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## The effects of video game play on the characteristics of saccadic eye movements



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### ABSTRACT

Video game play has become a common leisure activity all around the world. To reveal possible effects of playing video games, we measured saccades elicited by video game players (VGPs) and non-players (NVGPs) in two oculomotor tasks. First, our subjects performed a double-step task. Second, we asked our subjects to move their gaze opposite to the appearance of a visual target, i.e. to perform anti-saccades. As expected on the basis of previous studies, VGPs had significantly shorter saccadic reaction times (SRTs) than NVGPs for all saccade types. However, the error rates in the anti-saccade task did not reveal any significant differences. In fact, the error rates of VGPs were actually slightly lower compared to NVGPs (34% versus 40%, respectively). In addition, VGPs showed significantly higher saccadic peak velocities in every saccade type compared to NVGP. Our results suggest that faster SRTs in VGPs were associated with a more efficient motor drive for saccades. Taken together, our results are in excellent agreement with earlier reports of beneficial video game effects through the general reduction in SRTs. Our data clearly provides additional experimental evidence for a higher efficiency of the VGPs on the one hand and refutes the notion of a reduced impulse control in VGPs on the other.

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### 1. Introduction

Nowadays, playing video games is a widespread leisure activity. A recent survey (Rideout, Foehr, & Roberts, 2010) indicates that 60% of young people between the ages of 8 and 18 years in the U.S. play video games at least 1 h per day. Despite this general dissemination, the consequences of video game play are still heavily debated. On the one hand, negative effects like decreased pro-social and increased aggressive behavior were reported (Anderson et al., 2010). However, if parental involvement was assured, pro-social behavior and civic engagement of subjects increased – which was explained by the team-oriented multiplayer options in action video games (Ferguson, 2011).

On the other hand, playing video games is associated with multiple enhancing effects: amongst others, a better control of the negative effects of bottom-up attentional capture (Chisholm et al., 2010), improved working memory (Colzato et al., 2012), a superior contrast sensitivity function (Li et al., 2009), better signal detection (West et al., 2008), more precise multisensory temporal processing (Donohue, Woldorff, & Mitroff, 2010), enhanced change detection (Clark, Fleck, & Mitroff, 2011) and even better laparoscopic surgical

skills (Rosser et al., 2007). Even an increase of grey brain matter after 2 months of video game playing (30 min per day) was recently reported (Kuhn et al., 2013).

Besides documenting a correlation between beneficial effects on performance and video game play, some studies have also established a causal relationship by comparing the performance of subjects before and after training periods (Green & Bavelier, 2003; Li et al., 2009). However, extensive video game practice did not always improve the performance of subjects, for example in an enumeration task (Boot et al., 2008). In summary, video game players (VGPs) react faster than non-video game players (NVGPs) in a variety of tasks (Dye, Green, & Bavelier, 2009).

Despite this large body of evidence, reasons for the short reaction times of VGPs are still unknown. This reduction is most likely of attentional nature, since VGPs are faster in tasks ranging from spatial cueing over n-Back to visual search. Indeed, a recent study showed an altered attentional network in VGPs compared to NVGPs (Bavelier et al., 2012), especially an increased activation of the fronto-parietal network.

Interestingly, most of the above mentioned studies used rather indirect measures of the attentional mechanisms based on costs or benefits in perceptual tasks. It has been shown that subjects express perceptual benefits at the location of the target of subsequently executed saccadic eye movements (Deubel & Schneider,

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1996; Hoffman & Subramaniam, 1995; Kowler et al., 1995). These findings suggest that even without explicitly measuring perceptual thresholds there might exist a possibility to monitor the shifts of attention directly by simply measuring the saccadic eye movements. The above mentioned studies allow the conclusion that these fast jerky eye movements are always preceded by a shift of the spotlight of attention towards the future landing point of the eyes (Posner, 1980). In addition to the possibility of observing the shift of attention directly, it is feasible to monitor the competing attentional control systems in a special saccade paradigm: the anti-saccade task (Hallett, 1978). In this task, subjects are asked to perform a saccade in the opposite direction to the presentation of a visual target (the “anti-saccade”). However, since the appearance of the visual target itself attracts attention (Posner, 1980), subjects sometimes fail to suppress the reflexive saccade towards the target (the “pro-saccade”).

