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Visual asymmetry revisited: Mind wandering preferentially disrupts processing in the left visual field

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ABSTRACT

An emerging theory proposes that visual attention operates in parallel at two distinct time scales – a shorter one (<1 s) associated with moment-to-moment orienting of selective visuospatial attention, and a longer one (>10 s) associated with more global aspects of attention-to-task. Given their parallel nature, here we examined whether these comparatively slower fluctuations in task-related attention show the same visual field asymmetry – namely, a right visual field bias – as often reported for selective visual–spatial attention. Participants performed a target detection task at fixation while event-related potentials (ERP) time-locked to task-irrelevant visual probes presented in the left and right visual fields were recorded. At random intervals, participants were asked to report whether they were "on-task" or "mind wandering". Our results demonstrated that sensory attenuation during periods of "mind wandering" relative to "on-task", as measured by the visual P1 ERP component at electrodes sites contralateral to the stimulus, was only observed for probes presented in the left visual field. In contrast, the magnitude of sensory gain in the right visual field was insensitive to whether participants were "on-task" or "mind wandering". Taken together, our results support the notion that task-related attention at longer time scales and spatial attention at shorter time scales affect the same underlying mechanism in visual cortex.

1. Introduction

Fundamental to human neurocognitive function, mind wandering reflects transient periods of time during which our attention drifts away from the on-going task to focus on the internal milieu. These regular fluctuations in the extent of our engagement with the external environment have been shown to be normative to healthy functioning of the human brain (e.g., Schooler et al., 2011; Smallwood, 2013). Importantly, this oscillation between on-task and mind wandering states is a regular and periodic experience that occupies a notable portion of our mental life (e.g., Killingsworth & Gilbert, 2010; Klinger & Cox, 1987; Smallwood & Schooler, 2006). While much research has been devoted to examining the neural regions involved in mind wandering (e.g., Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; Kirschner, Kam, Handy, & Ward, 2012; Mason et al., 2007) and the content of these thoughts (Killingsworth & Gilbert, 2010; McVay, Kane, & Kwapil, 2009; Smallwood et al., 2011), a critical and related issue concerns how mind wandering changes how we process external stimuli. Specifically, given that mind wandering has been shown to attenuate early cortical processing of incoming visual information (Braboszcz & Delorme, 2011; Kam et al., 2011), does task-related attention differentially alter sensory processing of visual stimuli in the left vs. right visual fields?

On one hand, behavioral findings have associated selective spatial attention with a visual field asymmetry wherein attention favors, or is stronger in, the right visual hemifield (e.g., Chokron, Brickman, Wei, & Buchsaum, 2000; Reuter-Lorenz, Kinsbourne, & Moscovitch, 1990; Umilta & Nicoletti, 1985). The bias itself is manifest in shorter reactions times to target events in the RVF vs. LVF, which has been generally interpreted as enhanced processing efficiency in the RVF. For instance, in the context of rapid attentional orienting, reflexive or automatic attention appears to favor RVF as indicated by shorter reaction times (e.g., Castro-Barros, Righi, Grechi, & Riberiro-Do-Valle, 2008). Further, several studies have also reported shorter reaction times to stimuli presented in the RVF relative to the LVF in target detection tasks requiring inhibition of repetitive events (Chokron et al., 2000, 2003), as well as forced choice tasks (e.g., Anzola, Bertolini, Buchtel, & Rizzolatti, 1977; Umilta & Nicoletti, 1985), suggesting the RVF's superiority in selective attention over the LVF as indexed by behavioral measures. In a similar vein, this RVF advantage in visual processing is

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also present in some neurological conditions and clinical populations that have been associated with disrupted attentional control processes. For example, unilateral spatial neglect patients are more likely to experience neglect in the LVF as opposed to the RVF (Gainotti, D'Erme, Monteleone, & Silveri, 1986; Robertson & Marshall, 1993). Similarly, older adults with a history of falls exhibit reduced attentional facilitation to stimuli in the LVF (Nagamatsu, Liu-Ambrose, Carolan, & Handy, 2009). Of importance, while these lines of evidence point toward a RVF advantage in attentional processing over short time scales in both healthy and clinical populations, this is not to say that selective attention operates in a fundamentally different fashion between the two hemifields. Rather, these findings together suggest the spatial attention effect in the RVF is simply more robust or greater in magnitude.

On the other hand, event-related potential (or ERP) evidence has demonstrated that selective attention can equally modulate initial cortical responses in visual cortex to stimuli presented in both hemifields (e.g., Handy & Mangun, 2000; Luck et al., 1994; Mangun & Hillyard, 1991). For instance, sensory responses to visual inputs presented in the left visual field (LVF) and right visual field (RVF) were equally enhanced at the selectively attended location (Mangun & Hillyard, 1991). Moreover, voluntary attention appears to behave similarly across both LVF and RVF, such that quicker reaction time was associated with the visual input at the attended location, regardless of visual field (e.g., Castro-Barros, Lacerda, Righi, & Riberiro-Do-Valle, 2012; Posner, 1980). Accordingly, if directed visual attention can bias sensory responses in both visual hemifields, does task-related attention modulate visual sensory gain control in a similar, somewhat unbiased manner?

