



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 visuospatial 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.

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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, & Kwapiil, 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, & Buchsbaum, 2000; Reuter-Lorenz, Kinsbourne, & Moscovitch, 1990; Umiltà & Nicoletti, 1985). The bias itself is manifest in shorter reaction 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; Umiltà & 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 sub-second 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, Stanculescu, 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 ($1^\circ \times 1^\circ$, 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,

were then presented one after the other for 100 ms each. Following both probes was an inter-trial interval (ITI) that also randomly varied between 550 and 750 ms. The order of presentation of the two probes was randomized, but with the constraint that half the time the probes appeared in the LVF first and half the time the probes in the RVF came first. Within each block, the probability of target occurrence was quasi-randomized, with the constraints that (1) one to two targets were presented during each block, (2) for blocks having two targets, the targets would be separated by at least ten non-target events, and (3) targets did not appear in the last 12 s prior to the end of a trial block (see below). Participants completed up to 40 blocks and were permitted breaks in-between blocks, as requested. Each testing session lasted approximately 2 h.

2.3. Measure of task-related attention

We relied on an “experience sampling” method as a measure of the attentional state of our participants (e.g., Schooler et al., 2011; Smallwood & Schooler, 2006) for several reasons. Considered to be a direct measure of mind wandering, experience sampling relies on our ability to reliably report whether our thoughts center on the on-going task being performed (referred to as an “on-task” state), or alternatively, whether they have drifted off to other issues (referred to as a “mind wandering” state; for a review, see Gruberger, Ben-Simon, Levkovitz, Zangen, & Hendler, 2011). By using the attention report to categorize a participant’s attentional state in the 10–15 s immediately prior to the report, the methodology has been used to demonstrate reliable and replicable differences in neurocognitive functioning between “on-task” and “mind wandering” states (e.g., Christoff et al., 2009; Franklin, Smallwood, & Schooler, 2011; Kam et al., 2011; Kirschner et al., 2012; Mason et al., 2007; McKiernan, D’Angelo, Kaufman, & Binder, 2006; Smallwood et al., 2008; Stawarczyk, Majerus, Maquet, & D’Argembeau, 2011). In fact, recent evidence has suggested that the time course of task-related attention fluctuation approximates this time window (e.g., Christoff et al., 2009; Sonuga-Barke & Castellanos, 2007). As such, our approach to defining attentional states aligned with widely-accepted norms in the field of mind wandering research.

At the end of each trial block, participants were instructed to report their attentional state, as either being “on-task” (fully attentive to task performance at block’s end), or “mind wandering” (unattentive to the task at block’s end). To facilitate this, participants were provided with descriptions of these attention states prior to testing: “on-task” states were defined as when one’s attention was directed toward the task, whereas “mind wandering” states were described as when one’s attention was directed to other things than just the task. Attentional reports were recorded by the investigator at the conclusion of each trial block, and these reports were then used to categorize ERP and behavioral data based on “on-task” vs. “mind wandering” states as described above. The block duration itself was randomly varied between 30 and 90 s in order to (1) minimize predictability of block completion and (2) maximize variability of attentional state at the time of block completion (c.f. Kam et al., 2011, 2012, 2013; Smallwood et al., 2008).

2.4. Electrophysiological recording and analysis

Electroencephalograms (EEG) were recorded from 64 active electrodes mounted on a cap in accordance to the International 10–20 system using a Biosemi Active-Two amplifier system. Two additional electrodes (Common Mode Sense and Driven Right Leg) were used as ground electrodes, while two additional channels recorded potentials from the right and left mastoid to use for later re-referencing of the ERP waveforms. All EEG activities

were amplified with a band-pass filter of 0.1–30 Hz (1/2 amplitude cutoffs), digitized on-line at a sampling rate of 256 samples-per-second. To ensure proper eye fixation, vertical and horizontal electrooculograms (EOGs) were also recorded – the vertical EOGs from one electrode inferior to the right eye, and the horizontal EOGs from two electrodes on the right and left outer canthus.