The execution of saccades is controlled by circuits involving the superior colliculus, the parietal eye field, the frontal eye field and, ultimately, the two saccade generators in the brain stem responsible for horizontal and vertical saccades, respectively. These generators cause a fixed linear relationship between the saccade amplitude and its duration and peak velocity – known as the main sequence (Bahill, Clark, & Stark, 1975; Sparks, 2002). Data from animal experiments suggest that the correct execution of anti-saccades depends critically on the frontal cortex: single-unit activity in the supplementary and frontal eye fields of rhesus monkeys is increased during anti-saccades compared to pro-saccades (Munoz & Everling, 2004). Analogously, patients with frontal lobe lesions show an increased frequency of pro-saccades (Guitton, Buchtel, & Douglas, 1985). Therefore, the frequency of pro-saccades (“error rate”) can be used as a measure for the efficiency of the impulse control mediated by the frontal cortex. In normal subjects, saccadic reaction times (SRTs) are negatively correlated with the error rate: subjects with shorter SRTs show higher error rates (Evdokimidis et al., 2002). The contrary is shown in a study about the effects of ethanol: ethanol caused longer SRTs hand in hand with decreased error rates (Khan et al., 2003).

For these reasons, we addressed the effects of video game play upon eye movements as a handle to the orienting of attention with two different saccade paradigms. The double-step task (Becker & Jurgens, 1979; Lisberger et al., 1975) was used to enforce reflexive saccades with very short reaction times. The anti-saccade task (Hallett, 1978) allowed us to measure the ability to withhold the fast reflexive pro-saccades towards a visual target. We hypothesized that VGPs display shorter SRTs compared to NVGPs in general. This reduction may be caused by an impaired impulse control or alternatively by an increased efficiency of the visuo-motor system of VGPs. Independent of the exact nature of the second possibility, if the first explanation were true, the error rates of VGPs should be increased compared to NVGPs. Identical error rates in VGPs and NVGPs on the other hand would definitively exclude the explanation of impaired impulse control in VGPs. Finally, we asked whether the dynamic properties of the gaze shifts, determined by brainstem circuits, display any differences between VGPs and NVGPs.

## 2. Material and methods

### 2.1. Participants

All subjects were classified according to their daily video gaming time. The time was self-reported in a questionnaire before the measurement. Subjects who reported less than 1 h per day were classified as non-video game players (NVGPs), whereas subjects with equal or more than 1 h per day were classified as video game players (VGPs). The subjects were not told to which group they

belong before the experiment. This was done to avoid differential motivation effects which could have led to better performance in VGPs, simply because they think that they will perform better due to their expertise.

We measured a total of 67 subjects of whom 46 participated in both tasks. Some subjects completed only one of the two tasks. Therefore, the sample sizes are slightly different. In the anti-saccade task, a total of 56 subjects (26 NVGPs, 30 VGPs) were tested. The mean age of NVGPs was  $18.6 \pm 0.6$  years (mean  $\pm$  SE) and that of VGPs  $19.5 \pm 0.6$  years. In the double-step task, 57 subjects were measured (27 NVGPs, 30 VGPs). The NVGPs in this task were aged  $18.6 \pm 0.6$  years and the VGPs  $19.8 \pm 0.7$  years. There were no significant group differences regarding age in neither task (1-factorial ANOVA:  $p = 0.318$  in the anti-saccade and  $p = 0.191$  in the double-step task). All experiments were performed in accordance with the Declaration of Helsinki.

The analysis of the reported daily gaming times showed that there were similar amounts of video game consumption in each task. VGPs in the anti-saccade task played on average  $1.3 \pm 0.1$  h per day (mean  $\pm$  SE) whereas VGPs in the double-step task played and  $1.4 \pm 0.1$  h per day. All subjects had normal or corrected to normal vision.

### 2.2. Experimental setup

The experiments were performed on a PC (AMD Athlon 64 X2 4800+, 1 GiB DDR2 RAM, ATI Radeon Xpress 1150) with two 19 in. screens (HP L1950, refresh rate: 60 Hz, resolution:  $1280 \times 1024$  pixels). The main control screen was connected via the DVI-Port and the stimulus screen via the VGA-Port of the graphics adapter. Data analysis and stimulus presentation was done with Matlab 2008a (The Mathworks, Natick, MA) and the Psychophysics Toolbox Version 3 (Brainard, 1997; Pelli, 1997).

Horizontal eye position was recorded with an infrared limbus tracker in front of the subject’s left eye. The eye position was sampled at 1 kHz with a spatial resolution of approximately 6 arcmin (Ilg et al., 2006). Viewing distance in all experiments was kept at 57 cm and the stimuli were presented in white (luminance 60 cd/m<sup>2</sup>) on a black background.

### 2.3. Saccade tasks

The duration of the entire experimental session was at most 1 h and consisted of the anti-saccade task and/or the double-step task. In both tasks, a trial began with a random fixation time between 500 and 1000 ms. A white cross with 18 arcmin edge length was presented as the fixation target at the center of the screen. Saccade targets were filled white squares with an edge length of 7 arcmin.

