Acta Psychologica 167 (2016) 1–15

Contents lists available at ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/locate/actpsy

Attentional modulation of the carry over of eye-movements between tasks

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ARTICLE INFO

Article history:
Received 26 May 2015
Received in revised form 27 February 2016
Accepted 24 March 2016
Available online 8 April 2016

Keywords:
Visual search
Attention
Eye movements
Carry over
Inter-trial effects
tDCS
Inhibition

ABSTRACT

Task demands that influence scanning behaviour in one task can cause that behaviour to persist to a second unrelated task (carry over). This can also affect performance on a second task (e.g., hazard perception ratings), and has been attributed to a process of attentional bias that is modulated by top-down influences (Thompson & Crundall, 2011). In a series of experiments we explored how these top-down influences impact upon carry over. In all experiments, participants searched letters that were presented horizontally, vertically, or in a random array. They were then presented with a driving scene and rated the hazardousness of the scene. Carry over of eye-movements from the letter search to the scene was observed in all experiments. Furthermore, it was demonstrated that this carry over effect influenced hazard perception accuracy. The magnitude of carry over was correlated with task switching abilities, attentional conflicting, and attentional orienting (Experiment 1), and was affected by predictability of the primary task (Experiment 2). Furthermore, direct current stimulation of the left dorsolateral prefrontal cortex and parietal areas affected the magnitude of the effect (Experiment 3). These results indicate that carry over is modulated by the specific ability to orient attention and disengage from this orientation. Over orienting leads to increased carry over and insufficient task switching is detrimental to task performance. As a result the current experiments provide evidence that the carry over effect is strongly influenced by attentional processes, namely orienting, inhibition, and task switching.

1. Introduction

Observers tend to show highly stereotypical eye movements when viewing natural scenes in which they focus on and encode the most informative areas (e.g., Loftus & Mackworth, 1978; Mackworth & Morandi, 1967). Such visual search is task-specific; for example, when viewing faces observers will scan the eye-region more than other features (e.g., Hills, Sullivan, & Pake, 2012), and during driving, locations in the horizontal plane, centred at the focus of expansion, are attended most frequently (Crundall & Underwood, 1998; Konstantopoulos, Chapman, & Crundall, 2010).

In a series of visual search experiments, using realistic driving images and videos, Thompson and Crundall (2011) demonstrated that the carry over of top-down control settings (scanning behaviour) can occur between two unrelated tasks. During these experiments, participants performed a letter-search task with strings of letters that were arranged horizontally, vertically, or randomly across the screen. Immediately following this, they saw a road scene or video clip and were asked to memorise it (Experiment 1), rate it for hazardousness (Experiment 2), or respond to the onset of a hazard (Experiment 3). Even though the time spent completing the letter search was minimal, the orientation of letters in this task influenced eye movements (and by extrapolation, attentional allocation) when viewing the road scene. They observed an increase in the amount of vertical search following the vertically orientated letter-search task and decreased vertical scanning following a horizontal letter search. In their third experiment, responses to the hazards were made significantly quicker following letters presented horizontally compared to letters presented randomly or vertically.

These authors noted that traditional models of eye movements (e.g., Itti & Koch, 2000; Torralba, Oliva, Castelhano, & Henderson, 2006) fail to account for the influence of a preceding, but unrelated task when the information is not beneficial to the secondary task (i.e., exposure to a different scene or situation). As a result, the mechanisms that underlie this negative carry over effect are poorly understood. Due to this lack of understanding, it is prudent to first establish a comprehensive understanding of this effect before it can be considered it terms of any models of visual search. One mechanism thought to influence visual search is the biasing of attention. The biasing of attention (and eye movements) to specific objects and locations within a scene on the basis of task-relevance is achieved through a top-down

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http://dx.doi.org/10.1016/j.actpsy.2016.03.012
0001-6918/

attentional set. The attentional set benefits performance on a task as irrelevant information will be inhibited and resources can be directed towards relevant information.

Visual attention is the process by which the brain selects a particular element of the visual scene for detailed processing and allocates resources to process that element (Jonides, 1983). Attention is a complex neurological process that encompasses a wide array of subprocesses, including both stimulus selection and inhibitory mechanisms (Knudsen, 2007). These processes are located in specific parts of the brain (Corbetta & Shulman, 2011; Petersen & Posner, 2012). Petersen and Posner (2012) divide the global construct of attention into two primary subprocesses of alerting and orienting, and executive control. Alerting is the process in which the attentional system is prepared for when a stimulus is set to appear. Alerting is subsumed by thalamic areas of the brain (Sturm & Willmes, 2001). The orienting network prioritises the location or timing of the visual scene for sensory input (Petersen & Posner, 2012) by intensifying the incoming signal by limiting noise and increasing resolution and/or the size the attentional spotlight (Carrasco, 2011; Facoetti & Molteni, 2001; Reynolds & Chelazzi, 2004; Reynolds & Heeger, 2009). Orienting is subsumed by parietal areas (Posner & Raichle, 1994) and the frontal eye fields (Corbetta et al., 1998). Indeed, attention is related to the control and stabilisation of the eyes and microsaccades (Siegenthaler et al., 2014). Orienting leads to perceptual improvements in many visual tasks. Executive control is the top-down process in which conflicts are monitored across trials and in relation to task instructions and resources are allocated appropriately (Petersen & Posner, 2012). It is thought to be subsumed by the anterior cingulate cortex (Dosenbach et al., 2006, 2007). Deficits in attentional processing seem to be linked to some important neurodevelopmental disorders such as dyslexia and autism spectrum disorder (Gori, Cecchini, Bigoni, Molteni, & Facoetti, 2015; Franceschini, Gori, Ruffino, Pedrolli, & Facoetti, 2012; Franceschini et al., 2013; Ronconi et al., 2013, for review see: Vidyasagar & Pammer, 2010). This further outlines the importance of investigating carry over as it may indicate possible limitations in attention processing.

