Global Effect for Numbers

The Influence of Physical Magnitude and Numerical Magnitude on Saccadic Landing Position

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Abstract

Previous studies have shown that the global effect is influenced by the low-level features of objects such as size and salience. Saccades land towards the larger, more salient object. In this study the influence of higher level properties such as numerical value was researched. To this end an experiment was designed in which the size congruency effect for numbers was introduced into a task triggering saccadic averaging. The size congruency effect involves the response to numbers as symbols in relation to their physical appearance. Participants were triggered to make fast saccades in a *physical* condition presenting dots varying in physical size only and a *numerical* condition presenting numbers differing in symbolic size only. This study shows that the saccadic landing position in the *physical* condition portrays a distinct deviation towards the larger, more salient stimulus. This deviation was not present in the *numerical* condition. An effect of numerical magnitude was not recorded. These results are in line with the notion that saccadic averaging is driven by low-level processes.

Introduction

We move our eyes without thinking, in other words, our eyes move as a natural response to our surrounding. Fast eye movements are important to ensure we collect all information, global and detailed, necessary to move around, read a text, catch a ball or avoid dangers. The world around us contains a lot of complex information. This information can only be fully assessed if we shift the most sensitive part of our retina, the fovea, onto it. This shift needs to be fast and precise. So where does our gaze land and on what information is that landing position based? Is it the swiftly processed low level information such as size, contrast, movement and orientation that catches our eyes? But what about higher level information that tells us what an object means, how it can be used, what it represents and what happened in previous encounters with this object? Both types of information are important for us to be able to determine if an object is worth looking at. So the question is: is it just low-level information or are we able to integrate higher-level information in saccade programming?

Saccades are rapid eye movements that shift the fovea onto peripheral targets of interest (Aitsebaomo & Bedell, 2000). In order to investigate the influence of low-level and high-level processing of information on saccades, two known and robust effects were integrated into one experiment. The first, known as the global effect or saccadic averaging, is a shift in saccadic endpoint when objects are presented in close proximity of each other. The amount and direction of this shift is influenced by the relative position and salience of these objects. The second, known as the size congruency effect, involves the processing of higher-level symbolic numerical value of numbers in relation to their low-level non-symbolic physical appearance.

Coren and Hoenig (1972) first noted that primary saccades are directed to an intermediate position between targets. When adjoining stimuli presented in the same hemifield evoke a short-latency saccade the saccade tends to land on a location towards the midpoint between stimuli (Coren & Hoenig, 1972; Ottes, Van Gisbergen, & Eggermont, 1984; Ottes, Van Gisbergen, & Eggermont, 1985; Van der Stigchel & Theeuwes, 2005). This saccadic averaging occurs when stimuli are presented in near periphery, with an eccentricity of less than 15° (Findlay & Gilchrist, 1997), and within a 20° angular distance of each other (Walker, Deubel, Schneider, & Findlay, 1997). Stimuli at greater eccentricity or at greater distance of each other influence the latency of the saccade but not the landing position (Walker et al., 1997). Stimuli appearing within the 1.5° of the foveal region do not evoke an averaging effect (Vitu, Lancelin, Jean, & Farioli, 2006) supporting the assumption that saccadic averaging is elicited by the global information obtained from peripheral vision. Detailed vision in the fovea overrides the necessity to average saccade landing (Vitu et al., 2006; Vitu, 2008).

Saccadic averaging is most present in very short latency saccades. A trade-off is observed between saccade averaging and target selection accuracy. In other words, as latency increases the averaging effect gradually disappears and saccades land, uninfluenced by distractors, more accurately on a target (Ottes et al., 1984; Ottes et al., 1985). It is assumed that the increase of latency allows more time to process visual information making it possible to direct the saccade more accurately to a predefined target (Coëffé & O'Regan, 1987).

A number of studies explored visual low-level properties of stimuli that direct the saccadic landing position away from the midpoint between targets. Relative properties such as size (Findlay, 1982; Findlay, Brogan, & Wenban-Smith, 1993), intensity (Deubel, Wolf, & Hauske, 1984), contrast and surface structure (Deubel, Findlay, Jacobs, & Brogan, 1988) or density (Menz & Groner, 1987) influence the global landing position in such a way that the saccade deviates towards the approximated ‘center-of-gravity’ of these properties. These studies show that saccades land towards the larger, more intense, presented with higher contrast or denser target. These findings support the suggestion that the saccadic endpoint is determined by the relative salience of stimuli, landing towards the more salient object (Coren & Hoenig, 1972).