#### 2.3.1. The double-step task

In the double-step task, two consecutive targets were presented with an inter-stimulus interval (ISI) of 50, 100, 250 or 500 ms. Targets could appear at 5 and 10 deg to the left and right of the fixation spot. The second target always appeared at a different position as the first target, resulting in twelve target position combinations. The subjects were asked to perform saccades towards these targets as fast as possible. A measurement consisted of two blocks of 144 trials (three repetitions for each of the four ISIs and the twelve target position combinations). For the evaluation, the datasets from the two blocks were merged. The duration of each trial was fixed to 2000 ms. Saccades towards the first target (“saccade 1”) were defined as being closer to this target than to the second target. Otherwise they were considered saccades towards the second target (“saccade 2”). Corrective saccades towards either target were also detected but not include in this analysis. Entire trials were excluded from analysis if no saccade 2 was found, either saccade

1 or 2 was anticipatory (e. g. had a reaction time of less than 90 ms) or its amplitude gain was outside the range of 0.4–1.6. In addition, trials were excluded if eye position changed more than 2.5 deg in a 250 ms interval prior to saccade onset.

### 2.3.2. The anti-saccade task

In the anti-saccade task, subjects were asked to perform a saccade towards the mirror position of a presented target. A measurement consisted of 240 trials (40 repetitions for each of the six target positions at 5, 10 and 15 deg to the left and right of the fixation spot). The trial duration was fixed to 1500 ms. The first saccade in each trial after target presentation was considered as anti-saccade if its end point was opposite to the target eccentricity otherwise it was considered as pro-saccade. Trials were discarded if eye position changed more than 2.5 deg in a 250 ms interval prior to saccade onset, if this saccade occurred before 90 ms after target presentation (anticipatory response) or if the absolute amplitude gain was outside the range of 0.4–1.6. The error rate was calculated as the number of pro-saccades divided by the number of valid saccades.

### 2.4. Data processing

Eye velocity was computed by differentiation of the eye position; acceleration was computed by differentiation of eye velocity. Saccades were detected based on an acceleration threshold ( $3.500 \text{ deg/s}^2$ ) on a trial-by-trial basis. In a first step, all acceleration peaks were selected from smoothed acceleration data (running average across 31 ms) and peaks with opposing signs were paired. Then, pairings were rated according to their temporal distance and similarity – with close and similar peaks being preferred. In the last step, each two pairings with a time distance smaller than 20 ms were considered to be blinks and removed. The remaining pairings were the detected saccades. For these, saccadic reaction time, amplitude, duration and peak velocity were determined. To prevent artificial prolongation of the duration through smoothing, the start and end time of the saccades were computed from the only very slightly smoothed velocity data (running average across 5 ms). In order to determine the SRT of a given subject in a given condition, we calculated the median values across the SRTs of all valid trials.

We used saccade duration, peak velocity and amplitude to calculate the main sequence for each subject independently. The

linear regression equation describing the peak velocity as a function of saccade amplitude was determined through robust linear regression with iteratively reweighted least-square (Holland & Welsch, 1977) to diminish any outlier influence of single saccades on the individual equations. To compare saccadic peak velocities in VGPs and NVGPs, we evaluated the peak velocity of a 10 deg saccade from this individual linear regression equation.

