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Research report

The perception of text triggers reflexive oculomotor orienting

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ABSTRACT

As you read this text, your brain is busy integrating numerous different processes—perceptual, cognitive and motor. While you acquire the semantic and linguistic contents of this abstract, your eyes traverse its lines with speed and coordination. The oculomotor response to text is so rapid and precise that it is hypothesized it to be partially based on reflexive orienting mechanisms. In this study we examined the hypothesis that the presentation of written text triggers reflexive orienting toward the direction of reading, similarly to the effect of peripheral stimulation or that of symbolic directional cues (arrows or gazing eyes).

In three experiments, participants (N = 120) were presented with task-irrelevant text, shortly followed by a left/right pro-saccade task. The first experiment confirmed the hypothesis by showing that saccades which are congruent with the direction of reading are faster than those which are incongruent. This was observed both in right-to-left (Hebrew) and in left-to-right (English) reading-systems and similarly in native-Hebrew and native-English readers. A second experiment showed that this directional bias is found not only for readable text but also for meaningless strings of letters. This confirmed that the bias is driven pre-reading non-lexical processes. The third experiment examined the time-course of this effect. We conclude that text-perception actives early reflexive eye-movements programs and suggest that this link is an essential building-block of fast and effortless reading.

1. Introduction

As you read this text, your brain is busy integrating numerous different processes—perceptual, cognitive and motor. You interpret this series of abstract visual shapes (which we call letters) and string them into meaningful statements which are coded into your memory. While you do all this your eyes are busy traversing these lines with astonishing speed and coordination. The complicated task of reading requires an efficient system integrating various components into a well-orchestrated mechanism. Understanding how the brain achieves this rapid integration has been the focus of decades of research.

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A basic assumption is that since reading is a relatively recent cultural invention in evolutionary terms, it has not yet developed hardwired neural modules through natural selection. However, since humans acquire reading at an early age and use it extensively throughout life, it was suggested that neural processes become gradually specialized for the different components of reading and specifically for the perception of written text. Studies using functional MRI found that the presentation of text activates a spatialized region of the visual cortex called the *visual word form area* (VWFA), which is tuned specifically for the perception of letters (Cohen et al., 2002; Polk et al., 2002).

This line of studies focused on the spatialized mechanisms of text perception from a visual-sensory point of view. However, text is a unique stimulus, not only because it triggers specific perceptual programs, but also because it acts as a cue for the initiation of complex reading processes involving oculomotor and attentional mechanisms. During reading the eyes make rapid and short (typically around 6–9 characters) movements called "saccades" and then stay stationary for ~200–250 ms periods of time called "fixations" (Reichle, Rayner, & Pollatsek, 2003). Saccades are critical for shifting the center of fixation (the 'fovea'), where visual acuity is highest, to the words. The temporal and spatial control of saccades during reading was extensively studied and characterized by various computational models (Engbert, Nuthmann, Richter, & Kliegl, 2005; Legge, Klitz, & Tjan, 1997; Morrison, 1984; Reilly & Radach, 2003; Yang & McConkie, 2004). The latencies of saccades during reading are modulated by local factors related to the processing of each foveated word (Trukenbrod & Engbert, 2014); and also by more global factors, such as the text's luminance (Bowers & Reid, 1997), task demands (Bohn & Kliegl, 2007; Hyönä & Niemi, 1990; Rayner, 2009; Wotschack, 2009) and reader's experience (McConkie et al., 1991; Rayner, Yang, Castelhano, & Liversedge, 2011); There is an ongoing discussion regarding the involvement of cognitive and non-cognitive processes in the local modulations of fixation durations. Some theories supported a full cognitive control, assuming that the decision to execute a saccade is based solely on the processing of visual input during fixation and is therefore modulated by the identity of the foveated word (e.g., its familiarity) (Reichle, Pollatsek, Fisher, & Rayner, 1998). Others claimed that saccades cannot be triggered solely by the identity of the foveated word because there is not enough time during a single fixation to complete full lexical access (which takes around 100–300 ms) and plan and execute a saccade (which takes around 180–250 ms) (Reichle et al., 2003). Therefore, these theories suggested that saccades are triggered after a random time interval by an autonomous process, adjusted by low-level visual information and by global characteristics of the text and the task (Yang & McConkie, 2004; Hooge & Erkelens, 1998; Kolers, 1976; Reilly & O Regan, 1998; Yang & McConkie, 2001). Others combined these two approaches and suggested that indeed there is an autonomous generating mechanism but this mechanism is modulated by local cognitive features (Henderson & Ferreira, 1990; Trukenbrod & Engbert, 2014). In this study, we hypothesize that the perception of written letters triggers an autonomous perception-for-action mechanism which activates reflexive oculomotor and attentional orienting towards the direction of reading. Consistently with the third view, we hypothesize that this autonomous orientation process is modulated by the orthographic content of the text, which is necessary to identify the relevant writing-system and its natural reading direction.

Spatial orienting is the deployment of cognitive resources toward a specific location in space (Posner, 2007). Orienting could be covert (purely attentional with no eye movements) or it could be accompanied by a shift of gaze toward the oriented location. Additionally, orienting could be either voluntary (endogenous), or reflexive (exogenous). The experimental definition of "reflexive orienting" is somewhat inconsistent between different studies. In this manuscript we adopted the operational definition of reflexive orienting as orienting which is triggered by a non-predictive cue despite an explicit instruction to ignore it (Friesen & Kingstone, 1998; Jonides, 1981; Kuhn & Kingstone, 2009) (See more on this in the Discussion). Reflexive orienting, even when it is covert, is tightly linked to the activation of oculomotor programs for performing eye movements (saccades) toward the oriented direction (Awh, Armstrong, & Moore, 2006; Deubel & Schneider, 1996; Gregoriou, Gotts, & Desimone, 2012; Juan, Shorter-Jacobi, & Schall, 2004; Pouget et al., 2009; Smith & Schenk, 2012). It is a basic assumption that when two opposing orienting processes are activated simultaneously, they compete and delay each other, even when one is reflexive and one is voluntary. Therefore, quantifying reflexive orienting is often based on comparing saccadic reaction times (SRT) for voluntary saccades performed toward the oriented direction and those performed away from it. A delay in the SRT for saccades away from a specific direction is interpreted to reflect the activation of a competing reflexive saccadic program toward that direction, which needs to be cancelled before the correct opposite response could be initiated (Fischer & Weber, 1992; Hallett, 1978).

The most common procedure for inducing reflexive orienting is by presenting an abrupt and salient peripheral stimulus. Saccades performed in the direction of such a peripheral stimulus ("pro-saccades") are faster than those performed away from it ("anti-saccades"). However, reflexive orienting can be also triggered by centrally-presented symbolic cues. Stimuli which are highly associated with direction, such as arrows and eyes gazing sideways, were shown to have a similar effect on saccades as peripheral onsets. Saccades congruent with the direction of such centrally-presented symbolic cues are faster than those performed opposite the cue. These findings were taken as evidence that symbolic central cues, such as arrows or gazing eyes, activate reflexive oculomotor programs orienting toward the symbolized direction (Driver, 1999; Friesen & Kingstone, 1998; Frischen, Bayliss, & Tipper, 2007; Kuhn & Kingstone, 2009; Langton & Bruce, 1999).

In the present study, we examined whether orienting processes can be activated by text, as a symbolic stimulus with strong directional contents. We hypothesize that the perception of text would trigger reflexive orienting toward the direction of reading. Confirming this hypothesis would imply that there is a direct perception-for-action link between the processing of text and the initiation of oculomotor programs. We further hypothesized that this effect is a