Howard Tipper and colleague’s (1997) present an explanation for saccadic averaging in the vector coding theory developed in relation to selective reaching to grasp objects. It is suggested that each stimulus is represented by a population vector that encodes the movement towards the stimulus. The more salient an object is, the stronger the vector is. The saccadic endpoint is determined by the direction of the average vector. When objects are presented in close proximity of each other the population vectors overlap (Tipper, Howard, & Jackson, 1997). This could explain why adjoining objects evoke an average saccadic landing position. This also means the more salient target has more weight in the saccadic averaging and explains why the saccadic endpoint shifts towards the more salient object (Van der Stigchel, Meeter, & Theeuwes, 2006).

There are also studies suggesting that saccadic averaging is not entirely low-level. When higher-level strategies based on the expected location of a stimulus are applied the accuracy of the saccade can be influenced regardless of salience (He & Kowler, 1989). Coëffé and O’Regan (1987) show, using a predefined target letter in letter strings, that saccade accuracy can also be facilitated by increasing the predictability of the target location or delaying the moment of saccade triggering allowing more time to process perceptual information. The global effect can also be influenced by information that is expected, but not presented. This was shown by Guez et al. (1994) in a study using shapes with non-existing, illusory, corners (see Figure 1). Since this information is not physically present some higher-level processing can be expected.

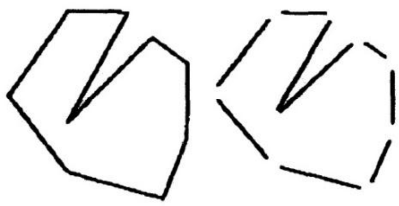

Figure 1. **An example of stimuli used by Guez et al. (1994), on the left a stimulus with corners and on the right a stimulus with non-existing corners. Non-existing corners also had an effect on the saccadic landing position.**

The principle that objects can contain information while the information is not physically present in the shape can be seen in numbers. The physical form of a number, irrespective of it being a word, a symbol or roman numeral, has no relation to its symbolic magnitude (Fias, Lammertyn, Reynvoet, Dupont, & Orban, 2003). Representations of numbers carry symbolic and non-symbolic information. Non-symbolic information is carried in the physical form, (font) size, curves, line thickness, color or font. Symbolic information is carried by their cardinal magnitude (e.g. six representing the presence of six objects) and their ordinality (e.g. six being the number between five and seven) (Findlay & Blythe, 2009). The influence of symbolic information on saccadic averaging is unknown.

In different studies using Stroop-like tasks in which numerical and physical properties of stimuli were varied independently, it is suggested that different types of magnitudes (e.g. physical and numerical) apply the same magnitude processing mechanisms (Cohen Kadosh, Lammertyn, & Izard, 2008; Gebuis, 2009). When participants are asked to decide which number is physically larger in size the response to congruent conditions (e.g. a small six and a large nine) is usually faster than to incongruent conditions where the lower number is largest (e.g. a large six and a small nine). Congruent conditions avoid the necessity to process ambiguous information of numerical and physical magnitude and are therefore faster (Algom, Dekel, & Pansky, 1996; Cohen Kadosh & Henik, 2006).

In this experiment, the size congruency paradigm was integrated in a global effect task. This investigated whether the symbolic information in numbers can shift the saccadic endpoint just like non-symbolic information can. In a number pair consisting of two numbers, such as two and five, the number of larger numerical magnitude, five in the example, is associated with an object of larger physical size. The number of lower numerical magnitude, two in the example, is associated with an object of smaller physical size. If saccadic averaging is influenced not only by low-level non-symbolic properties such as size but also by symbolic information such as numerical magnitude this association could affect the saccade landing position. When a number pair consisting of two numbers of equal physical shape, size and salience (e.g. ‘6’ and ‘9’) is presented in a global effect-task the saccadic landing position could deviate towards the numerically higher number. Although the two numbers are of equal physical size, the higher number could be considered more salient, thus representing a larger population vector which results in a deviation towards it.

The experiment used in this study applied the principles of physical magnitude and numerical magnitude to answer the question whether our view is directed by low-level information only or are whether we able to integrate higher-level symbolic information in saccade programming. Under the assumption that the saccadic landing position is also influenced by higher-level symbolic information, the symbolic information in the numerical stimuli pairs should influence the saccadic landing position deviating towards the higher number. It is expected that numerical, symbolic information needs longer to be processed than physical, non-symbolic information. Therefore the influence of symbolic information on the saccadic endpoint could become more apparent for saccades of longer latency.

Methods

Participants

Ten participants (5 male, 5 female, M = 40.7, sd = 13.6) participated in the experiment. All had normal or corrected-to-normal visual acuity.

Apparatus

Eye movements were recorded using the Eyelink 1000 eye tracker system (SR Research Ltd., Mississauga, Ontario, Canada) in the desktop mount configuration. This infrared video based eye tracker has a 1000HZ (1ms) temporal resolution and a spatial resolution of 0.2° and was used in monocular mode. The left eye was recorded and analyzed. The task was displayed on a laCie Electron 22" Blue CRT monitor (60 Hz, 1024 x 768 pixels). The participants' head was stabilized using a chinrest at 65 cm from the display. The experiment took place in a dimly lit room.

