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Number magnitude determines gaze direction:
Spatial-numerical association in a free-choice task

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Abstract

Since Dehaene et al. (1993) reported the SNARC (Spatial-Numerical Association of Response Codes) effect, researchers have repeatedly documented an influence of number magnitude on reaction time in various motor tasks. In addition, thinking about numbers induces shifts of visuo-spatial attention (Fisher et al., 2003). The present study examined whether number magnitude affects a person's eye movement in a free-choice task. After the presentation of a number in the middle of the screen, two pictures of human faces were simultaneously presented on either side of the screen. Participants were asked to explore the screen after the presentation of a number. Analyses performed on first eye fixations confirmed that number magnitude affects gaze direction in this free-choice task. The present study shows that the influence of number magnitude on visuo-spatial attention affects the choice of where to look first.

Keywords: SNARC-effect, Free-choice task, Eye movement responses

1. Introduction

Previous studies have reported an association between numbers and space (e.g., Moyer and Landauer, 1967; for reviews see Dehaene, 1997, and Fias and Fischer, 2005). Specifically, the results of these studies suggest that numbers are cognitively placed along a horizontal “mental number line” with small numbers (e.g., 1 or 2) represented on the left and large numbers (e.g., 8 or 9) represented on the right. Evidence for this spatial representation of numbers provides, for example, the SNARC effect (Spatial-Numerical Association of Response Codes effect), which was first reported by Dehaene et al. (1993). In their study, a number was presented in the middle of the screen and participants were asked to decide whether the presented number was odd or even by pressing a left or a right response key. Results showed that left hand responses were faster for small numbers whereas right hand responses were faster for large numbers.

Such number-space interactions have been demonstrated in various tasks (e.g., Ben Nathan et al., 2009; Dehaene and Akhavein, 1995; Fias et al., 1996; Fischer, 2001, 2003), with different response modalities, such as manual (e.g., Fias, 2001; Fischer and Rottmann, 2003), verbal (Brybaert, 1995; Stoianov et al., 2008; Zorzi et al., 2002), foot responses (e.g., Schwarz and Müller, 2006), and eye movement responses (e.g., Fischer et al., 2004; Schwarz and Keus, 2004).

Consistent with the notion of a mental number line, there is also evidence that thinking about numbers affects the free choice of a response (Daar and Pratt, 2008; Loetscher et al., 2010). Participants in the study of Daar and Pratt had to choose between making either a left or a right manual

response when a number or a neutral character appeared in the middle of the screen. Participants produced more left (right) hand responses when small (large) numbers were presented, supporting the notion that number magnitude influences the selection of manual responses. Participants in the study of Loetscher et al. acted as a “random number generator” by naming subsequently 40 numbers between 1 and 30 in a random sequence. Verbal responses of participants were recorded and synchronized with their eye movements. The results of this study showed that leftward eye movements were associated with smaller numbers, whereas rightward eye movements were associated with larger numbers. Because the methodological approach taken by Loetscher et al. (2010) was correlational, it is possible that gaze direction influenced the mental selection of numbers, that thinking about numbers influenced gaze direction, or both. Therefore, the direction of the causal link between gaze direction and the reported number is unclear. It is thus premature to conclude that number magnitude influences gaze direction in free-choice response situations.

Nevertheless, it is possible that thinking about numbers may influence the direction of gaze. For example, it has been documented that number magnitude affects the direction of spatial attention (e.g., Fischer et al., 2003; Knops et al., 2009; Ristic et al., 2006; Stoianov et al. 2008), that is, participants tend to shift their spatial attention to the left (right) after the presentation of small (large) numbers. This shift of attention has been also attested by the results of event-related potentials (e.g., Priftis et al., 2008, Ranzini et al., 2009; Salillas et al. 2008, 2009). In addition, it is known that there is a strong link between eye movements and spatial attention (e.g.,

Hoffman, 1998). Specifically, the pre-motor theory of attention (Rizzolatti et al., 1987) holds that spatial attention involves the pre-programming of eye movements towards the spatial region that is covertly attended. Therefore, according to this theory and the established effect of number magnitude on spatial attention, one should expect that number magnitude significantly influences gaze direction in a free-choice situation.

Hence, the purpose of the present study was to examine whether an influence of number magnitude on eye movements can be observed in a free-choice task. We expected that the mere presence of a number would be sufficient to activate its spatial number representation and thus would influence gaze direction. A small or a large number was presented in the middle of the screen followed by two faces displayed simultaneously on its left and right side. Participants were asked to explore the screen after the presentation of the number. According to the spatial association of numbers, we expected that participants tend to look to the left after presentation of a small number and to the right after presentation of a large number.

2. Method

2.1. Participants. One hundred and fifty participants ($M = 22.3$ years, $SD = 2.9$) took part in this 20-min experiment. They reported normal or corrected-to-normal vision. All participants received course credits for their participation.