The fundamental underlying cognitive mechanism(s) involved in the carry over effect are likely to be specific aspects of attention rather than the global construct. Attention in the letter search task, according to Thompson and Crundall (2011), may have been allocated in two different ways: activation of task-relevant locations, or inhibition of task-irrelevant locations. The transference of scanning behaviour to a second task would then reflect a bias towards previously relevant locations, or a bias away from previously irrelevant locations. This effect is opposite to inhibition of return. Inhibition of return is the effect whereby previously searched locations are not subsequently searched again (Klein, 2000). This effect can last for a few seconds (Snyder & Kingstone, 2000) or much longer (Tipper, Grison, & Kessler, 2003). It is apparently an automatic orienting process in which previously searched locations are inhibited. In the carry over effect, the same locations as previously searched are not inhibited, suggesting the carry over effect is distinct from the inhibition of return effect, potentially due to the sudden change in context from one image to the next.

One aim of the current work was to explore the relative importance of selection compared to inhibition involved in the carry over effect. Even if carry over does reflect the inhibitory processing component of attention, heterogeneity among standard tests of inhibition suggests this, too, is a broad concept (Friedman & Miyake, 2004). Indeed, evidence for strong correlations between standard tests of inhibitory control is limited (Kramer, Humphrey, Larish, & Logan, 1994; Shuster & Toplak, 2009), and the ability to isolate specific task effects is often complicated by a failure of published studies to adequately describe or identify the possible underlying mechanisms employed during task preparation and/or execution (Friedman & Miyake, 2004). Here, the inclusion of additional cognitive tasks may help identify or rule out the involvement of non-inhibitory mechanisms. Equally, by using a range of cognitive tests it will enable us to clarify those aspects of inhibition most closely related to the carry over effect.

Inhibition is a form of cognitive control that functions to limit the processing of information in our environment (Frith, 1979). Based on the work of Harnishfeger (1995) and Rafal and Henik (1994), Nigg (2000) has identified three distinct forms of inhibition: executive, motivational, and automatic. Within this, the effect of each type of inhibition can be summarised and measured accordingly.

Executive inhibition is formed of four dimensions: interference control, cognitive inhibition, behavioural inhibition, and oculomotor inhibition. Interference control is the process of response suppression in order to serve longer term goals. This can be measured using the Stroop task (Stroop, 1935); the basic form of which involves presenting participants with colour words and asking them to name the colour of the ink the word is written in (and therefore inhibit the automatic response of naming the word). It can also be measured by the flanker task, in which participants must respond to the direction of a centre arrow presented among congruent or incongruent flanking arrows (Eriksen & Eriksen, 1974). Cognitive inhibition is the ability to hold an item in working memory and subsequently ignore it (Nigg, 2000). This process is best measured by the latent inhibition paradigm (Lubow & Kaplan, 1997), in which pre-exposed irrelevant stimuli become the target stimuli in subsequent tasks (Cohen et al., 2004; Lubow & Gewirtz, 1995). Latent inhibition refers to the inability to re-learn previously irrelevant stimuli as target stimuli (Granger, Prados, & Young, 2012) with findings showing that performance on the subsequent task is poorer than in the pre-exposure task or when compared to novel stimuli (Braunstein-Bercovitz & Lubow, 1998; Escobar, Arcediano, & Miller, 2002; Kaplan & Lubow, 2011). The third dimension of executive inhibition is behavioural inhibition of a primary motor response caused by changing contextual cues, and is best demonstrated by the Go–No-Go task (Nigg, 2000). Participants in the Go–No-Go task are required to make a response to a target stimulus and inhibit their response to a less frequently presented 'stop' stimulus (Kok, 1986). The more frequent 'go' signals cause the action of responding to become a prepotent response. This task involves sustained attention in addition to response control, as participants need to pay attention to both the target and the 'stop' stimuli, which do not appear simultaneously. Finally, oculomotor inhibition is described as the effortful suppression of reflexive saccades and differs from the other types of executive inhibition tasks described above as it does not involve language or motor responses. Rather, it involves simple ocular reflexes and is often investigated using the antisaccade task in which participants must inhibit a reflexive response to the presentation of a stimulus. A typical antisaccade task requires the participant to move their gaze in the opposite direction to a presented stimulus (Hutton & Ettinger, 2006). In order to do this successfully, participants must inhibit the prepotent oculomotor response of directing their gaze towards a newly presented stimulus.

Automatic inhibition of attention is conceptualised in two forms: inhibition of return and attentional orienting which requires suppression of information at unattended locations. Although Nigg (2000) does not provide an example measure for these types of inhibition, we believe these forms can be captured by two of the three separate anatomically and functionally defined attentional networks identified by Fan, McCandliss, Sommer, Raz, and Posner (2002). These comprise: orienting, alerting, and executive control. Fan, McCandliss, Fossella, Flombaum, and Posner (2005) devised the attentional network task (ANT) in order to assess these types of attention (Posner & Rothbart, 2007). The task incorporates a cued reaction time task and a flanker task, and the efficacy of each network is assessed by the reaction time differences between conditions. Within each trial, the target (often an arrow-head pointing to the left or right) may be preceded by a cue that provides either temporal or spatial information about the target (there are also no-cue trials). The target then appears above or below a fixation cross with congruent or incongruent flankers either side of it. The flankers are also arrow-heads but they are distractors and