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The saccadic Stroop effect: Evidence for involuntary programming of eye movements by linguistic cues

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ABSTRACT

The effect of automatic priming of behaviour by linguistic cues is well established. However, as yet these effects have not been directly demonstrated for eye movement responses. We investigated the effect of linguistic cues on eye movements using a modified version of the Stroop task in which a saccade was made to the location of a peripheral colour patch which matched the "ink" colour of a centrally presented word cue. The words were either colour words ("red", "green", "blue", "yellow") or location words ("up", "down", "left", "right"). As in the original version of the Stroop task the identity of the word could be either congruent or incongruent with the response location. The results showed that oculomotor programming was influenced by word identity, even though the written word provided no task relevant information. Saccade latency was increased on incongruent trials and an increased frequency of error saccades was observed in the direction congruent with the word identity. The results argue against traditional distinctions between reflexive and voluntary programming of saccades and suggest that linguistic cues can also influence eye movement programming in an automatic manner.

1. Introduction

Unlike other animals humans can coordinate visuo-motor behaviour in response to spoken and written language. This process is usually assumed to rely on poorly specified cognitive mechanisms, although a number of studies have now shown how motor response programming can be invoked in a more "automatic" manner by linguistic and symbolic cue. These effects have been demonstrated using press button manual and vocal response reaction time measures (Hommel, Pratt, Colzato, & Godijn, 2001; Logan, 1995; Logan & Zbrodoff, 1998), although no research to date has directly investigated whether such effects occur in the control of eye movements.

A common task used to study such interactions in the non-oculomotor domain has been the Stroop task (MacLeod, 1991; Stroop, 1935). In this task, participants are asked to respond to the colour of the ink in which a word is printed, whilst ignoring the word itself. Sometimes the identity of the irrelevant word conflicts with the colour to be named (e.g. the word "red" printed in yellow). Increased response times and overt response errors are observed for such stimuli relative to those for which there is no conflict (e.g. "top" in yellow or "yellow" written in yellow). The influence of word identity cannot be entirely suppressed even when subjects are instructed to respond only to the colour in which it is printed.

Given the evidence for automatic activation of manual/vocal responses by linguistic cues in the Stroop task, it is notable that no studies have shown such effects on saccade programming. Instead, a large number of studies have demonstrated involuntary programming of saccades to peripheral visual onsets. For example, the latency of saccades increases under conditions for which a task irrelevant visual stimulus is presented prior to saccade execution (McSorley, Haggard, & Walker, 2004; Ross & Ross, 1980; Walker, Deubel, Schneider, & Findlay, 1997). The presence of "Distractor" stimuli also influences the spatial parameters of saccades (i.e. trajectory and amplitude) and often results in the execution of involuntary saccades (e.g. Hallett & Adams, 1980; Ludwig & Gilchrist, 2002; Theeuwes, Kramer, Hahn, & Irwin, 1998). The frontal lobe of the cerebral cortex is thought to mediate inhibitory influences over saccades in order to suppress the majority of such "capture errors" in healthy individuals. Damage in this region has been shown to be associated with increases in involuntary saccades to peripheral onsets (Hodgson, Chamberlain, Parris, James, Gutowski, Husain & Kennard, 2007; Guitton, Buchtel, & Douglas, 1985; Machado & Rafal, 2004; Paus et al., 1991; Husain, Parton, Hodgson, Mort, & Rees, 2003; Walker, Husain, Hodgson, Harrison, & Kennard, 1998).

Other work in the domain of psycho-linguistics suggests that automatic programming of saccades may also occur in response to linguistic cues. In the so-called "visual world" paradigm and its variants, participants listen to an auditory description of a

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required action and associated object–object/object–action relationships whilst viewing a naturalistic visual scene (Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). The manner in which participants direct their gaze to components of the display is found to mirror the process of linguistic disambiguation occurring whilst decoding the sentence. For example, Allopenna, Magnuson, and Tanenhaus (1998) constructed displays in which distractor items could be phonologically similar or unrelated to target items in the display. Within 300 ms of onset of the relevant auditory word, eye movements were more likely to be directed to the target stimulus and phonologically related items compared to unrelated items. Other work has shown that even during passive viewing of a picture whilst hearing an acoustically presented sentence, eye movements are spontaneously directed to the relevant components of the scene (Cooper, 1974; Eberhard, Spivey-Knowlton, Sedivy, & Tanenhaus, 1995; Altmann & Kamide, 1999). This strongly suggests that linguistic stimuli cause automatic programming of saccades, although this has not been directly tested in a task for which the semantic content of word stimuli must be ignored to perform the task efficiently. Establishing the existence of such direct linkages between language and saccades would considerably simplify our understanding of the processes underlying some types of linguistic communication, such as the conversational language used by individuals cooperating in the performance of a visuo-spatial task (Tanenhaus & Brown-Schmidt, 2008).

