SLOW FLUCTUATIONS IN ATTENTIONAL CONTROL OF SENSORY CORTEX

by

JULIA WING YAN KAM

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ABSTRACT

Top-down control of visual sensory cortex has long been tied to the orienting of visual spatial attention on a rapid, moment-to-moment basis. Here we examined whether sensory responses in visual cortex are also modulated by natural and comparatively slower fluctuations in whether or not one is paying attention to the task at hand. Participants performed a simple visual discrimination task at fixation as the event-related potentials (ERPs) to task-irrelevant probes in the upper visual periphery were recorded. At random intervals, participants were stopped and asked to report on their attentional state at the time of stoppage—either "on-task" or "off-task." ERPs to the probes immediately preceding these subjective reports were then examined as a function of whether attention was in an "on-task" vs. "off-task" state. We found that sensory-evoked responses to the probes were significantly attenuated during "off-task" relative to "on-task" states, as measured by the visual P1 ERP component. In two additional experiments we replicated this effect while (1) finding that "off-task" sensory attenuation extends to the auditory domain, as measured by the auditory N1 ERP component, and (2) eliminating state-dependent shifts in general arousal as a possible explanation for the effects. Collectively, our findings suggest that sensory gain control in cortex is yoked to the natural ebb and flow in how much attention we pay to the current task over time.

PREFACE

The following publication arose from work presented in this thesis:

Kam, J. W. Y., Dao, E., Farley, J., Fitzpatrick, K., Smallwood, J., Schooler, J. W., & Handy, T. C. (in press). Slow fluctuations in attentional control of sensory cortex. Journal of Cognitive Neuroscience.

The content in this publication are located in various parts of this thesis across all the chapters, and have been integrated into this thesis.

Elizabeth Dao, James Farley, and Kevin Fitzpatrick assisted with data collection for each of the three experiments, while Jonathan Smallwood, Jonathan Schooler, and Todd Handy made intellectual contributions at various stages of this research. Todd Handy was also involved in editing the manuscript, and provided assistance and guidance whenever needed.

Julia Kam, as main author, crafted the research questions, programmed the tasks, trained research assistants, collected and analyzed research data, and prepared the manuscript. Preparation of the manuscript consisted of drafting the manuscript, finalizing tables and figures for publication purpose, and communicating with the journal administrators.

This research was approved by the UBC Clinical Research Ethics Board, and the Certificate Number of the Ethics Certificate is H05-70344.

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Chapter 1: INTRODUCTION

One of the idiosyncrasies of human cognition is that the amount of attention we pay to task performance naturally ebbs and flows over time (e.g., Smallwood & Schooler, 2006). During some periods our attention will be tightly focused on what we're doing, yet during other periods our thoughts will inevitably drift off-task without any conscious intent to do so. Notably, the practical consequences of this natural human quirk are non-trivial. For example, when attention is in an off-task phase, we're more prone to making errors and slip-ups in what we are doing (e.g., Smallwood et al., 2008; Carriere et al., 2008; Weissman et al., 2006). Should this happen at the wrong time and place—such as when driving or using power tools—the outcome can be serious.

1.1 Task-Related Attention

The experience of our attention orienting away from a task is a ubiquitous phenomenon. We are no strangers to the experience of our minds wandering elsewhere while attending lectures, reading newspapers, or watching television. While the nomenclature has widely varied, ranging from stimulus independent thought (Antrobus, 1968; Teasdale, Lloyd, Proctor & Baddeley, 1993) to task-unrelated images and thoughts (Giambra, 1995), task-unrelated thoughts (Smallwood et al., 2004), tune-outs and zone-outs (Schooler, 2002), much research previously devoted to this topic have all attempted to characterize this shifting of our attention away from the current task to some internally driven thoughts.

Much research sought to identify factors associated with the frequency of mind wandering. For example, using a pursuit-rotor task and memory load task, Teasdale and

colleagues (1995) reported that the role of practice and the time spent on task independently increase the frequency of being off-task. This suggests that practice effect alone did not account for the increased off-task reports, thereby implicating other factors like interest and motivation in the tendency for our attention to drift off-task. In addition, the frequency of off-task states has been associated with the difficulty level of the task. Specifically, more mind wandering reports were found in the easy versus the difficult condition in a signal detection task. Nevertheless, in a reading comprehension task, the ratings of subjects' interest in the text, and not its difficulty level, were related to the frequency of mind wandering. That is, those who reported the text to be uninteresting tended to mind wander more frequently (Grodsky & Giambra, 1990). Thus, various context-relevant factors appear to be implicated in the fluctuations of attention-to-task.

This omnipresent phenomenon of fluctuations in task-related attention has been described as the decoupling of attention, as attention is divided between external and internal stimulus. Such description adequately characterizes attention as being competed by both internal and external stimulus for its limited resource. Previous research has consistently associated off-task or mind wandering states with impaired performance in tasks of various domains. For instance, poorer performance on the random number generation task has been reported during periods of off-task attentional states relative to on-task attentional states (Baddeley, 1996; Teasdale et al., 1995). This task typically asks participants to generate numbers, either verbally or via key presses, as randomly as possible. Both groups of researchers have suggested that the generation of random numbers require controlled processing, and periods of mind wandering states appear to

compete with resources necessary for controlled processing, thereby affecting their performance on the task.

Further, reading comprehension and memory performance also appears to be impaired during off-task attentional states. Schooler, Reichle, and Halpern (2005) reported poorer comprehension, assessed after participants were probed to report their attentional states, during periods of mind wandering relative to periods of on task. This finding was replicated in another study whereby subjects were required to read the text one word at a time (Schooler, Smallwood, McSpadden, & Reichle, 2005). Similarly, poorer performance on both immediate retrieval (Smallwood et al., 2002) and delayed retrieval tasks (Smallwood et al., 2004) has also been associated with off-task attentional states.

While off-task attentional states have often been associated with negative experiences, recent evidence suggests that is not necessarily always true. Researchers have reported that individuals who mind wander with the meta-awareness of themselves doing so showed superior performance on a creative task, suggesting similar cognitive processes underlying both off-task and creative thinking (Smallwood et al., in preparation). As such, the cost of off-task thinking may be mitigated such that if it occurs at an appropriate time, it may facilitate creative thoughts.

1.2 Neural Networks

Given the ubiquity and importance of these attentional cycles in everyday life, there has been growing interest in understanding their neurocognitive underpinnings.

Most prominent have been the efforts to identify the neural networks in cortex controlling these transient shifts in attention to task performance (e.g., Dosenbach et al., 2008; Mason et al., 2007; Sonuga-Barke & Castellanos, 2007). For example, Dosenbach et al., (2008) suggested that multiple control networks operate in parallel but at separable temporal scales allowing the system to be stable and flexible. The fronto-parietal network operates on a sub-second timescale and is optimized for control on a trial-to-trial basis. In contrast, the cingulo-opercular network, comprised of the anterior prefrontal cortex, anterior insula/frontal operculum, dorsal anterior cingulate cortex and medial superior frontal cortex, operates at a comparatively slower timescale similar to that of task-related attention and is responsible for stable set-maintenance over the entire task epoch. Together, these dual-network controls allow for resilience to perturbation.

Consistent with the concept of a dual-network system, Sonuga-Barke and Castellanos (2007) suggested that spontaneous fluctuations between the task-positive and task-negative networks characterize the typical pattern of attention. The task-positive network is engaged when sustained and effortful attention is required, and is therefore associated with extrospective experiences. On the other hand, the task-negative network tends to be associated with introspective, or task-independent, experiences. The task-positive and task-negative networks map nicely onto the on-task and off-task attentional states, respectively. These two networks are temporally anti-correlated, and are related to distinctive brain areas related to different cognitive functions. Specifically, the task-positive network consists of the dorsal lateral prefrontal cortex, supplementary motor areas, and regions of parietal cortex, while the task-negative network includes the medial

and lateral parietal cortex, medial prefrontal cortex, precuneus and posterior cingulate cortex. The authors proposed that given only one network is present at any given time, the task-negative network has the potential to introduce interference into the current task, thus competing with goal-directed activity performed by the task-positive network. This explains the periodic attentional lapses during task performance. Their description of the task-positive and task-negative networks mirrors the fluctuations of the fronto-parietal and cingulo-opercular networks, respectively, of the dual-network systems previously mentioned in this chapter. Nevertheless, comparison of the neural regions implicated in the task-negative network and cingulo-opercular networks reveal stark differences in the brain areas involved.

