The effects of training on fast saccades: the global effect can not be diminished by training

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Abstract

Saccades are fast eye movements which we make in order to check our surroundings. The global effect is the phenomenon that due to competition, a saccade lands between two stimuli, instead of on one of the stimuli. To research whether it is possible for participants to make fast saccades that are directed more at a target-stimulus, after training, an experiment was set up. In this experiment participants were trained at making fast and accurate saccades towards a target-stimulus, while there was also a distractor-stimulus present. The differences in relative saccadic landing position and saccadic latency of the first half of the experiment and the second half of the experiment were compared. Also, the influence of saccadic latency on the saccadic endpoint and the absolute distance between saccadic endpoints and the target and distractor were examined.

All in all, the outcome of the experiment is that it is not possible to diminish the global effect by training for half an hour. Results showed that it is possible to initiate saccades faster after training for half an hour and because it is harder to influence the saccadic endpoint by top-down information for saccades with a shorter latency, the fact that participants initiated saccades faster after training might explain why it is not possible for participants to make more accurate saccades.

1 Introduction

Saccades are fast eye movements which we make all the time in order to check our surroundings. These eye movements are necessary to subject all different areas and objects of interest to a detailed analysis by the fovea. Saccades can be induced by top-down or task-driven information, or by bottom-up or stimulus-driven information, where top-down signals reflect goals and intentions of a person at a certain moment, while bottom-up signals reflect the influence of visual information of the world. Because people can only make one saccade at a time, there is a constant competition between the bottom-up and the top-down factors about where the next saccade is going to end (Ludwig & Gilchrist, 2002, Ludwig & Gilchrist, 2003, Van der Stigchel & Nijboer, 2011, Van der Stigchel & Nijboer, 2013, van Zoest, Donk & Theeuwes, 2004).

Saccade averaging, also known as the global effect, is the phenomenon that, due to this competition, a saccade lands between two stimuli, instead of on the center one of the stimuli (Van der Stigchel & Nijboer, 2011, Theeuwes, Kramer, Hahn & Irwin, 1998, Walker, Deubel, Schneider & Findlay, 1997). This also happens when one of the stimuli is designated as the target-stimulus (Coren & Hoenig, 1972, Van der Stigchel & Nijboer, 2011), which means that the saccade ends on an intermediate location or deviates towards the distractor-stimulus, instead of landing on the center of the target-stimulus (Findlay, 1982, Van der Stigchel, Heeman & Nijboer, 2012, Van der Stigchel & Nijboer, 2011). Because the saccade lands between two stimuli, it is called saccade averaging; the saccadic endpoint is the average of the goal of the top-down and bottom-up signals. The global effect emerges when a target-stimulus and a distractor-stimulus are presented simultaneously and close to each other, and is strongest when the distance between the target and the distractor is about 20° in polar coordinates (Ottes, van Gisbergen, & Eggermont, 1984, Van der Stigchel et al., 2012, Van der Stigchel, & Theeuwes, 2005, Walker et al., 1997). Also for larger distances, a global effect was observed, but above distances of 45° between target and distractor the endpoint distribution became bimodal (Van der Stigchel and Nijboer, 2013). A bimodal distribution means that the saccade landed on either the target-stimulus or the distractor. Also for larger distances a bimodal end distribution is observed (Ottes et al., 1984, Van der Stigchel et al., 2012, Van der Stigchel & Nijboer, 2011,Van der Stigchel, de Vries, Bethlehem, & Theeuwes, 2011).

Saccade latency was defined as the interval between the target onset and the initiation of the saccade and is known to influence the global effect (Findlay, 1982). To find out how the latency influences saccadic accuracy, Ottes and colleagues (1985) performed an experiment in which the participants were shown two stimuli, of which one was designated as the target. Before every trial, participants got one of two assignments: Either they had to react as fast as possible to keep the latency short, or they had to be to be as accurate as possible, ignore the distractor-stimulus and make a saccade that landed straight on the target. Results showed that only if the participant waited at least 300 ms before initiating a saccade, it was possible to prevent a global effect. When waiting less than 300 ms before initiating a saccade, the saccade endpoint would be between the target and the non-target, even though the task was to ignore the distractor-stimulus. Furthermore, they discovered that when the saccade latency was longer, the global effect was weaker. Coeffe and O'Regan (1987) also researched the influence of the saccadic latency on the global effect, by having participants delay the initiation of saccades. Participants got the task to keep looking at the fixation cross until it disappeared, even if the target and distractor had already appeared. When the fixation cross disappeared after the stimuli had already appeared, the global effect was weaker than when the fixation cross disappeared at the moment of stimulus-onset. A stronger global effect for saccades with a short latency can be explained by the fact that fast saccades are mostly modulated by bottom-up information (Ludwig & Gilchrist, 2002, Ludwig & Gilchrist, 2003, Van der Stigchel & Nijboer, 2011, van Zoest et al., 2004). So, the global effect seems to be the strongest for saccades with a short latency, because those saccades do not seem to be influenceable by top-down signals. However, researchers have shown that it is possible for saccade averaging to be influenced by higher order signals. Coeffe and O'Regan (1987) showed that the global effect decreased (but not disappeared completely) when participants knew where to expect the target. He and Kowler (1989), by varying the probability of a target appearing in one of two places, showed that saccades were biased towards the most likely target location. The target appearing in the other location, did not influence the saccade. Because this effect was reduced when the target was easier to discriminate from the distractor, higher order information is shown to be able to regulate the degree of global effect. This is why Van der Stigchel and Nijboer (2013) claimed that the global effect is a result of absence of top-down signals. However, it was not yet known whether it is possible to increase the influence of top-down information to diminish the global effect, or whether it is possible to learn to suppress the bottom-up signals that cause the global effect, by training.