The question itself speaks to the temporal nature of top-down attentional control of visual sensory processing. In this regard, a recent theory has proposed that attentional control operates at two distinct time scales (Dosenbach, Fair, Cohen, Schlaggar, & Petersen, 2008) – a shorter one associated with rapid shifts of selective attention (e.g., Mangun & Hillyard, 1991; Posner, 1980), and a longer one associated with slower temporal fluctuations of task-related attention (Kam et al., 2011; Smallwood & Schooler, 2006). For example, in the context of visual attention, we can selectively orient our attention to discrete locations in space on a subsecond time scale (e.g., Posner, 1980), an ability tied to an executive control network in dorsolateral frontal and superior parietal cortices (e.g., Hopfinger, Buonocore, & Mangun, 2000). On the contrary, more recent evidence indicated the strength of our sensory response to visual stimuli also fluctuates over slower (>10 s) time scales (e.g., Braboszcz & Delorme, 2011; Kam et al., 2011). These effects were linked to the default mode network localized in more medial brain regions, including the ventral anterior cingulate cortex, precuneus and the temporoparietal junction (e.g., Christoff et al., 2009; Kirschner et al., 2012; Mason et al., 2007). Given that visual processing is labile to attentional control at multiple time scales, the question we examined here is whether slow fluctuations in visual sensory gain control conform to the RVF bias as seen in selective attention at a behavioral level, or whether they show a more homogenous modulatory capacity across the two lateral visual hemifields, as evinced by ERP-based measures of sensory gain control?

How might recent evidence on mind wandering shed light on this issue? For one, mind wandering has been shown to attenuate sensory level responses to visual inputs in a target detection task (e.g., Kam et al., 2011). This mind wandering effect in ERP measure however did not correspond to impairments in reaction time during mind wandering. The absence of attentional state modulations in the behavioral measure highlights the importance and utility of ERP measures in examining the underlying neural mechanism that may not manifest as differences in manual reaction times. In addition, other EPR studies have that mind wandering periods are associated with disruptions in a range of cognitive responses, including stimulus evaluation and categorization (Barron, Riby, Greer, & Smallwood, 2011; O'Connell et al., 2009; Smallwood, Beach, Schooler, & Handy, 2008), affective processing (Kam, Xu, & Handy, 2014), and performance monitoring (Kam, Dao, Stanciulescu, Tildesley, & Handy, 2013). Of relevance, given that visual stimuli used in these previous studies have been presented along the midline of the visual field (e.g., Barron et al., 2011; Kam et al., 2011; Smallwood et al., 2008), to what extent would we observe a similar attenuation of sensory gain to task-irrelevant visual stimuli across both hemifields?

The present study to our knowledge is the first to examine whether task-related attention shows an asymmetry in mechanisms of visual sensory gain control. While participants performed a target detection task at central fixation, we periodically asked them to report their attentional state as either "on-task" or "mind wandering". We then examined the ERPs elicited by task-irrelevant lateral visual probes in order to assess the magnitude of visual sensory gain in each hemifield as a function of whether or not attention was on task. To the extent that task-related attention's effect on sensory gain control conform to the RVF advantage as seen in selective attention at a behavioral level and in certain clinical conditions, one would predict the attenuation of sensory gain control normally observed during mind wandering states may be spared in the RVF. On the other hand, to the extent that task-related attention exerts similar forms of top-down attentional control on visual sensory gain control as selective spatial attention as reported in previous ERP studies (e.g., Mangun & Hillyard, 1991), one would predict similar attenuation of the sensory gain control during mind wandering across both visual hemifields.

2. Methods

2.1. Participants

Fourteen undergraduate students (11 females; mean age = 21.36 years, range 18–25 years) from the University of British Columbia completed the study in exchange for $20 (Canadian dollars). All participants were right-handed and had corrected or corrected-to-normal vision. They provided informed consent to the experimental procedure, according to the guidelines of the UBC Behavioral Review Ethics Board.

2.2. Stimuli and paradigm

Participants performed the sustained-attention-to-response task (SART), which has been used extensively in mind wandering experiments to elicit fluctuations in task-related attentional states given its monotonous nature (e.g., Christoff et al., 2009; Kam et al., 2011; Kirschner et al., 2012; Smallwood et al., 2008). They were presented with a continuous stream of stimuli at fixation. Participants were instructed to make a manual button press for frequently presented numbers (0–9), which we refer to as non-targets, and to withhold their response when presented infrequently with the letter "X", which we refer to as targets. To assess the effects of mind wandering on visually-evoked responses in cortex, small black square-wave gratings ($1° \times 1°$, 2 cycles per degree) in the LVF and RVF were temporally interspersed between each target/non-target stimulus. Participants were informed that these probes were irrelevant to the task, and therefore they could ignore their presence with no decrement to task performance.

Each target or non-target was presented for 500 ms followed by an interstimulus interval that varied between 550 and 750 ms. Two task-irrelevant probes, one on each side of the visual field,