On the other hand, using experience sampling as a more direct examination of task-related attention, Mason and colleagues (2007) revealed that the default network associated with greater incidence of mind wandering consisted of the bilateral medial prefrontal cortex, anterior cingulated, bilateral posterior cingulated and precuneus, and left and right superior temporal. They provided direct evidence that the default network, which is more activated at rest and less engaged during task performance with high central executive demand, was implicated in mind wandering. Also using online experience sampling, others have reported that activated neural regions during episodes of mind wandering included the ventral and dorsal anterior cingulate cortex, precuneus, temporoparietal junction, and dorsal lateral prefrontal cortex, suggesting brain recruitment in both default and executive networks was associated with off-task thinking (Christoff et al., 2009). While debate continues over the specific brain areas involved in

these networks, a critical and related question concerns how task-related attention alters the initial cortical processing of incoming sensory information.

1.3 Sensory Gain

The question is of interest because it directly recalls the classic debate in selective attention research regarding whether the attentional gating of visual inputs occurs relatively early or relatively late in the afferent visual processing stream (e.g., Broadbent, 1958; Deutsch & Deutsch, 1963; Treisman, 1960). In particular, selective attention is known to facilitate the perceptual processing of visual inputs by biasing the sensitivity of sensory-evoked responses in visual cortex (e.g., Heinze et al., 1994; Mangun & Hillyard, 1991; Woldorff et al., 1997). This was first reported by Mangun and Hillyard (1991), who found an enhanced P1 Event-Related Potential (ERP) component to validly versus invalidly cued stimuli over lateral occipital sites using reaction time tasks across three experiments. Heinze and colleagues (1994) later confirmed this finding and revealed that the early P1 ERP component is maximal over lateral occipital cortex, and greater in occipital regions contralateral to the attended hemifield, suggesting that the P1 ERP component originates from V4 of the extrastriate visual cortex. Subsequent studies have consistently reported similar findings, suggesting that sensory gain control mechanisms are at work during spatial selective attention (Woldorff et al., 1997).

In an analogous manner, if the cognitive processing of visual stimuli is attenuated when attention drifts off-task, do we dampen or bias the sensory signal itself in cortex when in an off-task state? If so, it would suggest that attentional control of sensory

activity in cortex is yoked to at least two distinct control systems operating in parallel—one associated with rapid shifts of selective visual attention (e.g., Corbetta, Miezin, & Dobmeyer, 1991; Hopfinger, Bouncocore & Mangun, 2000), and a second associated with slower temporal fluctuations in attention to task performance (e.g., Dosenbach et al., 2008). Specifically, the neural networks associated with selective visual attention consist of the dorsal fronto-parietal network responsible for top-down control of attention, and the ventral fronto-parietal network responsible for stimulus-driven control of attention (Corbetta & Shulman, 2002). Whereas the dorsal frontal-parietal network consisting of the intraparietal sulcus and frontal eye field is engaged in voluntary or endogenous visual selection, the ventral fronto-parietal network consisting of the temporoparietal junction cortex and ventral frontal cortex lateralized to right hemisphere is engaged in direct attention to behaviorally relevant sensory stimulus. In contrast, the neural network associated with attention-to-task includes the anterior prefrontal cortex, anterior insula/frontal operculum, dorsal anterior cingulate cortex and medial superior frontal cortex, as previously mentioned (Dosenbach et al., 2008).

1.4 Recent Findings

Towards addressing this issue, recent event-related potential (ERP) evidence has demonstrated that the extent to which we cognitively engage or evaluate visual stimuli is reduced when attention drifts off-task, as indicated by subjective reports of attention (Smallwood et al., 2008), and an objective measure using error rate (O'Connell et al., 2009). To the point, Smallwood and colleagues (2008) found that the amplitude of the P3 ERP component indexing cognitive processing of visual stimuli was reduced

immediately prior to subjects' report of off-task relative to on-task. Similarly, a reduction in the P3 amplitude was also found immediately prior to errors made in a detection task, as indication of attentional lapse (O'Connell et al., 2009). Yet in both of these studies, no corresponding effect of task-related attention was found in the sensory-evoked responses elicited by visual stimuli. Given that attenuation of these sensory responses is the ERP signature of early attentional selection (e.g., Mangun & Hillyard, 1991; van Voorhis & Hillyard, 1977), this would seem to suggest that task-related attention may not actually affect sensory-evoked responses in cortex.

However, the paradigm used in both of these studies (O'Connell et al., 2009; Smallwood et al., 2008) may not have provided a sensitive test of whether task-related attention can modulate sensory-level processing in visual cortex. To the point, whereas selective visual attention is well-known to modulate sensory responses to parafoveal stimuli (e.g., Mangun & Hillyard, 1991; van Voorhis & Hillyard, 1977), sensory responses to foveated stimuli appear to be much less susceptible to attention-related modulation (e.g., Handy & Khoe, 2005). Given that these previously used stimuli were all presented at fixation (O'Connell et al., 2009; Smallwood et al., 2008), this indicates that these paradigms were less than optimal for assessing whether in fact task-related attention can bias sensory responses in visual cortex. Accordingly, the goal of the present study was to examine this issue using a version of Smallwood et al.'s paradigm specifically adapted to allow for measuring parafoveal sensory responses as a function of task-related attentional state. That is, our aim was to determine the influence of task-related attention on the sensory processing of external stimuli.

That task-related attention may affect visual sensory gain is supported by a recent study by Weissman and colleagues (2006). Using fMRI, they found decreases in hemodynamic activity in visual cortex when people's attention lapsed on a trial-by-trial basis during a target discrimination task, as defined by slower vs. faster RTs to the targets. However, whether visual sensory processing—and visual sensory gain, in particular—is affected by the comparatively slower fluctuations in attention to task as under study here remains an open question. If we find such effects here, in conjunction with the aforementioned ERP studies of attention and visual sensory gain, the findings of Weissman et al. (2006) only underscore our central point that visual sensory processing may be subject to multiple controlling inputs with different time courses of influence.

Chapter 2: EXPERIMENT ONE

In this chapter, we conducted the first of three experiments, whereby the aim of the experiment was to examine the influence of task-related attentional control on visual processing in the sensory cortex. In order to address this question, we had participants perform a simple task while recording their electro-encephalograms (EEG). Occasionally, we asked participants to report their attentional state at that particular point in time – on-task or off-task. We then analyzed the data occurring within a particular time frame prior to the report of attention. The EEG responses to stimuli were examined as a function of whether participants were on-task or off-task. We found that the amplitude of P1 ERP component, which indexes sensory processing of visual stimuli, was attenuated during periods of off-task versus periods of on-task. Our results reveal that task-related attention does bias the initial sensory level of processing.

<u>2.1 Methods</u>

Participants

22 participants (10 males, 12 females) completed the experiment in exchange for $20 (Canadian dollars). They were all right handed, with no history of neurological problems and had normal or corrected-to-normal vision. Participants provided written informed consent to the experimental procedure, according to the guidelines of the UBC Clinical Review Ethics Board.