Thus, the goal of the current experiment was to research whether it is possible to learn to increase the influence of top-down information to make the global effect smaller for fast saccades, by training. To research whether it is possible to make fast saccades to a target-stimulus and ignore a distractor-stimulus after training, the following experiment was set up. In the experiment, two stimuli of equal size and shape were presented simultaneously at a distance of 20° to evoke a strong global effect. Participants, after being informed which stimuli was the target, were asked to make a saccade to the target as fast as possible after the stimulus-onset. The goal was to have participants initiate a saccade within 220 ms after stimulus-onset and the saccadic endpoint had to be closer to the target than to the distractor. If a participant failed to meet both criteria, a very unpleasant sound was played, to motivate participants to really try their hardest to make a saccade that was both fast and accurate. Also, participants got feedback after each trial, so they knew what they had to improve to prevent the sound from being played again. After a fast and accurate saccade, participants also got feedback, but no sound. The feedback consisted of a screen with the text "correct" or "incorrect" and "In time" or "Too slow". The current experiment resembled experiment 1 of Van der Stigchel and colleagues (2012), with the difference that there was not a specific target in that experiment; participants were given the task to look at a stimulus as fast as possible, but it was not specified which one. The current experiment also resembled experiment 2 of Ottes and colleagues (1985), with the difference that in the current experiment, participants had to satisfy both criteria, instead of having to focus on either speed or accuracy. Also, in the resembling experiments, participants were not 'punished' if they did not meet any of the criteria.

To see how participants performed when there is no global effect, 25 percent of trials consisted of only a target-stimulus and no distractor. The results of these one-stimulus trials were used to calculate the participant's baseline, in order to be able to measure the influence of the global effect on saccadic landing positions. For these one-stimulus trials, the task was the same as for trials with two stimuli; Participants still had to make a fast and accurate saccade to the target-stimulus. Because research has shown that it is easier to make a fast saccade when there is only one stimulus (Walker et al., 1997), these trials were regarded as easier trials. These one-stimulus-trials were also included in the experiment to keep participants motivated and assure them that they were able to perform fast and accurate saccades. To find out if it is possible to learn to suppress bottom-up information and suppress the global effect in fast saccades by training, participants had to repeat the experimental task in which they were asked to make fast and accurate saccades to a target-stimulus, for about an hour. If the results showed that participants made faster and more accurate saccades after repeating the task for a while, it seemed plausible that it is possible to suppress the bottom-up signals that cause the global effect after training.

There was no existing research to be found on training and its impact on the global effect, so it was hard to predict the outcome of this experiment, but the expected outcome of this experiment was that it would not be possible to improve accuracy for fast saccades. It was to be expected that even with training, participants would either make accurate or fast saccades. As discovered by Ottes and colleagues (1985), the only way to prevent the global effect was to wait at least 300 ms before initiating a saccade and in this experiment, participants were punished if they waited more than 220 ms before initiating a saccade.

2 Method

2.1 Experiment

2.1.1 Participants

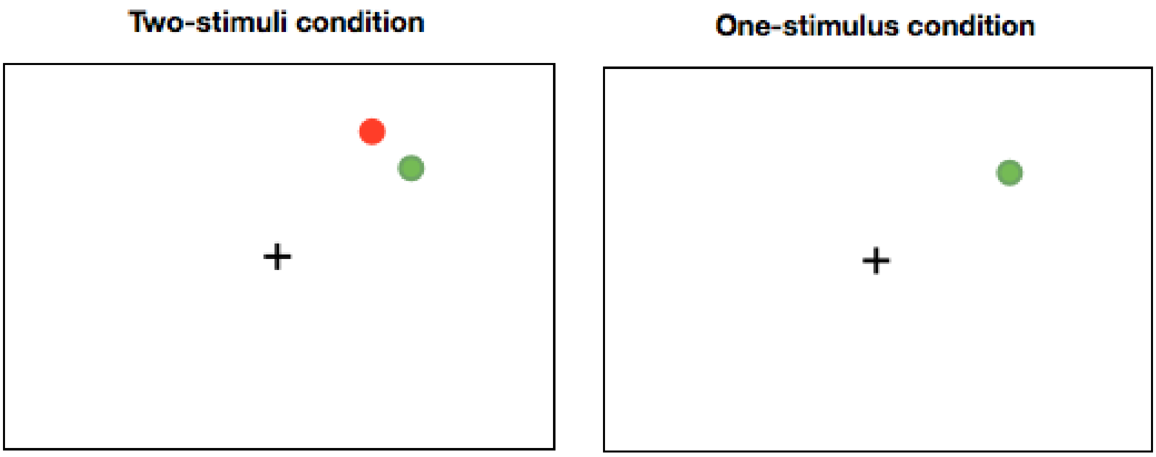
Twelve participants in the ages of nineteen to twenty-seven, of which eight subjects were male, participated in the experiment. All participants were naive to the purpose of the experiment, and all of the participants had normal or corrected-to-normal visual acuity.

2.1.2 Equipment

For tracking the eye-movements of the left eye, an Eyelink 1000 system was used. This is an infra-red video-based eye tracker that has a 1000 Hz temporal resolution and a spatial resolution of 0.01°. The participants head was stabilized with a chin rest, and an infrared remote tracking system compensated for any head motion. Participants were viewing a display monitor from a distance of 67 cm. An eye movement was measured when either eye velocity exceeded 35°/s or eye acceleration exceeded $9500°/s^2$ and only if the point of fixation became more than 2° away from the position of the fixation mark.

2.1.3 Stimuli and procedure

At the start of every trial, while participants were looking at the screen, instructions were being displayed to notify the participant what the target was. This was either the text "Target is: red" or "Target is: green". After 2000 ms the instructions disappeared and participants viewed a gray screen with a black cross (0.5× 0.5°) in the center of the display. This was used as a fixation mark. After a random interval of 750-1250 ms, the fixation mark disappeared and for a random interval of 400-600 ms, a blank screen was visible. The disappearing of the fixation mark before stimulus-onset, helped participants to make faster saccades (Fischer & Rampsberger, 1986, Saslow, 1967). The blank screen was followed by the stimulus-screen. The stimulus-screen consisted of a green and a red filled circle (size of both: 0.83°), with a distance between them of 20° from center to center, presented simultaneously. The distance between the center of the circle and the middle of the screen was 9.9° for both circles. The two stimuli



(a) (b)

Figure 1: Example of a stimulus-screen for the two-stimuli condition(a) and the one-stimulus condition(b).

were presented in the same quadrant and were positioned around one of the four principal axes (polar coordinates: 45°, 135°, 225°, 315°). Each stimulus appeared on either side of the axis at equal distance from the axis. To make the experiment less frustrating for participants, the target-display was presented for as long as it took a participant to make a saccade towards the stimuli plus 1000 ms after the participant finished making a saccade. The extra time allowed participants to really focus on the target, because if the stimulus would have disappeared at the exact same moment a participant finished making a saccade towards the target, the experiment would have been frustrating for participants.