The task was programmed in C++ using Microsoft Visual C++ Express Edition 2006.

Stimuli and design

Participants were required to give a short-latency saccadic response to an appearing stimulus pair. The task consisted of two conditions. One condition, referred to as the *physical* condition, presented a pair of circles. The stimuli in this condition differed in non-symbolic physical size only. A second condition, referred to as the *numerical* condition, involved a pair of numbers. These stimuli differed in symbolic numerical size but were of equal physical size.

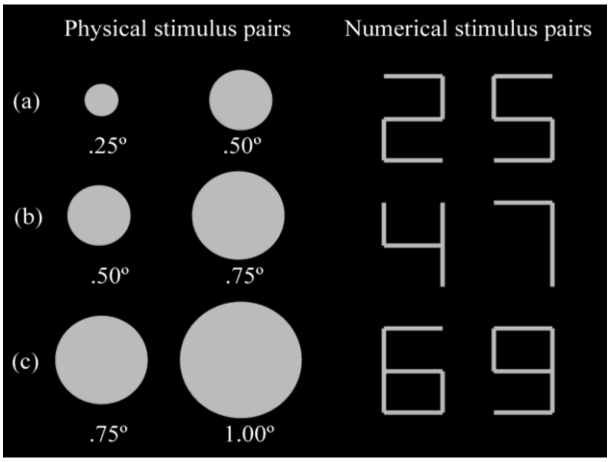

Figure 2. **Stimulus pairs used in the *physical* condition using stimuli differing in physical size and stimulus pairs used in the *numerical* condition equal in physical size but differing in numerical size. Each condition has three pairs, (a) a small pair, (b) a medium pair and (c) a large pair.**

Vital to the experiment was the use of numbers of equal size and salience. For the *numerical* condition three number pairs with equal absolute difference and of similar shape and equal physical size were selected. The three stimulus pairs consisted of a low and a high grey number of equal physical size (.50° x .75°) and salience, pairs being: small (2-5), medium (4-7) and large (6-9). To ensure equal salience, digital numbers were used (see

Figure 2). For the *physical* condition three physical stimulus pairs of equal shape and absolute difference in size were used. The three target pairs consisted of a small and a large grey filled circle, pairs being: small (diameters .25°- .50°), medium (diameters .50°- .75°) and large (diameters .75°- 1.00°) (see Figure 2). The focus was on the comparison of numerical and physical magnitude only, leaving out the broader field of overall salience (e.g. influences of luminance or contrast).

The stimuli in each trial appeared in the same hemifield and were separated by 1.47° visual distance (15° angular distance) at 8° eccentricity from the fixation cross. This layout is within the range that should evoke a global effect (Walker et al., 1997). The pair was presented in one of four quadrants (first, upper right; second, upper left; third, bottom left; fourth, bottom right) around four principal axes (45°, 135°, 225°, 315°). One stimulus appeared on either side of the axis at equal distance from the axis (see Figure 3). Two configurations, low (or small) to the left of the axis and high (or large) to the right of the axis and vice versa as seen from fixation, were used.

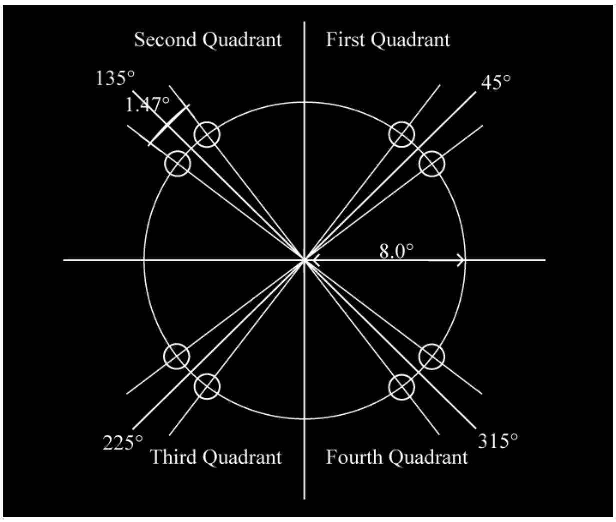

Figure 3. **Template of the on screen dimensions and possible stimulus locations. The stimulus pair appears in one quadrant with the low or small stimulus on one side of the axis and the high or large stimulus on the mirror side of the axis.**

In both conditions, the trials started with a grey central fixation point (upright cross (+), 1.08° x 1.08°) against a black background. To trigger a fast response the stimulus pair appeared, after a variable period of between 500 en 1,000 ms, simultaneously with the offset of the fixation cross (see Figure 4) (Walker et al., 1997).