Stimuli and Paradigm

Participants performed a sustained-attention-to-response task (SART) adapted from Smallwood et al. (2008). The task involved presenting a serial stream of stimuli at

fixation. Participants were asked to make a manual button press for numbers (0-9, which we will refer to as targets and which were presented frequently), and they were asked to withhold a response when presented with a letter (X, which we will refer to as non-targets and which were infrequent). The timing and sequence of stimuli are shown in Figure 1. Within each block of stimuli, non-target probability was quasi-randomized, with the constraints that (1) one to two non-targets were presented during each block, and (2) for blocks having two non-targets, the non-targets would be separated by at least ten target events. Each testing session lasted approximately two hours.

Paradigm
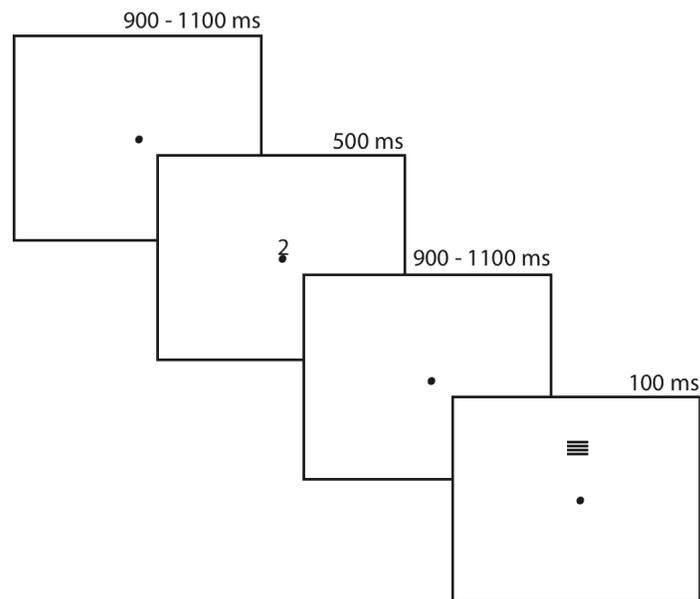
Figure 1

Figure 1. Task Paradigm. Timing and sequence of stimuli in Experiment 1.

To assess possible effects of task-related attention on sensory-evoked responses in cortex, a small, yellow square-wave grating (1° x 1°, 2 cycles per degree) was temporally interspersed between each target/non-target stimulus. This "probe" was presented approximately 3° above fixation on the vertical meridian. Participants were informed that these probes were irrelevant to the task, and therefore they could ignore their presence with no decrement to task performance. Reprinted with the permission of the Journal of Cognitive Neuroscience.

To measure task-related attention, participants were instructed to report their "attentional state" at the end of each trial block. Specifically, they were asked to identify their state immediately prior to the block termination as either being "on-task" (fully attentive to task performance at block's end), or "off-task" (unattentive to the task at block's end). Importantly, participants were provided with verbal descriptions and examples of these two "attentional states" prior to starting the testing session. "On-task" states were defined as when one's attention was firmly directed towards the task, whereas "off-task" states were described as when one is aware of other things than just the task. Examples of these attentional states were given in the context of reading, during which "one may be fully attentive to the content of the reading material, or thinking about something completely unrelated to the content, reflective of "on-task" and "off-task" states respectively." Attentional reports were recorded by the investigator at the conclusion of each trial block, and these reports were then used to sort ERP data based on "on-task" vs. "off-task" states as described below. The block duration itself was randomly varied between 30 and 90 seconds in order to (1) minimize predictability of block

completion and (2) maximize variability of attentional state at the time of block completion.

Electrophysiological Recording and Analysis

Scalp potentials were recorded from 28 tin electrodes (Electro-Cap International) mounted in a custom elastic cap: standard sites were O1, O2, OZ, T5, T6, T3, T4, P1, P2, P3, P4, P5, P6, PZ, C3, C4, CZ, F3, F4, F7, F8, FP1, FP2, FZ, along with PO1 and PO2, OL and OR (midway between O1/O2 and T5/T6); an additional channel recorded potentials from the right mastoid to use for later re-referencing of the ERP waveforms. All electroencephalographic (EEG) activities were amplified (Grass Instruments, Model 12 Neurodata Acquisition System) with a band-pass of 0.1 – 30 Hz (1/2 amplitude cutoffs), digitized on-line at a sampling rate of 256 samples-per-second, and recorded relative to a left mastoid reference. To ensure proper eye fixation, vertical and horizontal electro-oculograms (EOGs) were also recorded, the vertical EOGs from two electrodes inferior to both eyes, and the horizontal EOGs from two electrodes on the right and left outer canthus. The electrode under the left eye was used as ground. EOG recordings were calibrated as reported in Handy and Khoe (2005). All electrode impedances were kept below 5 kΩ.

Off-line, computerized artifact rejection was used to eliminate trials during which detectable eye movements (> 1°), blinks, muscle potentials, or amplifier blocking occurred. While trials with eye movements, blinks, and muscle potentials were removed if they exceeded the minimum-to-maximum threshold within the artifact rejection time window, trials with amplifier blocking were eliminated when there were more than 10

continuous time points with the same data value. An average of 13% of the total number of trials across participants were rejected due to these signal artifacts. The number of trials rejected in each of the two conditions did not significantly differ from each other in all three experiments ($P > 0.21$). For each participant, ERPs for each condition of interest were then averaged into 3000 ms epochs, beginning 1500 ms before stimulus onset. Subsequently, all ERPs were 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. All ERP data analyses were performed using custom scripts, and they were all based on mean amplitude measures using repeated-measures ANOVAs, with specific time-windows of analyses identified below as per each reported ANOVA. These analysis time-windows were centered on the peak of the relevant component as identified at each electrode site in the grand-averaged waveform. A -200 to 0 ms pre-stimulus baseline was used for all ERP component analyses and displays.

The ERP waveforms for each condition of interest were themselves based on averaging together the EEG epochs for the six probes preceding each of the two attentional state conditions (on-task vs. off-task). Although we had no knowledge as to how long participants had actually been in a particular attentional state at the time a subjective report was given, our analyses were based on the assumption that the 12 seconds prior to each report would, on average, reliably capture the given attentional state. In fact, recent evidence has suggested that the time course of off-task thinking approximates this time window (e.g. Christoff et al., 2009; Sonuga-Burke & Castellanos,

2007). Moreover, given our prior use of this window (Smallwood et al., 2008), we wanted to facilitate comparison of results between studies by adopting the same window here. While a shorter pre-marker time-window for averaging non-target EEG epochs would more accurately capture attentional state, it would also reduce the number of events included in the ERP analysis. The choice of how many pre-marker events to include in the averages was therefore an attempt to maximize the number of events per each waveform average while not extending the window back so far in time as to consistently capture the preceding attentional state or transition period between states.

2.2 Results

Subjective Reports

Participants completed an average of 37.3 trial blocks, of which 65.6% (*SEM* = 3.58) ended with an "off-task" report and 34.4% ended with an "on-task" report. The average reaction times for on-task trials was 339.26 ms (*SEM* = 11.12 ms) and was 346.59 ms (*SEM* = 13.01 ms) for off-task trials; the difference was non-significant, $t(42) = -0.43$, $P = 0.67$.

ERPs

The primary focus of ERP data analysis was to assess sensory-level effects of task-related attention via mean amplitude measures of the lateral occipital P1 component elicited by the parafoveal probe stimuli. A secondary aim was to assess whether task-related attention affected the cognitive analysis of stimuli, as measured via the P3 component elicited by the targets. In both cases, ERP waveforms for "on-task" and "off-

task" states were based on probes/targets presented within the last 12 s of each trial block, as described above. All statistical analyses were based on repeated-measures ANOVAs with factors of attentional state (on- vs. off-task) and electrode location; in the interest of brevity and of relevance to our aim, we only report effects associated with the former.

