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RUNNING HEAD: Attentional modulation of carry over of eye-movements

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

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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.

Keywords: visual search; attention; eye movements; carry over; inter-trial effects; tDCS; inhibition

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

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 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; Peterson & Posner, 2012). Peterson 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, 2000; 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 (Peterson & 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 (Franceschini, Gori, Ruffino, Pedrolli, & Facoetti, 2012; Franceschini, Gori, Ruffino, Viola, Molteni, & Facoetti, 2013; Ronconi, Gori, Giora, Ruffino, Molteni, & Facoetti. 2013; Gori, Cecchini, Bigoni, Molteni, & Facoetti, 2015, 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, & Strayer, 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 Henrik (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 summarized 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, Sereni, Kaplan, Weizman, Kikinzon, Weiner, & Lubow, 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 participants are instructed to respond to the direction of the target as quickly as possible. The difference in response times to congruent and incongruent trials (the standard Flanker task) denotes the efficiency of the executive functioning network, while the difference between response times in a temporal cue trial and no cue trial reflects alerting ability. Finally, the difference between response times in cued trials when the spatial location of the target is either cued or non-cued provides a measure for orienting proficiency. The orienting network controls the ability to focus attention towards the source of specific sensory signals, by way of identification and selection of sensory stimuli. The ability to encode the relevant stimulus while ignoring the irrelevant stimulus, throughout the duration of a task is also crucial to success at the continuous performance task (Cohen, Barch, Carter, & Servan-Schreiber, 1999; Oades, 2000).

The current experiments employ Nigg's distinction between executive and automatic inhibition, but do not include an assessment of motivational inhibition, which is associated with emotional processing and is thought to reflect distinct neurological systems (Nigg, 2000). Arguably, these theories of separate inhibitory functions can be viewed as discrete components occurring at different stages of information processing (Friedman & Miyake, 2004). Whilst some tasks incorporate inhibition at the input stage of processing, others are associated with later, more cognitive control stages. Tasks such as the anti-saccade task and the go/no-go task occur early in cognitive processing. These tasks involve the early inhibition of a prepotent response. Cognitive inhibition is typically later in information processing, whereby the meaning of the information presented has to be processed (in terms of the direction of the arrow in the ANT conflicting, and the colour word in the Stroop task). The tasks involving sustained attention typically involve mid-level processing as they do not relate to stored semantic information, but the building up of activation.

Within this taxonomy Nigg (2000) has identified the neural correlates associated with each form of inhibition. For example, interference control has been associated with activity in the dorsolateral prefrontal cortex. Neuroimaging data provides empirical support for this, as responding to the Stroop task, a cognate measure of interference control, is associated with activity in the dorsolateral prefrontal cortex and the anterior cingulate gyrus (Cabeza & Nyberg, 1997; Diamond, Prevor, Callender, & Druin, 1997). Alongside this, automatic inhibition, and particularly attentional orienting, is thought to be subserved by the posterior parietal cortex (Posner & Raichle, 1994). That said, these data only speculate on the relationship between task performance (as an index of executive control or visual attention) and activation in brain areas. Critically they do not directly consider the causal nature of these relationships and it is therefore difficult to conclude anything about the brain regions activated and shared between these types of attentional control and the carry over effect.

Against this background, transcranial Direct Current Stimulation (tDCS) can be a useful tool in examining the causal relationship between top-down attentional control and the areas thought to subserve executive processes. tDCS consists of the application of a weak direct electric current, and these currents, delivered via electrodes on the scalp, are able to reach the neuronal tissue and induce polarization-shifts on the resting membrane potential (Stagg & Nitsche, 2011). It is generally accepted that the polarity of the current has differential effects on cortical activity and subsequent performance. Typically, anodal stimulation facilitates cortical excitability, and an increase in task performance (see e.g., Nitsche *et al*., 2008), while cathodal tDCS has opposite effects.

Recent work has indicated that direct current stimulation improves attention. For example, anodal stimulation to the left dorsolateral prefrontal cortex (site F3) has been shown to increase performance in selective attention tasks (Gladwin, den Uyl, Fregni, & Wiers, 2012; Kang, Baek, Kim, & Paik, 2009) that are thought to relate to task switching and executive control. Bolognini, Fregni, Casati, Olgiati, and Vallar (2010) have also demonstrated that anodal stimulation to the parietal lobe enhances spatial orientation, indicating its role in visual orientation of attention. Further, de Tommaso *et al.* (2014) applied anodal stimulation to site P3 in the parietal lobe and showed improvement in spatial attention in their participants. These results indicate that the parietal lobe and the frontal cortex are potential sites for stimulation that may influence the carry over effect.

1.1. The Present Work

In summary, the current underlying mechanisms of carry over are poorly understood, but it has been speculated that the negative effect of carry over is representative of top-down processes. The aim here is to investigate the attentional correlates of carry over in order to better understand these operations. This will be explored using a correlational analysis of the cognitive constructs that are predicted to relate to carry over effects, including attention, cognitive control, interference control, motor inhibition, cognitive inhibition, visual working memory, and executive functioning. It is clear that carry over of eye movements could be caused by any of these constructs. To explore the cause of the carry over effect our task will be combined with the tDCS procedure (Experiment 3).

2. Experiment 1

The main purpose of Experiment 1 was to examine the relationship between top-down attentional processes and the magnitude of the carry over effect. Experiment 1 provides a comprehensive analysis of the relationship between carry over and attentional control, based on Nigg's (2000) taxonomy. To measure attentional control, we used a battery of standardised tests that were briefly outlined in the Introduction, and are summarised in Table 2. These tasks are considered, at least in some part, to measure different cognate abilities (Friedman & Miyake, 2004). A further aim of Experiment 1 was to establish if there were any effects of carry over on hazard perception accuracy. Thompson and Crundall (2011) found that carry over influenced speed of hazard detection but they did not explore the impact of carry over on accuracy to detect hazards. On the basis of their previous findings we predicted that there would be a carry over of eye movements from the letter-string task to the hazard-rating task and that the presentation of stimuli in the first task (the orientation of the letter strings) would have an impact on accuracy to appraise hazards in the rating task. This experiment also allows us to tentatively explore Nigg's (2000) taxonomy of inhibition.

2.1. Method

2.1.1. Participants

Seventy naïve participants (31 male, modal age 24 years) recruited from an opportunity sample of staff and students from Anglia Ruskin University took part in this study. Sixty participants completed the full battery, ten completed a subsection. Each participant was paid £20 for their participation, and they completed the study over the course of 2-4 separate days. All participants self-reported that they had normal or corrected-to-normal vision such that they would be legally able to drive in the UK.

2.1.2. Design

Participants completed each task in a within-subjects design that manipulated the orientation of the letter strings (horizontal, vertical, or random). Eye movements were recorded whilst participants searched, gave a hazard rating to the road images, and identified the hazard. The magnitude of the carry over effect, operationalised as the proportion of eye movements during presentation of the hazard consistent with the letter-string orientation relative to all eye movements, was subsequently correlated with the measures of attentional control and inhibition described below and in Table 2.

2.1.3. Apparatus

The battery of cognitive tests (summarised in Table 2) and the carry over task was implemented using E-Prime 2.0 (Psychology Software Tools, Inc., Sharpsburg, PA) and PEBL Software (Mueller, 2012) and presented onto a 17” (1280 x 1024 pixel) LCD full colour monitor. Eye movements were recorded using a Tobii 1750 eye-tracker (Falls Church, VA), with embedded infrared cameras with a sampling rate of 50Hz. The eye-tracker emits near infra-red light, which reflects from a participant’s eyes, and is then detected by the eye-tracker’s camera. The minimum fixation duration was 100ms and the fixation dispersion threshold was 100 pixels. Participants were tested individually and the task order was randomised, with the proviso that the switch task always immediately followed the standard go-no-go task. In all tasks, participants sat approximately 60 cm from the computer screen. Table 2 shows how each test was operationalised. Unless otherwise specified, all analyses for the tests described here were conducted only on correct responses.