The *physical* condition and a *numerical* condition each comprised 12 blocks of 24 trials, totaling 288 trials per condition and 576 trials in the whole experiment. The sequence of configurations (low/high or high/low) in the trials was randomly assigned in all four quadrants. Each condition was preceded by a training block of 24 trials.

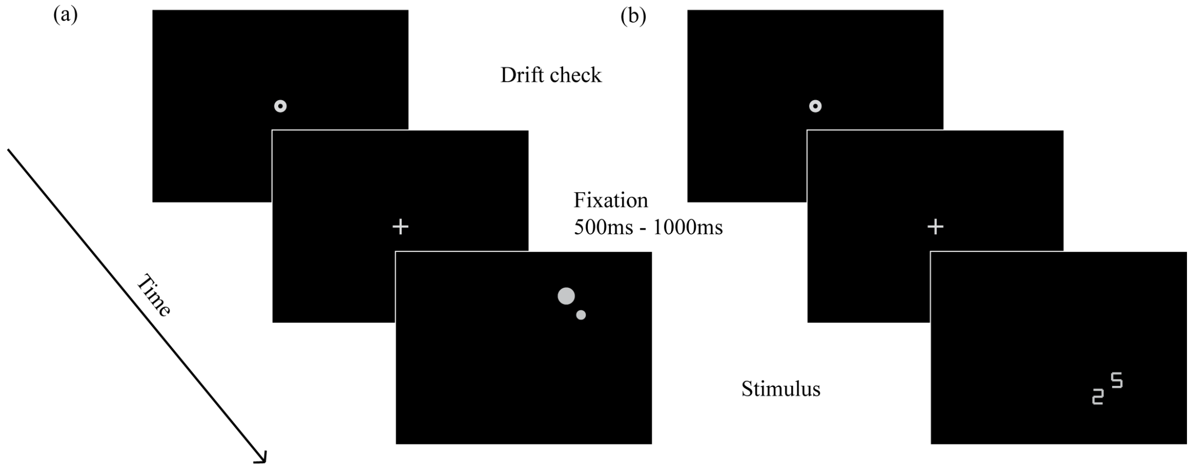

Figure 4. **An example of the trial sequence in (a) the *physical* condition and the trial sequence in (b) the *numerical* condition.**

Procedure

The experiment was carried out using a procedural script that was the same for all participants. First the participant was informed about the experiment. After making sure the chair and position of the participant was comfortable the system was calibrated. Calibration was carried out before each condition.

Participants were instructed to fixate on the central fixation cross and to move their eyes to whatever appeared on the monitor as quickly as possible without special preference for any type of stimulus. In the training block the participants were made familiar with the stimuli used. In the case of the *numerical* condition participants also practiced identifying the number by naming them. After the training block all participants were able to do this accurately. Half the participants started with the *physical* condition and the other half of the participants started with the *numerical* condition.

Analysis

Saccadic landing position was defined as a proportion of the angle between the stimuli. The axis around which the stimuli were positioned, representing the geometric midpoint between the stimuli, was used as a null-reference (see Figure 6). This means saccades that landed on the axis were defined as having a deviation score of zero (Φ = 0.0). This method of scoring defines the landing positions deviating towards the small or low stimulus as negative and landing positions deviating towards the large or high stimulus as positive. The location of the low or small stimulus is equivalent to a deviation score of minus one (Φ = -1.0) and the location of the high or large stimulus is equivalent to a deviation score of plus one (Φ = 1.0). The amplitude[1] of the saccade is not taken into account in this method of scoring. Landing positions for all four quadrants were collapsed to one quadrant (first, upper right) and all trials were normalized to having the small or low stimulus to the left of the axis and the large or high stimulus to the right of the axis as seen from fixation. If a landing position in any of the conditions was further than two and a half standard deviations away from the average landing position per condition of the participant, both in amplitude and deviation score, the trial was marked as an outlier and removed from the analysis.

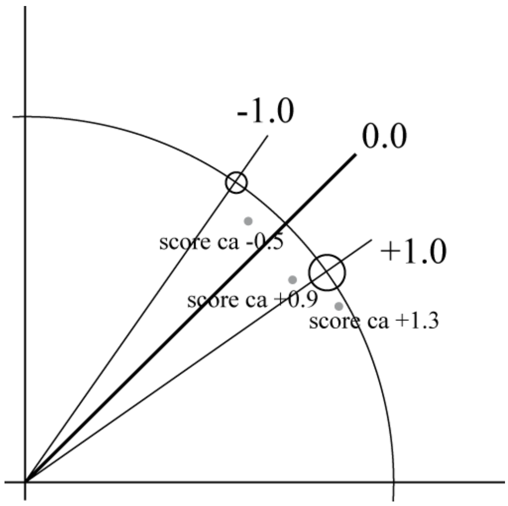

Figure 6. **Saccade landing position was defined as a proportion of the angle between the stimuli. The axis around which the stimuli are positioned, representing the midpoint between stimuli, was used as null-reference. Saccades landing on the axis were scored as having a deviation score (Φ) of zero, saccades landing towards the small or low stimulus were scored as negative and saccades landing towards the large or high stimulus were scored as positive. The stimulus locations were defined as Φ = ±1.0.**

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[1] Saccade amplitude was defined as the length of the saccade, in degrees visual angle, measured from fixation to the saccadic endpoint.

