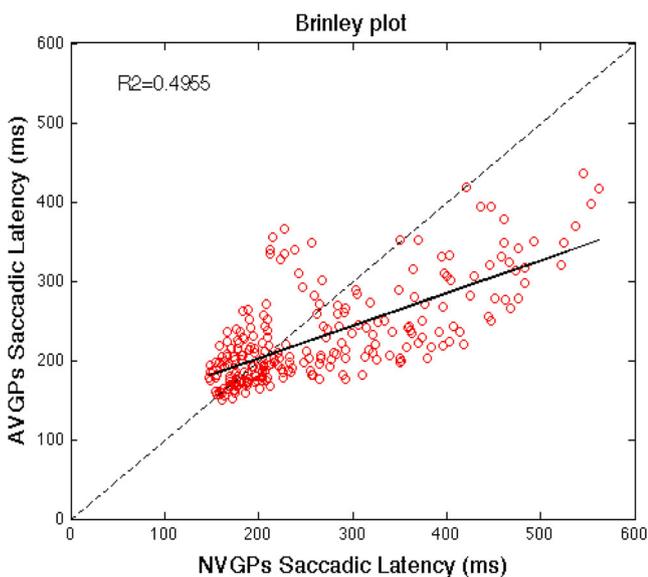


Fig. 2 Brinley plot for the 15 data points available for each participant (i.e., 3 saliency conditions \times 5 quintiles). Saccadic latencies from 16 NVGPs (*x*-axis) are plotted against saccadic latencies from the 15 good AVGPs, plus an additional 15 points representing the AVGP group mean for each data point. We used a linear function ($y = mx$) to describe the relationship between the latencies for AVGPs and NVGPs (black continuous line). The R^2 value is reported in the plot. All plots confirm that the latency distributions of the two groups diverge only for slower saccades, which are slower for NVGPs than for AVGPs

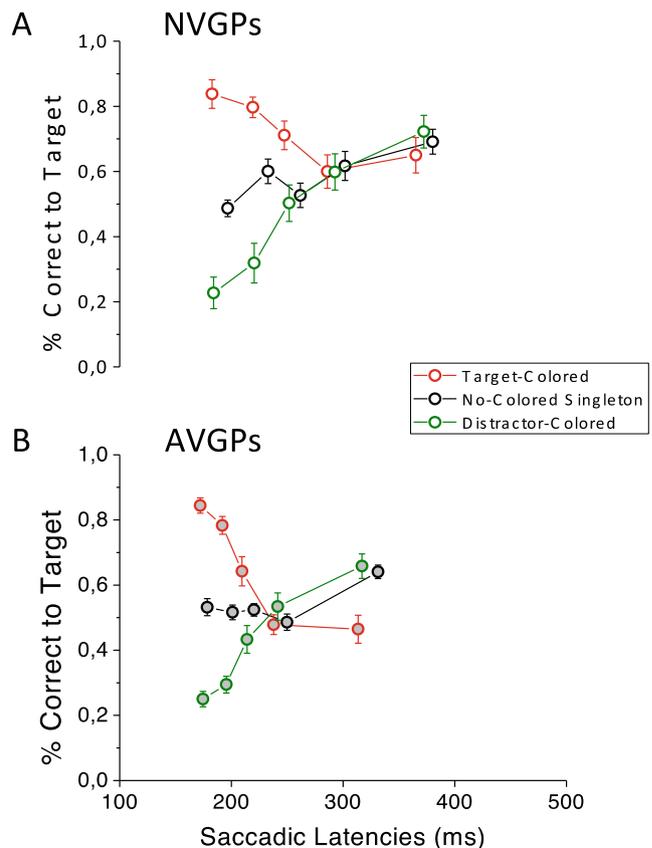


Fig. 3 Proportions of saccades correctly directed to the target as a function of saccade latency. There were three saliency conditions: target red (colored target), target and distractor white (no colored singleton), distractor green (colored distractor). See Table 2 for means and standard errors of the saccadic latencies and proportions of correct saccades to the target, for each saliency condition and each quintile, reported separately for each group. (A) Time-course of performance for non-videogame players (NVGPs). (B) Time-course of performance for action videogame players (AVGPs)

< .0002). In addition, the main effect of saliency condition also reached significance [$F(2, 58) = 46.34, p < .000001, \eta_p^2 = .61$], due to a significant difference in accuracy among the three saliency conditions (all p values < .0001), with overall the highest accuracy for the colored-target condition (mean = 68 %, $SE = 2$ %) and the overall least accuracy for the colored-distractor condition (mean = 45 %, $SE = 3$ %). Importantly, the two-way interaction between saliency condition and quintile also reached significance [$F(8, 232) = 51.17, p < .000001, \eta_p^2 = .64$]. This interaction confirmed that our saliency manipulation had different effects on participants' behavior over time, such that early-initiated saccades were mainly driven by saliency, and later-initiated saccades were mainly driven by goal-directed selection strategies (see also van Zoest & Donk, 2005, 2008; van Zoest et al., 2004).

Finally, but most importantly, we also found a significant two-way interaction between quintile and group [$F(4, 116) = 3.92, p = .005, \eta_p^2 = .12$]. Post-hoc analyses revealed that this interaction was driven by differences between the two groups for the final, fifth quintile, in which AVGPs were overall less accurate (mean = 59 %, $SE = 3$ %) than NVGPs (mean = 69 %, $SE = 3$ %; $p = .03$; See Table 2 for mean correct saccades to the target reported separately for each quintile in each of the three saliency conditions). No other main effects or interactions reached significance (all other F values < 3.43).