After that, during 1500 ms a screen appeared with feedback about how the participant had performed in the trial. if the saccade had not been accurate and/or fast enough, an unpleasant buzzing sound (frequency = 440 Hz, length = 100 ms) was played. As stated earlier, a trial was fast enough if the saccade latency was shorter than 220 ms and accurate enough if the saccadic endpoint was closer to the target than the distractor-stimulus. After the feedback-screen, the instruction-screen for the next trial appeared on the display. There was another condition, in which only a target-stimulus appeared on the screen and no distractor. In the one-stimulus condition, the stimulus-location was determined as if there was a distractor, so it was presented at a distance of about 10° of one of the four principal axes. The one-stimulus condition was added to determine to which location a participant makes a saccade if there is no global effect. Trials with only a target-stimulus were also used to keep participants motivated during the entire experiment. Because these trials were regarded as easier, participants were more likely to be fast and accurate enough, and less likely to hear the unpleasant sound. For these reasons, 25 percent of trials was replaced by trials with only one stimulus. Except for the number of stimuli on the screen, there was no difference between the two types of trials. In Figure 1 a possible stimulus-screen for each condition is shown.

Participants were instructed to fixate on the fixation mark until it disappeared and to move their eyes to the target on the monitor as quickly and precise as possible, as soon as it appeared. Each session started with a nine-point grid calibration procedure. In addition, simultaneously fixating the central fixation point and pressing the space bar re-calibrated the system by zeroing the offset of the measuring device every five trials.

The sequence of trials was randomized, so for every trial it was random if the target was red or green, in which quadrant of the screen the stimuli would appear and there was a chance of 0,25 for the trial to consist of only a target stimulus. The experiment consisted of 400 experimental trials and 10 practice trials.

2.2 Data analysis

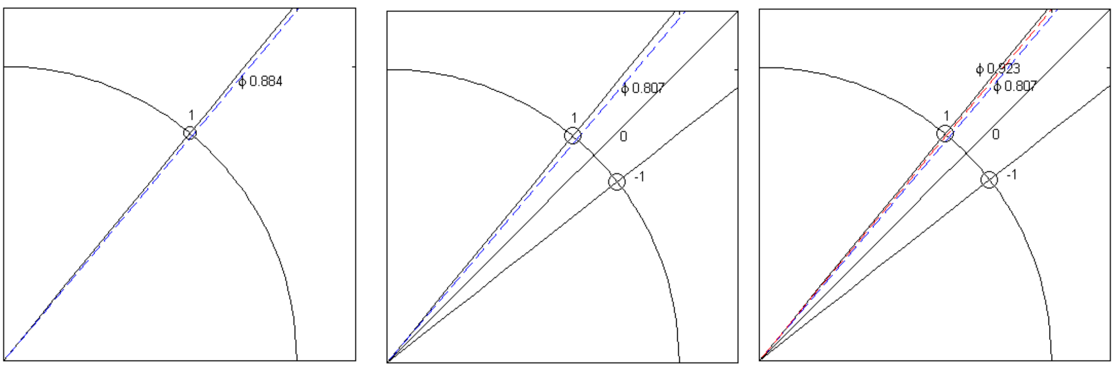
2.2.1 Saccade endpoint

Before analyzing the data, some assumptions were made. Van der Stigchel and colleagues (2012) found that there was no difference in saccadic endpoints when stimuli were presented in different quadrants. It was assumed that for this experiment, this was also the case. Also, it was assumed that the actual position of the target-stimulus and the color of the target-stimulus did not influence the saccade latency, saccadic endpoint or the global effect.

In order to be able to compare data regarding saccadic endpoints from all quadrants, all starting and landing positions were mapped onto the upper right quadrant. The relative endpoints were computed the same way Van der Stigchel and colleagues (2012) did. After mapping all saccadic starting points and endpoints onto the upper right quadrant and the left stimulus being the target-stimulus for every trial, the relative landing positions were calculated by mapping the saccadic endpoints onto a scale where -1 was the value for saccades that landed exactly in the direction of the distractor-stimulus, 0 for saccades that landed exactly on the the 45° axe and the geometric midpoint between the stimuli, and 1 was the value for saccades that landed in the direction of the target stimulus. A relative value of more than 1 or less than -1 means that the stimulus did not land between the stimuli. These scaled saccadic endpoints were calculated relative to the starting point of a saccade.

Also, the landing positions of the saccades from the one-stimulus condition from the participant were used to scale the saccadic endpoints of the two-stimuli condition from -1 to 1. The average landing positions from the one-stimulus condition were used as a personal baseline. For instance, if a participant had the tendency to look a little left from a stimulus in the one-stimulus condition, this was taken into account in the calculation of the relative endpoint in the two-stimuli condition. Figure 2 shows how this was done.

If a saccade did not end in the quadrant where the stimuli were presented, it was regarded as an outlier and removed from the analysis. Also, trials with landing positions which were further than two and a half standard deviations away from the average landing position of a condition of a participant, both in amplitude and relative landing position, were marked as outliers and removed from the analysis. This was calculated first for the one-stimulus condition because the average relative landing position of trials from this condition was necessary to calculate the relative landing positions in the two-stimuli condition. A one tailed paired sample Student's t-test was run to compare relative landing positions from the first 200 trials to those of the last



(a) (b) (c)

Figure 2: An example of how the relative saccadic endpoint was adjusted. Suppose the average relative landing position for the one-stimulus condition (target at 1), is 0,884 (a). If the relative saccadic endpoint was 0,807 (blue line) for the two-stimuli condition (b), this was corrected (red line) using the average relative saccadic endpoint of the one-stimulus condition (c). Here, the corrected relative saccadic endpoint was 0,807 + (1-0,884) = 0,923.