In order to directly test whether saccade programming is subject to automatic influences by linguistic cues we devised a version of the Stroop task which required a saccadic response rather than a verbal or press button response. Each trial in the task involved the presentation of a written "cue" word at the fixation point. The word either referred to a particular location ("up", "down", "left", "right") or colour ("red", "blue", "green", "yellow"). In each case the subjects' task was to respond by looking towards one of four colour patches that matched the colour in which the word was written and to ignore the word form/identity. An effect of word form on saccade latencies and/or the direction of overt errors in the task would be consistent with a direct effect of linguistic stimuli on saccade generation similar to that found for peripheral onsets.

2. Materials and method

2.1. Participants

Ten University of Exeter students and staff participated in the study (four male) aged between 22 and 40 ($M = 27$ yrs 10 mths; $SD = 5$ yrs 4 mths). All participants had normal or corrected to normal visual acuity and normal colour vision. The study was approved by the School of Psychology ethics committee, University of Exeter.

2.2. Display and stimuli

Stimuli were presented on an Iyama vision master Pro452 21 in colour monitor operating at 100 Hz. Participants were seated 60 cm from the screen and made saccadic responses towards one of four target colour "patches" in the periphery (Fig. 1). The colour patches subtended approximately 3° of arc at an eccentricity of 7.5° from the fixation point. The Stroop word stimuli were presented at fixation. In the Colour Word condition, the Stroop stimulus consisted of the word 'red', 'blue', 'green' or 'yellow' in Times New Roman font. On Congruent trials the colour words were always presented in their corresponding "ink" colour i.e. the word 'red' in red. For incongruent trials the colour words were displayed in an alternative colour which matched one of the peripheral response boxes i.e. the word 'red' displayed in blue. In the Direction Word condition the centrally presented Stroop stimulus was one of the four direction words 'up', 'down', 'left' and 'right'. Congruent stimuli in this condition were composed of the direction words presented in the same colour as the patch in the corresponding location. For example the blue square was presented at the top of the screen therefore the word 'up' displayed in blue was congruent whereas the word 'up' displayed in yellow was incongruent. In both conditions Neutral trial stimuli consisted of four capital X's presented at fixation, displayed in a colour matching one of the peripheral response location.

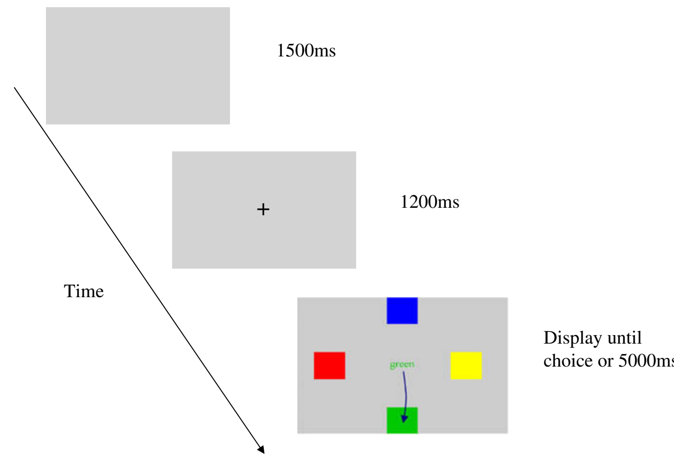

Fig. 1. Schematic of the oculomotor Stroop task showing the sequence of events on a congruent cue trial in the Colour Word condition.

2.3. Procedure

Each condition (Colour Word/Direction Word) consisted of 108 trials run as a single block containing 36 trials each of the congruent, neutral and incongruent stimuli presented in a pseudorandom order that varied between subjects. Each congruent and neutral stimulus type was presented nine times. The order of the blocks was counterbalanced across subjects. Participants were instructed to respond to the colour of the font in which the word was presented as quickly and as accurately as possible by directing their gaze towards the colour patch which matched the font colour of the word presented in the centre of the screen. They were told that the identity of the word itself was irrelevant to the task. Instructions were displayed on the screen prior to the start of each block and the experimenter checked with each participant prior to commencing that they fully understood the task requirements. A short practice block of 10 words was presented prior to each block and excluded from the main analysis.

Each individual trial contained the following sequence of events (Fig. 1). Prior to the start of the trial a fixation point stimulus was presented centrally. This was extinguished following a period of continuous fixation lasting 1200 m. The Stroop word stimulus was then displayed at the central location simultaneously with the onset of the four peripheral colour patches. A tone sounded when participant's gaze had been recorded at the correct target location for a period in excess of 1200 ms or at the end of a 5000 ms time out period. A blank screen was then presented for 1500 ms prior to the commencement of the next trial.

2.4. Eye movement recording and analysis

Eye movements were recorded using an Eyelink II Eyetracking system (SR research Ltd.), a video based pupil/CR tracker with head