Disengaging attention from the distractor

Our paradigm also allowed for assessing whether AVGPs were quicker than NVGPs at disengaging attention from the distractor, when their eyes were first incorrectly directed to this element. To investigate this question, we conducted a mixed, repeated measures ANOVA on the fixation durations of first saccades to the distractor when the second saccade was correctly directed to the target, with Saliency Condition (colored target, colored distractor, no colored singleton) as a within-subjects factor and Group (NVGPs, AVGPs) as a between-subjects factor. All post-hoc analyses were conducted using the Newman-Keuls test. This analysis revealed only a main effect of saliency condition [$F(2, 58) = 6.08, p = .04, \eta_p^2 = .17$], due to shorter fixation durations when the distractor was colored (mean = 154.01 ms, $SE = 6.10$) than in the other two conditions (colored target, mean = 180.31 ms, $SE = 10.25$; no colored singleton, mean = 171.79 ms, $SE = 6.11$; all p values < .04). No effect involving the Group factor or any other effect was significant (all F values < 0.58).

Interim discussion

First of all, the present results confirmed that early-initiated saccades are mainly driven by saliency, and later-initiated

saccades are mainly driven by goal-directed selection strategies (see also van Zoest & Donk, 2005, 2008; van Zoest et al., 2004). Notably, this supports the general notion that goal-driven behavior takes time to be implemented in selection (e.g., van Zoest et al., 2010).

Moreover, the results showed that for the final quintile, AVGPs were relatively faster to initiate their saccades, but also less accurate than NVGPs. Importantly, we also showed that AVGPs were as fast as NVGPs at disengaging attention when saccades were incorrectly directed to the distractor instead of to the target (see also Chisholm et al., 2010).

Overall, our behavioral results indicate that AVGPs and NVGPs were initially equally affected by stimulus saliency; however, contrary to our hypothesis (see, e.g., West et al., 2013), AVGPs were not better than NVGPs at implementing an efficient goal-driven strategy to correctly select the target. Although the behavioral pattern showed by AVGPs was different from the expectations, ultimately this finding does further corroborate the notion that modulations driven by videogame playing occur mostly for endogenous, rather than exogenous, processes (e.g., Chisholm et al., 2010; Chisholm & Kingstone 2012; West et al., 2013).

The behavioral pattern of AVGPs (i.e., being faster but less accurate than NVGPs) suggests the presence of a speed–accuracy trade-off, which may have two possible explanations. One possibility is that the different behavioral patterns of performance of AVGPs and NVGPs are the result of a difference in the underlying control mechanisms. In other words, these behavioral results bring out the possibility that the underlying stimulus-driven and goal-driven processes controlling oculomotor selection behavior may fundamentally differ in AVGPs and NVGPs.

A second possibility is that AVGPs showed a “strategic” speed–accuracy trade-off relative to NVGPs: In line with the task instructions, AVGPs might have prioritized speed over accuracy, with the result that they were faster than NVGPs to initiate an eye movement; as a consequence of this strategy, though, they were also less accurate in correctly selecting the target. If this “strategic” account is correct, the underlying temporal interplay between the stimulus- and goal-driven components of visual selection should be the same in both groups, and the observed difference in the behavioral pattern may be most plausibly related to a lower decision bound for releasing saccades in AVGPs than in NVGPs. Interestingly, a result in this direction would be in line with a growing body of evidence suggesting that some of the improvements observed in this population might be ascribed to differences in the strategies adopted for solving the tasks in AVGPs versus NVGPs, rather than to differences related to the underlying attentional processes (e.g., Anderson, Bavelier, & Green, 2010; Clark, Fleck, & Mitroff, 2011; see Nelson & Strachan, 2009, for similar results after short gaming exposure; for a review, see Boot, Blakely, & Simons, 2011).

In order to further characterize the evolution over time of the two underlying components of attentional selection in AVGPs and NVGPs, we fitted a multinomial model to our behavioral data, allowing us to assess whether the underlying temporal development of stimulus-driven and goal-driven processes in AVGPs and NVGPs are comparable or different, while taking into account differences in response latencies. By modeling the data, we could explore whether the performance of AVGPs and NVGPs was best described by a single model, suggesting a similar underlying time course in the two groups, or whether the performance in both groups was best described by two separate models, suggesting that the underlying processing functions are different in the two groups.

Formal model

The model that we adopted is based on three main assumptions. The first assumption is that the observed visual selection behavior is the outcome of the operation of two independent underlying biases, a goal-driven bias driving the eyes toward the target and a stimulus-driven bias driving the eyes toward the most salient singleton in the display. A second assumption is that for each eye movement, either one of these biases can be present or absent; that is, each eye movement is assumed to be the outcome of either the absence of both a goal-driven and a saliency-driven bias, the presence of a goal-driven bias only, the presence of a saliency-driven bias only, or the presence of both a goal-driven and a saliency-driven bias. Finally, a third assumption is that the probability that the visual system is affected by a goal-driven bias increases with time whereas the probability that the visual system is affected by a saliency-driven bias decreases with time (e.g., Jonides, 1981; Müller & Findlay, 1988; Nakayama & Mackeben, 1989; Weichselgartner & Sperling, 1987). Therefore, within the model, the probability that the visual system is subjected to a goal-driven bias is assumed to be an increasing function of time since the presentation of a display and equals $G(t)$, which is given by

$$G(t) = 1 - e^{-r_G(t-t_{0G})} \quad \text{for } t > t_{0G}; \quad G(t) = 0 \quad \text{for } t \leq t_{0G}, \quad (1)$$

with t representing the time since the presentation of a display, r_G indicating the rate of the function, and t_{0G} representing the moment in time since the presentation of the display at which the function starts to increase. The function ranges between 0 and 1.

When two simultaneously presented singletons differ in relative saliency (with one being more distinct from its direct surrounding than the other), selection behavior may also be affected by a saliency-driven bias. Within the model, the probability that the visual system is biased toward the most

salient element in a display on the basis of stimulus-driven processes is assumed to be a decreasing function of time since the presentation of a display and equals $S(t)$, which is given by

$$S(t) = e^{-r_S(t-t_{0S})} \quad \text{for } t > t_{0S}; \quad S(t) = 1 \quad \text{for } t \leq t_{0S}, \quad (2)$$

with t representing the time since the presentation of a display, r_S reflecting the rate of the function, and t_{0S} indicating the moment in time since the presentation of the display at which the function starts to decrease. The function ranges from 1 to 0.