Sensory Effects. The P1 elicited by probe stimuli as a function of attention state are shown in Fig. 2a, and was examined at lateral occipital scalp electrode sites, OZ, PO1, and PO2, where the amplitude of the P1 to vertical meridian stimuli tends to be maximal (e.g., Handy & Khoe, 2005; Handy, Soltani, & Mangun, 2001). Mean amplitude measures were taken across a 130-150 ms post-stimulus time window. We found a significant main effect of attention state $(F (1,21) = 7.35, P = 0.01)$, such that the amplitude of the P1 was greater when attention was in an "on-task" vs. "off-task" state.

Cognitive Effects. The P3 elicited by target stimuli as a function of attention state are shown in Fig. 2b, and was examined at midline scalp electrode sites, CZ and PZ, where the amplitude of the P3 is typically maximal (e.g., Coles & Rugg, 1995). Mean amplitude measures were taken across a 200-250 ms post-stimulus time window. We found a significant main effect of attention state $(F (1,21) = 7.60, P = 0.01)$, such that the amplitude of the P3 was greater when attention was in an on-task vs. off-task state.

Table 1. ERP Results from Experiment 1.

| Component | Electrodes | Attentional State | |
		On-Task	Off-Task
Visual P1 (probes)	OZ	1.77 (0.44)	0.95 (0.28)
	PO1	2.15 (0.54)	1.34 (0.34)
	PO2	1.61 (0.43)	0.76 (0.28)
P3 (targets)	CZ	5.20 (0.71)	3.96 (0.73)
	PZ	3.93 (0.61)	3.01 (0.64)

Table 1. Mean P1 amplitudes (and standard errors) for probes (top) and mean P3 amplitudes for targets (bottom) are presented below by attentional state (on-task vs. off-task). Mean amplitudes were taken across a 130-150 ms post-stimulus time window for probes, and across 200-250 ms post-stimulus time window for targets, both measured relative to a -200 to 0 baseline. Reprinted with the permission of the Journal of Cognitive Neuroscience.

Experiment 1

a. P1: Visual Probes
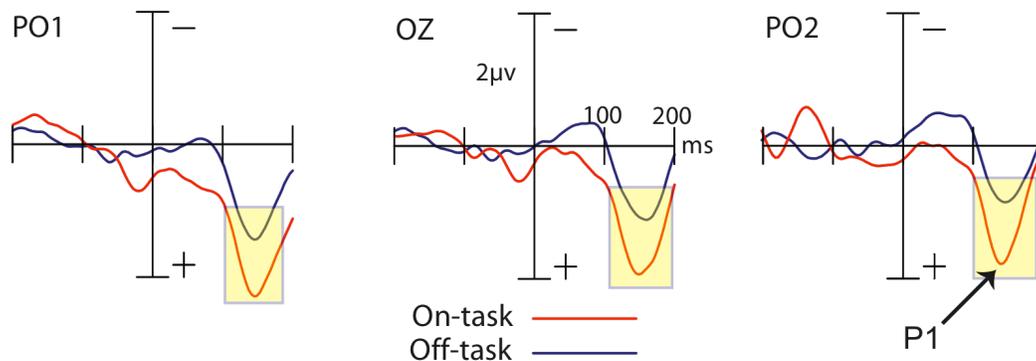
b. P3: Targets
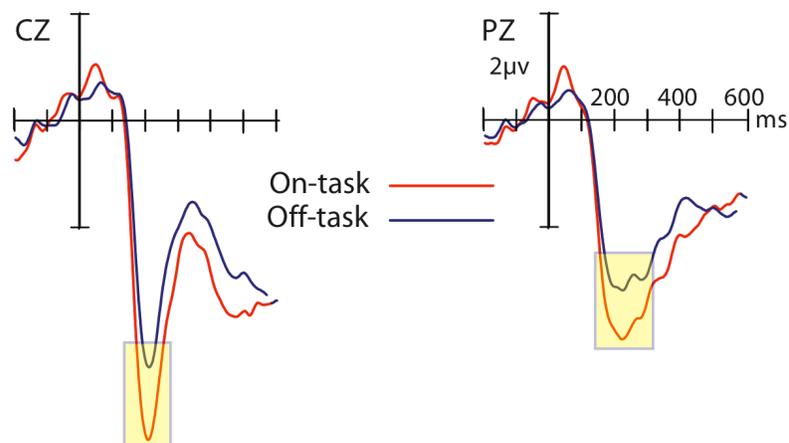
Figure 2

Figure 2. Results from Experiment 1. (a) Sensory effects: visually-evoked P1 ERP component at lateral occipital scalp sites, as a function of "on-task" vs. "off-task" state. The amplitude of P1 was significantly reduced during periods of off-task relative to periods of on-task attention (significant results highlighted in box). (b) Cognitive effects: P3 ERP component elicited by targets at midline scalp sites as a function of attention state. The P3 amplitude was significantly greater when attention was in on-task vs. off-task state. Reprinted with the permission of the Journal of Cognitive Neuroscience.

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The data from Experiment 1 indicates that the sensory-evoked responses to parafoveal visual stimuli were reduced when attention was in an off-task state, as measured by the amplitude of the P1 ERP component. This finding suggests that task-related attention can indeed bias the initial sensory-level processing of visual stimuli. In the second experiment we thus sought to replicate this result from Experiment 1, while examining whether sensory attenuation during "off-task" attention states extends to other sensory domains.

In particular, the sensory-evoked midline N1 ERP component elicited by auditory stimuli has been shown to reduce in amplitude when selective attention is oriented away from the ERP-eliciting stimulus. (Hackley et al., 1987; Woldorff & Hillyard, 1991). This effect directly parallels the attenuated P1 amplitude observed for unattended visual stimuli (Mangun & Hillyard, 1991). Hence the goal of Experiment 2 was to examine whether the effect of task-related attention on sensory-level cortical processing extends to the auditory domain, as measured via the midline N1 ERP component. If so, it would suggest that task-related effects of attention are not restricted to the visual domain.

Chapter 3: EXPERIMENT TWO

This chapter delineates the second experiment whose goal was to determine whether the influence of task-related attentional control on sensory processing in the visual domain is extended to the auditory domain. In order to address this question, we had participants perform the same task as in the first experiment, with the exception of additional auditory stimuli. Occasionally, we again asked participants to report their attentional state at that particular point in time – on-task or off-task. We then analyzed the data occurring within a particular time frame prior to the report of attention. The EEG responses to both the auditory and visual stimuli were examined as a function of whether participants were on-task or off-task. We replicated results from our first experiment such that the amplitude of P1 was attenuated during periods of off-task versus periods of on-task. We also found that the N1 amplitude, which indexes sensory processing of auditory stimuli, was attenuated during periods of off-task versus periods of on-task, suggesting that task-related attention modulates sensory processing across multiple sensory domains.

3.1 Methods

We tested another 15 right-handed participants (4 males, 11 females) with normal or corrected-to-normal vision. All procedures and methods were identical to Experiment 1, except that each interval between each target/non-target included two task-irrelevant probe stimuli: one visual and one auditory. The auditory probe was a brief tone beep (1200 Hz, 75 dB SPL) presented through an external speaker placed directly on top of the video monitor along the vertical midline. The visual probe was identical in form and location to that used in Experiment 1. The order of presentation of these two probes was

randomized, but with the constraint that half the time the visual probe appeared first and half the time the auditory probe came first. Similar to the first experiment, each target or non-target stimulus was presented for 500 msecs. This was followed by an inter-stimulus interval (ISI), which varied between 550 and 750 msecs. The first probe was then presented for 100 msecs, followed by another ISI, and the second probe appeared for 100 msecs. The inter-trial interval (ITI) also randomly varied between 550 and 750 msecs.

3.2 Results

Subjective Reports

Participants completed an average of 38.2 trial blocks, of which 57.5% (*SEM* = 3.54) ended with an "off-task" report and 42.5% ended with an "on-task" report. The difference in reaction times between on-task trials (*M* = 308.86 ms, *SEM* = 9.66 ms) and off-task trials (*M* = 321.34 ms, *SEM* = 11.06 ms) was statistically non-significant, $t(28)$ = -0.85, $P = 0.40$.