2.1.3.1. Carry over task: Letter search and hazard perception task

Eye movements were calibrated using a 5-point calibration screen before this task started. Each letter search began with a fixation cross presented to the centre of the screen for 500ms (see Figure 1 for a schematic representation of the task). Participants then viewed strings of letters arranged horizontally, vertically, or randomly across the screen. These were series of nine-character-long letter strings, consisting of either 5 consonants and 4 vowels, or 6 consonants and 3 vowels. The letters were presented in black font (Verdana 18, 0.95° x 0.95°) on a white background within an invisible 9 x 9 grid. The letter position depended upon the orientation of the search: letters were arranged down the horizontal centre line in the vertical search, across the vertical centre line in the horizontal search, and randomly across the grid in the random search. Letters could be shown in upper or lowercase. The letter 'I' was not included as it could have been mistaken for a lower-case 'L'; participants were made aware of this during the experiment instructions. When the letter string included two of the same vowels, they were counted as two, rather than one vowel. Participants were asked to count the number of vowels present (3 or 4) and respond using the keyboard. The letters remained on the screen until a response had been made. Following the participants' response, feedback was given for 1000ms. For a correct response the screen was green and for an incorrect response the screen was red.

In half the trials, a road image was then presented for 2000ms and participants were asked to identify the hazard. The road photographs (35.14° x 28.07°) were taken from a driver's perspective in urban, suburban, and rural settings (there was an equal number of these). The images contained everyday hazards (such as a pedestrian crossing onto the road, a parked car, and a car entering the road at a junction), as we were interested in realistic driving conditions. Hazards were equally distributed among all perspectives and across conditions. From the centre of the screen, hazards were equally distributed on the left and right side and were equally likely to be in line with the centre and below the centre of the screen.

Accuracy of hazard perception was recorded by the participants identifying the hazard verbally immediately following the hazard rating. This response initiated an ITI in which the Experimenter keyed whether this was correct or incorrect. The participants then rated the hazardousness of each road using a 1 to 7 Likert-type scale with the anchor points "no hazard" and "extremely hazardous." Participants made their responses on the numerical keypad, but were instructed not to look down to the keypad. Their response initiated the subsequent trial.

In the other half of the trials a further 2 letter searches of the same orientation were presented before the road scene was shown (to increase unpredictability of the onset of the road image). There were 108 trials, 36 for each orientation, with 18 incorporating one letter search and

18 incorporating three letter searches, presented in a random order. In each trial, participants were presented with the letter search task followed by the hazard perception task. Once all trials had been completed, participants were given a short demographic questionnaire which explored their driving experience.

Figure 1 about here

2.1.3.2. Executive inhibition: Interference control - Stroop and Simon tasks

Participants completing the Stroop task (Stroop, 1935) were asked to identify the colour of the ink of colour words that appeared sequentially in the centre of the screen. This consisted of five colour words - red, green, yellow, blue, and purple - which were presented in one of 5 colours (either congruent, e.g., the word "red" presented in red; or incongruent, e.g., the word "red" presented in green), on a white background. Each word was presented in block capitals in Courier New font size 150 (subtending 6.29° visual angle in the vertical axis). For each colour word, participants were asked to respond to the colour of the ink that the word was presented in by pressing the appropriate key on the keyboard ("r" = red, "g" = green, "y" = yellow, "b" = blue, and "p" = purple). Each trial was response terminated. A reminder of the response keys was presented in the top right corner of the screen during the whole task and the response keys were colour coded. All participants completed 50 trials (25 congruent and 25 incongruent) that were presented in a random order. The Stroop effect was operationalized by the difference in response times between congruent and incongruent trials.

In the Simon task (Hommel, 1993), participants were required to respond to the colour (either red or blue) of a circle presented in one of five locations on the screen (the centre, 3° and 6° to the left and right). Participants answered with the left "shift" button to respond to red and the right "shift" button for blue. Each trial consisted of a fixation cross for 250ms, followed by the circle that remained on screen until the participant responded (up to a maximum of 2s). There were a total of 150 trials (distributed equally among locations and colours and presented in a random order). In this task, responses are usually faster when the location of the stimulus is congruent to the response (i.e., a red circle presented to the left). The Simon Effect was thus operationalised as the difference in reaction time between the congruent and incongruent stimulus-location pairs.

2.1.3.3. Executive inhibition: Cognitive control - Latent inhibition, negative priming, and the continuous performance task

The latent inhibition effect was generated using a two-phase visual search procedure (Kaplan & Lubow, 2011). Both phases require detection of one unique target (a shape consisting of five randomly connected straight black 1 cm lines on a white background; see Lubow, Kaplan, Abramovich, Rudnick, & Laor, 2000) among 19 similar distractors. In each trial, participants were instructed to identify whether the target was present or absent. The stimuli were presented in a random position within an invisible 8 x 12 grid. All participants completed a 'pre-exposure' phase followed by a 'test' phase and target and distractor stimuli were changed from pre-exposure to test. Both phases involved 96 (48 target-present and 48 target-absent) trials presented in a random order. Latent inhibition is exhibited by slower target detection time for the condition in which the target item in the test phase was the distractor item in the pre-exposure stage and the distractor item in the test phase was the target in the pre-exposure phase, compared to the test phase condition in which a novel target was presented among distractors that had previously been distractors. This represents a difficulty to process a target that was previously irrelevant.

The negative priming task (Park, Püschel, Sauter, Rentsch, & Hell, 2002; Tipper, Weaver, Cameron, Brehart, & Bastedo, 1991) consisted of a series of prime and probe displays. Each trial began with a central fixation cross for 800ms. Following this, a target ("O") and a distractor (+) could be presented in one of the four quadrants of the screen (each one separated by 8.3^0 of visual angle). Participants were instructed to locate the target by responding with a key that corresponded with the location ("D", "C", "K", and "M"). This prime display was on screen until the participant responded. This was followed by a 1350ms pause, in which a central fixation cross was presented during the final 800ms, before the probe display was presented. The probe screen followed. This was identical to the prime display except that the location of the target and the distractor varied and participants again had to respond to the location of the target. This was followed by a 6.4s random noise visual mask in order to prevent negative priming effects occurring across trials. The negative priming effect is revealed through increased reaction time to locate the probe target when it appeared in a location that held a distractor during the prime display. Control trials were included where the target and the distractor were in different locations in the two displays, and neutral trials presented no distractors. There were 72 trials, presented at random, and distributed evenly among trial types. Participants took rest breaks after every 18 trials.

In the continuous performance task (Lee & Park, 2006), participants were presented with single letters sequentially at the centre of the screen for 250ms in cue-target pairs. Each trial consisted of a fixation cross, the cue (either an "A" or "B"), a fixation cross, and then the target (either an "X" or a "Y"). Participants were instructed to press a button when they saw an “X” following an “A”. Each stimulus was on screen for 250ms. The cue-target sequence occurred on 30% of the randomly presented 273 trials. There was an ITI of 500ms to allow participants to make their response. Cue detection accuracy of responses was recorded.

2.1.3.4. Executive inhibition: Intentional motor inhibition - Go-No-Go/Switch tasks

In the Go-No-Go task (Rubia *et al.*, 2001), an arrowhead (presented for 1000ms) preceded either the letter "X" or "T” presented in the centre of the screen for 1300ms. Participants were instructed to respond to the direction of the arrowhead with a button press when they saw the "X" (go trials) but do nothing when they saw the "T" (no-go trials). A central fixation cross was presented between each letter for 500ms. Between each trial, there was an ITI of 1000ms. Letters and arrowheads were displayed in white on a black background. Participants were given 12 practice trials and 100 experimental trials (presented in a random order), of which 80 were go trials. Failures to inhibit resulted in increased errors during the no-go trials.

This task was immediately followed by the switch task, which was identical to the Go-No-Go task except for the instructions given to the participants. Participants were instructed to respond to the direction of the arrowhead using a button press when they saw the "X" but when they saw the "T" they were asked to respond with the opposite hand (switch trials). This task consisted of 100 trials, of which 20% were switch trials. These two tasks measure response inhibition. Reaction time differences between the go and switch conditions provide a measure of the switch cost.