The model then assumes that the observed time course of oculomotor selection, as depicted in Fig. 2, is the outcome of the underlying functions $G(t)$ and $S(t)$. Even though, these functions cannot be directly observed, it is possible to estimate the parameters of these functions (i.e., r_G , t_{0G} , r_S , and t_{0S}) separately per condition (colored target, colored distractor, no colored singleton) and group (NVGPs, AVGPs), using the tree diagrams presented in Fig. 4 (Batchelder & Riefer, 1999).

The tree models presented in Fig. 4 outline how $G(t_i)$ and $S(t_i)$ lead to particular responses (either an eye movement toward the target or an eye movement toward the distractor) in each of the five quintiles (bins) of the saccadic latency distributions in the three different conditions. Consider, for instance, the lower-right tree corresponding to the colored-distractor condition. For a given bin i , an observer may or may not have a goal-driven bias toward the target and may or may not have a saliency-driven bias toward the distractor. If there is a goal-driven bias toward the target [i.e., $G(t_i)$], but not a saliency-driven bias [i.e., $1 - S(t_i)$], the response in bin i will be an eye movement toward the target. Similarly, if an observer has neither a goal-driven bias [i.e., $1 - G(t_i)$] nor a saliency-driven bias [i.e., $1 - S(t_i)$], the resulting eye movement will be equally likely to be directed toward the target and the distractor. Finally, if an observer only has a saliency-driven bias [i.e., $S(t_i)$] but no goal-driven bias [i.e., $1 - G(t_i)$], the resulting response in bin i will be an eye movement toward the most salient element, which in this condition is the distractor.

The overall probability of a particular response in a particular bin i equals the sum of the paths leading to that response in bin i (see Dombrowe, Donk, Wright, Olivers, & Humphreys, 2012, for a similar approach). For instance, the probability to correctly saccade toward the target in bin i , $p(T_i)$, in the colored-distractor condition is given by

$$p(T_i) = \{G(t_i) * S(t_i) * 0.5\} + \{G(t_i) * [1 - S(t_i)]\} + \{[1 - G(t_i)] * [1 - S(t_i)] * 0.5\}. \quad (3)$$

On the basis of the averaged binned proportions of target saccades [$p(T_i)$], the averaged binned proportions of distractor saccades [$p(D_i)$], and the corresponding averaged saccadic

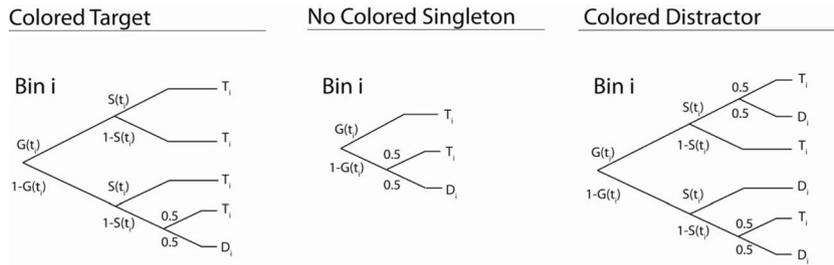


Fig. 4 Tree diagrams depicting how $G(t_i)$ and $S(t_i)$ determine the occurrence of eye movements toward the target (T_i) and eye movements toward the distractor (D_i) in each bin i of each saliency condition. $G(t_i)$ corresponds to the probability that the visual system is affected by a goal-driven bias at time t_i that equals the averaged saccadic latency of the

corresponding bin i of the response latency distribution; $S(t_i)$ corresponds to the probability that the visual system is affected by a saliency-driven bias at time t_i that equals the averaged saccadic latency of the corresponding bin i of the response latency distribution.

latencies, we estimated $G(t)$ and $S(t)$ separately per each condition and group. For each group, there were three saliency conditions (colored target, no colored singleton, and colored distractor), five bins (1–5), and two possible response categories (target saccade and distractor saccade), resulting in $3 \times 5 \times 2 = 30$ cells in each group data matrix.

We fitted the tree models depicted in Fig. 4 to the data, consisting of the frequencies of responses¹ in the different cells of the group data matrices with their concomitant saccadic latencies, either assuming $G(t)$ and $S(t)$ to be different for AVGPs and NVGPs (unequal-groups model fits) or assuming $G(t)$ and $S(t)$ to be equal for AVGPs and NVGPs (equal-groups model fits).

In the full unequal-groups model fits, r_G , t_{0G} , r_S , and t_{0S} were estimated separately for each condition and each group, with ten free parameters per group—that is, r_G , t_{0G} , r_S , and t_{0S} in the colored-target condition; r_G and t_{0G} in the no-colored-singleton condition; and r_G , t_{0G} , r_S , and t_{0S} in the colored-distractor condition, resulting in a total of 20 free parameters. In the full equal-groups model fits, r_G , t_{0G} , r_S , and t_{0S} were separately estimated for each condition but equalized over AVGPs and NVGPs, resulting in a total of ten free parameters.

In the restricted unequal-groups model fits, r_G , t_{0G} , r_S , and t_{0S} were assumed to be equal across conditions (i.e., r_G and t_{0G} in the colored-target condition = r_G and t_{0G} in the no-colored-singleton condition = r_G and t_{0G} in the colored-distractor condition, and r_S and t_{0S} in the colored-target condition = r_S and t_{0S} in the colored-distractor condition), resulting in four free parameters per group and a total of eight free parameters. Finally, in the restricted equal-groups model fits, r_G , t_{0G} , r_S , and t_{0S} were assumed to be equal across all conditions and groups, resulting in a total of four free parameters.

We used maximum likelihood estimation (MLE), with the constraint that all parameter values were larger than or equal to

0 and the rate parameters were smaller than 1. The maximum likelihood estimates are those parameters that maximize $\ln(L)$, which is given by

$$\ln(L) = \sum_j \left((f_j) * \ln(p_j) \right), \tag{4}$$

with f_j referring to the response frequency in cell j of the group data matrices, and p_j to the probability at the response according to the model. $\ln(L)$ was maximized using the Solver function in Excel. Table 3 depicts the parameter estimates obtained from the best-fitting models along with the numbers of free parameters per model, the degrees of freedom, and the G^2 values.² For interpreting Table 3, it is important to highlight that the smaller the G^2 values, the better the fit. Furthermore, in order to accept a model as adequate, G^2 values should be smaller than the corresponding χ^2 value.