ERPs

Sensory Effects. The ERP waveforms for visual and auditory probes are shown in Figures 3a and 3b, respectively. For the P1 elicited by visual probes, mean amplitude measures were taken across a 110-120 ms post-stimulus time window at electrode sites OZ, PO1, and PO2. We found a significant main effect of attention state ($F(1,14)$ = 4.95, $P = 0.04$), such that the amplitude of the P1 was greater when attention was in an on-task vs. off-task state. For the N1 elicited by auditory probes, data analysis was constrained to midline electrode sites FZ, CZ, and PZ, where the N1 amplitude to

auditory tones tends to be maximal (Woldorff & Hillyard, 1991). Mean amplitude measures were taken across a 85-95 ms post-stimulus time window. A significant effect of attentional state was again observed (F (1,14) = 6.02, P = 0.03), such that the amplitude of the N1 ERP component elicited by auditory probes was significantly attenuated during periods of "off-task" relative to periods of "on-task" attention. Notably, although there was some residual between-condition variance in the -200 to 0 ms baseline portion of the ERP waveforms, analysis of mean baseline amplitude across successive 50 ms time windows revealed no significant main effect of state or significant window x attention state interactions.

Cognitive Effects. The P3 elicited by target stimuli as a function of attention state are shown in Fig. 3c. Mean amplitude measures were taken across a 405-440 ms post-stimulus time window, again from electrode sites CZ and PZ. Although the amplitude of the P3 was greater when attention was in an "on-task" relative to "off-task" state, the effect only approached significance (F (1,14) = 3.51, P = 0.08).

Table 2. ERP Results from Experiment 2.

Component	Electrodes	Attentional State	
		On-Task	*Off-Task*
Visual P1 (probes)	OZ	2.37 (0.51)	0.59 (0.62)
	PO1	1.35 (0.44)	0.59 (0.58)
	PO2	1.72 (0.33)	0.65 (0.56)
Auditory N1 (probes)	FZ	-3.48 (0.61)	-2.29 (0.55)
	CZ	-4.46 (0.61)	-3.28 (0.67)
	PZ	-3.25 (0.52)	-2.46 (0.58)
P3 (targets)	CZ	7.17 (1.06)	6.10 (1.30)
	PZ	5.17 (0.94)	3.97 (0.94)

Table 2. Experiment 2: Mean P1 amplitudes (and standard errors) for visual probes (top) and N1 amplitudes for auditory probes (middle) are presented below by attentional state (on-task vs. off-task). Mean amplitudes were taken across a 110-120 ms and 85-95 ms post-stimulus time window for visual and auditory probes respectively. Mean P3 amplitudes taken across a 405-440 ms post-stimulus time window for targets are shown at the bottom. All amplitudes are measured relative to a -200 to 0 baseline. Reprinted with the permission of the Journal of Cognitive Neuroscience.

Experiment 2

a. P1: Visual Probes
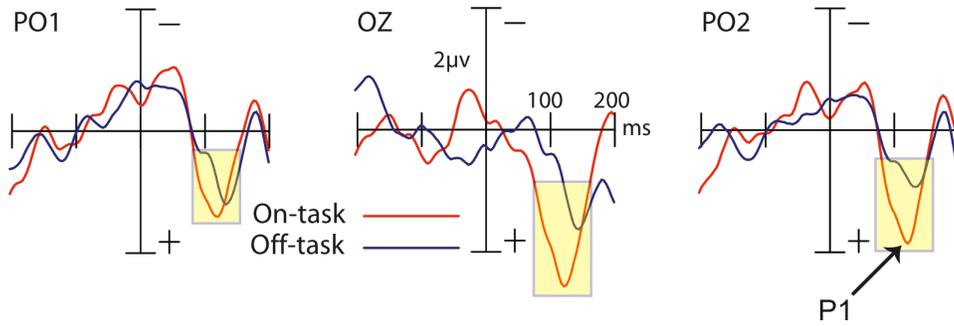
b. N1: Auditory Probes
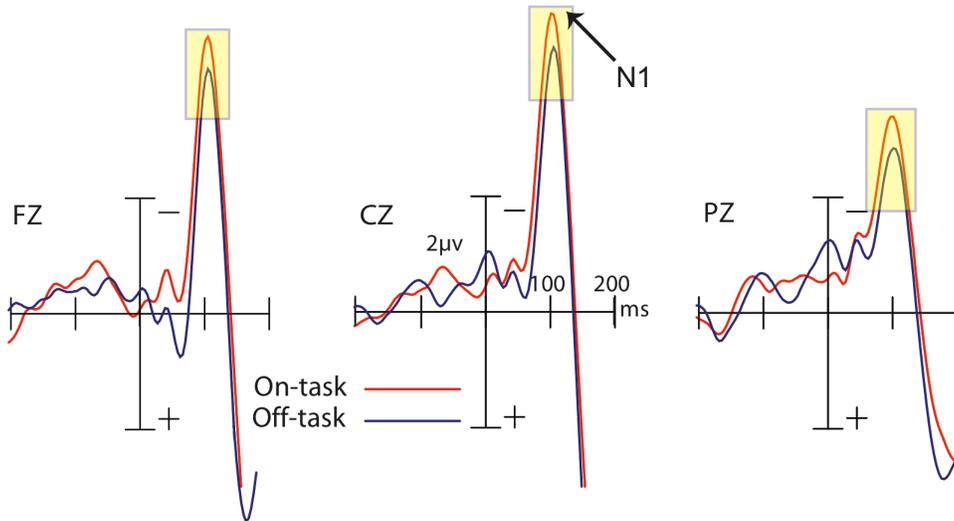
c. P3: Targets
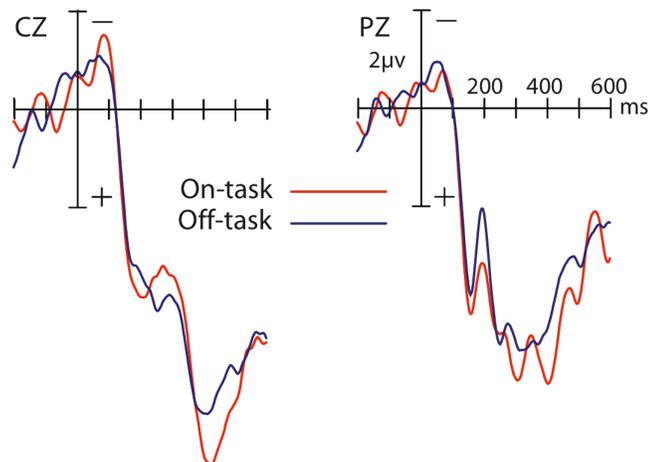
Figure 3

Figure 3. Results from Experiment 2. Sensory effects: while P1 was elicited by visual probes as a function of attention state (a), the N1 ERP component at midline scalp sites was elicited by auditory probes (b). The amplitudes of both P1 and N1 were significantly attenuated during periods of off-task relative to periods of on-task attention, indicating that sensory responses during off-task states are reduced. (c) Cognitive effects: There is a trend that the P3 amplitude at midline scalp electrode sites was greater when attention was in on-task vs. off-task state. Reprinted with the permission of the Journal of Cognitive Neuroscience.

3.3 Discussion

Two key points emerge from Experiment 2. First, we replicated our finding from Experiment 1 that visual sensory-evoked responses for parafoveal stimuli are reduced during "off-task" relative to 'on-task" attentional states. Second, we found a corresponding effect in the auditory domain, such that sensory-evoked auditory responses in cortex were also reduced in "off-task" relative to "on-task" attentional states. Taken together, these data support the conclusion that when our attention drifts off-task, this can lead to transient reductions in the intensity of sensory-evoked cortical activity across multiple sensory domains.