## 3. Results

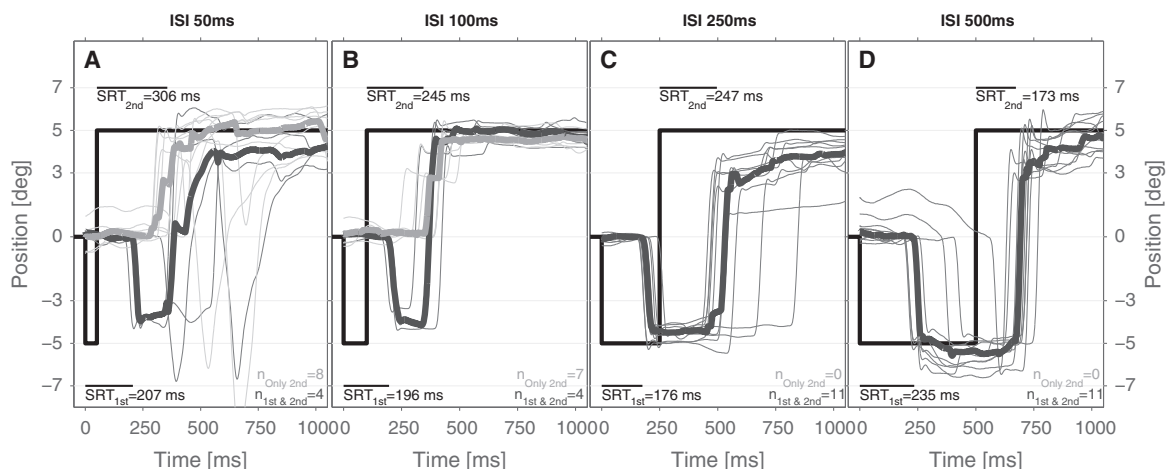
### 3.1. The double-step task

The double-step task forced our subjects to perform reflexive saccades as fast as possible. Fig. 1 shows single-trial eye position traces of a typical subject (Subject 64, 18 years old, male, played between 1 and 2 h per day VGP) together with the resulting median traces for all four ISI values.

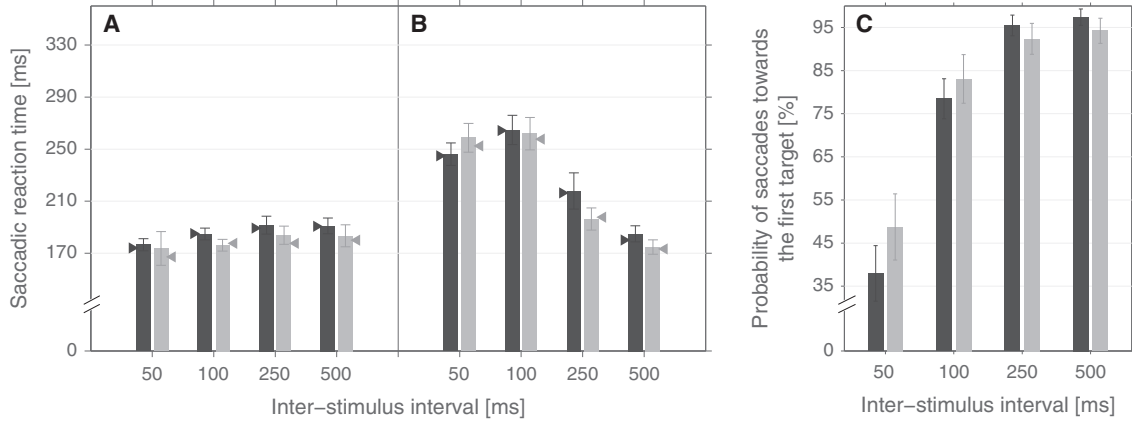
The probability to actually execute two saccades clearly increased from short to long ISI values. The SRT for saccades towards the first target are rather independent of the ISI whereas the reaction times of the saccades directed towards the second target are clearly prolonged for the 50 ms and 100 ms ISI condition. We analyzed the SRTs of all subjects with respect to ISI and video game play and performed appropriate statistical testing. We pooled our data obtained from different target positions. For saccades directed towards the first target (see Fig. 2A), a 2-factorial ANOVA showed significant effects of ISI ( $p = 0.002$ ) and video game play ( $p = 0.011$ ), while the interaction of both factors was not significant ( $p = 0.859$ ). Therefore, VGPs had shorter SRTs independent of the specific ISI and short ISIs evoked short SRTs in both groups equally.

For saccades directed towards the second target (see Fig. 2B), a different pattern emerged. The 2-factorial ANOVA revealed significant differences only for ISI ( $p < 0.001$ ). Video game play had no significant effect on the SRTs ( $p = 0.115$ ). But the interaction of both factors was significant ( $p = 0.006$ ). SRTs for the short ISIs were clearly longer than for the long ISIs. Shortest SRTs (which were comparable to the SRTs from the first target) in both groups were only found in the 500 ms ISI condition. Interestingly, VGPs had shorter SRTs for long ISIs and longer SRTs for the shortest ISI than NVGPs.

In case of the short ISIs, subjects often omitted the saccade towards the first target. Instead, they only performed a single saccade targeted towards the second target. Fig. 2C shows the



**Fig. 1.** Single trial eye position traces of subject 64 in the double-step paradigm. Exclusively trials where the first target appeared at 5 deg left followed by the second target at 5 deg right or vice versa are shown for all four ISI conditions (A–D). Trials where the subject performed saccades towards both targets are shaded dark gray whereas trials with only saccades towards the second target are shaded light gray. Bold lines represent medians; SRTs are given as median across all trials for each condition. Subject 64 was 18 years old, male, and played between 1 and 2 h per day (VGP).