2.1.3.5. Executive inhibition: Oculomotor inhibition - Antisaccade task

In the Antisaccade task (Mueller, 2012; see also, Brenner, McDowell, Cadenhead, & Clementz, 2001), participants were presented with a fixation cross in the centre of the screen and had to fixate on this for 200ms before the trial would begin. The fixation then illuminated green to indicate a pro-saccade trial in which participants had to move their eyes toward a target; or red to indicate an anti-saccade trial in which participants had to look to the opposite side of the screen to where the target appeared. A laterally displaced target, presented in white, on a black background, appeared 8° of visual angle to the left or right of the centre. It disappeared once it (or an invisible target on the opposite side of the screen in anti-saccade trials) had been fixated upon for 200ms. There was a random ITI of between 2000 and 2500ms. The time to make the correct saccade (as recorded using the Tobii eye tracker) was measured. Participants were given 10 practice trials and 180 experimental trials (divided equally among pro- and anti-saccade trials of which half involved a target presented to the left and half involved a target presented to the right). The difference in reaction times to the pro- and anti-saccade conditions provides a measure of inhibition.

2.1.3.6. Attention Network Task.

The Attention Network task (ANT, Fan et al., 2002) involves a combination of the Posner cueing paradigm and the flanker task. Participants were instructed to identify the direction of a central arrow pointing to the left or right by responding with the appropriate arrow keys. Each trial consisted of: a central fixation period (400-1600ms); followed by a second fixation period with or without a warning cue in the form of an "*" (100ms); a third fixation period (400ms); and the target (with six flanking arrows that were congruent, incongruent, or neutral to the target: three arrows on each side) was then presented above or below the central fixation cross until the participant responded to the direction of the central arrow (up to a maximum of 1700ms). There was a variable ITI to ensure that each trial lasted for a total of 4000ms. There were four conditions of warning during the second fixation period (no-cue, centre-cue, double-cue, and spatial cue). The order of presentation within the four trial blocks was randomised. In the first block, feedback was provided and consisted of 24 trials. Subsequent trial blocks consisted of 96 trials each and did not include feedback. All stimuli were white against a black background.

Attentional orienting is defined as the ability to focus attention on relevant task characteristics and is operationalised as the reaction time to the spatial cue trials subtracted from the central cue trials. Attentional alerting measures awareness of cues and is operationalised as the reaction time difference between the double cue and the no cue conditions. Attentional conflicting is the standard flanker task and measures executive inhibition and specifically interference control. This is operationalised by taking the reaction time difference between congruent and incongruent trials.

2.1.3.7. Cattell's Culture Fair

The Culture Fair Intelligence Test (CFIT, Cattell, 1940) was employed as a measure of nonverbal fluid intelligence, in which participants are required to find relationships between a series of geometric shapes. There are four subtests within the test: The first requires participants to select from five choices a geometric shape that completes a progressive series; The second subtest requires participants to identify the odd geometric shape from a series of five; The third subtest requires participants to complete a matrix of geometric shapes by selecting one from five presented; and finally, the fourth subtest requires participants to select from five shapes, a geometric shape that duplicates some form of topological relationship among the other shapes. We employed Scale 2, Form A, which has good concept and concrete validity scores (.81 and .70 respectively), test-retest, internal, and external reliability scores (.73, .76, and .67 respectively) (Institute for Personality and Ability Testing, 1973).

2.1.3.8. Operation Span (OSPAN)

The automated-OSPAN (Turner & Engle, 1989; Unsworth, Heitz, Schrock, & Engle, 2005) was employed to measure working memory capacity (see Unsworth *et al.*, 2005 for a diagram of the experimental protocol). This task required participants to solve a series of maths problems (e.g., "(10*2)-5=15 TRUE OR FALSE?") while trying to remember a series of letters. The participants saw one maths problem followed by one letter at the centre of the screen. The maths problem-letter pairs were presented in sets of between two and seven pairs. Immediately after the final pair was presented in each set participants were required to recall the letters in the correct sequence. When participants were prompted to recall the letters, 23 letters (correct and incorrect) were presented as a 4 x 3 matrix and participants had to click a box next to the appropriate letters in the correct order using the computer mouse. Three trials of each set size were presented in a random order. Participants were required to have a criterion accuracy of 85% in the maths trials. Practice blocks preceded the main trials to ensure that participants understood the task. The absolute-OSPAN score is the number of correct letters remembered in the correct order from the trials in which participants recalled all letters correctly.

2.3. Results

2.3.1. Data Preparation

Analysis of eye movements in the picture task was only completed on trials in which the preceding letter-search task(s) had been completed correctly; 2% of trials were removed due to incorrect responses. Data from one participant was also removed due to poor calibration. For all analyses, we included driving experience as a between-subjects variable (both as a binary variable – driver or not – and a scalar variable – how long have you driven and how much do you drive a week). There were no main effects of driver experience on any dependent variable nor any interactions with this variable, largest $F(2, 74) = 1.34$, smallest $p = .26$, largest $\eta_p^2 = .04$. Therefore, driver experience was not considered further. Orientation of the letter strings had no impact on accuracy and no impact on RT in incorrect trials.

The key analysis was conducted on the angle of the first saccade in the picture task, based on the orientation of stimuli in the letter task. We employed an analytical structure similar to Gilchrist and Harvey (2006) and Thompson and Crundall (2011). Saccadic direction was measured in degrees (zero degrees represented a vertical upwards saccade and 180 degrees represented a vertical downwards saccade). The angles were then coded into one of twelve 30 degree bins. Given that we were not interested in whether the first eye movement was up or down, or left or right, we collapsed across these bins to create three bins representing vertical, horizontal, and non-axial movements, therefore collapsing across left and right, and up and down directions. Figure 2 highlights this coding structure.

Figure 2 about here

2.3.2. Carry over, response times, and hazard ratings.

The resulting data was then analysed according to the proportion of eye movements in the horizontal direction and the proportion of eye movements in the vertical direction on the basis of letter-search orientation. Table 1 displays the means and standard error for proportion of horizontal and vertical eye movements, hazard rating response time (ms), hazard rating, and hazard perception accuracy for Experiment 1. The proportions of horizontal and vertical first eye movement data were subjected to parallel within-participants univariate ANOVAs[1] with the factor of letter-string orientation (horizontal, vertical, and random).

Letter string orientation affected the proportion of both horizontal and vertical eye movements, $F(2, 134) = 43.81$, $MSE = 0.01$, $p < .001$, $\eta_p^2 = .40$ and $F(2, 134) = 45.22$, $MSE = 0.01$, $p < .001$, $\eta_p^2 = .40$, respectively. Bonferroni-corrected pairwise comparisons revealed that there were more horizontal first eye movements following the horizontal letter string than the vertical letter string (mean difference = .13, $p < .001$) and the random letter string (mean difference = .09, $p < .001$). There were also more horizontal first eye movements following the random letter search than the vertical letter search (mean difference = .04, $p = .003$). There were more vertical first eye movements following the vertical letter search than following the horizontal letter search (mean difference = .12, $p < .001$) and the random letter search (mean difference = .09, $p = .003$). There were also more vertical first eye movements following the random letter string than the horizontal letter string (mean difference = .03, $p = .049$).

Table 1 about here

There was a significant effect of letter-string orientation on hazard ratings, $F(2, 136) = 4.04$, $MSE = 0.33$, $p = .026$, $\eta_p^2 = .06$. Bonferroni-corrected pairwise comparisons showed that hazard

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[1] For all ANOVAs reported, Mauchley's Test of sphericity was significant, so the Huynh-Feldt correction was applied.

ratings were lower following the vertical letter search than the horizontal letter search (mean difference = 0.25, p = .062) but not the random letter search (mean difference = 0.16, p = .124). A parallel analysis was conducted on the reaction time to identify the hazard. This revealed a significant effect of letter-string orientation, $F(2, 136) = 12.95$, $MSE = 6{,}164$, $p < .001$, $\eta_p^2 = .16$. Bonferroni-corrected pairwise comparisons revealed that participants were faster at hazard perception following the horizontal letter string than the random letter string (mean difference = 31 ms, p = .068) and the vertical letter string (mean difference = 68 ms, $p < .001$). Hazard perception was also faster following the random letter string than the vertical letter string (mean difference = 37 ms, p = .018).