However, at least two important questions arise from our findings and interpretations. For one, the notion that we reduce the intensity of visual sensory processing in cortex when our attention drifts off-task is seemingly at odds with the fact that while attentional drifts are frequent and ubiquitous in everyday life, we are quite

adept at moving and acting in the world even when our minds wander elsewhere. As anyone who has ever mind wandered while walking down the street knows, how is it that our motor systems can continue to accurately respond to current environmental contingencies when we're apparently attenuating the sensory inputs critical for these visually-guided actions?

A second question to consider is whether there may be an entirely different explanation for our data. As we discuss below, we interpret our results as reflecting a direct influence of task-related attentional control systems on sensory-level cortical processing (see Dosenbach et al., 2008). Yet an alternative possibility is that these transient shifts in sensory-evoked responses might be due to fluctuations in general arousal rather than reflecting task-related attentional control. The goal in our final experiment was to address these two key questions.

Chapter 4: EXPERIMENT THREE

The third experiment is covered in this chapter. The purpose of this experiment was to investigate the possibility of alternative explanations for the findings in our first two experiments. Again, we had participants perform the same task as in the first two experiments, except that we presented additional visual stimuli presented in the lower periphery. The reason for this addition is explained below. We replicated results from our first experiment such that the amplitude of P1 in response to the visual stimuli presented in the upper periphery was attenuated during periods of off-task versus periods of on-task. However, we did not find significant differences in the P1 amplitude in response to the visual stimuli presented in the lower periphery between on-task and off-task states. This suggests that task-related attention indeed biased the processing of sensory stimuli, and we eliminated the possibility that shifts in general arousal accounted for our findings.

Experiment 3 was based on the hypothesis that the lower visual field (LVF) is more salient or important for visuomotor processing, relative to the upper visual field (UVF) (e.g. Previc, 1990). Not only does this stand to reason, given that the hands and feet are typically moving in the lower rather than upper hemifield, but this point is borne out in experimental evidence as well. For example, visually guided actions are more accurate in the LVF vs. UVF (e.g., Danckert & Goodale, 2001; Krigolson & Heath, 2006), as is attentional resolution (e.g., He et al., 1996; 1997). The interactions between visual attention and visuomotor processing have also been shown to be comparatively stronger in the lower hemifield as well (Handy et al., 2003).

Given these considerations, if transient shifts in general arousal explain our findings, then it predicted that we should see comparable sensory attenuation at both visual field locations during off-task states. Alternatively, if sensory attenuation in off-task states reflects a more adaptive or functional-sensitive cognitive mechanisms, it predicted that sensory attenuation should be less prevalent in the LVF vs. UVF, due to the greater importance of preserving visual sensory responses in the LVF as a means of supporting visual-motor processing even when attention drifts off-task. In order to address this issue, experiment 3 replicated the same basic paradigm used in our prior two experiments, except that two visual probes were presented during each target/non-target interval, one in the upper visual field (UVF) as per Experiments 1 and 2, and the other in the lower visual field (LVF).

4.1 Methods

All methods and procedures were identical to Experiment 1, excepting that an additional visual probe was included in the LVF during each target/non-target interval. This probe was identical to the one presented in the UVF, and was centered on the vertical meridian approximately 3° below fixation. The timing and ordering of the two probes was identical to that described in Experiment 2. We tested another 12 participants (7 males, 5 females), all of whom were right-handed and had normal or corrected-to-normal vision.

4.2 Results

Subjective Reports

Participants completed an average of 39.6 trial blocks, of which 57.6% (*SEM* = 6.77) ended with an "off-task" report and 42.4% ended with an "on-task" report. The average reaction times for on-task trials was 331.07 ms (*SEM* = 13.24 ms) and 366.13 ms (*SEM* = 26.84 ms) for off-task trials; the difference was non-significant, t (22) = -1.17, P = 0.25.

ERPs

Sensory Effects. The ERP waveforms for visual probes in the UVF and LVF are shown in Figures 4a and 4b, respectively. For UVF probes mean amplitude measures were taken across a 105-115 ms post-stimulus time window, and for LVF probes mean amplitudes were taken across a 105-120 ms post-stimulus time window. We found a significant interaction between attentional state and probe location (F (1,11) = 4.73, P = 0.05). Separate analyses within each location revealed a significant main effect of attentional state for the UVF probes (F (1,11) = 6.01, P = 0.03) but not LVF probes (F (1,11) = 0.45, P = 0.52). Specifically, there was a significant reduction in the P1 amplitude elicited by probes in UVF during periods of "off-task" relative to periods of "on-task", however this was not observed for probes in LVF.

Cognitive Effects. The P3 elicited by target stimuli as a function of attention state are shown in Fig. 4c. Mean amplitude measures were taken across a 190-240 ms post-stimulus time window, again from electrode sites CZ and PZ. The effect of attentional state on the P3 amplitude was not significant (F (1,11) = 1.79, P = 0.21).

Table 3. Results from Experiment 3.

| Component | Electrodes | Attentional State | |
		On-Task	Off-Task
	OZ	2.20 (0.32)	1.14 (0.37)
Upper Visual Field P1 (probes)	PO1	1.93 (0.34)	1.04 (0.26)
	PO2	2.03 (0.40)	0.93 (0.30)
	OZ	-0.28 (0.85)	-0.04 (0.64)
Lower Visual Field P1 (probes)	PO1	-0.14 (0.45)	0.19 (0.24)
	PO2	-0.67 (0.67)	1.04 (0.40)
	CZ	5.41 (0.58)	4.24 (0.74)
P3 (targets)	PZ	4.37 (0.48)	3.69 (0.60)

Table 3. Results from Experiment 3: Mean P1 amplitudes (and standard errors) for upper visual probes (top) and lower visual probes (middle) are presented below by attentional state (on-task vs. off-task). These mean amplitudes were taken across a 105-115 ms and 105-120 ms post-stimulus time window for UVF and LVF probes respectively. Mean P3 amplitudes taken across a 190-240 ms post-stimulus time window for targets are shown at the bottom. All amplitudes are measured relative to a -200 to 0 baseline. Reprinted with the permission of the Journal of Cognitive Neuroscience.

Experiment 3

a. P1: Upper Visual Field Probes
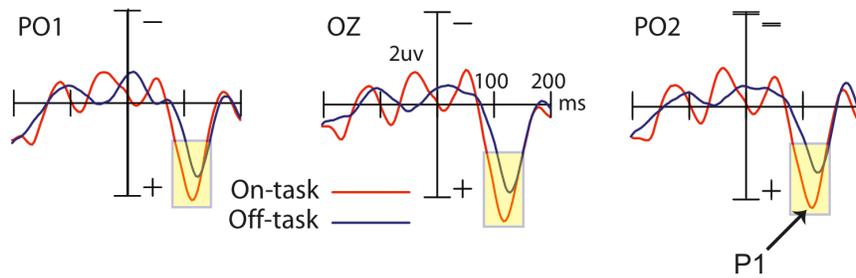
b. P1: Lower Visual Field Probes
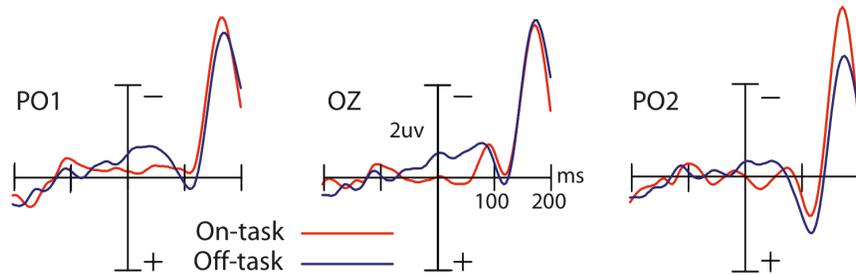
c. P3: Targets
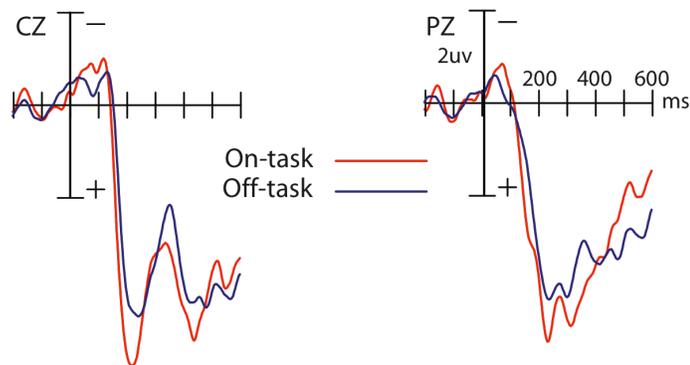
Figure 4