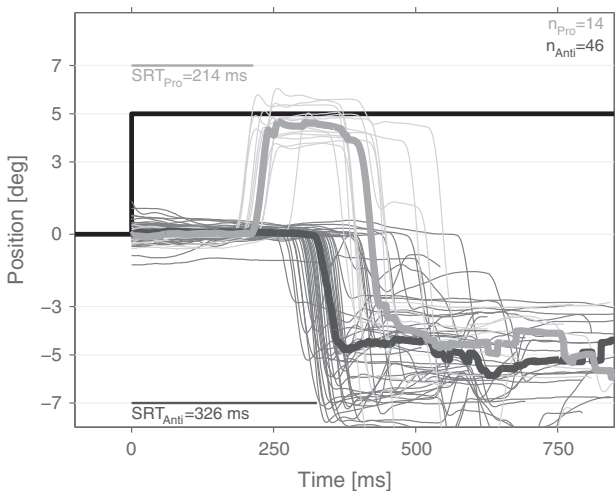


**Fig. 2.** Comparison of saccadic parameters obtained from VGP and NVGPs, respectively, in the double-step paradigm. In (A), the saccadic reaction times for all four ISI conditions towards the first target are shown (all possible target positions were pooled). In (B), saccadic reaction times toward the second target are shown. In (C), the probability of saccades directed towards the first target is shown. Bars show mean values across subjects; error bars represent 95% confidence intervals; triangles in (A and B) indicate median values across subjects.

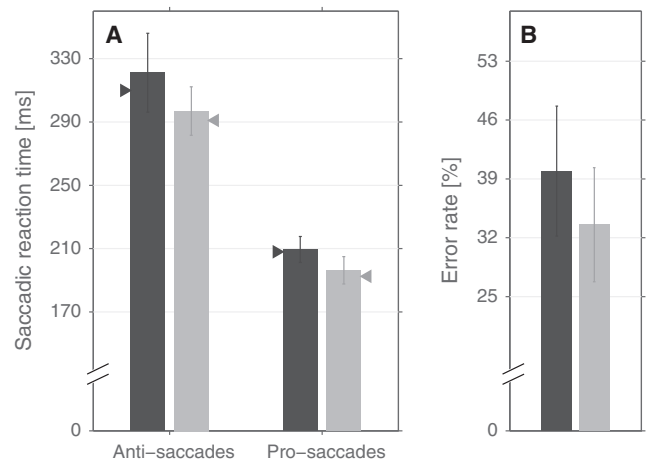
probability that a saccade towards the first target was executed. At the 50 ms ISI condition, the probability dropped down substantially, even more pronounced in the case of NVGPs. For the long ISIs, no difference in saccade probability was present. The 2-factorial ANOVA revealed a significant effect of ISI on saccade probability ( $p < 0.001$ ); the influence of video game play was not significant ( $p = 0.178$ ). However, the interaction of both factors was significant ( $p = 0.008$ ). This suggests that a video game play effect was only present for the short ISIs, for which the VGPs were more able to catch the first target despite its brief presentation. A ceiling effect for longer ISIs may have prevented any differences between VGPs and NVGPs becoming visible.

3.2. The anti-saccade task

Fig. 3 gives single-trial eye position traces of our typical subject 64 (VGP) obtained from the anti-saccade experiment. The target was presented 5 deg to the right, and the subject was asked to execute a saccade towards the left. These anti-saccades are shown in black; the erroneous pro-saccades are shown in grey.



**Fig. 3.** Single trial eye position traces of subject 64 in the anti-saccade paradigm. Only trials are shown in which the target appeared 5 deg (left and right pooled). Trials where the subject performed an anti-saccade are shown in dark gray; pro-saccades are shown in light gray. Bold lines represent medians; SRTs are given as median across all given trials.



**Fig. 4.** Comparison of saccadic parameters obtained from VGPs and NVGPs, respectively, in the anti-saccade paradigm. In (A), saccadic reaction times for anti- and pro-saccades are shown. (B) Gives the error rate expressed as the frequency of pro-saccades. Bars show mean values across subjects; error bars represent 95% confidence intervals; triangles in (A) indicate median values across subjects.

The SRT of pro-saccades (214 ms) are clearly shorter compared to anti-saccades (326 ms). The error rate of this subject was  $14/(46 + 14) = 23\%$  in this example.

The SRTs of all subjects in the anti-saccade task were in agreement with the literature (Hallett, 1978; Munoz & Everling, 2004): Reflexive pro-saccades had shorter SRTs than anti-saccades in both groups (see Fig. 4A). More interestingly, VGPs showed shorter reaction times for both saccade types compared to NVGPs. The 2-factorial ANOVA revealed a significant effect of saccade type ( $p < 0.001$ ) and video game play ( $p < 0.014$ ), whereas the interaction of both factors was not significant ( $p = 0.466$ ).