200 trials of the two-stimuli condition, to see if training caused participants to be able to make saccades that were more directed towards the target. If relative landing positions of the last 200 trials were closer to 1, saccades were more directed towards the target-stimulus.

2.2.2 Saccade latency

As stated earlier, the saccade latency was defined as the interval between target on-set and the initiation of the saccadic eye movement. For both conditions, trials with a saccade latency of less than 50 ms or more than 450 ms were excluded because these saccades were regarded as anticipatory saccades. All trials with a latency of more than two and a half standard deviations away from the mean latency of a participant of a condition, were excluded from the analysis as they were regarded as outliers. Also for the saccade latencies a one-tailed paired sample Student's t-test was run to compare saccadic latencies from the first 200 trials to those of the last 200 trials of the two-stimuli condition, to see if training caused participants to be able to initiate saccades faster.

3 Results

The exclusion criteria led to a loss of 12,39% of trials. Also, for one participant the exclusion criteria led to a loss of more than 25% of data so all data of this participant (female) has been excluded from analysis, because there was not enough data left for a reliable analysis.

Data of the one-stimulus condition was only used to calculate a participant's baseline. Unless otherwise specified, the results are derived from data from the two-stimuli condition.

3.1 Saccadic landing position

As mentioned before, in the one-stimulus condition there was only a target-stimulus, which was presented at location 1. Naturally, in this condition there was no global effect. Still, average landing positions were not 1, but the average relative landing positions of participants for this condition were between 0,884 and 1,058. The deviation of this value in comparison to 1 was the personal deviation for participants and was used to correct the participants relative landing position in the two-stimuli condition to make sure that all deviation left, was caused by the global effect. As Figure 3 and Figure 4 show, in the two-stimuli condition, participant's saccadic endpoints were influenced by the global effect. This is shown in Figure 3 by the unimodal distribution of the relative landing points in the two-stimuli condition, and the fact that the peak is between 0,5 and 1. Unimodal means that there is one range of values that is the most frequent and one peak in the distribution graph. If saccades would not have been influenced by

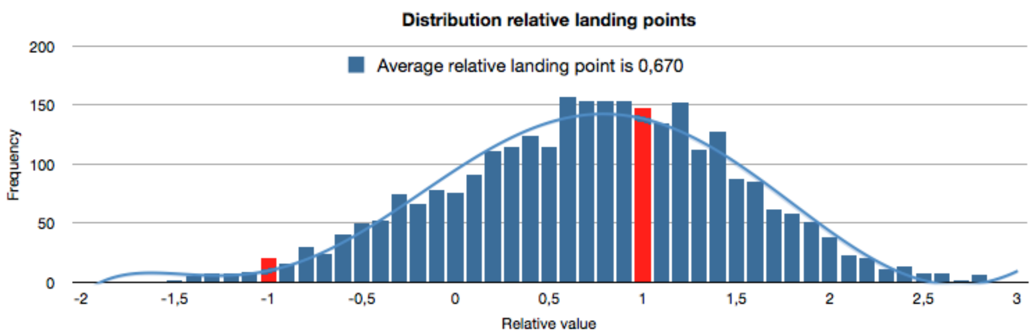


Figure 3: A frequency plot of all relative landing positions of the two-stimuli condition. The target was presented on 1 and the distractor was presented on -1. It shows that the distribution of relative landing positions was unimodal.

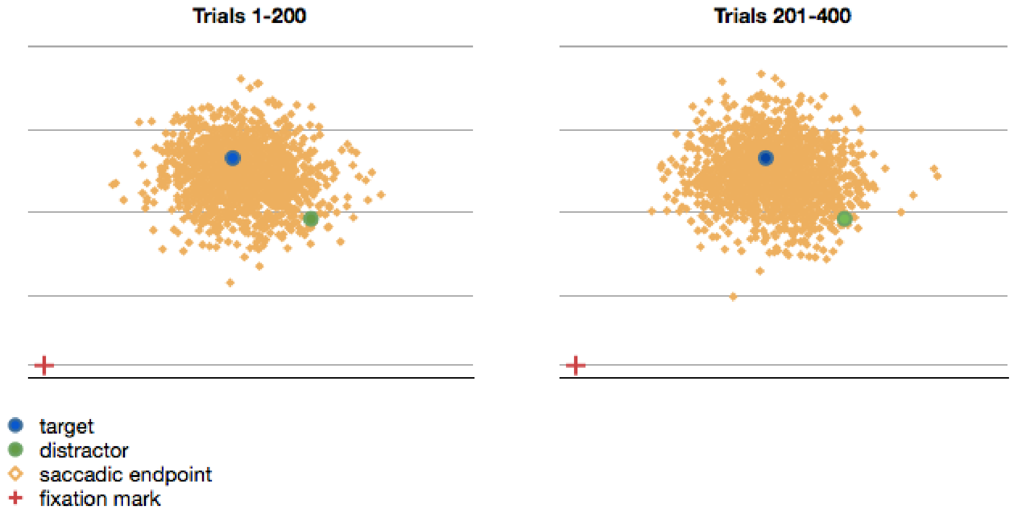


Figure 4: The distribution of actual saccadic endpoints, mapped onto one quadrant. The left image contains all endpoints of trials 1-200 and the right image contains all endpoints of trials 201-400.

the global effect, the average relative landing point would have been 1, which was the location of the target-stimulus. However, the average saccadic landing point was 0,670, which means that participants were able to look in the direction of the target more than in the direction of the distractor, but the distractor still influenced the direction of saccades. For all participants the distribution of the relative landing positions was unimodal. Figure 4 shows that saccades from trials 1-200 seem to end closer to the target, than saccades from trials 201-400 and saccades from trials 201-400 seem to end further away from the distractor than saccades from trials 1-200. Therefore, the differences between the first 200 trials and the last 200 trials in absolute distance between saccadic endpoints and the target and saccadic endpoints and the distractor were also analyzed.