The results reported in Table 3 clearly show that all values of G^2 are well below the corresponding critical χ^2 values at an alpha level of .05. The table also shows that the G^2 values corresponding to the equal-groups model fits are larger than those corresponding to the unequal-groups model fits. The latter result is not surprising, considering the fact that the numbers of free parameters in the equal-groups model fits are half of those in the unequal-groups models fits, thus obviously decreasing the corresponding goodness of fit. To determine whether the differences between these two models were statistically different—in other words, whether the unequal-groups model fits described the data significantly better than the equal-groups model fits—we subtracted the G^2 values obtained with the unequal-groups model fits from

² The goodness-of-fit measure G^2 is given by

$$G^2 = \sum_j \left(\left(2 * f_j \right) * \ln \left(\frac{f_j}{pf_j} \right) \right),$$

with f_j referring to the observed response frequency in cell j of the group data matrices, and pf_j to the predicted response frequency in cell j according to the model. The value of G^2 can be interpreted as a χ^2 value.

¹ To obtain the averaged frequencies of responses—that is, the numbers of target saccades and the numbers of distractor saccades in the different bins of the different conditions—we multiplied the averaged proportions of target saccades and distractor saccades, as depicted in Fig. 2, by the averaged numbers of trials in each bin of each condition.

Table 3 Parameter estimates derived from the best-fitting models, shown separately for NVGPs and AVGPs, along with the numbers of free parameters (ν), the degrees of freedom (df), the G^2 values, and the corresponding critical χ^2 values at $\alpha = .05$

	Colored Target				No Colored Singleton		Colored Distractor				ν	df	G^2	Critical χ^2 Value ($\alpha = .05$)
	r_G	t_{0G}	r_S	t_{0S}	r_G	t_{0G}	r_G	t_{0G}	r_S	t_{0S}				
Full Different-Groups Model														
NVGPs	.001	105	.010	146	.003	195	.008	145	.004	143	20	10	4.01	18.31
AVGPs	.000	—*	.027	160	.004	250	.014	139	.003	153				
Full Equal-Groups Model														
NVGPs	.001	238	.016	153	.003	208	.009	142	.003	120	10	20	10.83	31.41
AVGPs	.001	238	.016	153	.003	208	.009	142	.003	120				
Restricted Different-Groups Model														
NVGPs	.002	161	.016	157	.002	161	.002	161	.016	157	8	22	9.26	33.92
AVGPs	.001	128	.029	159	.001	128	.001	128	.029	159				
Restricted Equal-Groups Model														
NVGPs	.002	161	.021	155	.002	161	.002	161	.021	155	4	26	14.42	38.89
AVGPs	.002	161	.021	155	.002	161	.002	161	.021	155				

*This value could not be determined, due to r_G equating 0.

those obtained with the equal-groups model fits (Dodson, Prinzmetal, & Shimamura, 1998). These differences then can be perceived as χ^2 values with degrees of freedom (df) corresponding to the differences in the numbers of free parameters between the models. The resulting differences were $\Delta G^2 = 6.81$ for the full model fits [critical χ^2 value ($df = 10, \alpha = .05$) = 18.31] and $\Delta G^2 = 5.16$ for the restricted model fits [critical χ^2 value ($df = 4, \alpha = .05$) = 9.49]. The analysis showed that both of these difference values were well below the corresponding critical χ^2 values at an alpha level of .05. These results then suggest that for both the full and the restricted models, the unequal-groups models do not outperform the equal-groups models, indicating that the simplest models adequately fitting our data are those assuming the groups to be equal with respect to the underlying control mechanisms.

A final comparison between the goodnesses of fit of the most parsimonious model, the restricted equal-groups model, and the least parsimonious model, the full unequal-groups model, revealed no difference: $\Delta G^2 = 10.40$ [critical χ^2 value ($df = 16, \alpha = .05$) = 26.30]. Thus, the simplest model that adequately fits the observed data patterns is the restricted equal-groups model, which assumes that AVGPs and NVGPs have equal underlying $G(t)$ and $S(t)$ functions that additionally do not vary over conditions.

For illustrative purposes, Fig. 5 shows the observed and predicted proportions correct of the least parsimonious model—the full unequal-groups model—and the most parsimonious model—the restricted equal-groups model—along with the corresponding underlying model functions.

To further test for any potential difference between AVGPs and NVGPs, both the full and restricted models were also

separately fitted to the data patterns obtained from each individual participant in each group. To obtain a direct measure of the relative contributions of goal-driven and saliency-driven processes to individual oculomotor selection performance, we calculated the areas under the individually obtained best-fitting $G(t)$ and $S(t)$ functions between 0 and 600 ms.³ The area under each function provides a comprehensive measure that simultaneously incorporates both its slope (i.e., the rate of increasing/decaying of the functions, r) and its onset (t_0).

A repeated measures mixed ANOVA on the individual $G(t)$ areas obtained from the best-fitting full model fits, with Saliency Condition (colored target, colored distractor, no colored singleton) as a within-groups factor and Group as a between-groups factor (NVGPs, AVGPs) showed only a

³ The areas under $G(t)$ and $S(t)$ between 0 and 600 ms reflect the total contributions of goal-driven and saliency-driven processes to oculomotor selection performance up to 600 ms (which represents the maximal saccadic latency for a trial to be denoted as valid). The area under $G(t)$ for the time interval between 0 and t_{0G} equals 0. The area under $G(t)$ for the time interval between t_{0G} and 600 ms is given by the definite integral of the function $G(t)$:

$$\int_{t_{0G}}^{600\text{ms}} 1 - e^{-r_G \cdot (t - t_{0G})} dt = \left(\frac{e^{r_G \cdot (t_{0G} - 600)}}{r_G} + 600 \right) - \left(\frac{1}{r_G} + t_{0G} \right).$$