Off-line, computerized artifact rejection was used to eliminate trials during which detectable eye movements, blinks, or muscle potentials occurred. These eye artifacts were detected by identifying the minimum and maximum voltage values on all recorded EOG channels from –200 to 800 ms post-stimulus for each event epoch, and then removing the trial from subsequent signal averaging if that value exceeded 200 μV , a value calibrated to capture all blinks, saccades, and other eye movements exceeding approximately 1 degree of visual angle. An average of 13% of the total number of trials across participants were rejected due to these signal artifacts. The percentage of trials rejected during on-task vs. mind wandering periods did not significantly differ from each other ($t(13) = -0.85$, $p = .409$). EEG data were then algebraically re-referenced to the average of the left and right mastoid signals, and filtered with a low-pass Gaussian filter (25.6 Hz half-amplitude cut-off) to eliminate any residual high-frequency artifacts in the waveforms. The resulting EEG data were used to generate grand-averaged waveforms.

All ERP data analyses were based on mean amplitude measures using repeated-measures ANOVAs, with specific time-windows of analyses identified below as per each reported ANOVA. The analysis time-windows were centered on the peak of the relevant component as identified at each electrode site and experimental condition in the grand-averaged waveform. These measures were all taken relative to a –200 to 0 ms pre-stimulus baseline. The ERP waveforms were based on averaging together the EEG epochs for the six LVF and RVF probes separately that were presented in the 12 s preceding each attention report (on-task vs. mind wandering) – a time window we have used previously with ERP data (e.g., Kam et al., 2011, 2012, 2013; Smallwood et al., 2008). Our analyses were based on the assumption that the 12 s prior to each report would, on average, reliably capture the given attentional state. The number of pre-marker events included in the averages was designed to maximize the number of events that can be included in the ERP averages while still maintaining a reasonable fidelity to the actual attentional report (i.e., as the time window increases, the signal-to-noise ratio of the ERP averages improves, but the validity of the attention report for individual events decreases). Statistical analyses were performed in Event-Related Potential Software System, custom software specifically designed for analyzing ERP data.

3. Results

3.1. Attentional state report

Participants completed an average of 38.5 trial blocks (range: 28–40). On average, 38% ended with a “mind wandering” report and 62% ended with an “on-task” report ($SEM = 4.27$).

3.2. Behavioral data

Reaction time data for two subjects were corrupted, and therefore not included in the analysis. The difference in reaction time between trials preceding on-task reports ($Mean = 319$ ms; $SD = 40$ ms) and trials preceding mind wandering reports ($Mean = 320$ ms; $SD = 54$ ms) was not significant ($t(11) = -0.17$, $p = 0.867$). The absence of attentional modulations in the reaction time measure is consistent with previous studies employing

experience sampling during SART (e.g., Kam et al., 2011). We also examined the relationship between percentage of on-task reports and overall reaction time, but the correlation was not significant ($r(12) = 0.38, p = .225$).

With respect to accuracy, participants successfully withheld their response from targets (i.e., X) 61.70% ($SD = 15.21\%$) of the time. Further, accuracy rate was positively correlated with the percentage of on-task reports ($r(14) = 0.61, p = .020$). That is, those who showed higher propensity for staying on-task were also more successful in withholding their response to targets, thus providing validation for our task-related attention reports.

3.3. ERP data

The primary objective of the ERP data analyses was to examine whether mind wandering differentially influenced visual sensory gain control in the LVF and RVF, as measured by the lateral occipital P1 component elicited by the parafoveal probe stimuli presented in both visual fields. As a secondary aim, we also assessed whether attentional states affected the cognitive analysis of visual inputs, as measured via the P3 component elicited by the non-targets. In both cases, ERP waveforms for on-task and mind wandering states were based on probes/non-targets presented within the last 12 s of each trial block, as described above.

3.3.1. Sensory response

For the P1 component, we conducted repeated-measures ANOVAs with factors of attentional state (on-task vs. mind wandering), probe location (LVF vs. RVF), laterality (ipsilateral vs. contralateral), and lobe (occipital: O1 and O2, vs. parieto-occipital: PO7 and PO8); in the interest of brevity, we only report effects associated with attentional state, probe location, and laterality. The P1 components elicited by LVF and RVF probes examined at lateral occipital scalp electrode sites, O1, O2, PO7 and PO8 as a function of attentional state are shown in Fig. 1A and B. The time-windows were centered on the peak of the P1 component as identified at each electrode site in the grand-averaged waveform for each condition. Given that peak latency of the P1 component shifts depending on whether the electrode site is ipsi- or contra-lateral to lateralized stimulus (e.g., Handy & Mangun, 2000), the time-windows of our analyses will shift accordingly, with the peak latency at contra-lateral sites typically occurring earlier than at ipsi-lateral sites.