3.2 Saccade latency

As you can see in Figure 5, for most trials of the two-stimuli condition the saccade latency was under 200 ms, which means that participants made very fast saccades. Also, according to the eye-tracker, there were quite a lot of trials with a saccade latency that was even shorter than 50 ms. Of those saccades, most had a latency of 0 ms. These trials were excluded from the analysis so they did not influence the results, but it is still strange that they existed. The reason for this strange latency to be measured so often, is probably that the eye-tracker was instructed not to start tracking an eye-movement until the point of fixation became more than 2° away from the center of the screen. This was done to prevent the eye-tracker from tracking micro-saccades. Data showed that trials with a saccade latency of 0 ms did have starting points that were more than 2° away from the center of the screen. The extra requirement probably caused the eye-tracker to immediately start tracking a saccade at the moment of stimulus-onset, if the point of focus was more than 2° away from the center of the screen at that moment. It is also possible that participants were already making a saccade before stimuli had appeared, and the eye-tracker immediately started registering that saccade at the moment of stimulus-onset.

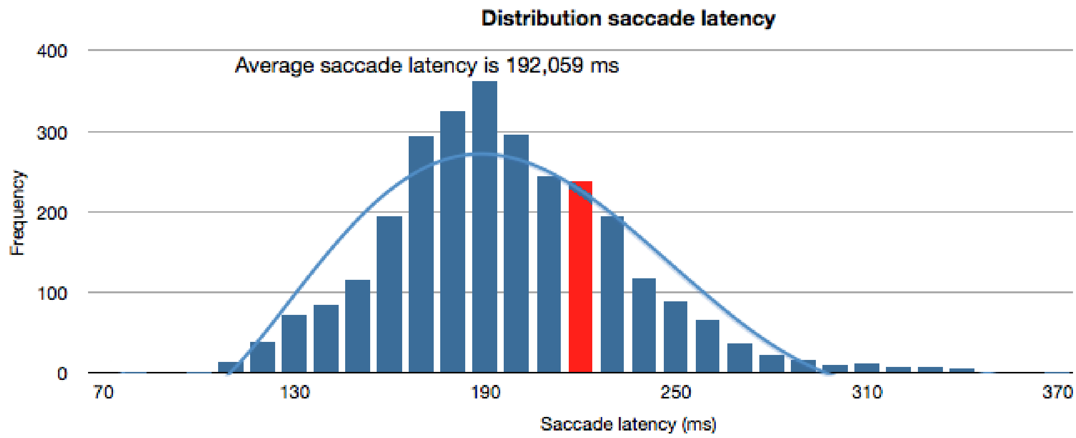


Figure 5: A frequency plot of saccade latencies of all trials from the two-stimuli condition. If the saccade latency was 220 ms (red bar) or longer, participants heard an unpleasant sound to motivate them to react faster.

3.3 Effects of training on the relative landing position

As stated earlier, relative landing positions of the two-stimuli condition were distributed unimodal and showed a global effect for all participants. Figure 6 shows a trend towards 1 in the relative endpoints, which suggests that saccades ended more in the direction of the target after training. Before training, the average landing position was 0,642 and after training it was 0,679, so the difference between relative endpoints of the first 200 trials and the relative endpoints of the last 200 trials was 0,036 closer to the target-stiulus. However, this difference was not big enough to be significant (p >0,05) so there was no actual improvement. Figure 7 shows how small this difference is. In table 1 you can find the differences in saccadic latency and saccadic relative endpoint between trials 1-200 and trials 201-400 per participant.

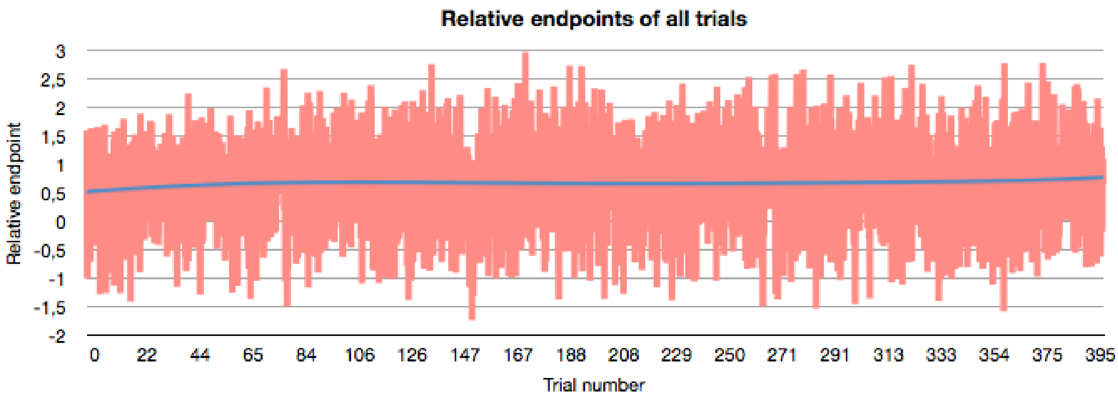


Figure 6: The relative endpoints of all two-stimuli trials in the order of the experiment. The blue line is the trend-line and as you can see, it is slightly tilted, which indicates that towards the end of the experiment, participant's saccades were initiated more in the direction of the target. However, the difference between the direction of the saccade in the beginning of the experiment and the direction of saccades at the end of the experiment was not significant.

	difference in latency (ms)	difference relative endpoint
pp1	3,048	0,104
pp2	29,724	0,050
pp3	-2,798	0,114
pp4	19,412	-0,058
pp5	0,251	0,116
pp6	9,877	0,059
pp7	16,217	-0,021
pp8	14,186	-0,080
pp9	20,600	-0,127
pp10	27,604	0,034
pp11	7,623	0,207
Average difference	13,249	0,036
t-value	4,093	1,207
p-value	0,001	0,128

Table 1: Differences per participant in saccadic latency and saccadic relative endpoint between trials 1-200 and trials 201-400. A positive difference in latency means a participant initiated saccades faster in the second half of the experiment and a positive difference in relative endpoint means saccades ended more in the direction of the target-stimulus in the last 200 trials of the experiment than in the first 200 trials of the experiment.