A parallel analysis was completed on hazard perception accuracy. This revealed a significant effect of letter-string orientation, $F(2, 136) = 45.23$, $MSE < 0.01$, $p < .001$, $\eta_p^2 = .40$. Bonferroni-corrected pairwise comparisons revealed that hazard perception accuracy was lower following the vertical letter search than the horizontal letter search (mean difference = 8.0%, $p < .001$) and the random letter search (mean difference = 6.4%, $p < .001$). Horizontal letter searches produced higher accuracy than random letter searches (mean difference = 1.6%, p = .009): this is to be expected as there were more hazards in the horizontal plane than either of the other bins (vertical or non-cardinal).

We also explored the correlation between the magnitude of the carry over effect and the hazard perception accuracy. Magnitude of the carry over effect was operationalised as the proportion of eye movements consistent with the letter-string orientation. We found that the magnitude of carry over predicted accuracy following the vertical letter-string, $r(66) = .25$, p = .039, but not following the horizontal letter-string $r(66) = .07$, p =.592.

We also compared driving experience with the magnitude of carry over in a series of one-way ANOVAs and found no significant effects (largest $F = 0.02$, smallest p = .980.). This convincingly demonstrates that the carry over effect occurs for both experienced and novice drivers, and for non-drivers.

2.3.3. Relationship between magnitude of the carry over, inhibition and driver experience

We correlated the magnitude of the carry over effect with each measure of inhibition and attention. Only the significant correlations are reported in text. All the correlation coefficients are reported in Table 2. This analysis revealed that the carry over effect was positively related to switch cost, $r(58) = .34$, p = .009, and the conflicting score, $r(56) = .27$, p = .042, and negatively related to the orienting score from the Attention Network Task, $r(56) = -.32$, p = .017. Taken together these correlations suggest that participants with less cognitive control (in terms of task switching and inhibiting distractors), but more orienting behaviour, were more susceptible to carry over. Given that there is collinearity between different measures of inhibition, we conducted a regression with carry over magnitude as the dependent variable and the measures that significantly correlated with it as predictors to establish which inhibition test predicted carry over most effectively. The overall regression analysis was significant, $R(54) = .43$, $F(3, 52) = 3.97$, $p = .013$. Semi-partial correlations revealed that the most unique predictor of carry over was the ANT orienting score, $\beta = .23$, $r_{sp} = .22$ followed by ANT conflicting, $\beta = .23$, $r_{sp} = .21$, with the switch difference explaining less of the unique variance of the carry over effect, $\beta = .14$, $r_{sp} = .13$.

Table 2 about here

2.3.4. Testing the relationship between the subtypes of inhibition

To our knowledge, this is one of the first studies to use the taxonomy of inhibition described by Nigg (2000) extensively. This gives us an opportunity to explore this model. We utilised measures that he indicated were indicative of each type of inhibition. While we do not have sufficient power in this study to fully explore these relationships, we can make some tentative comments regarding the findings, shown in Table 3. We found that several measures within constructs (for example, the Stroop, Simon, and ANT conflicting) did not necessarily correlate with each other as strongly as we might have expected. This could be due to subtle differences in the tasks (including spatial layout, for example) that may prevent correlations between what appear to be theoretically very similar tasks (see e.g., Jones, Hills, Dick, Jones, & Bright, 2016). In addition, there were more correlations across the types of inhibition, as described by Niggs taxonomy, than one might expect. Both findings indicate that there may be potentially other ways to view how measures of inhibition might be related to each other. Further work is needed to fully explore this.

Table 3 about here

Attentional orienting was an independent construct to the measures of inhibition we tested, as indicated by the lack of significant correlations between scores on the ANT orienting component and every measure of inhibition. This supports the view that orienting is distinct to other forms of attention, subsumed by a different neural network (Fan et al., 2005). Indeed, the nature of orienting is that it is about maintaining focus on a particular spatial location (Fan et al., 2002), whereas the other tasks measure attentional conflict and the ability to inhibit or ignore information.

We also found that none of our measures correlated significantly with working memory capacity. This may refer to the fact that the OSPAN measures memory capacity for and manipulation of information, whereas the tasks used to investigate inhibition did not measure storage or manipulation. We also found that our measures of inhibition had limited correlations with intelligence. This might be due similar reasons. CCIT measures the ability to solve problems and see patterns. Our measures of inhibition were more low-level, not requiring the manipulation or storage of information.

2.4. Discussion

This study independently replicates and extends the carry over of eye movements findings of Thompson and Crundall (2011), whereby the scanning strategy used in one task transfers to an unrelated second task. The presence of increased vertical search following a vertical letter search (compared to a random letter search) has also been replicated. In addition, there was only a small increase in horizontal searching following the horizontal letter search which also supports previous findings (Thompson & Crundall, 2011). Given that scanning driving scenes typically involves horizontal scanning because more hazards are in this direction than in other directions, it is no surprise that horizontal search is harder to influence with a preceding task. Attention would be directed to the horizontal axis on the basis of top-down influences; search is therefore at ceiling so cannot be increased further with the letter search task (Crundall & Underwood, 1998). Indeed, accuracy in hazard perception is mainly related to horizontal eye movements and the avoidance of vertical eye movements.

We have also demonstrated that the transfer of eye movements influences how fast participants respond to the hazard rating task. Following vertical scanning, participants responded slower to the road image than following the horizontal scanning, consistent with the third experiment conducted by Thompson and Crundall, (2011). The horizontal condition may have led to faster responses in the rating task due to the more focused horizontal eye movements required during driving and other tasks (Crundall & Underwood, 1998); therefore ensuring a more appropriate search for detecting hazards. Yet it is unclear why a random search would also lead to faster responses (compared to the vertical condition). More plausibly, the vertical search slows hazard detection. One potential explanation is that a switch from the vertical search in the letter task to the horizontal search in the images required more cognitive effort than a switch from the random search.

Importantly, we have established that the carry over effect is associated with hazard perception accuracy, whereby more vertical scanning leads to lower accuracy than horizontal or random scanning. This is not due to any form of speed-accuracy trade-off as hazard perception responses were made faster following the horizontal than vertical letter-search. It may therefore be argued that stimuli that evoke a vertical search will have a negative effect on accuracy to perceive hazards.

With the current findings we have begun to establish the mechanisms underlying the carry over effect. We have established that this effect is correlated primarily with measures of attention conflicting, orienting, and switch task performance. This pattern of correlation suggests that some element of motor conflict is related to the carry over effect. One would expect this effect to be related to executive functioning (Redick & Engle, 2006). Indeed, conflicting, as measured by the ANT, is invoked when there is information conflicting with other information. Additionally, the conflicting aspect of the ANT suggests that participants who are able to inhibit visual distraction information immediately around the point of fixation show a smaller carry over effect. Executive control must be invoked to cope with the incongruity. However, there was no correlation with working memory capacity (measured by the OSPAN), which is often considered to be related to executive functioning. This lack of correlation is likely due to the fact that high and low capacity individuals may actually use their attentional systems differently from one another and this may not be captured in the indices within the ANT (*cf*., Bleckley, Durso, Crutchfield, Engle, & Khanna, 2003). Nevertheless, given the extensive literature on what executive control is associated with, we can make further predictions regarding which brain regions may be related to the carry over effect. Specifically, executive functioning is associated with the prefrontal cortex and the anterior cingulate (Bush, Luu, & Posner, 2000; MacDonald, Cohen, Stenger, & Carter, 2000). Future work also has the potential to investigate whether there are groups of participants who would suffer these effects more. For instance, it may be the case that individuals who show attentional deficits on the basis of developmental disorders (Franceschini et al., 2012; 2013) would suffer from the carry over effect to a greater extent.