Figure 4. Results from Experiment 3. Sensory effects: visually-evoked P1 was elicited by visual probes in the UVF and LVF as a function of attention state. There was significant attenuation of sensory-evoked visual cortical activity indexed by P1 during off-task states in the upper visual field (a), but no comparable effect in the lower visual field (b). This indicates that the strength of visual responses is reduced in UVF but maintained in LVF when attention is in off-task state. (c) Cognitive effects: Although the P3 amplitude at

midline scalp electrode sites was greater when attention was in on-task vs. off-task state, this result was non-significant. Reprinted with the permission of the Journal of Cognitive Neuroscience.

4.3 Discussion

We found greater sensory attenuation in the UVF vs. LVF during "off-task" states, as measured by the amplitude of the P1 ERP component. That sensory attenuation wasn't uniform across the visual field suggests that our findings in the first two experiments were not simply due to attention-related shifts in general arousal. If so, this would have predicted equivalent attenuation in both visual hemifields. Rather, it appears that sensory responses are relatively preserved in the LVF during off-task attentional states. We discuss the broader implications of these results below.

While the interaction between attentional state and visual field in the P1 is consistent with the hypothesis that upper visual field effects aren't simply being driven by shifts in general arousal, it's also important to consider a possible alternative explanation for the absent P1 effect in the LVF. In particular, the overall P1 amplitude is relatively small across attention conditions, relative to the P1 observed for UVF stimuli. One concern here might be that with a smaller P1 amplitude, it may be less susceptible to changes in sensory gain. While we can not rule this possibility out, it remains for future investigations to examine whether there is actually a relationship between overall P1 amplitude and the extent to which sensory gain can affect it.

Chapter 5: CONCLUSION

Our study addressed the question of whether slow fluctuations in task-related attention can attenuate sensory inputs at a cortical level. In three experiments we found consistent evidence that both visual and auditory sensory responses in cortex were selectively reduced during "off-task" relative to "on-task" states, as measured by the visual P1 and auditory N1 ERP components, respectively. Importantly, we also eliminated the possibility that our results were accounted for by global shifts of arousal, as sensory attenuation was not evident across the entire visual field. Our results thus provide direct electrophysiological evidence suggesting that sensory gain control in cortex is engaged when our minds naturally drift off-task. Given these findings, at least four key issues follow.

5.1 Experimental Issues

First, our data suggests that sensory gain is not yoked to a single, unitary control network. In particular, attention-related control of sensory responses in cortex has long been linked to top-down, strategic decisions about where to orient visual spatial attention on a relatively rapid, moment-to-moment basis (e.g., Mangun & Hillyard, 1991). In turn, this form of attentional control is mediated by a well-established network comprising of prefrontal and superior parietal regions of cortex (e.g., Corbetta, Miezin, & Dobmeyer, 1991; Corbetta et al. 1993; Corbetta & Shulman, 2002; Hopfinger, Buonocore, & Mangun, 2000). Our results, however, suggest that sensory gain is also subject to modulation by comparatively slower fluctuations in whether or not one is paying attention to task performance. Not only is this a form of attentional control that is distinct

from attentional orienting in terms of its functional purpose, time scale of influence, and control network in cortex (e.g., Dosenbach et al., 2008), but the stability of a dynamic cortical system is optimized when there are multiple controlling inputs operating at multiple scales of time (e.g., Honey et al., 2007). It would thus appear that sensory gain control may have a functional benefit by operating under a dual control network structure.

Second, although we found consistent effects of task-related attention on sensory-evoked activity, a comparable pattern of activity was not observed in the P3 ERP component elicited by target stimuli. Specifically, whereas off-task attention reduced sensory-evoked responses in all three experiments, we only found significant or near-significant effects of off-task attention on the P3 in Experiments 1 and 2 respectively. Why might there have been variability in this P3 response to targets? In our original study that had no task-irrelevant probes included in the paradigm, we found significant P3 attenuation during off-task states (Smallwood et al., 2008), whereas here we found comparable effects with one probe in the paradigm (Experiment 1) but not two probes (Experiments 2 and 3). What this raises is the possibility that as one adds extra "distracting" elements to the display, it may alter to a degree how targets are processed at a cognitive level—for example, by increasing the complexity and unpredictability of spatial-temporal patterns of stimulation. Indeed, these are precisely the kinds of contextual factors that modulate P3 amplitude (e.g., Donchin & Coles, 1988).

Regardless of what may drive variability in the P3 effect, however, this finding suggests that there may be a decoupling of sensory vs. cognitive effects of task-related attention. That is, effects appear to arise in the former without necessarily always co-occurring in the latter. Importantly, this possibility is not without precedence in the attention literature. To the point, although canonical models of visual selective attention have often implicitly assumed that cognitive-level effects of attention positively co-vary with sensory-level effects (e.g., Luck et al., 1994; Mangun & Hillyard, 1995), more recent evidence has demonstrated that the effects of selective attention on these stages of processing can be independent (e.g., Handy & Khoe, 2005)—and specifically, attention effects can arise in the P3 when none are apparent in the P1. Our data here hint that this same independence of attention effects at sensory vs. cognitive levels may apply to task-related attention as well.

In this regard, it is also interesting to note that we found no effect of attentional state on the reaction times to the targets, despite consistent decreases in the sensory responses to task-irrelevant probes. To the point, if the inclusion of task-irrelevant probes was sufficient to alter the cognitive context of target processing relative to when no probes are included (Smallwood et al., 2008) as measured by the P3, it is thus not surprising that no effect of attentional state was observed in reaction times as well. Indeed, this is exactly what the P3 data would predict. When one considers that effects of attentional state were in fact reliably observed for task-irrelevant stimuli presented away from the fovea, the implication is that under conditions such as those here, attention drifting away from a task at hand can alter peripheral sensory processing while leaving

the cognitive and perceptual processing of foveal information comparatively unchanged. Such spatially-mediated effects may help to explain our behavioral functionality in the face of frequent mind wandering episodes such as when driving, walking and the like.

A third issue of note concerns the apparently adaptive nature of sensory attenuation during off-task states. Namely, we found that sensory-evoked activity remained unaffected in the lower visual field despite significant attenuation in the upper visual field – attenuation that was reliably observed in all three experiments. As such, our findings converge on a diverse body of evidence indicating that the lower visual field plays a specialized role in visuomotor processing (e.g., Danckert & Goodale, 2001; Krigolson & Heath, 2006; He et al., 1996; 1997: Handy et al., 2003). While our hypothesis – lower visual field sensory responses are preserved during off-task attention states in order to support on-going visuomotor processing – remains to be directly tested, the possibility does have intuitive appeal. That is, the lower visual field may specifically resist tuning out so that our bodies can respond to current environmental contingencies regardless of where in time and space our mind may have wandered.

Finally, given our findings, an important question concerns how our data relate if at all to the recent report of Weissman et al. (2009) showing that sensory processing for "task-irrelevant" stimuli actually *increases* during attentional lapses. The critical issue here, as we see it, concerns the nature of the "task-irrelevant" stimuli used in the two studies. Specifically, the auditory "task irrelevant" stimuli used by Weissman et al. were auditory analogs of their visual targets (Xs and Os), and thus the "irrelevant" stimuli were

designed to engender response conflict a la an Eriksen flanker task. As such, optimal performance in their task required actively attending to the visual targets while actively suppressing the auditory inputs. It is thus not surprising that when attention lapsed in their paradigm, sensory processing decreased for visual inputs but increased for auditory inputs. In this manner, their task is consistent with directly and/or consciously engaging sustained attention and then examining what happens to stimulus processing when that attention lapses or wanes.