Saccade latency was defined as the interval between target onset and the initiation of the saccadic eye movement. Trials with a saccadic latency lower than 100 ms or higher than 450 ms were excluded (Walker et al., 1997). These bounds were chosen because these saccades may have anticipatory (Becker, 1989; Findlay & Harris, 1984; Weber, Latanov, & Fischer, 1993) or not visually triggered (Walker et al., 1997) respectively. All trials with a latency of more than two and a half standard deviations away from the participants' mean were excluded from the analysis, as they were regarded as outliers.

Eye movements sometimes portrayed a small drift ($\leq 1°$) from fixation at the start of the saccade. Since this influences the relative position of the stimuli in relation to the start of the saccade, the deviation score (Φ) was calculated relative to the actual starting point of the saccade (see appendix A).

Statistical analyses

First, two statistical tests were done to compare the data of both conditions with regards to a saccade amplitude and number of included trials to make sure they could be disregarded in the main analyses. Amplitude is not a factor in the definition of scoring used to quantify the landing position in this paper. The average amplitude for the *numerical* and *physical* condition therefore needed to be at baseline level. A one-way analysis of variance (ANOVA) was used to analyze the average saccade amplitude in the *physical* and the *numerical* condition. In a second one-way ANOVA the number of included trials per condition was compared in order to investigate the possibility of a significantly different number of trials influenced by type of condition.

After pre-processing, the data the saccadic landing position was analyzed to answer the main question in this study: Is it only low-level information that directs our view or are we able to integrate higher-level symbolic information in saccade programming?

To start, the landing position was analyzed. A 2x3 repeated measures ANOVA with condition (*physical* and *numerical*) and stimulus pairs (small: .25-.50/2-5, medium: .50-.75/4-7 and large: .75-1.00/6-9) as within-subject factors was performed to test if the landing position in both conditions differed from each other. After this, two one-sample t-tests were performed to test whether both conditions elicited a global effect. These tests compared the average landing position of each condition to the stimulus location ($\Phi = 1.0$). A second set of one-sample t-tests compared the mean saccadic landing position in the *physical* and *numerical* condition against the reference line through the midpoint between the stimuli ($\Phi = 0.0$). This tested whether any deviation from the reference line was recorded. A post-hoc analysis using t-tests with Bonferroni correction was done on the mean landing position of the stimulus pairs to obtain more information about the interaction between stimulus pair and condition.

Since it can be expected that higher order processing of symbolic information takes more time than the processing of low-level information, a 2x2 repeated measures ANOVA with condition (*physical* and *numerical*) and latency[1] (long and short) as within-subject factors was performed on the mean landing position of both conditions. This tested the hypothesis that the mean landing position in physical and numerical short latency trials is predominantly determined by low-level physical properties whereas in long-latency trials the influence of the symbolic information in numbers becomes more apparent.

Latency influences the time available to process higher order symbolic information. Increased latency diminishes the global effect and increases available processing time for stimuli (Ottes et al., 1984; Ottes et al., 1985). To analyze latency a one-way ANOVA comparing the average saccade latency per condition was performed.

Results

Trials were excluded when they deviated more than two and a half standard deviations from the participants mean or when the latency of the saccade exceeded the bounds set in earlier studies (<100 ms or >450 ms, (Walker et al., 1997)). On the basis of these criteria 7.9% of the total number of trials in the *physical* condition was excluded (228 trials out of 2880) and 7.3% of the total number of trials in the *numerical* condition was excluded (210 trials out of 2880) and. An overview of the grounds on which these trials were excluded is shown in Table 1.

No main effect was found on the number of included trials ($F(1,9) = .248$, $p = .630$) indicating the number of included trials in the *physical* condition (2652 trials) and the *numerical* condition (2670 trials) was the same. Additionally no main effect was found of amplitude on the saccadic landing position ($F(1,9) = 3.171$, $p = .109$)) indicating the undershoot (i.e. amplitude too short) and the overshoot (i.e. amplitude too long) of the saccadic landing position in the *physical* ($M = 7.67°$, $sd = .51$) and *numerical* ($M = 7.85°$, $sd = .47$) condition was also similar. These tests showed the two conditions did not evoke different behavior and can therefore be compared to answer the main question of this paper.