Finally, and most crucially, the aspect of attention that most uniquely correlated with the carry over effect was a measure of orienting. This is where participants respond to a cue that provides spatial information about where a target will appear (Fan *et al.*, 2002). In such cases, attention has to be disengaged if the target appears in a location that was not previously cued (Corbetta, Kincade, Ollinger, McAvoy, & Shulman, 2000). The ANT measures the ability to focus attention at one location despite a change in stimulus and we are arguing that the same thing happens in the carry over effect: – the magnitude of carry over shows the ability to focus on the location of the letters which then persists when the driving hazards are presented. This will slow down responses to the hazard perception task following the vertical letter search, since the vertical letter search causes attention to be cued in a direction in which the hazard is less likely to be found (based on the notion that drivers typically scan in the horizontal plane). This, therefore, suggests two mechanisms involved in the carry over effect: orienting and disengagement (switching) from one task set to another. This finding is consistent with recent work by Thompson, Howting, & Hills (2015) who found that the carry over effect was greater the longer participants spent in the first task. This was assumed to reflect the effort they put into the first task and in establishing their attentional set. Increased effort in establishing an attention set means that it is more difficult to disengage/switch from this set when the task changes.

One caveat with this explanation is the lack of correlation between the carry over effect and other measures of inhibition or interference: the Stroop and Simon tasks. While, non-significant results are hard to interpret (due to a lack of power, for example), we can make some tentative suggestions for this lack of a correlation. The absence of a relationship may be due to the different task demands (Treisman, 1969). The Stroop effect is a measure of cognitive interference (Nigg, 2000), whereas there are limited cognitive aspects involved in the ANT Conflicting; it is purely a visual interference effect. The Simon task is also a measure of visual interference, but involves higher-level inhibition due to the distance from the fovea than conflicting in the ANT. This highlights that the carry over effect is due to low-level visual inhibition associated with ignoring distractors in close proximity spatially, though not temporally.

In a similar vein, we can also explore why the carry over effect was not correlated with other measures tested. The effect did not correlate with the anti-saccade task, suggesting it is unrelated to oculomotor interference. This indicates that the effect is arguably driven by attentional allocation rather than pure eye movements. It is also not correlated with measures of inhibition as a result of sustained attention: the latent inhibition effect, the negative priming effect, the continuous performance task, and attentional alerting. These tasks all contain elements that are not present in the carry over effect and may therefore explain this lack of relationship. The latent inhibition effect relies on a carry over of information stored in visual working memory from one round of visual search to a second. The negative priming effect involves the instructed active inhibition of a previous location as directed by task demands. The continuous performance task simply requires sustaining attention on a single location. These demands are not present in the carry over task; in particular, the similarities between the negative priming effect and the carry over effect seem apparent, but the need for instructions encouraging participants to inhibit the location in the negative priming effect make this a more conscious and controlled effect, whereas the carry over effect is more basic and automatic. In terms of alerting, the carry over task as defined presumably contains elements of alerting (participants could develop an expectation of the timing of the stimuli). However, it would not aid them in completing the task of being prepared for a change in attentional set.

3. Experiment 2

Experiment 1 implicated that the single most important cognitive ability associated with the carry over effect was participants' ability to orient their attention. Participants who more strongly orient their attention to the letter-string task fail to adjust their attentional set in the second task. The result of this is that anything that can increase participants' attentional orientation to the letter-string task should increase the carry over effect. Experiment 2 was, therefore, designed to increase participants' attentional orientation to the letter-string task.

One might think that increasing the number of letter-strings performed prior to the road scene might increase attentional orientation to this task. Thompson and Crundall (2011) have demonstrated that having either one, two, or three letter-strings preceding the road scene does not impact on the magnitude of the carry over effect differently. That is, increasing the number of letter-strings performed prior to the road scene does not increase the size of the carry over effect. However, Thompson *et al.* (2015) have shown that the number of letter-strings preceding the hazard task can influence the carry over effect, provided that the participant invests in developing an attentional set during the letter-string tasks. This suggests that anything which can increase the attentional set during the letter-string task will increase the carry over effect.

In the published studies on this carry over effect, there could be one, two, or three letter-strings before the road scene (and one, four, or eight letter strings in the study of Thompson et al., 2015). This element of unpredictability is crucial in maintaining the carry over effect according to unpublished data from Thompson (2010). If participants know how many letter strings they will be presented with prior to the road scene, the carry over effect disappears. This suggests that participants can prepare to disengage their attention from one task if they know that a second task is going to occur. This implies that the lack of predictability as to when the road scene will appear causes participants to more strongly orient their attention to the letter-string task. When participants cannot determine when they should change their attentional set, they are more likely to retain the set from one task to the second.

This line of reasoning suggests that if we can manipulate the predictability of the onset of the road scene, we should be able to manipulate the magnitude of the carry over effect. When the presentation of the road scene is less predictable due to there being a more random number of letter-strings presented prior to it, the carry over to the road scene should be greater than when the number of letter-strings is more predictable. In this second experiment, we manipulated the predictability of the number of letter-strings presented prior to the road scene. When there is less predictability (between 1 and 10 letter-strings before the road scene), we predict that the carry over effect will be marginally greater than when there is more predictability (between 1 and 3 letter-strings before the road scene).

3.1. Method

Thirty six naïve participants (14 male, modal age 19 years) recruited by opportunity sampling took part in this study. Each participant was paid £7 or given course credits for their participation. All participants self-reported that they had normal or corrected-to-normal vision.

The same experimental set-up was used here as in the previous Experiment, but without the additional battery of cognitive tasks. The only modifications to the procedure was the number of letter-strings presented to participants before the road scene and the amount of trials presented. In the previous version of the task the letter string comprised either one or three letter-strings before the hazard scene was presented. As such, the presentation of the hazard scene could be reliably predicted following the first letter string or the third. In this experiment, we termed this condition more predictable. We also included a second version of the task that made the presentation of the hazard difficult to predict. In this instance, there was between 1 and 10 letter-strings, set at random, before the presentation of the hazard scene (less predictable). As a result of the increased number of conditions the amount of stimuli presented in each condition was split. The original 108 hazard scenes were divided into two sets of 54 images. Each condition therefore had 54 trials that presented a hazard scene. The presentation of hazard scenes was counterbalanced across the two blocks such that each set of 54 images was presented an equal number of times in each block across participants. The order of task presentation was also counterbalanced such that half the participants received the more predictable condition first and half received the less predictable condition first. Additionally, participants indicated when they had detected the hazard by pressing the space bar and subsequently verbalised the hazard.

3.2. Results

The analysis protocol was identical to the previous experiment. Table 4 summarises the means and standard errors for proportion of horizontal and vertical eye-movements, hazard rating, and response time to detect the hazard for Experiment 2. These dependent variables were subjected to parallel 2 x 2 within-subjects ANOVAs with the factors: predictability of the number of letter-strings and orientation of the letter-strings.

There were a greater proportion of vertical saccades made following the vertical letter-string than the horizontal letter-string (mean difference = .18), $F(1, 29) = 139.18$, $MSE = 0.07$, $p < .001$, $\eta_p^2 = .83$. More vertical saccades were made following more predictable letter searches than less predictable letter searches (mean difference = .53), $F(1, 29) = 8.17$, $MSE = 0.01$, $p = .008$, $\eta_p^2 = .22$. Crucially, the interaction between predictability and letter-string orientation was also significant, $F(1, 29) = 5.56$, $MSE = 0.01$, $p = .025$, $\eta_p^2 = .16$. Bonferroni-corrected pairwise comparisons revealed that, while there were more vertical eye movements following the vertical letter string than the horizontal letter string when the number of letter-strings was more predictable (mean difference = .15, $p < .001$, Cohen's $d = 1.16$) and less predictable (mean difference = .21, $p < .001$, Cohen's $d = 1.70$), the effect size was larger when the number of letter strings was less predictable than when it was more predictable.