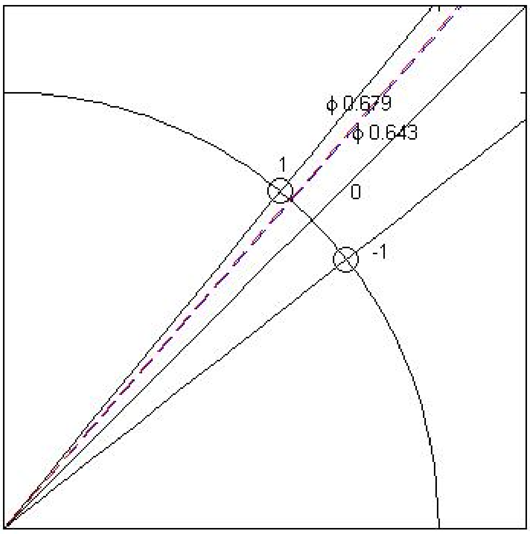


Figure 7: The difference in relative saccadic endpoints of the first half of the experiment (blue line) and the second half of the experiment (red line). The difference is very small and not significant, so training does not diminish the global effect.

3.4 Effects of training on the stimulus-distance

Because Figure 4 indicated that saccades from trials 1-200 ended closer to the target than saccades from trials 201-400, the differences in distance between target and absolute saccadic endpoints from the first 200 trials and the last 200 trials were analyzed.

Before training, the average distance between a saccadic endpoint and the target was 47,904 pixels. After training, this distance was 50,261 pixels, so the difference was 2,357 pixels. This was a significant difference ($t(10) = -2,927$, $p<0,01$), so saccades ended further away from the target after training. Figure 4 also indicated that saccades from trials 201-400 ended further away from the distractor than saccades from trials 1-200, so the differences in distance between the absolute saccadic endpoints and the distractor before and after training were analyzed too. Before training, the average distance between saccadic endpoints and the distractor was 90,840 pixels. After training, this distance was 93,241 pixels, so the difference was 2,401 pixels. This was not a significant difference ($p>0,05$), so saccades did not end further away from the distractor after training. In Figure 8 the mean distance between saccadic endpoints and the target of the first 200 trials and the mean distance between saccadic endpoints and the target of the last 200 trials are shown. Mean distances between saccadic endpoints and the distractor are also shown.

3.5 Effects of training on the saccadic latency

As Figure 9 shows, saccade latencies seemed to get shorter after participants had performed the task for a longer period. Before training, the average saccade latency was 199,197 ms and after training it was 185,947 ms. So, saccade latencies of the first 200 trials were on average 13,249 ms longer than saccade latencies of the last 200 trials, and this was a significant difference ($t(10) = 4{,}093$; $p<0{,}01$). This shows that after training for a while, participants initiated saccades faster than when the experiment had just started. In Figure 9 the gradual change over time is shown, and table 1 shows the differences in saccadic latency between the first half and second half of the experiment per participant. This makes it even more apparent that saccade latencies were shorter after training.

Because the saccade latency had shifted significantly due to training, while the relative saccadic endpoint had not, the relation between saccadic latencies and the relative endpoint was also examined.

3.6 Effects of saccade latency on the relative landing position

To examine the relation between saccadic latency and the relative landing position, each participant's data was split in two groups of which one group contained all trials with saccade latencies that were under the median of latencies of the participant and the other half contained trials with saccade latencies that were above the participant's median. Trials with the same latency were always in the same group (fast group or slow group) and the data was split at a point such

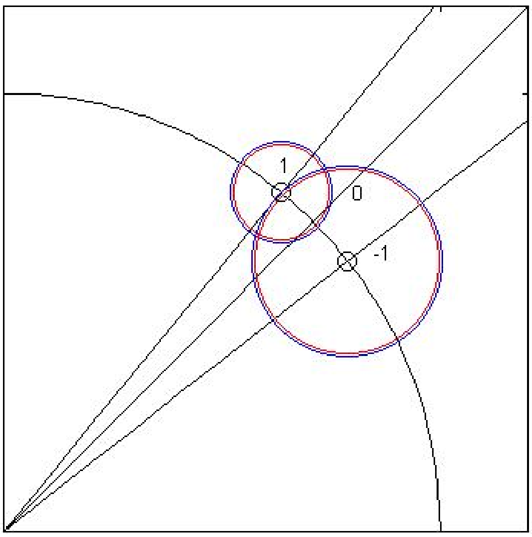


Figure 8: The difference in distance between saccadic endpoints and the target and saccadic endpoints and the distractor of the first half of the experiment (red circles) and the second half of the experiment (blue circles). Saccades did not end significantly closer to the target, while saccades did end significantly further away from the distractor-stimulus after training.

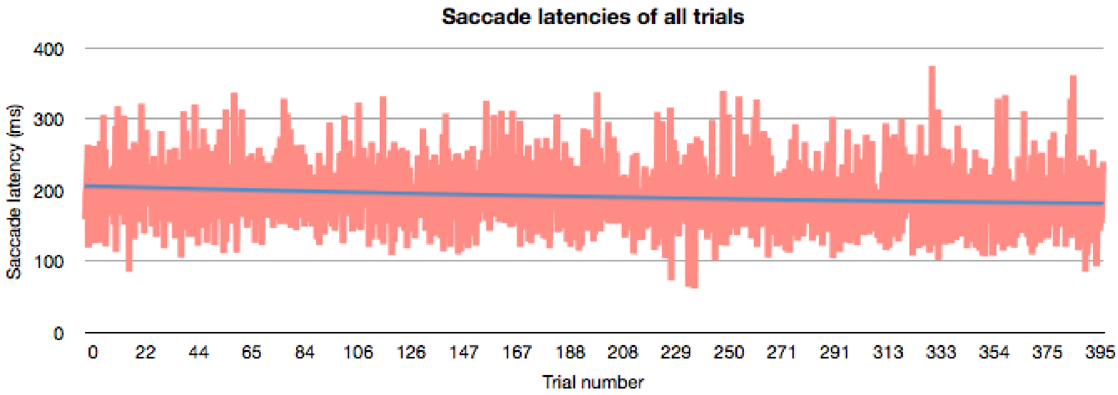


Figure 9: The saccade latencies of all two-stimuli trials in the order of the experiment. The blue line is the trend-line and as you can see, it is slightly tilted, which indicates that towards the end of the experiment, participants initiated saccades faster.