2.2. Apparatus. Participants were tested individually in a sound-attenuated room. They sat in a chair at a distance of approximately 40 cm from an overhead projector (50 Hz) upon which the visual stimuli were

presented. Head movements were constrained by a head restraint and a chin rest. Eye movements were monitored using an ASL (Applied Science Laboratories) Eye Tracker System model 504. The horizontal (0-260 ocular movements, 800 pixels, 28.9° of visual angle) and vertical position (0-240 ocular movements, 600 pixels, 21.6° of visual angle) were sampled at 60 Hz with an infrared camera situated at a distance of 60 cm from the left eye (resolution better than 0.2°).

2.3. Procedure and Design. Each trial started with a black screen (0.23 cd/m²) for 500 msec, followed by the presentation of a white fixation cross (38 cd/m², size 0.51 x 0.51°) in the middle of the screen for further 500 msec. Then the fixation cross was replaced by a white number from 1 to 9 (38 cd/m², size 0.76° on average). After 1,000 msec the number disappeared and two faces (Karolinska Directed Emotional Faces Database; Lundqvist et al., 1998) --- one on the left and the other on the right side of the previously presented number --- appeared simultaneously on the screen for 3,500 msec. The next trial was indicated by the reappearance of the fixation cross. Each participant performed 36 trials: 16 trials in the condition with smaller numbers (1 to 4), 16 trials in the condition with larger numbers (6 to 9) and 4 trials for the number 5.

Participants were given written instructions at the beginning of the experiment. They were told to look continuously at the fixation cross presented in the middle of the screen and to remain looking there when the fixation cross was replaced by the number. When the faces appeared, they were told to explore the screen until the fixation cross appeared again.

3. Results

Participants with more than 30% of not registered eye movements were excluded from further analysis (11 participants). As the number 5 was the middle number of the number range, trials including this number were also excluded. The first eye fixation after the presentation of the number was collected. Three areas of interest were defined: the center of the screen and the left and right positions where the faces appeared. In order to exclude saccades or false apparatus feedback, an eye fixation was defined as an eye movement to a screen position with a visual angle of 1° and with a minimal duration of 100 msec (e.g., Bradley et al., 2000; Caseras et al., 2007).

Participants tended to shift their first gaze more often to the left (67.2%) than to the right, a result that is consistent with the idea that scanning patterns enhance the tendency to gaze to the left (see Dehaene, 1997; Fischer et al., 2004). Despite this basic gaze tendency and most crucially, the choice of the first gaze direction was affected by number magnitude as the following statistical tests revealed. First, a t-test analysis showed that participants tended to look towards the left face more often when a small number (1, 2, 3, or 4) compared to a large number (6, 7, 8, or 9) preceded the presentation of the faces (70.0% vs. 64.7%), $t(138)=3.83$, $p<.001$. This result was also confirmed by a Wilcoxon test for paired samples, $z=3.45$, $p<.001$.

Furthermore a trend analysis revealed a highly significant linear trend of number magnitude on the percentage of first left gaze, $F(1, 966)=15.51$, $p<.001$, but no quadratic trend, $F(1, 966)=1.07$, $p=.302$. Figure 1 depicts the percentage of first left gaze as a function of number magnitude along with the

linear regression function. The within-subject error bars were computed according to Cousineau (2007).

4. Discussion

The purpose of the present experiment was to examine whether number magnitude influences the choice of gaze direction. Participants were asked to explore visually the screen after the presentation of a number. Gaze direction was not constrained by the experimenter. The results of this study show that the direction of the first gaze (i.e., left or right eye movement) was clearly affected by the magnitude of the preceding number (i.e., small or large respectively). This means that thinking about numbers influences the choice of gaze direction. Specifically, participants tended to look to the left (right) after the presentation of a small (large) number. Therefore, these results demonstrate for the first time that number magnitude causally affects the choice of gaze direction.

In the present study, the percentage of gazes to the left tends to decrease with increasing number magnitude. This finding is in line with the notion of a linear representation of number magnitude (e.g., Brannon et al., 2001; Fischer et al., 2004; Verguts et al., 2005). The two different types of analyses carried out in our study (i.e., t-tests and linear trends) yielded a significant effect of number magnitude on gaze direction. Whereas the present results do not allow a definite discrimination between categorical and linear effects of number magnitude on first eye fixation, they clearly show that number magnitude influences participants' decision where to look first.

The results are in accord with the pre-motor theory of attention (Rizzolatti et al., 1987). This theory holds that covert spatial attention activates motor routines (e.g., in oculomotor areas such as the superior colliculus) to execute a saccade to the attended location. Since it has been experimentally demonstrated that number magnitude shifts spatial attention (Fischer et al., 2003), the effect of number magnitude on gaze direction in the present study is most likely mediated by such an attentional shift.

In conclusion, the present findings show that number magnitude affects a person's decision where to look. This shows that the oculomotor system is especially useful in uncovering the mechanisms that relate number magnitude and spatial attention.

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Figure caption

Figure 1. Mean percentage (\pm SE) of first gaze to the left as a function of number magnitude. The solid line is the linear regression function that reveals the significant linear trend.