[1] The saccades were divided into short latency saccades and long latency saccades, short latency saccades being the faster 50% of the trials and long latency saccades being the slower 50% of the saccades. The latency median per condition of each participant was used as the divider.

Table 1

Grounds on which trials were excluded; trials can be excluded on the basis of more than one criterion.

Exclusion criteria		Physical	Numerical
Landing position	Deviation score (sd ± 2.5)	1.2%	1.3%
	Amplitude (sd ± 2.5)	6.4%	6.0%
Latency	Latency (sd ± 2.5)	3.7%	3.3%
	Too short (< 100 ms)	2.3%	2.8%
	Too long (> 450 ms)	0.3%	0.1%

Landing position

The 2x3 ANOVA with condition and stimulus pairs as factors showed a main effect of condition indicating that the saccadic landing position in the *physical* condition (M = .30 , sd = .07) landed significantly more towards the large stimulus than the saccadic landing position in the *numerical* condition (M = -.02, sd = .07; $F(1,9) = 198.62$, $p < .001$). In the following post-hoc analysis it was tested whether the average landing position in the *physical* condition landed at a distance from the target location ($\Phi = 1.0$). This test showed a significant effect ($t(9) = -46.17$ $p < .001$) . The same significant effect was observed for the average landing position in the *numerical* condition ($t(9) = -33.42$ $p < .001$). This means that the saccades in both conditions showed a distinct global effect and did not land on a stimulus but on an intermediate position between the stimuli. The next step in the post-hoc analysis showed that the mean landing position for the *physical* condition had a significant deviation from the reference line ($\Phi = 0.0$) towards the large stimulus ($t(9) = 14.359$, $p < .001$)(see Figure 7a). The same test for the mean landing position for the *numerical* condition against the reference line ($\Phi = 0.0$) showed no significant deviation from the reference line towards either stimulus ($t(9) = -.907$, $p = .388$) meaning the saccade landed in the midpoint between the stimuli (see Figure 7b). These last two tests showed that stimuli in the *physical* condition elicited a deviation towards the larger stimulus but the numerical stimuli did not elicit a deviation towards the higher stimulus.

This showed that the saccadic landing position for a stimulus pair depended on the condition. To gain more insight in the effects of the individual stimulus pairs on the saccadic landing position a post-hoc analysis with Bonferroni correction was performed. The mean