Shorter SRTs were in line with our first hypothesis. To decide whether this effect is due to impaired impulse control, we determined the error rates of both groups shown in Fig. 4B. A linear regression analysis across all subjects revealed a negative slope ( $\text{error}_{(\text{SRT pro-saccade})} = -0.2 * \text{SRT} + 70.0$ ;  $R^2 = 0.044$ ), so there is a non-significant tendency that subjects with long SRT express rather low error rates. However, in support of the latter explanation, a 1-factorial ANOVA showed no significant differences in error rates between NVGPs and VGPs. ( $p = 0.207$ ). In fact, there was even a tendency that VGPs (34%) produced slightly less errors than NVGPs (40%).



### 3.3. SRT comparison

In order to compare SRTs obtained from all experiments in our study, we plotted SRT of VGPs versus SRT of NVGPs, usually known as a Brinley plot (not shown). The resulting linear ordinary least squares regression ( $R^2 = 0.946$ ) had a slope of 0.95 and was significantly different from unity ( $p = 0.003$ ). Therefore, SRTs of VGPs are shorter than that of NVGPs in general. This result is in perfect alignment with earlier reported data (Dye, Green, & Bavelier, 2009; Hubert-Wallander et al., 2011).

### 3.4. Dynamic properties of the saccades

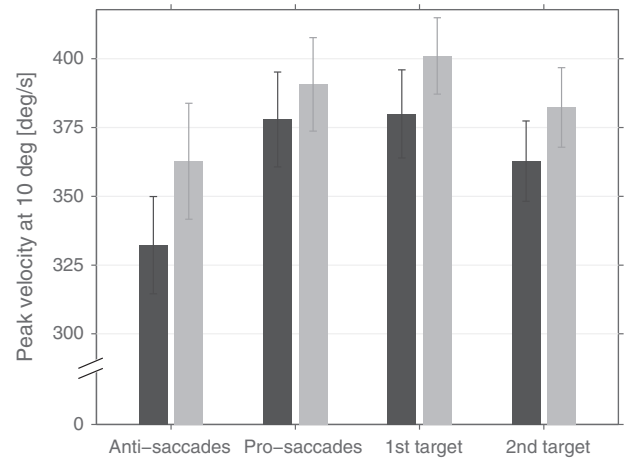
So far, we analyzed the latencies of the elicited saccades. However, since we measured the eye movements with high spatial and temporal resolution, we were also able to analyze the dynamic saccade properties, especially the maximal eye velocity during each saccade (peak velocity). The dependence of the peak velocity on saccade amplitude (main sequence) for typical subject 64 (VGP) is shown in Fig. 5.

Pro-saccades were characterized by higher peak velocities compared to anti-saccades. The peak velocity of saccades directed to the first or second target, respectively, was not different.

To be able to compare the peak velocities of different types of saccades executed by VGPs and NVGPs, we determined the peak velocity of saccades with amplitude of 10 deg for each subject independently (see Section 2.4). The linear robust regression yielded  $R^2$  values between 0.51 and 0.83. The mean values across all subjects are shown in Fig. 6.

The peak velocity of anti-saccades was clearly lower compared to that of pro-saccades and saccades elicited in the double-step task. Moreover, VGPs had higher peak velocities than NVGPs. The 2-factorial ANOVA showed a significant effect of saccade type ( $p < 0.001$ ) and video game play ( $p < 0.001$ ). The interaction of both factors was non-significant ( $p = 0.754$ ). This suggests that faster SRTs in VGPs were also associated with a more efficient motor drive for saccades.

Finally, we analyzed the correlation of peak velocity and saccadic reaction times for all our subjects. It is important to note that we included all saccade types, pro- and anti-saccades as well as saccades towards the first and second target, in this analysis. As Fig. 7 shows, the peak velocity is inversely related to the SRT. However, the correlation obtained from VGPs is clearly different from



**Fig. 6.** Comparison of peak velocities of 10 deg saccades performed by VGPs and NVGPs. Bars show mean values across subjects; error bars represent 95% confidence intervals.