Similarly, the area under $S(t)$ for the time interval between 0 and t_{0S} equals t_{0S} . The area under $S(t)$ for the time interval between t_{0S} and 600 ms is given by the integral of the function $S(t)$:

$$\int_{t_{0S}}^{600\text{ms}} e^{-r_S \cdot (t - t_{0S})} dt = \left(-\frac{e^{-r_S \cdot (t_{0S} - 600)}}{r_S} \right) - \left(-\frac{1}{r_S} \right).$$

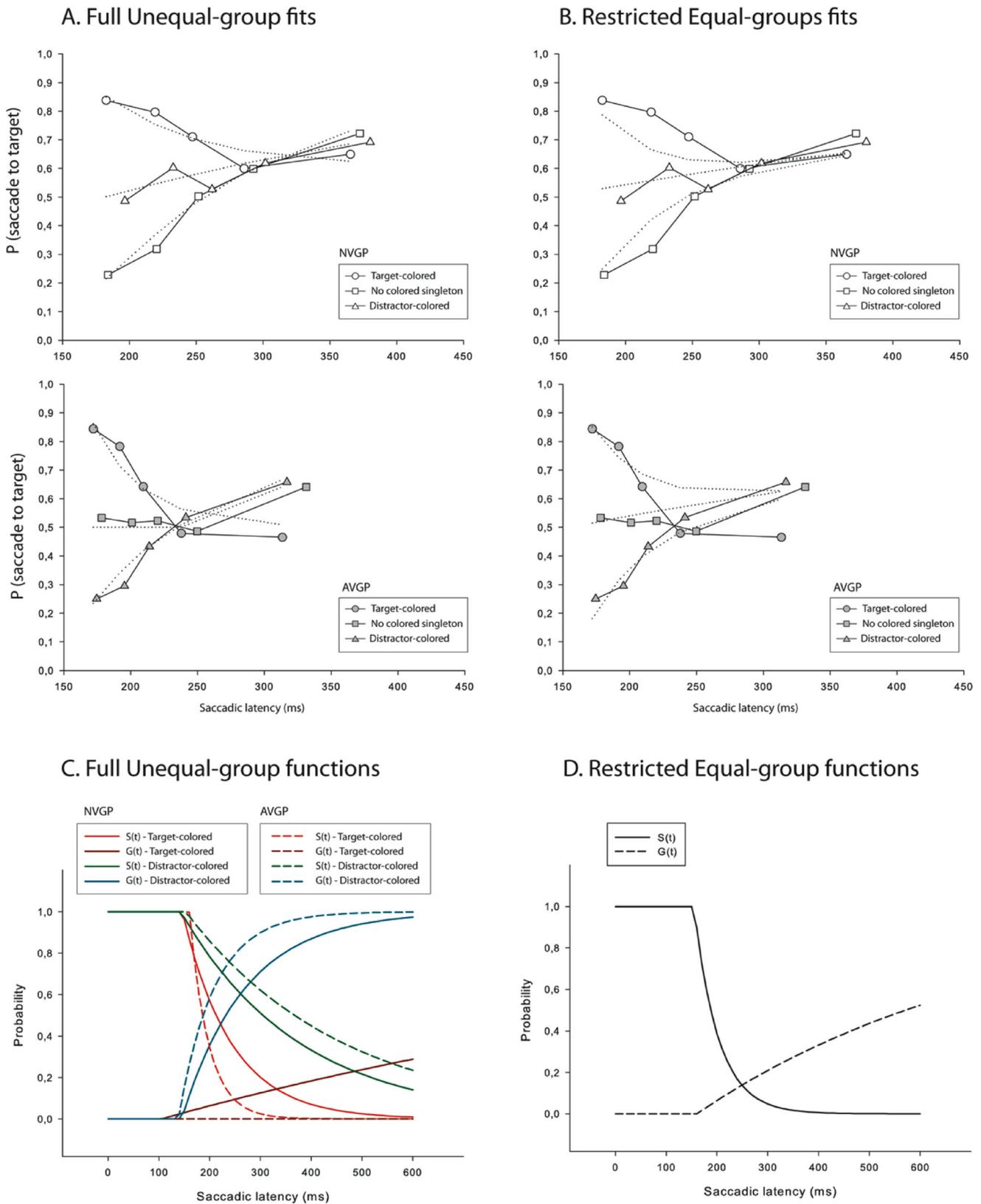


Fig. 5 Observed (solid lines) and predicted (dashed lines) proportions correct as a function of saccadic latencies, depicted separately per bin (quintile), saliency condition, and group for the full unequal-groups

model (A) and the restricted equal-groups model (B), along with the corresponding best-fitting $S(t)$ and $G(t)$ functions derived from the full unequal-groups model (C) and the restricted equal-groups model (D).

significant main effect of saliency condition [$F(2, 58) = 57.03$, $p < .001$, $\eta_p^2 = .66$], but neither the main effect of group [$F(1, 29) = 3.05$, $p = .09$] nor the two-way interaction [$F(2, 58) = 2.43$, $p = .10$] reached significance. Newman–Keuls post-hoc test revealed that the contribution of goal-driven processes decreased from the colored-distractor condition [$G(t)$ area = 310] to the no-colored-singleton [$G(t)$ area = 128] to the colored-target condition [$G(t)$ area = 78] (all p values $< .04$).

Similarly, a repeated measure mixed ANOVA on the individual $S(t)$ areas obtained from the best-fitting full model fits, with Saliency Condition (colored target, colored distractor) as a within-groups factor and Group (NVGPs, AVGPs) as a between-groups factor also showed only a significant main effect of saliency condition [$F(1, 29) = 31.06$, $p < .001$, $\eta_p^2 = .52$]. Neither the main effect of group [$F(1, 29) < 1$, $p = .99$] nor the two-way interaction [$F(1, 29) < 1$, $p = .46$] reached significance. Post-hoc tests revealed that the contribution of saliency-driven processes was larger in the colored-distractor condition [$S(t)$ area = 307] than in the colored-target condition [$S(t)$ area = 190] (all p values $< .001$).