When examining LVF probes, mean amplitude measures for electrode sites O1/PO7 and O2/PO8 were taken across a 140–160 ms and 100–120 ms post-stimulus time window respectively, based on the latencies of the P1 peaks in the grand-averaged waveforms. While examining RVF probes, mean amplitude measures were taken across a 90–130 ms and 100–140 ms post-stimulus time window for electrode sites O1/PO7 during on-task and mind wandering periods respectively; as for O2/PO8, mean amplitude measures were taken across a 130–160 ms post-stimulus time window, again based on the latencies of the P1 peaks in the grand-averaged waveforms. The mean P1 amplitudes in response to probe stimuli in the LVF and RVF are reported separately for each of the two attentional states in Table 1.

Neither main effects of attentional states nor probe location were significant (all p 's > 0.800). There was a significant interaction between attentional states and probe location ($F(1, 13) = 10.80, p = 0.006$). Critically, we found a marginally significant interaction between attentional states, probe location and laterality ($F(1, 13) = 4.42, p = 0.056$). To follow up on this interaction, we conducted separate analyses within each probe location. For LVF probes, while the main effect of attention was not significant ($F(1, 13) = 2.04, p = 0.176$), there was a significant interaction between attentional state and laterality ($F(1, 13) = 8.31, p = 0.013$). Follow-up analyses revealed that periods of mind wandering relative to on-task were associated with a significant reduction in the P1 amplitude at the contralateral electrode sites for the LVF probes ($F(1, 13) = 4.78, p = 0.048$), but not at the ipsilateral sites ($F(1, 13) = 0.06, p = 0.812$). However, this attentional state by laterality interaction was not observed for RVF probes ($F(1, 13) = 2.06, p = 0.175$). The main effect of attention for RVF probes was also not significant ($F(1, 13) = 1.51, p = 0.242$).

3.3.2. Cognitive response

For the P3 component, repeated measures ANOVAs included factors of attentional state (on-task vs. mind wandering), and electrode sites (P1, Pz, P2). The P3 components elicited by target stimuli as a function of attentional state are shown in Fig. 2, and were examined at parietal scalp electrode sites, P1, Pz, and P2. Mean amplitude measures were taken across a 250–400 ms post-stimulus time window. The main effect of attentional state was not significant ($F(1, 13) = 0.94, p = 0.349$), neither was the attentional state by electrode site interaction ($F(1, 13) = 0.67, p = 0.522$).