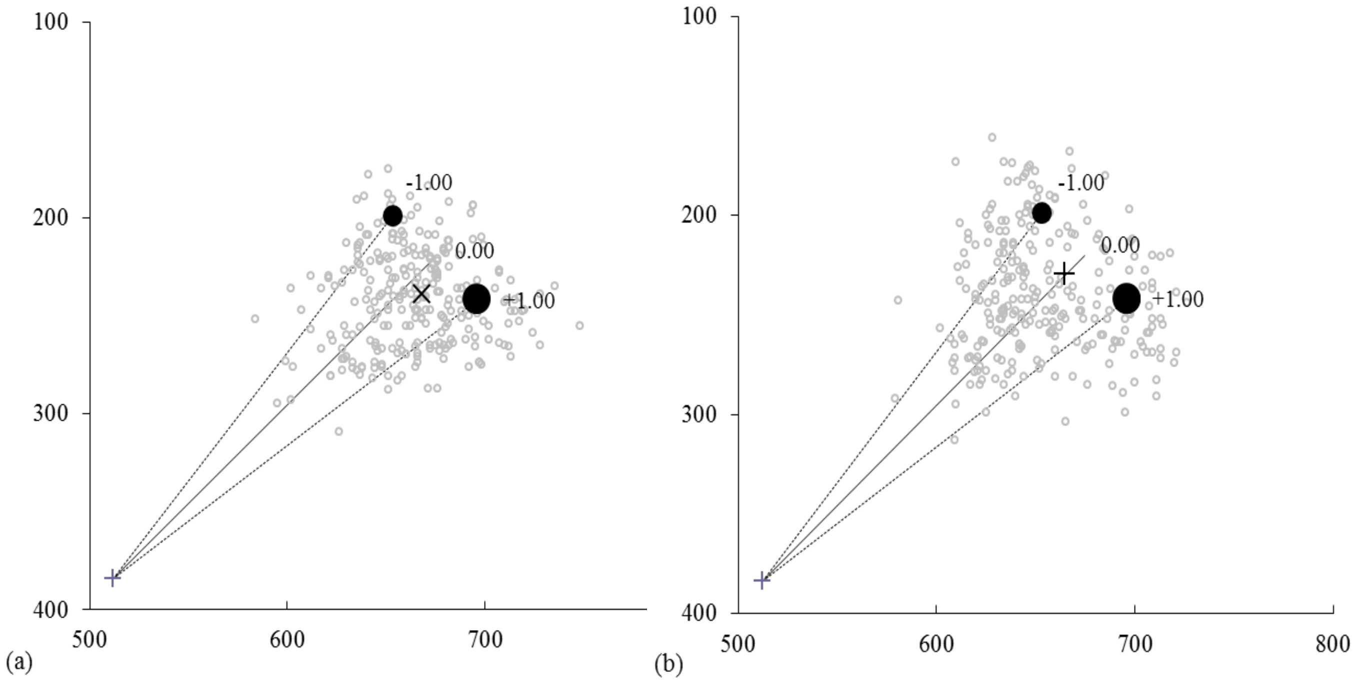

Figure 7. **Saccadic landing positions per trial (gray circles) and mean saccadic landing position collapsed to the first quadrant for (a) *physical* condition (×, M = .30, sd = .07) and (b) *numerical* condition (+, M = -.02, sd = .07).**

Table 2

Results of the t-tests (Bonferroni corrected, α = 0.0083) testing the mean saccade landing position of all individual pairs, physical and numerical, against the reference line with test value 0.

				test value = 0	
	Stimulus pair	Mean landing position	sd	t	p
numerical	2-5	.032	.094	1.076	.310
	4-7	-.065	.096	-2.130	.062
	6-9	-.028	.080	-1.108	.296
physical	.25-.5	.493	.105	14.794	<.001
	.5-.75	.187	.086	6.875	<.001
	.75-1	.217	.087	7.881	<.001

saccade landing position of all individual pairs, physical and numerical, was tested against the reference line using one-sample t-tests with test value 0 (see Table 2). All physical pairs evoked saccadic landing positions at significant distance from the reference line towards the large stimulus whereas none of the numerical pairs did.

The main effect of stimulus pair ($F(2,18) = 29.70$, $p < .001$) showed that in general the stimulus pairs used evoked significantly different saccadic behavior. Post-hoc testing revealed that this effect was seen in all conditions. Presenting the small stimulus pair (2-5 & .25-.50; $M = .26$, $sd = .03$) evoked saccades that landed significantly more towards the large stimulus than presenting the medium (4-7 & .5-.75; $M = .06$, $sd = .02$; $t(9) = 17.56$, $p < .001$) and large stimulus pairs (6-9 & .75-1.00; $M = .10$, $sd = .22$; $t(9) = 20.14$, $p < .001$). Medium stimulus pairs evoked saccades that landed significantly more towards the center than large stimulus pairs ($t(9) = -3.22$, $p = 0.01$).

There was a significant interaction ($F(2,18) = 19.65$, $p <.001$) between stimulus pair and condition. This showed that the type of condition had a different effect on landing positions depending on which stimulus pair was presented. The post-hoc analyses showed that this interaction effect was due to the difference in response to the small stimulus pair and the large stimulus pair for the *numerical* and *physical* condition. The saccades in the *physical* condition landed much closer to the large stimulus when the small stimulus pair was presented than when the large stimulus pair was presented ($t(9) = 7.87$, $p < .001$) whereas the responses to the two pairs in the numerical condition was similar ($t(9) = 2.24$, $p = .05$). The responses to the medium stimulus pairs showed no interaction with the small stimulus pair nor with the large stimulus pair.

To test whether the influence of numerical magnitude in slower saccades was greater than in faster saccades, the effect of condition and latency was compared. The mean divide between short and long latency saccades was 171 ms ($sd = 22.7$). Testing this effect with an ANOVA showed, as could be expected, a main effect of condition ($F(1,9) = 203.984$, $p < .001$). An effect of latency did *not* show ($F(1,9) = 0.097$, $p = .762$) nor did an interaction effect show ($F(1,9) = .208$, $p = .659$). This means that the saccadic landing position for the *physical* and *numerical* condition remained the same even when more processing time was available (see Table 3).

Table 3

Mean saccadic landing position subdivided by the median per participant in short latency saccades and long latency saccades.

	short		long	
	mean	sd	mean	sd
numerical	.02	.11	.02	.09
physical	.31	.10	.29	.09

Latency

No main effect was found on average saccade latency for the *physical* (M = 178.48, sd = 23.86) and *numerical* (M = 182.85, sd = 25.24) condition ($F(1,9) = 2.662$, $p = .137$), indicating the mean latency for the *physical* and *numerical* condition were the same.

Discussion

The question we tried to answer in this paper was: Does higher-level information such as symbolic numerical magnitude influence deviation towards the higher stimulus in the same way as low-level non-symbolic information does? By integrating the size congruency effect into the global effect task, the influence of symbolic properties on saccadic programming was assessed. This study confirmed that presenting two targets in near periphery in the same hemifield and in proximity of each other generates a global effect. The saccadic response to all stimulus pairs used in this experiment landed in an intermediate position between the stimuli. This is in accordance with previous studies (Coren & Hoenig, 1972; Ottes et al., 1984; Ottes et al., 1985; Van der Stigchel & Theeuwes, 2005) showing the global effect to be a very robust response.