In a similar vein, when horizontal saccades were the DV, there were a greater proportion of horizontal saccades following the horizontal letter-string than the vertical letter-string (mean difference = .40), $F(1, 29) = 396.79$, $MSE = 0.01$, $p < .001$, $\eta_p^2 = .93$. More horizontal saccades were made following more predictable letter searches than less predictable letter searches (mean difference = .08), $F(1, 29) = 20.05$, $MSE = 0.01$, $p < .001$, $\eta_p^2 = .41$. The interaction between these two variables (predictability and letter-string orientation) was not significant, $F(1, 29) = 0.16$, $MSE = 0.07$, $p = .694$, $\eta_p^2 = .01$.

To test the hypothesis regarding whether predictability of the number of letter-strings affected this carry over effect, we ran a within-subjects *t*-test between the magnitude of the carry over effect (as calculated in Experiment 1) in the less and more predictable conditions. The less predictable the number of letter-strings, the larger the carry over effect, $t(29) = 5.50$, $p < .001$.

Table 4 about here

Consistent with Experiment 1, we also found that participants rated the road scenes as less hazardous following the vertical letter-strings than the horizontal letter-strings (mean difference = 0.20), $F(1, 29) = 40.44$, $MSE = 0.03$, $p < .001$, $\eta_p^2 = .58$. This main effect interacted with the effect of predictability, $F(1, 29) = 19.83$, $MSE = 0.03$, $p < .001$, $\eta_p^2 = .41$. This interaction revealed itself through a non-significant difference in hazard ratings when the letter-strings were more predictable (mean difference = 0.06, $p = .89$). However, when the letter strings were less predictable, road scenes were rated as less hazardous following the vertical letter string than the horizontal letter strings (mean difference = 0.34, *p* < .001).

There was also a significant effect of letter-string orientation on response time to detect the hazard, *F*(1, 29) = 4.98, *MSE* = 33211, *p* = .033, η_p^2 = .15, in which hazards were detected faster following horizontal letter-strings than vertical letter-strings (mean difference = 74ms). This effect did not interact with predictability. This non-significant effect seems to be inconsistent with the hypothesis that decreased predictability would enhance the effects of the carry over effect. While the decreased predictability of the number of letter-strings did enhance the carry over effect, this did not have as large an effect on the behavioural measures. Potentially, this is due to the relatively small size of the carry over effect and that its effect on reaction time is mediated by another unknown factor.

3.3. Discussion

These results suggest that the less predictable the number of letter-strings and thereby the onset of the road scene, the larger the carry over effect. This would indicate that the participants oriented their attention more strongly to the letter-string task and were less able to switch to the road task. This suggests that when participants are able to predict when they need to change their attentional set, they are able to do so. We cannot guarantee that our participants had oriented their attention more strongly in the predictable condition, but it seems the more plausible suggestion. The less predictable version of the task essentially avoids any element of prediction whereas the predictable condition still maintains some predictability about what is to come. The predictability manipulation confounded the number of letter-strings relative to hazard images. In the less predictable version, there are approximately 270 letter-strings. In the more predictable version, there are 108 letter-strings to the same number of hazard images. Nevertheless, the increase in number of letter-strings ensures that the participants must be putting more effort into developing their attentional set prior to the hazard image (Thompson *et al.*, 2015). This highlights the importance of attentional orienting, which is thought to be subsumed by the parietal cortex (Fan *et al.*, 2002), in the carry over effect.

The preceding argument could be experimentally tested by increasing or decreasing the activity of these associated brain areas and measuring the carry over effect. We reasoned that if carry over is a biasing of attention achieved through the top-down attentional set (Thompson & Crundall, 2011), then modulation of the associated areas could reduce or increase the magnitude of the carry over effect.

4. Experiment 3

Experiments 1 and 2 indicated that participants' ability to orient their attention is correlated with the magnitude of the carry over effect, and that unpredictability in the number of letter strings before the hazard can influence the magnitude of this effect. That is, when participants are less able to determine when they should change their attentional set they are more likely to retain their attentional set: their orienting has enhanced the activation of a particular location to a point that releasing from this is more difficult. Attentional orienting is associated with activation in the parietal cortex (Posner & Raichle, 1994). While orienting is not directly nor causally related to the ability to disengage, there is a marginal negative correlation between orienting measured through the ANT and measures of disengagement such as the switch cost (Experiment 1, r = .24) and the latent inhibition effect (Experiment 1, r = .42). Therefore, we can suggest that participants whose attentional orienting is too strong cannot easily disengage from one task to the second. The inability to disengage means that the attentional set from the letter search is more likely to persist to the picture search. This orientation is not under the participants' conscious control given that they have no reason to adjust their orienting based on instructions. This indicates that increasing activation of the parietal cortex should increase the magnitude of the carry over effect in most participants.

That said, Experiment 1 also indicated that participants' ability to switch attention as a result of conflicting information correlates with the carry over effect. This ability is thought to correlate with executive function and be subsumed by frontal lobe functioning (Bush *et al*., 2000; MacDonald *et al*., 2000). Therefore, we would predict that increasing the activation in the frontal lobes should increase participants’ ability to disengage from one attentional set and switch to a different attentional set.

We tested these hypotheses in Experiment 3, using the same general procedures as Experiment 2. To alter the activation of the frontal and parietal lobes, we applied transcranial direct current stimulation (tDCS) to the parietal and frontal lobes to assess the involvement of these areas in attentional orienting and conflicting in the carry over effect. To reiterate, we are making a directional prediction (therefore, α = .1) that anodal stimulation to the parietal cortex would increase attentional orienting and therefore the carry over effect, and anodal stimulation to the dorsolateral prefrontal cortex would enhance task switching and dealing with attentional conflicts, thereby reducing the carry over effect.

4.1. Method

4.1.1. Participants

Eighteen naïve participants (6 male, modal age 19 years) recruited by opportunity sampling took part in this study. Participants were paid £7 an hour for their time. Prior to the experiment, all participants completed a pre-screening questionnaire. All participants met the following inclusion criteria: no history of neurological or psychiatric disorders; not taking medications currently that may alter brain function; not having a recent high intake of drugs/alcohol/caffeine; no medical implants; normal or corrected-to-normal vision; and no history of head injuries or concussions resulting in loss of consciousness or hospitalization. A brief interview was administered before each stimulation session to ensure this remained unchanged.

4.1.2. Materials, Design, and Procedure

The same materials, design, and procedure used in Experiment 2 were employed here, with the addition of tDCS. A double-blind procedure was employed whereby the tDCS device was programmed by a third party according to the specification of the authors. The procedure was administered by an experimenter who was unaware of whether the procedure was anodal or sham.

Half of participants were stimulated at P3 (parietal), the other half of participants at F3 (frontal) site according to the 10-20 EEG placement system. The reference electrode was positioned over the right suprafrontal area (just above the right eyebrow). Stimulation was delivered using a BrainSTIM transcranial stimulator (BrainSTIM, EMS) using two 5cm × 5cm electrodes encased with saline-soaked sponges. In the active condition, a direct current of 1.5mA was delivered. Stimulation in both conditions ramped-up and faded-out during the first and last 10s, but delivered no current for the duration of the task in the sham condition.

Stimulation was delivered for 10 minutes immediately prior to the task. During this 10 minutes participants completed a small filler task whereby they answered a questionnaire and listened to the instructions of the task. After stimulation participants completed the carry over task. Stimulation and the associated tasks were performed across two days. All participants completed both sessions (active and sham). Each session was administered at least 24 hours apart. The order of stimulation was also counterbalanced across participants such that half received active stimulation in their first session and the other half received sham.

4.2. Results

The analysis protocol was identical to the previous experiments. Table 5 summarises the means and standard errors for proportion of horizontal and vertical eye-movements, hazard rating, and response time to detect the hazard for Experiment 3. These dependent variables were subjected to parallel 2 x 2 x 2 x 2 mixed ANOVAs with the factors: site of stimulation (F3 or P3), nature of stimulation (active or sham), predictability of the number of letter-strings, and orientation of the letter-strings.