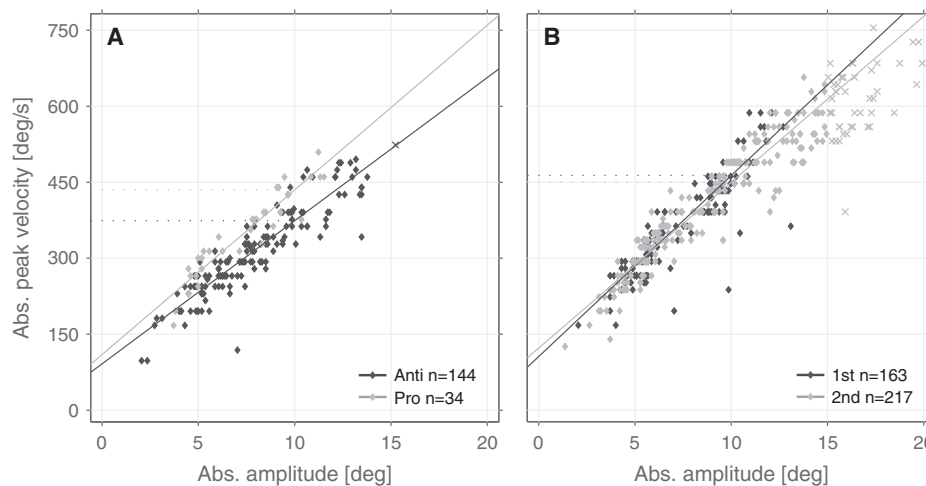
the correlation obtained from NVGPs. This is another support for the notion of higher efficiency of the visuo-motor system of VGPs.

## 4. Discussion

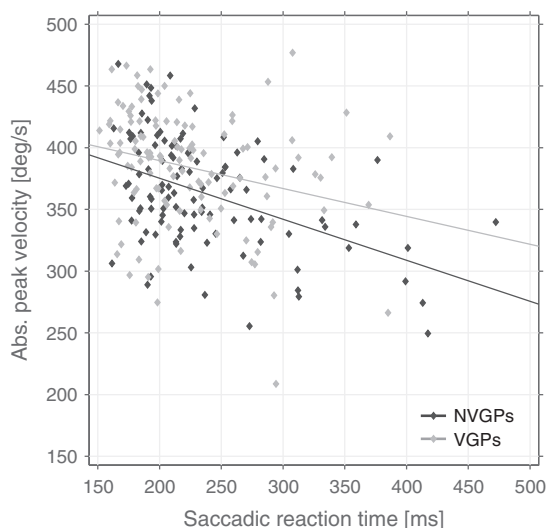
Using two different saccade tasks, we found several differences between NVGPs and VGPs. VGPs showed shorter saccadic reaction times for voluntary as well as reflexive saccades. The error rate of VGPs and NVGPs was not different in the anti-saccade task. Surprisingly, the saccades of VGPs had higher peak velocities than those of NVGPs.

### 4.1. VGPs react faster

In line with our first hypothesis, we found reduced SRTs in VGPs. This reduction was not restricted to reflexive or cognitively driven saccades and was present in data obtained from both saccade tasks. Hence, this speed-up seems not to be related to the generation of a specific saccade type. Instead, it appears to occur earlier in processing. One possibility is that it happens in the selection of a possible saccade target, a mechanism relying on attentional control. Consequently, the shorter reaction times of VGPs may be attributed to faster attentional processing since the spot-



**Fig. 5.** Main sequence of saccades performed by subject 64. (A) Gives anti- and pro-saccades, (B) shows all saccades executed in the double-step paradigm. Lines show robust linear regressions, computed only for saccades with amplitudes between 0 and 15 deg indicated by dots. Saccades with larger amplitudes are shown by crosses and were not used for the regression, since these large amplitude saccades were mainly performed towards the second target.



**Fig. 7.** Correlation of peak velocity and saccadic reaction time. Peak velocity is plotted as a function of SRT for each subject and every experimental condition (dark and light gray dots). Linear regressions were computed for VGPs and NVGPs, respectively (dark and light gray lines).  $R^2$  of VGPs was 0.065 whereas  $R^2$  of NVGPs was 0.207. For both groups, the regression slopes are negative, showing a tendency that peak velocity is inversely correlated with SRT. Importantly, the resulting linear regressions are clearly different for VGPs and NVGPs.

light of attention is shifted prior to the execution of saccades (Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Kowler et al., 1995). However, we do not have the experimental data to proof faster attentional processing in VGPs. Attentional enhancement would result in faster reaction times and in lower perceptual thresholds. Since we did not address perceptual thresholds, we cannot attribute our effects to superior attentional processing in VGPs. So the differences in VGPs and NVGPs definitively represent the higher efficiency of the specifically trained visuo-motor system which may be explained by increased attentional mechanisms, increased motor effects, or by arousal effects, to name the most likely reasons.