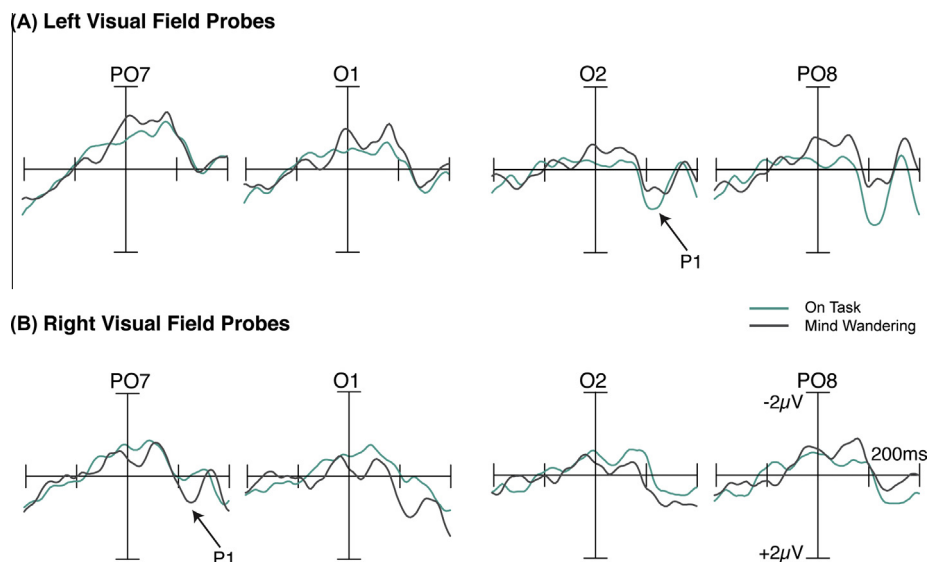


Fig. 1. Sensory response: P1 elicited by visual probes in the (A) LVF and (B) RVF, as a function of attentional state. The amplitude of P1 at contralateral electrode sites was significantly attenuated during mind wandering periods relative to on-task periods in response to LVF probes but not RVF probes.

Table 1
Mean P1 amplitudes (and standard errors) for left visual probes (top) and right visual probes (middle) and mean P3 amplitudes for non-targets (bottom) are presented below by attentional state (on-task and mind wandering). For task-irrelevant visual probes, these mean amplitudes were measured at electrode sites O1/PO7 or O2/PO8. For task-relevant non-targets, mean P3 amplitudes were measured at P1, Pz, and P2. All amplitudes were measured relative to a –200 to 0 baseline.

Component	Laterality	Electrodes	Attentional state	
			On-task	Mind wandering
P1 (probes) left visual field	Ipsilateral	O1	0.50 (0.21)	0.40 (0.38)
		PO7	0.04 (0.14)	0.02 (0.20)
	Contralateral	O2	0.89 (0.32)	0.47 (0.34)
		PO8	1.28 (0.31)	0.32 (0.30)
P1 (probes) right visual field	Ipsilateral	O2	0.41 (0.39)	0.70 (0.40)
		PO8	0.66 (0.42)	0.32 (0.30)
	Contralateral	O1	–0.01 (0.49)	0.86 (0.67)
		PO7	0.02 (0.51)	0.47 (0.52)
P3 (targets)		P1	4.70 (1.19)	4.49 (1.14)
		Pz	4.26 (1.22)	3.99 (1.12)
		P2	4.10 (1.23)	3.57 (1.11)

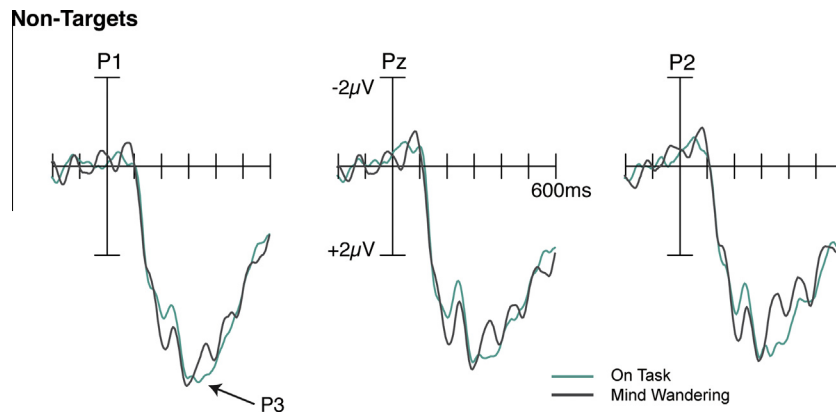


Fig. 2. Cognitive response: P3 ERP component elicited by targets as a function of attention state. The P3 amplitude did not significantly differ between on-task vs. mind wandering state.

4. Discussion

In the current study, we examined whether task-related attention has a differential effect on sensory gain control in the LVF and RVF. Our findings revealed that only the LVF is subject to modulation by mind wandering states. In particular, we found attenuation of the sensory response to the contralateral sites of task-irrelevant stimuli presented in the LVF during periods of mind wandering relative to on-task, but we did not observe this for probes presented in the RVF. These results indicate that mind wandering appears to preferentially disrupt visual sensory gain control of stimulus inputs in the LVF, suggesting that task-related attention can in fact differentially bias the sensory gain mechanism in visual cortex across both visual hemifields. Based on this conclusion, several key issues and implications follow.