We also performed two one-way between-groups ANOVAs on the individual $G(t)$ and $S(t)$ areas obtained from the restricted model fits, using Group (NVGPs, AVGPs) as a between-groups factor. These analyses did not result in any group differences [$G(t)$ area, $F(1, 29) = 1.29$, $p = .26$; $S(t)$ area, $F(1, 29) < 1$, $p = .86$].

Notably, the analyses on the individual fits further confirm the conclusion that even though AVGPs were ultimately faster in responding than NVGPs, the temporal development of the contributions of goal-driven and stimulus-driven processes was most likely the same between the two groups.

General discussion

On the basis of previous findings showing the crucial role of time in disambiguating between the contributions of stimulus-driven and goal-driven selection behaviors (van Zoest & Donk, 2005, 2008; van Zoest et al., 2004), we assessed the properties of this temporal interplay in a group of AVGPs in comparison to a group of NVGPs.

First of all, our behavioral results replicated previous findings confirming that time does indeed play a crucial role in determining oculomotor selection behavior. Indeed, fast-initiated saccades were saliency-driven, meaning that the majority of these saccades were directed toward the most salient singleton in the display, independently of whether it was the target or the distractor. This resulted in overall high accuracy in the colored-target condition and low accuracy in the colored-distractor condition. Instead, slower initial saccades (i.e., with latencies longer than 250 ms) were more controlled and tended to go toward the target stimulus even in trials on

which the distractor was the most salient singleton in the display.

Importantly, our findings also showed differences in the behavioral performance of AVGPs relative to NVGPs. In particular, AVGPs were faster and less accurate than NVGPs. Crucially, we developed a multinomial model to investigate whether there were any differences between groups in the underlying stimulus-driven and goal-driven processes. We subsequently fitted our model to both the averaged group data patterns and the individual data patterns and showed that the manners in which the underlying stimulus-driven and goal-driven components evolved over time were entirely comparable in the two groups.

Lower decision bound for releasing saccades in AVGPs

The analyses on the modeled data consistently showed that the unequal-groups models did not outperform the equal-groups models. Moreover, the analyses on the individually estimated contributions of goal-driven and stimulus-driven processes also did not result in any significant differences between groups. These findings clearly suggest that the underlying temporal interplays between goal-driven and stimulus-driven processes are similar in AVGPs and NVGPs. Accordingly, the observed difference in behavioral patterns between AVGPs and NVGPs is most likely the result of a lower decision bound for releasing saccades in the former as compared to the latter population, most plausibly due to strategic differences adopted by the two groups for solving the task.

Interestingly, one other study has modeled the behavioral data of AVGPs and NVGPs to infer the underlying processes contributing to the differences in performance observed between the two populations (Green et al., 2010). Green and colleagues (2010) tested AVGPs and NVGPs in a motion-direction discrimination task and reported, at the behavioral level, faster reaction times for AVGPs but equal accuracies between the two groups (Green et al., 2010). Importantly, by modeling their behavioral data, the authors found that the speeded behavior of AVGPs derived from a faster rate of accumulation of information over time, which led to a lower decision bound for response releasing in this population than in NVGPs (Green et al., 2010). The latter results, then, may seem to be at odd with the present findings. However, it is important to note that, unlike the present paradigm, in the task used by Green et al. (2010) there was no stimulus competition, since only the target was presented in each trial. Thus, even though it is possible that AVGPs accumulate information over time faster than NVGPs in the absence of stimulus competition, the present results suggest that this might not be the case in the presence of competing stimuli.

Overall, the present results suggest that the observed behavioral differences in the performance of AVGPs relative to

NVGPs were likely due to a difference in strategy between the two groups. In particular, AVGPs may have followed instructions more carefully than NVGPs, thus implementing a different strategy to perform the experiment. Specifically, at the beginning of the experiment we instructed participants to prioritize speed over accuracy, and participants received feedback solely on their saccadic speed at the end of each block. This strategic difference may have directly depended on the action videogame experience, which may have implicitly biased AVGPs to prioritize speed over accuracy (see Nelson & Strachan, 2009, for results in this direction obtained through short-term AVGP training). However, it may also be explained by a general higher motivation to perform well in the task in AVGPs than in NVGPs. The latter possibility may be linked to the recruitment procedures through which we selected the AVGP participants (see the [Participants](#) section for further details on these procedures), ultimately possibly implicitly biasing AVGPs to commit more than NVGPs to perform well in the task. In the present study, we cannot disambiguate between these two accounts, because we did not engage our participants in any type of direct training. Future studies might address this crucial issue of that causality of AVGP-related modulations in order to shed further light on the properties of intensive action videogame playing during stimulus-competition tasks. Notably, though, what clearly emerges from these data is that differences in behavioral performance between AVGPs and NVGPs can depend on strategic modulations rather than on modifications of the underlying attentional mechanisms (e.g., Anderson et al., 2010; Clark et al., 2011; for a review, see Boot et al., 2011).

Overt and covert attention in AVGPs

Previous works that have investigated the effects of irrelevant information on performance based on covert reaction time measures have typically reported decreased response speed, together with enhanced accuracy, in AVGPs as compared to NVGPs (Bavelier et al., 2012; Chisholm et al., 2010; Mishra et al., 2011). However, the aforementioned studies were different from the present study in that in the majority of the previous work, only manual responses were collected. In the present study, we investigated overt rather than covert attentional selection. While playing at action videogames, the requirements for the eyes and hands might be very different: The eyes need to efficiently and rapidly monitor the visual scene, but the hands need to respond only when necessary. Thus, our results may differ from previous findings addressing similar tasks because of the different behavior that we were tapping (i.e., covert vs. overt behavior) and the different requirements that these behaviors might fulfill while playing videogames. Indeed, the work by Chisholm and colleagues allows us insight in this respect. They used a covert version of an attentional capture task that was in many ways similar to

the paradigm used in the present work. In their task, Chisholm and colleagues collected only manual responses (see the introduction for more details) and reported faster responses and a better performance in trials in which a distractor was present in AVGPs rather than in NVGPs. Furthermore, Chisholm and Kingstone (2012) tested AVGPs and NVGPs in an oculomotor version of the attentional capture task and reported comparable initial saccade latencies, as well as comparable fixation durations on the distractor when participants made an incorrect saccade toward this location instead of a correct saccade toward the target location, between the two groups. Nonetheless, fewer overall saccades toward distractors were found in AVGPs than in NVGPs (Chisholm & Kingstone, 2012). Future investigations could more systematically investigate (1) the extent to which behavioral differences measured in overt attention tasks in AVGPs are indeed different from those reported for covert attention tasks, (2) the extent to which different abilities (i.e., reacting to events through eyes vs. reacting to events through hands) might be differently modulated by videogame playing, and (3) the extent to which these potential differences are related to differences in the time courses between response modalities, the fact here being that manual responses tend to be significantly slower than eye movement responses (Hunt, von Mühlenen, & Kingstone, 2007).