Nevertheless, the shorter reaction times for VGPs are consistent with a recent report from Chisholm and colleagues (Chisholm et al., 2010). They analyzed the effects of video game play on attention and also found decreased reaction times in VGPs. This was attributed to a better endogenous control over the attentional orienting response. The authors proposed that VGPs assess the relevance of a stimulus faster. The results of our study would support this view, since this is the common processing step in which the speed-up is possible for all saccade types.

Short ISIs (50 and 100 ms) result in a substantial prolongation of the SRT towards the second target. This effect can be explained by a suppressive effect of the first target on the execution of the second saccade. It is known that suddenly appearing stimuli block the execution of successive saccades which was described as “saccadic inhibition” (Reingold & Stampe, 2002). This effect seems to cancel the overall pattern of shorter reaction times in VGPs compared to NVGPs.

#### 4.2. No impaired impulse control in VGPs

We had two alternative explanations for the reduced reaction times in VGPs: first, impaired impulse control; second, higher efficiency of the visuo-motor system. The fact that the error rates of VGPs are slightly lower than that of NVGPs clearly contradicts the notion of impaired impulse control in VGPs. The higher efficiency of the visuo-motor system is in perfect agreement with a recent study combining perceptual performance and EEG record-

ings (Mishra et al., 2011). In that study, subjects had to report the presence of a target either in the central or peripheral visual field. VGPs performed better and reacted faster than NVGPs. In addition, the amplitude of steady-state visual evoked potentials elicited by peripheral non-attended stimuli was smaller in VGPs. Once more, this argues in favor of a better control of the reflexive allocation of attention in this group.

#### 4.3. VGPs have increased saccadic peak velocities

Higher peak velocities of pro-saccades compared to anti-saccades have been reported earlier (Smit, Van Gisbergen, & Cools, 1987). There is general agreement that saccades directed towards a visual target reach highest peak velocities whereas saccades directed to targets presented in a different modality, recalled from memory, or reconstructed by spatial transformation, reach lower peak velocities. However, the mechanism responsible for this dichotomy is still unknown.

Recently, it was suggested that the lower peak velocities of memory-guided saccades compared to visually-guided saccades can be traced back to the increased probability of blinks accompanying memory-guided saccades (Powers, Basso, & Evinger, 2013). Although the blink-induced curvature of saccade trajectories is able to explain the difference in peak velocities of visual and memory-guided saccade, this explanation is not able to explain the difference of peak velocities of pro- and anti-saccades since there is no reason to assume that the blink frequency is different for pro- and anti-saccades. In addition, we excluded trials with blinks from our analysis.

The brainstem circuitry for the motor generation of saccades is well understood and consists of a few specialized neuronal circuits. These neurons generate the pulse-step characteristic of the firing rate of extra-ocular-motoneurons observed during the execution of saccades. It is unknown how these circuits are modulated for the different saccade types on the one hand and what the difference between VGPs and NVGPs is on the other. VGPs produce higher peak velocities during all types of saccades. It has been shown earlier in monkeys that the saccadic peak velocity can be altered by the anticipated amount of reward (Takikawa et al., 2002). In humans it was shown that the peak velocity increases with the intrinsic value of the stimulus (Xu-Wilson, Zee, & Shadmehr, 2009). Saccades towards targets which have to be discriminated are faster compared to targets without behavioral significance (Bieg et al., 2012; Montagnini & Chelazzi, 2005). Finally, the peak velocity of saccades can be altered by reinforcement learning; for a review see (Madelain, Paeye, & Darcheville, 2011). The latter review emphasizes a correlation of short SRTs with higher peak velocities, which is in perfect agreement with our data shown in Fig. 7. In addition to the general correlation between SRT and peak velocity, our data additionally document the increased efficiency of the visuo-motor system of VGPs compared to NVGPs.

#### 4.4. Differences due to different motivation of VGPs and non-players?

Recently, it was argued that the beneficial effects of video games may be due to methodological flaws (Boot, Blakely, & Simons, 2011). The major criticism was that most studies recruited specifically VGPs. This may cause the selection process itself to act as motivation for the VGPs to outperform NVGPs. We are convinced that our study is not affected by this, because we did not search explicitly for VGPs when we recruited our subjects. In addition, the subjects did not know in advance how they were classified according to their daily gaming time.

Finally, the benefits of playing video games might be explained by perceptual learning (Censor, Sagi, & Cohen, 2012). Perceptual learning during video game play might affect saccade execution

in our study. However, perceptual learning was shown to be specific for simple stimulus attributes and depends on the specific task (Sagi & Tanne, 1994). Therefore, there is no reason to assume that the benefits of playing video games in our saccade tasks can be explained by perceptual learning.

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