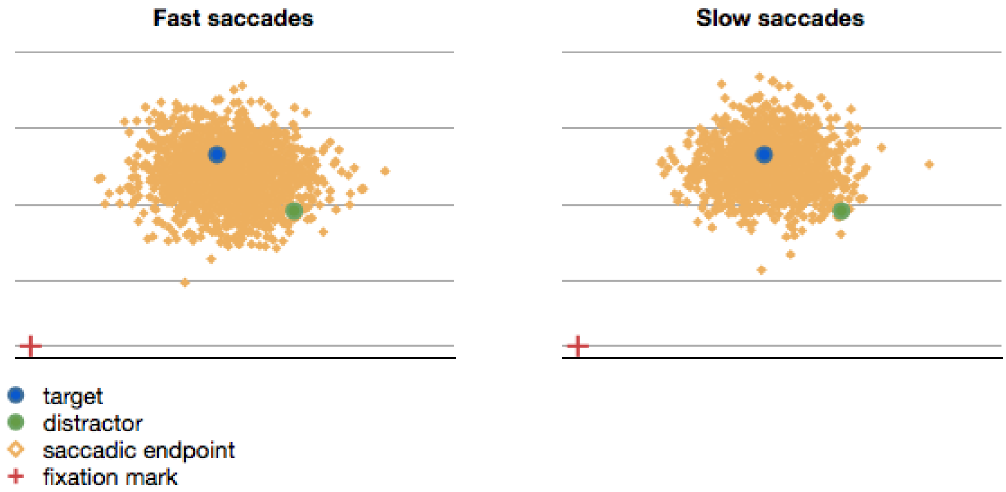


Figure 10: Distribution of mapped saccadic endpoints. Slow saccades (right) seem to end closer to the target while fast saccades (left) seem to be more scattered and end closer to the distractor.

that the group sizes had the least possible difference. In Figure 10 all mapped endpoints of the fast and slow group are shown.

Slow saccades ended more in the direction of the target (average landing position was 0,791) than fast saccades (average landing position was 0,531). A one-tailed paired sample t-test showed that this difference was significant ($t(10) = 3{,}992$; $p<0{,}01$), with a mean difference of 0,260 between relative endpoints of fast and slow saccades. Figure 11 shows that this is a notable difference.

3.7 Effects of saccade latency on the stimulus-distance

Because Figure 10 indicated that slow saccades ended closer to the target than fast saccades, the relation between the saccade latency and the distance between the saccadic endpoint and the target was analyzed.

The average distance between endpoints of fast saccades and the target was 53,574 pixels. For slow saccades, this distance was 44,640 pixels, so the difference was 8,934 pixels. This was a significant difference ($t(10) = 4{,}826$, $p<0{,}01$), so fast saccades ended further away from the target. Figure 10 also indicated that slow saccades ended further away from the distractor

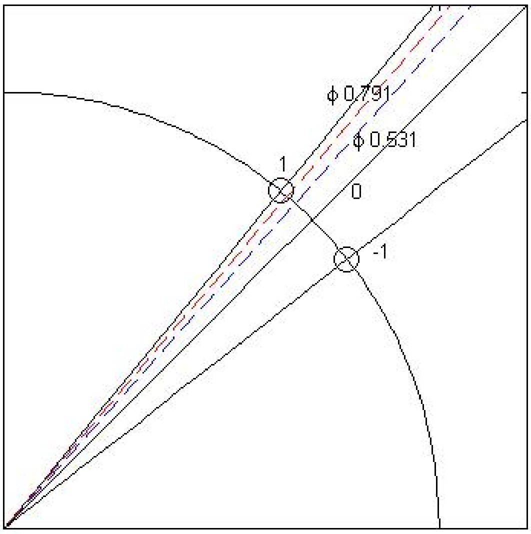


Figure 11: Difference in relative saccadic endpoints of fast (blue line) and slow (red line) saccades. The difference is notable and the global effect is shown to be significantly stronger for faster saccades.

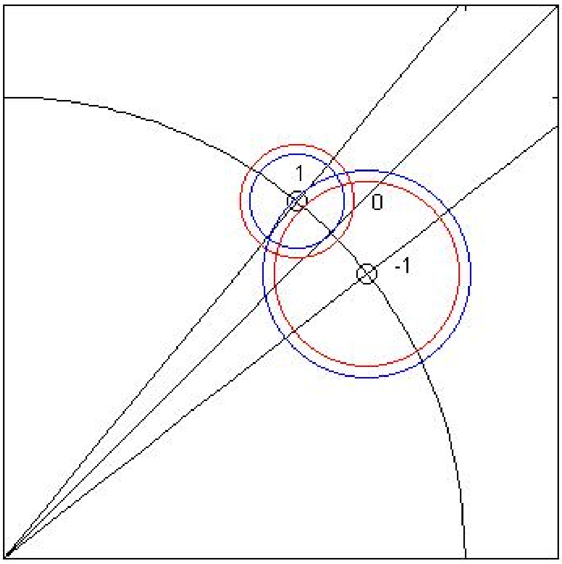


Figure 12: The difference in distance between saccadic endpoints and target and saccadic endpoints and distractor of fast and slow saccades. Slow saccades (blue circles) ended significantly closer to the target and significantly further away from the distractor-stimulus. Fast saccades (red circles) ended significantly further away from the target-stimulus and significantly closer to the distractor-stimulus, than slow saccades.

than fast saccades, so the differences in distance between the absolute saccadic endpoints and the distractor for fast and slow saccades were analyzed too. The average distance between endpoints of fast saccades and the distractor was 86,681 pixels. For slow saccades, this distance was 97,482 pixels, so the difference was 10,801 pixels. This was a significant difference ($t(10) = 3{,}519$, $p<0{,}01$), so slow saccades ended further away from the distractor. In 12 the differences in distance between saccadic endpoints and the target of fast and slow saccades are shown. The differences in distance between saccadic endpoints and the distractor are also shown.