In this study, however, an influence of higher-level information on saccadic averaging was *not* recorded. Very clearly and consistently, all saccadic responses landed in what can be considered the ‘center of salience’ of two stimuli. Note that salience in this experiment is based solely on the low level physical size of the stimuli. Saccades landings in the *physical* condition all deviated significantly towards the larger stimulus and saccades in the *numerical* condition all landed at or around the geometric midpoint between the stimuli. The difference in numerical magnitude between the stimuli in the *numerical* condition seemed to have no effect.

However one might argue there are more associations involved in using numbers than numerical magnitude only that could have affected the results. For instance, the internal representation of numbers such as seen in the SNARC effect (Cohen Kadosh et al., 2008) positions a ‘2’ more leftward than a ‘5’. This might give a slight preference for a ‘2’ positioned left of a ‘5’ than the other way around. And like the SNARC effect tells us something about the horizontal representation you can also think of vertical associations that could affect the results. Numbers can be associated with a list, ‘2’ being at the top of the list and ‘5’ at the bottom. Or vice versa when numbers are associated with the floors of a building where the second floor is below the fifth floor. These mental representations could have given a slight preference for a certain number based on their relative position rather than their magnitude and might have cancelled out any effect of numerical magnitude.

Earlier studies found a trade-off between speed and accuracy (Ottes et al., 1984; Ottes et al., 1985). In the analysis of the data with regard to short and long latency saccade no such trade-off was found. This might be due to the instructions that participants should respond as fast as possible resulting in the fact that even the long latency saccades were relatively fast. The average divide between short and long latency saccade was 171 ms. This latency is still well under the 300 ms above which longer processing time has been seen to cause a significant effect (Ottes et al., 1985).

But are we done now? Several questions emerge from this experiment. First of all, what happens if latency is increased to allow more processing time? Does that perhaps enlarge the influence of higher level properties? The other question is: were the stimuli close enough to fixation to be identifiable as numbers? In piloting this experiment participants were able to identify the numbers after a training period while focusing on fixation. Perhaps identifying the numbers was not easy enough. Was it easy enough to allow the higher level properties to influence the saccade in a fast response? And last but not least, could the relative position of the numbers used have influenced the results. These questions warrant further research into the topic of this paper.

From the findings in this study it can be concluded that the global effect is a low-level automated response influenced by size and does not take into account any high-level symbolic properties of elements such as numerical magnitude. Assuming the vector coding theory of Tipper et al. (1997) numerical magnitude is not a factor in the size of the population vector. An effect of symbolic size does not seem to be present in saccadic programming under current conditions.

Appendix A.

The landing position of the saccades was defined as a proportion of the angle between the two stimuli. This resulted in a deviation score (Φ). Since not all saccades start exactly in fixation all deviation scores were calculated relative to the exact starting point of the saccade (see figure 8).

$$\Phi = \frac{\beta}{\alpha} \cdot 2$$

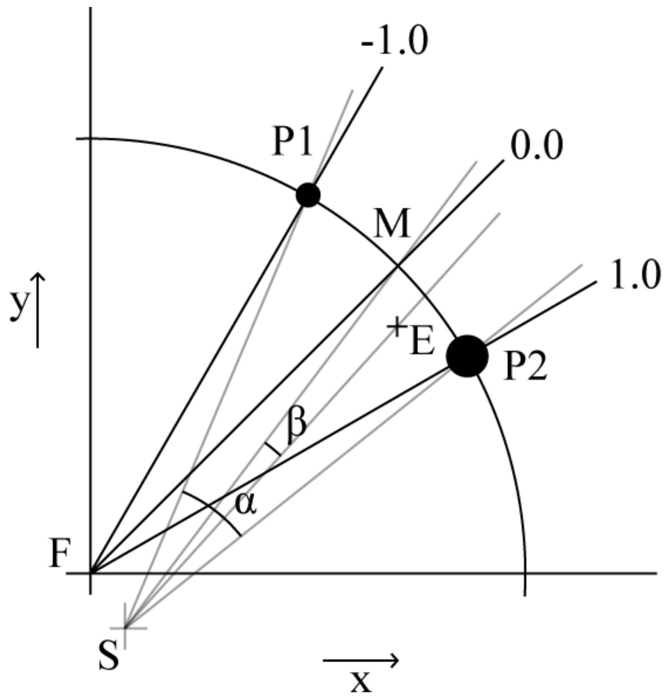

Figure 8. **Fixation (F), start of the saccade (S), end of the saccade (E), location of the small/low stimulus (P1), location of the large/high stimulus (P2), midpoint between stimuli (M), angle between stimuli seen from start of the saccade (α), angle between midpoint and end of the saccade as seen from start saccade (β).**

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