Time-course analyses

Another innovative aspect of the present work, relative to previous studies in AVGPs, is the fact that we looked at the time course of performance. Previous evidence had suggested that responses triggered earlier in time reveal vastly different outcomes than do responses delivered later in time (e.g., Godijn & Theeuwes, 2002; Ludwig & Gilchrist, 2002; van Zoest et al., 2004; van Zoest et al., 2010). This dynamic aspect of performance has rarely been addressed explicitly in experimental research investigating differences between AVGPs and NVGPs (but see Hubert-Wallander et al., 2011; West et al., 2013). The present findings clearly show the benefit of adopting this time-course approach in order to better characterize selection behavior in the AVGP population. Such an approach may also benefit studies that investigate covert attentional selection, and this is something that may prove insightful in the future to better characterize the effects of intensive action videogame playing on performance.

It is worth noting that the only other study on overt attention that has directly investigated the temporal interplay between stimulus-driven and goal-driven contributions to performance in AVGPs (West et al., 2013) reported somewhat different results from those in the present work. West and colleagues (2013) observed comparable stimulus-driven selection early in time between AVGPs and NVGPs, but better goal-driven behavior in AVGPs for later-initiated saccades,

which nonetheless was observed only in the last part of the experiment. However, they used a saccade trajectory deviation task in which participants had to look as quickly as possible at a target while ignoring a concomitant distractor (see the introduction for further details). In this task, target locations were prespecified, as were the locations of the irrelevant distractors. Thus, unlike our paradigm, in the task used by West et al. (2013) target selection was relatively straightforward, in that competition between target and distractor was limited, and very few saccades went incorrectly to the distractor. Therefore, the different results arising from the work by West et al. (2013) and the present study may be explained by differences in task difficulty between the two tasks adopted. In other words, it may be that weak or strong stimulus competition may involve different processes in AVGPs when implementing overt selection behaviors. Future studies may look into directly investigating this issue by manipulating task difficulty within the same paradigm.

Concluding remarks

Taken together, our findings ultimately strengthen the idea that modulations in performance as a result of avid action videogame playing might arise also from differences in the strategies implemented by the two groups to solve the task, rather than from modifications of the underlying exogenous and endogenous processes of attentional selection (see also Boot et al., 2011). Furthermore, the present findings also show that behavioral modulations related to AVGPs do not unavoidably result in performance advantages in this population.

Overall, the results of the present study argue against the idea of a general enhancement of top-down control in AVGPs. Like NVGPs, AVGPs clearly required time to establish control in saccadic selection. Even though AVGPs were faster to respond than NVGPs, we found no evidence suggesting that this speeded saccadic behavior was paired with a faster ability to implement efficient goal-driven selection strategies in this population. Therefore, the present findings contribute to the literature on visual selection per se by showing that time is essential in the acquisition of top-down control, and furthermore, that the time needed to implement efficient goal-driven behaviors may be rather fixed and hardly modifiable. In other words, the present results suggest that if participants are quick at initiating saccades, they are unlikely to have acquired top-down control, and their saccades will tend to be captured by stimulus saliency.

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References

- Anderson, A. F., Bavelier, D., & Green, C. S. (2010). Speed-accuracy tradeoffs in cognitive tasks in action game players [Abstract]. *Journal of Vision*, *10*(7), 748. doi:10.1167/10.7.748
- Bacon, W. F., & Egeth, H. E. (1994). Overriding stimulus-driven attentional capture. *Perception & Psychophysics*, *55*, 485–496. doi:10.3758/BF03205306
- Batchelder, W. H., & Riefer, D. M. (1999). Theoretical and empirical review of multinomial process tree modeling. *Psychonomic Bulletin & Review*, *6*, 57–86. doi:10.3758/BF03210812
- Bavelier, D., Achtman, R. L., Mani, M., & Föcker, J. (2012a). Neural basis of selective attention in action video game players. *Vision Research*, *61*, 132–143. doi:10.1016/j.visres.2011.08.007
- Bavelier, D., Green, C. S., Pouget, A., & Schrater, P. (2012b). Brain plasticity through the life span: Learning to learn and action video games. *Annual Review of Neuroscience*, *35*, 391–416. doi:10.1146/annurev-neuro-060909-152832
- 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
- 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. doi:10.1016/j.actpsy.2005.02.004
- Chisholm, J. D., Hickey, C., Theeuwes, J., & Kingstone, A. (2010). Reduced attentional capture in action video game players. *Attention, Perception, & Psychophysics*, *72*, 667–671. doi:10.3758/APP.72.3.667
- Chisholm, J. D., & Kingstone, A. (2012). Improved top-down control reduces oculomotor capture: The case of action video game players. *Attention, Perception, & Psychophysics*, *74*, 257–262. doi:10.3758/s13414-011-0253-0
- 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. doi:10.1016/j.actpsy.2010.10.003
- Dodson, C. S., Prinzmetal, W., & Shimamura, A. P. (1998). Using Excel to estimate parameters from observed data: An example from source memory data. *Behavior Research Methods, Instruments, & Computers*, *30*, 517–526.
- Dombrowe, I., Donk, M., Wright, H., Olivers, C. N., & Humphreys, G. W. (2012). The contribution of stimulus-driven and goal-driven mechanisms to feature-based selection in patients with spatial attention deficit. *Cognitive Neuropsychology*, *29*(3), 249–274.
- Dye, M. W. G., Green, C. S., & Bavelier, D. (2009a). The development of attention skills in action video game players. *Neuropsychologia*, *47*, 1780–1789. doi:10.1016/j.neuropsychologia.2009.02.002
- Dye, M. W. G., Green, C. S., & Bavelier, D. (2009b). Increasing speed of processing with action video games. *Current Directions in Psychological Science*, *18*, 321–326. doi:10.1111/j.1467-8721.2009.01660.x
- Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance*, *18*, 1030–1044. doi:10.1037/0096-1523.18.4.1030
- Godijn, R., & Theeuwes, J. (2002). Programming of endogenous and exogenous saccades: Evidence for for a competitive integration model. *Journal of Experimental Psychology: Human Perception and Performance*, *28*, 1039–1054. doi:10.1037/0096-1523.28.5.1039
- Green, C. S., & Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature*, *423*, 534–537. doi:10.1038/nature01647
- Green, C. S., & Bavelier, D. (2006). Effect of action video games on the spatial distribution of visuospatial attention. *Journal of Experimental*