4 Discussion

The goal of the current experiment was to research whether it is possible to diminish the global effect in fast saccades by half an hour of training. This was done by having people perform a task in which they had to make really fast and accurate saccades for an hour and 'punish' participants if they did not perform good enough. The results from the beginning of the experiment were compared to the results of the end of the experiment, to see if participant's results had improved after training. Paired sample t-tests were run on the differences in saccade latency and saccade accuracy between the first half of the experiment and the second half of the experiment, to find out if training had caused a significant improvement in saccadic latency and the direction in which the saccades were initiated. The expected outcome was that there would be no improvement in the direction in which saccades were initiated after training, because the global effect has been found to be very strong for fast saccades (Ottes et al., 1984, Van der Stigchel & Nijboer 2011, Coeffe & O'Regan, 1987). Therefore, it seemed unlikely that the effects of the global effect could be diminished in any way.

Results indeed showed that participants were not able to ignore the distractor-stimulus completely and look straight at the target, after training. In the second half of the experiment, relative ending positions were on average 0,036 more towards the target-stimulus. This was not a significant difference, so training did not diminish the global effect in fast saccades. Also, as Figure 4 and the significant relation between training and the stimulus-distance show, saccades in the second half of the experiment ended further away from the target-stimulus. Moreover, saccades in the second half of the experiment did not end further away from the distractor-stimulus. Thus, saccades ended further away from the target-stimulus in the second half of the experiment, than saccades in the first half of the experiment. This could be due to participants getting tired or being less focussed after more than half an hour of performing the same, not that interesting, task.

The research question also demanded looking at the difference in saccadic latency of the first and the last half of the experiment. Figure 9 suggests that there is an improvement in the second half of the experiment with respect to the saccadic latencies, and a t-test confirmed this improvement, so it is possible to diminish the saccade latency by training.

The fact that participants were able to make even faster saccades in the second half of the experiment, shows that being tired was not the reason the distances between saccadic endpoints and the target-stimulus were bigger. If participants had gotten tired, it would have been harder for participants to focus and loss of focus would have caused the saccade latency to go up (McPeek, Maljkovic, & Nakayama, 1999). Instead, the saccade latency went down, so loss of focus did not cause the saccades to end further away from the target.

Also the relation between saccadic latency and saccadic endpoint was analyzed. Some of the existing research has shown that the global effect is stronger for saccades with a shorter latency (Coeffe & O'Regan, 1987, Ottes, et al., 1984), however there have also been experiments in which this was not found (Van der Stigchel et al., 2012). In the current experiment it was found that endpoints of saccades with a shorter latency were significantly more in the direction of the distractor than saccadic endpoints of slow saccades. As Figure 10 suggested, the distance between saccadic endpoints and the target was significantly bigger for faster saccades, so faster saccades ended further away from the target than slow saccades. For slower saccades, the distance between the saccade endpoint and the distractor was also bigger than for fast saccades. Fast saccades ended significantly closer to the distractor and significantly further away from the target and slow saccades ended significantly closer to the target and significantly further away from the distractor. In Figure 12 this relation is shown.

This could explain why saccadic endpoints in the second half of the experiment were more spread out, when participants did not lose focus. Because participants made faster saccades in the second half of the experiment than in the first half, the distance between saccadic endpoints and the target was bigger. The fact that participants initiated saccades faster in the second half of the experiment, could also explain why there was no improvement in relative endpoints; faster saccades were more likely to end closer to the distractor and the global effect was stronger for fast saccades. The reason that the global effect is stronger for faster saccades, is that for saccades with a short latency, the execution is mostly based on bottom-up information(Coeffe & O'Regan, 1987, Van der Stigchel, & Nijboer, 2011). This implies that the improvement in saccade latencies in the second half of the experiment also makes it harder to make saccades to the correct location.

The hypothesis, that it is not possible to diminish the global effect for fast saccades and that even with training, participants will either be more accurate or faster, is confirmed by the results of eleven participants. Results showed a significant improvement in saccade latency, while the relative endpoint did not change significantly.

To get to know more about the influence of training on the influence of the global effect, more research is needed, for instance if a longer period of training can help participants to make more accurate fast saccades. In future research on this topic, it is important to take the following concerns into account. Because the only difference in instructions between different trials was which stimulus was the target, by the time participants had to execute a saccade, they had sometimes forgotten whether they had to make a saccade to the red or the green stimulus. To make sure all analyzed saccades are intended to land on the correct stimulus, it might be a good idea to ask participants after every trial which stimulus they were looking at. It is also important to ask participants not to stop looking at the fixation mark or the location of the fixation mark until the stimuli have appeared. This will most likely prevent the eye-tracker from registering saccades with a saccadic latency of 0 ms.

All in all, the outcome of the experiment is that it is not possible to diminish the global effect by training for half an hour. Results showed that it is possible to initiate saccades faster after training for half an hour and because it is harder to influence the saccadic endpoint by top-down information for saccades with a shorter latency, the fact that participants initiated saccades faster after training, might also explain why it is not possible for participants to make more accurate saccades.

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6 Links with cognitive artificial intelligence

This field of research is interesting for artificial intelligence, because it provides new insights in how the brain deals with to certain stimuli and if and how this reaction changes after repeating a task for a longer period. This kind of knowledge is interesting for artificial intelligence, because it is yet another step in understanding the brain. Before it is possible to create artificial intelligence or robots that mimic humans, it is important to have as much knowledge about the human brain as possible.

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