First, that the attenuation effect of mind-wandering on sensory processing was spared in the RVF is consistent with visual field asymmetries reported in behavioral studies of selective attention. Specifically, in addition to the RVF advantage previously reported in rapid attentional orientation (Chokron et al., 2000, 2003), we also observed it in slower forms of attentional control as in task-related attention. As such, it appears that visual attention operates at a superior level at the RVF relative to LVF regardless of the control system. Why might there be a RVF advantage? It has been well-established that the right hemisphere orients to both visual fields, whereas the left hemisphere attends exclusively to the RVF (e.g., Mangun et al., 1994). This suggests that the LVF may

be more susceptible to attentional deficits, while the RVF benefits from the attentional orientation from both hemispheres.

A second, related question concerns what might be contributing to this RVF bias in visual sensory processing and in particular whether the bias exist at the source of attentional control signals or the site of these control effects in visual attention. How might the dissociation between behavioral and neural findings of sensory gain symmetry and asymmetry shed light on this issue? On one hand, it is possible that the sensory gain mechanism itself in visual cortex is more labile to attentional modulation in the RVF. In this case, the attentional signals are equivalent between visual fields, and the RVF asymmetry arises owing to the greater sensitivity of the gain mechanism coding that hemifield in retinotopically-mapped visual cortex. Nevertheless, previous findings in selective attention showed no asymmetry in gain control (e.g., Handy & Mangun, 2000; Luck et al., 1994; Mangun & Hillyard, 1991), suggesting that sensory gain mechanism is labile to modulation in both visual fields.

In contrast, the RVF advantage observed in our data could appear to reflect an asymmetry at the control network level. That is, our findings raise the possibility that the right hemisphere, but not the left hemisphere, is subject to modulation by task-related attention. This inference remains to be substantiated however, as the few studies that have directly examined the neural regions implicated in task-related attention have all presented visual stimuli at fixation (e.g., Christoff et al., 2009; Kirschner et al., 2012; Mason et al., 2007). Future research is necessary to

determine whether the RVF advantage in visual sensory processing is driven by asymmetry in the control network, the sensory gain mechanism itself, or an interaction of both.

Third, this study further supports the emerging theory of attention being modulated by two control systems (e.g., Dosenbach et al., 2008). In the context of visual processing, although selective spatial attention and task-related attention operate at different time-scales, their scope of influence has been shown so far to be comparable. For example, previous studies have found that task-related attention affects sensory and cognitive level processing (Kam et al., 2011; Smallwood et al., 2008) in a manner akin to selective attention. Our data adds to this literature by suggesting a differential effect of task-related attention on sensory gain control across the two visual hemifields.

Notably, the conclusion drawn from our study should be considered with the following limitations. For one, the visual probes used in our study were irrelevant to the ongoing task. Although the manner in which we treat task-relevant and task-irrelevant stimuli has been shown to be comparable in task-related attention (e.g., Barron et al., 2011), whether this effect extends to parafoveal probes presented laterally has yet to be determined. Another point of consideration concerns the absence of attention effect for RVF probes. The waveforms would suggest differences in the P1 amplitude between the two attention states, and in fact, one where the P1 amplitude is greater during mind wandering compared to on-task states. That the difference was not significant however may be driven by the notably higher level of variance in the P1 amplitude for RVF probes, as evident from Table 1. Whether stimulus inputs in the RVF are not susceptible to modulation of attention, or show the opposite pattern as stimuli in the LVF remain to be empirically tested. Further, we did not replicate the attenuation of cognitive responses during episodes of mind wandering (Smallwood et al., 2008). This lack of attenuation effect was also observed in a previous study in which multiple task-irrelevant stimuli were presented in the same visual space as the external stimuli requiring cognitive processing (Kam et al., 2011). This raises the possibility that adding additional distracting, task-irrelevant elements to the visual environment may impact the extent to which task-relevant inputs are processed at a cognitive level. This is in fact one of the contextual factors that can modulate the amplitude of the P3 component (e.g., Donchin & Coles, 1988). This suggests that mind wandering reduces our cognitive evaluation of external inputs only in a relatively simple visual environment.

Overall, our findings suggest a basic difference in how we treat visual space. In addition to the RVF advantages previously shown in several domains, our results reveal an additional difference in processing across the two visual hemifields when our minds inevitably drift away from the external environment. Taken together, evidence thus indicates that disruption of the left visual field is susceptible to varying forms of attentional modulation.

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