- Psychology: Human Perception and Performance*, 32, 1465–1478. doi:10.1037/0096-1523.32.6.1465
- Green, C. S., Pouget, A., & Bavelier, D. (2010). Improved probabilistic inference as a general learning mechanism with action video games. *Current Biology*, 20, 1573–1579. doi:10.1016/j.cub.2010.07.040
- Green, C. S., Sugarman, M. A., Medford, K., Klobusicky, E., & Bavelier, D. (2012). The effect of action video game experience on task-switching. *Computers in Human Behavior*, 28, 984–994. doi:10.1016/j.chb.2011.12.020
- Hubert-Wallander, B., Green, C. S., & Bavelier, D. (2010). Stretching the limits of visual attention: The case of action video games. *Wiley Interdisciplinary Reviews: Cognitive Science*, 2, 222–230. doi:10.1002/wcs.116
- Hubert-Wallander, B., Green, C. S., Sugarman, M. A., & Bavelier, D. (2011). Changes in search rate but in the dynamic of exogenous attention in action videogame players. *Attention, Perception, & Psychophysics*, 73, 2399–2412. doi:10.3758/s13414-011-0194-7
- Hunt, A. R., von Mühlenen, A., & Kingstone, A. (2007). The time course of attentional and oculomotor capture reveals a common cause. *Journal of Experimental Psychology: Human Perception and Performance*, 33, 271–284. doi:10.1037/0096-1523.33.2.271
- Jonides, J. (1981). Voluntary versus automatic control over the mind's eye's movement. In J. Long & A. Baddeley (Eds.), *Attention and performance IX* (pp. 187–203). Hillsdale, NJ: Erlbaum.
- Kristjánsson, Á. (2013). The case for causal influences of action videogame play upon vision and attention. *Attention, Perception, & Psychophysics*, 75, 667–672. doi:10.3758/s13414-013-0427-z
- Li, R., Polat, U., Scalzo, F., & Bavelier, D. (2010). Reducing backward masking through action game training. *Journal of Vision*, 10(14), 33: 1–13 doi:10.1167/10.14.33
- Ludwig, C. J. H., & Gilchrist, I. D. (2002). Stimulus-driven and goal-driven over visual selection. *Journal of Experimental Psychology: Human Perception and Performance*, 28, 902–912. doi:10.1037/0096-1523.28.4.902
- McSorley, E., Haggard, P., & Walker, R. (2006). Time course of oculomotor inhibition revealed by saccade trajectory modulation. *Journal of Neurophysiology*, 96, 1420–1424.
- Mishra, J., Zinni, M., Bavelier, D., & Hillyard, S. A. (2011). Neural basis of superior performance of video-game players in an attention-demanding task. *Journal of Neuroscience*, 31, 992–998. doi:10.1523/JNEUROSCI.4834-10.2011
- Müller, H. J., & Findlay, J. M. (1988). The effect of visual attention on peripheral discrimination thresholds in single and multiple element displays. *Acta Psychologica*, 69, 129–155. doi:10.1016/0001-6918(88)90003-0
- Nakayama, K., & Mackeben, M. (1989). Sustained and transient components of focal visual attention. *Vision Research*, 29, 1631–1647. doi:10.1016/0042-6989(89)90144-2
- Nelson, R. A., & Strachan, I. (2009). Action and puzzle videogames prime different speed/accuracy tradeoffs. *Perception*, 38, 1678–1687. doi:10.1068/p6324
- van Zoest, W., & Donk, M. (2005). The effects of salience on saccadic target selection. *Visual Cognition*, 2, 353–375.
- van Zoest, W., & Donk, M. (2008). Goal-driven modulation as a function of time in saccadic target selection. *Quarterly Journal of Experimental Psychology*, 61, 1553–1572.
- van Zoest, W., Donk, M., & Theeuwes, J. (2004). The role of stimulus-driven and goal-driven control in saccadic visual selection. *Journal of Experimental Psychology: Human Perception and Performance*, 30, 746–759. doi:10.1037/0096-1523.30.4.749
- van Zoest, W., Hunt, A. R., & Kingstone, A. (2010). Visual representations in cognition: It's about time. *Current Directions in Psychological Science*, 19, 116–120.
- Walker, R., McSorley, E., & Haggard, P. (2006). The control of saccade trajectories: Direction of curvature depends on prior knowledge of target location and saccade latency. *Perception & Psychophysics*, 68, 129–138.
- Weichselgartner, E., & Sperling, G. (1987). Dynamics of automatic and controlled visual attention. *Science*, 238, 778–780. doi:10.1126/science.3672124
- West, G. L., Al-Aidroos, N., & Pratt, J. (2013). Action video game experience affects oculomotor performance. *Acta Psychologica*, 142, 38–42.
- West, G. L., Stevens, S. A., Pun, C., & Pratt, J. (2008). Visuospatial experience modulates attentional capture: Evidence from action video game players. *Journal of Vision*, 8(16), 13:1–9. doi:10.1167/8.16.13