Replicating the basic carry over effect, we found that there were more horizontal saccades following the horizontal letter-search than the vertical letter-search (mean difference = .31), $F(1, 16) = 323.31$, $MSE = 0.01$, $p < .001$, $\eta_p^2 = .95$. Similarly, there were more vertical saccades following the vertical letter-search than the horizontal letter-search (mean difference = .10), $F(1, 16) = 60.75$, $MSE = 0.06$, $p < .001$, $\eta_p^2 = .79$. Consistent with Experiment 2, this effect interacted with the predictability of the number of letter-strings, $F(1, 16) = 6.36$, $MSE = 0.02$, $p = .023$, $\eta_p^2 = .28$, whereby the carry over effect was greater when the number of letter-strings was less predictable (mean difference = 0.36, Cohen's $d = 2.19$) than when it was more predictable (mean difference = .25, Cohen's $d = 1.57$).

To directly assess whether stimulation altered the magnitude of the carry over effect, we conducted a 2 x 2 x 2 mixed-measures ANOVA on the magnitude of the carry over effect as calculated in Experiment 1 with the factors: stimulation site, nature of stimulation, and predictability of the number of letter-strings. This revealed a main effect of site of stimulation, $F(1, 16) = 4.78$, $MSE = 0.09$, $p = .044$, $\eta_p^2 = .23$, in which the carry over effect was larger following stimulation to site P3 than F3. There was a trend for this effect of site of stimulation to interact with stimulation type, $F(1, 16) = 3.39$, $MSE = 0.01$, $p = .084$, $\eta_p^2 = .18$ (significant using a one-tailed test). This interaction (shown in Figure 3) was revealed through a non-significant difference between the sites of stimulation during sham stimulation (mean difference < .01, $p = .85$), whereas during active stimulation, the site did affect the magnitude of the carry over effect (mean difference = .09, $p = .025$).

Table 5 about here

Figure 3 about here

Replicating the previous experiments, we found that the response time to detect the hazard was slower following the vertical letter-string than the horizontal letter-string (mean difference = 212 ms), $F(1, 16) = 22.69$, $MSE = 71975$, $p < .001$, $\eta_p^2 = .59$. As in the preceding experiment, we found that hazard ratings were lower following the vertical letter-strings than the horizontal letter-strings (mean difference = 0.07), $F(1, 16) = 4.16$, $MSE = 0.05$, $p = .058$, $\eta_p^2 = .21$. Once again, we did not find interactions with predictability nor any effects on reaction times. This is likely due to the smaller number of trials in these conditions in this Experiment compared to Experiment 1 and therefore increased error.

4.3. Discussion

These results were consistent with our hypotheses. The effect of the letter-string orientation was largely greater when participants received stimulation to their parietal cortex than when they received stimulation to their frontal cortex. The results indicated that frontal stimulation reduced the magnitude of the carry over effect relative to stimulation to the parietal cortex. The pattern indicates that stimulation altered the magnitude of carry over relative to sham stimulation. Assuming the parietal cortex is responsible for attentional orienting, these results indicate that participants who too strongly orient their attention to the letter-string task are more likely to use the same attentional set when viewing the subsequent road scene than participants who do not strongly orient their attention. Stimulation to the frontal cortex is thought to enhance task switching ability and dealing with attentional conflicts. The results indicate that enhancing activation in this area reduces the carry over effect as participants are able to more easily switch their attentional set from one task to a second task.

5. General Discussion

In three experiments, we have shown that the carry over of eye-movements from one task affects visual scanning, and performance in a second, unrelated task. Experiment 1 showed that carry over positively correlated with attentional orienting and negatively with attentional conflicting. Experiment 2 demonstrated that increasing participants' engagement in the initial task enhanced the carry over effect. Experiment 3 demonstrated that increasing activation in the parietal lobes produced a larger carry over effect compared to increasing activation in the frontal lobes. Models of visual search (such as that of Itti & Koch, 2000) typically do not include elements of carry over (Thompson & Crundall, 2011), and although the persistence of search strategy from an initial task is a relatively small effect (compared to the top-down and bottom-up influences associated with a task), accounting for this effect may improve the abilities of such models to predict visual search. Furthermore, the size of the carry over effect shows that the influence of a preceding task on subsequent eye-movements interacts with experience and knowledge (top-down influences) and the salience of visual information (bottom-up influences) in a second task. The transference of search between two unrelated tasks has now been replicated across a number of experiments and laboratories, showing it to be a robust finding. It is therefore important to account for the effect, and theorize as to the mechanism by which it occurs.

Based on the results of the three studies here, we are suggesting that during the letter-search task, participants orient their attentional resources in the plane consistent with the letter-strings. The strength of this orienting depends on whether the participants can accurately anticipate when they will need to shift their attention, the level of activation in their parietal cortex, and their own individual orienting abilities. When the task changes, the attentional system detects a conflict between the previous attentional orientation and the new task demands. The attentional set must then be switched from one to another. This second part of the carry over effect is based on frontal lobe functioning and the participants' own executive functioning.

In the letter-search task, attention may have been allocated in two different ways: activation of task-relevant locations (or task-relevant eye-movements); or inhibition of task-irrelevant locations (or movements). Thus, attentional allocation may be spatial or behavioural. Similar to visual marking or inhibition of return (Posner, Rafal, Choate, & Vaughan, 1985), task-irrelevant locations and eye movement behaviour may be marked in the letter search (Watson & Humphreys, 1997). Indeed, cells responsible for covert shifts of attention appear to hold the location of preceding cues during a delay interval (Armstrong, Chang, & Moore, 2009). Indeed, similar to the deactivation of the visual world in spatial neglect, the preceding task may enhance the saliency of particular spatial locations (Corbetta & Shulman, 2011). However, it is important to note that the empty space that surrounded the letter search, in all conditions, would not require any cognitive resources. Indeed, this is alluded to by Thompson and Crundall (2011) who discount this theory because of a lack of evidence for attentional allocation to blank space. Evidence from spatial neglect indicates that apparent increase in saliency of one area of the visual field may be the result of abnormally high saliency of these locations (Bays, Singh-Curry, Gorgoraptis, Driver, & Husain, 2010; Shomstein et al., 2010; Snow & Mattingley, 2006). Thus, if this strategy carried over to a second task, allocation of resources to these locations would be limited in this task. Alternatively, attention to the task-relevant locations in the letter search may be achieved using a weighting mechanism (cf., Bundesen, 1990); with the most relevant stimuli/locations receiving a higher 'weight' and resources then allocated on the basis of the weights. The carry over effect would then arise because these weights remain to the next visual scene where they interact with weights that are allocated on the basis of saliency (e.g., Itti & Koch, 2000), and past experience (e.g., Gilchrist & Harvey, 2006; Loftus & Mackworth, 1978).

The premise of selective attention is that it allows for effective processing because resources are allocated to the most relevant information. In our letter-search task , the task-irrelevant locations outnumber the task-relevant locations, meaning that inhibition of irrelevant locations/movements would potentially require greater resources than activation of relevant locations/movements. In addition, irrelevant locations in the letter search task are blank and (as stated above) there is some argument regarding the visual marking of empty space. As a result, we would favour a weighting mechanism that combines previous attentional allocation with saliency and past experience.

Despite supporting an ‘activation’ account of selection, the carry over effect may also involve an element of inhibition. Our finding that, participants who can inhibit information outside the immediately-attended point show a smaller carry over affect supports this claim. That is, we have demonstrated that magnitude of carry over varies between individuals, suggesting that some individual are more adept at inhibiting persisting signals (or weights) from a preceding task. The switch cost indicates that motor inhibition is also required to adequately prevent the carry over effect. In a literal sense, those who resolve conflicts between incoming visual signals and preceding information more efficiently are better able to inhibit motor (and oculomotor) responses. These effects may come under the umbrella of cognitive control.

Critically for the applications of this work, we have shown that the attentional strategies employed by an individual are not always altered in line with a change in task demands. Attention may therefore continue to be allocated based on the demands of a preceding task, having a potentially negative consequence on performance, and important implications. In driving settings, this impacts on the safety of the driver: reading road signs or information on a Sat-Nav may cause an alteration to scanning behaviour and increase the risk of a hazard being missed. It is imperative that research is directed to explore the extent of this effect and to what degree this carry over effect influences safety.

5.1. Conclusion

We have demonstrated that eye-movements carry over from one task to another with potentially deleterious effects. The carry over effect, although small in comparison to other influences upon visual scanning, suggests that the design of task-related stimuli should attempt to induce a scanning strategy that is most effect for the specific task one is completing (i.e., in driving this would be a wide horizontal search). Crucially, we have also shown that individuals who have difficulties switching, and who show poorer performance at conflict resolution and better orienting in the ANT are more likely to suffer from carry over. Stimulation of the parietal cortex appears to increase attentional orienting and therefore the carry over effect, relative to stimulation of the frontal lobe which appears to increase task switching abilities and reduced the carry over effect. These results highlight the complex nature of switching behaviours from one task to another and the interplay between attentional orienting, subsumed by the parietal cortex, and attentional conflict, subsumed by the frontal cortex.

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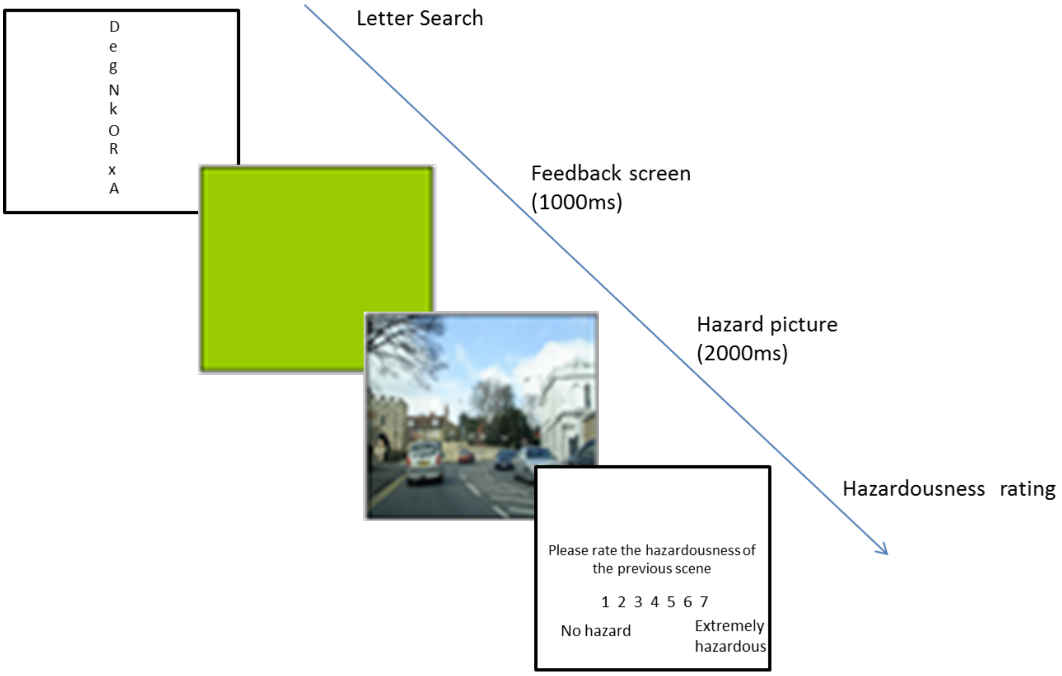
Figure Caption

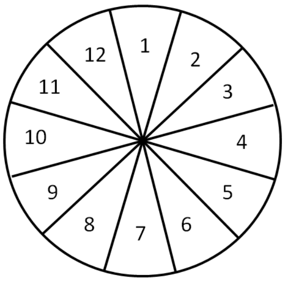
Figure 1. An example of the basic procedure, search conditions, hazards, and rating scale used during the letter search/hazard perception task. The figure displays an example of the vertical letter search condition.

Figure 2. The "binning" of the 'direction of the first saccade' measure. The first coding binned the angle of the eye-movement according to one of the 12 bins on a clock face. The second coding step ensured that the left and right and up and down movements did not cancel each other out by pairing the bins according to a coherent direction. The three resulting bins are shown in panel b. While more bins made up the non-axial movement, this is controlled for using the appropriate sums of squares. In addition, there are typically fewer saccades in these directions than in the vertical and horizontal planes (Leigh & Zee, 1999).

Figure 3. Mean magnitude of carry over of eye movements from the letter-string task to the hazard detection task for Experiment 3 split by site of stimulation (F3 or P3) and type of stimulation (active or sham). Error bars represent standard error.


D
e
g
N
k
O
R
x
A
Letter Search
Feedback screen
(1000ms)
Hazard picture
(2000ms)
Hazardousness rating
Please rate the hazardousness of the previous scene
1 2 3 4 5 6 7
No hazard
Extremely hazardous

a.



b.

Bin	Bins	Direction
1	1 (Up) and 7 (down)	Vertical movements
2	2, 3, 5, 6, 8, 9, 11, and 12	Non-axial movements
3	4 (right) and 10 (left)	Horizontal movements

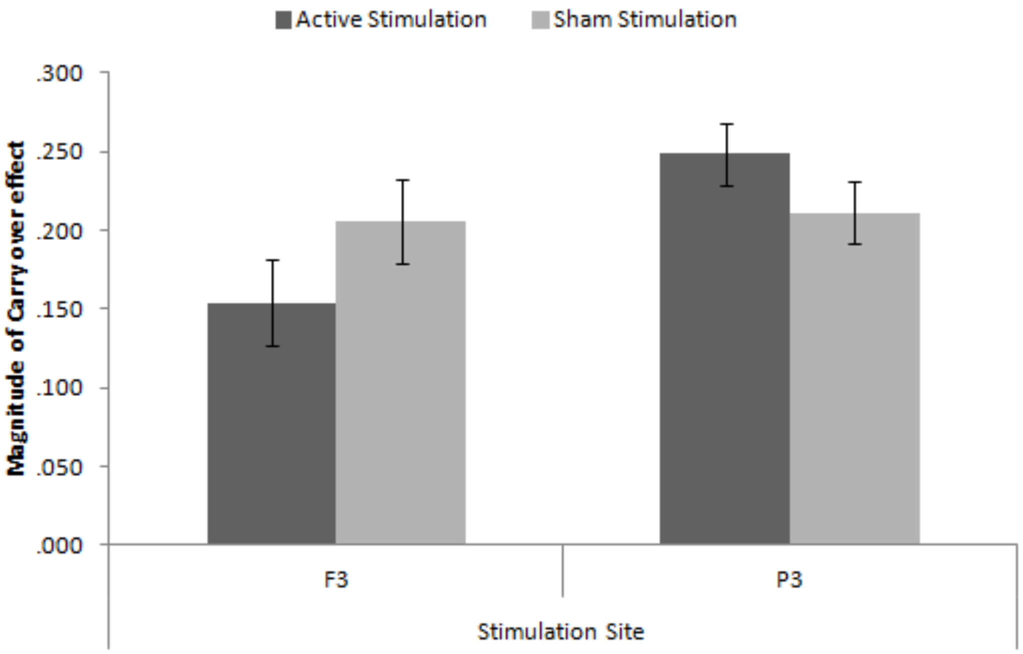


Table 1.

Mean (and standard error) proportion of horizontal and vertical first eye-movement, hazard rating response time (ms), hazard rating, and hazard perception accuracy for Experiment 1.

	Letter-String Orientation		
	Horizontal	*Vertical*	*Random*
Proportion of Horizontal First Eye-movement	.47 (.01)	.35 (.01)	.43 (.01)
Proportion of Vertical First Eye-movement	.25 (.01)	.36 (.01)	.28 (.01)
Hazard Reaction Time	1214 (28)	1282 (29)	1245 (27)
Hazard Rating	3.38 (0.09)	3.13 (0.07)	3.28 (0.09)
Hazard Perception Accuracy	97% (0.70)	88% (1.00)	95% (1.60)