In our study, however, the nature of the "irrelevant" stimuli were fundamentally different, in that the square-wave gratings used as visual "probes" had no direct mapping or bearing on the responses required by the task (discriminating letters vs. numbers). As such, there was no need for participants in our study to actively suppress these "task-irrelevant" stimuli to optimize their task performance. Accordingly, what our paradigm captures is not the consequence of lapsed sustained attention, but rather, the consequence of simply having one's mind drift off-task. In this case, with task-irrelevant stimuli that one doesn't need to actively suppress, the net consequence is that sensory processing can decrease. Within this context, however, one can logically ask how if at all "attentional lapses" may relate to attention drifting "off-task." From our perspective, these may often be one and the same phenomenon. The key difference is thus not with these two terms per se, but rather, whether a "lapse of attention" or "attention drifting 'off-task'" occurs when one is engaging sustained attention as part of current task goals. In our paradigm, sustained attention wasn't engaged during the task and that explains our pattern of results relative to Weissman et al. (2009). But if our understanding here is correct, it predicts

that if one monitored "attention to task" during a task that engages sustained attention in a manner similar to Weissman et al. (2009), then sensory-level effects should resemble their findings—task-irrelevant stimuli that are actively suppressed as part of optimal task performance should *increase* when attention drifts off-task.

5.2 Strengths and Limitations

Our findings highlight the value of emerging methodologies that are using subjective reports of cognitive states as a means by which to identify the conditions of interest in a study (e.g., Christoff et al., 2009; Handy et al., 2009; Mason et al., 2007; Smallwood et al., 2004; Smallwood et al., 2008). In this approach, cognitive states aren't placed under direct experimental control, but rather, systems and processes of interest are allowed to operate in their own natural, unconstrained manner. Within this context, experimental paradigms are designed to identify the status of the system or process at various intervals over time, as reported by the participant. While the reliability of any given subjective report may certainly be open to question, the overall validity of the collection of reports is borne out by state-dependent differences in objectively-measured neural-based signals. Having identified that sensory responses in cortex attenuate when people slip into off-task attentional states, our study illuminates the importance of such subjective report methodology in providing unique and useful information and thus complementing objective measures.

Although our findings provide important insight into the processes underlying the fluctuations of task-related attention, several limitations should be considered when

interpreting our results. First, there are substantial individual variations in the fluctuations in attention-to-task. An individual may have maintained focus on the task throughout the entire duration of the experiment, while another individual reported being in an off-task attentional state most of the time. Individual differences may also emerge in the pattern of attentional fluctuations. For instance, some individuals' attention may ebb and flow in cycles throughout the experiment, while others' attention may be focused for the first half of the experiment after which their attention becomes off-task. As such, despite ample empirical evidence suggesting that the time course of task-related attention approximates 12 seconds (Smallwood et al., 2008; Sonuga-Barke & Castellanos, 2007), this is a generalization based on an overall average across individuals. Accordingly, our results based on the 12-second time window should be interpreted with this constraint in mind, as they were meant to capture the general pattern of fluctuations in attention. Nevertheless, given our robust findings of sensory attenuation during off-task attentional states, the neural consequence of our attention drifting off-task appears to be resilient to individuals' distinct patterns of attentional fluctuations.

Another concern is a methodological issue regarding an unequal number of trials contributing to ERP averages of the two attentional states, which may potentially confound the results of the three experiments. Nevertheless, this assumption appears to be unfounded for several reasons. First, there is a rich ERP literature on endogenous spatial orienting showing that the P1 amplitude is typically larger for attended/cued vs. unattended/uncued targets. In these studies, there is typically a 3 to 1 ratio of cued to uncued targets, such that the condition with significantly *fewer* events in the average is

associated with a smaller P1 amplitude. In contrast, in the current sets of studies, not only is the disparity in ERP averages much less than 3 to 1 (closer to 1.4 or less to 1), but the condition having fewer events ("on-task") has a *larger* P1 amplitude. In contrast, the "unequal events" hypothesis would have predicted a smaller P1 for the "on-task" condition, based on the data from probablistic spatial cueing. Second, this concern is based on the implicit assumption that residual noise or variance in ERP waveforms linearly scales with the number of events in an ERP average. In practice, this may or may not be the case, depending on the stability of each individual's event-related response over time, as well as ambient noise in the person's non-event-related EEG activity.   Nevertheless, we did examine the amount of residual variance in our group ERP averages (as measured by standard error) and found no significant differences between on-task and off-task variance. Finally, if one might combat this problem by taking events *out* of the data set for one condition to bring it in line with the number of events in a second condition, it seems to run counter to the notion of trying to minimize variance in the first place. Indeed, it also introduces a concern over selection bias, as one is forced to come up with some solution for determining which events to remove. For these above reasons, this methodological issue does not appear to have any significant influence on our robust findings of sensory reduction during periods of mind wandering.

5.3 Research Significance and Potential Implications

Given that these attentional fluctuations are omnipresent, their significance is evident in various contexts. First, the ability to focus our attention on the task-at-hand is of great importance in the educational setting and is a notable challenge for educators. It

is not uncommon especially for grade-school children to lack the ability to maintain their focus on any particular task over extended periods of time. While off-task attentional states are associated with creative thinking (Smallwood et al., in preparation), this constant lack of attention renders teaching these children a rather difficult task. A related issue concerns the prevalent diagnosis of Attentional Deficit Hyperactive Disorder in children. Perhaps this is the common phenomenon of our minds wandering taken to a clinically disordered level, whereby such children are continuously in an off-task state. Education for this population presents itself to be an even greater challenge. Therefore, understanding the processes underlying such cognition is crucial as it facilitates the search for solutions to this problem.

That our attention-to-task waxes and wanes over time also has implications in the context of driving. Much research examining the influence of distracters to drivers have identified "external" factors. For example, ample evidence suggests that using cellular phones and listening to music or the radio proved to increase the risk of motor vehicle accidents. Our findings of reductions in sensory responses during mind wandering states potentially suggest that even in the absence of such external distracters, the risk of being involved in an accident on the road may increase if we are not paying attention to hazards in the surrounding environment. This is exemplified by the common explanations, "The car came out of nowhere" and "I didn't see the person cross the street", given by drivers after the accident. The consequences of such a phenomenon have broad implications, and thus should be thoroughly addressed.

In conclusion, our experiments provide consistent evidence suggesting the attenuation of sensory responses when our attention drifts off-task. Although this is an important finding, future research is necessary to further elucidate the extensive influences of task-related attention. While the current study and a previous related study have suggested that task-related attention influences the extent of sensory and cognitive processing, it is currently unknown what aspects of these types of processing are specifically affected. For instance, the processing of deviant stimuli as indexed by the mismatch negativity ERP component has been suggested to be relatively automated, such that the mismatch negativity component occurs regardless of whether attention was directed at the deviant stimuli (Escera et al., 1998; Shroger and Wolff, 1998). Nevertheless, attention thus far in this literature has been mainly characterized as selective attention. In this context whereby the processing of deviant stimuli is not modulated by selective attention, does task-related attention have an influence in such processing? This important question remains to be answered. Alternatively, the processing of errors is significant in the context of education, as the recognition of errors facilitates learning. Given the potential implications of attentional fluctuations in education, an important question concerns whether task-related attention influences the extent to which we process errors. If the processing of errors is attenuated during periods of off-task, then learning is less likely to take place, thereby decreasing the effectiveness of education at that point in time. Future research is necessary to clarify the task-related attentional influence on information processing.

Another outstanding question concerns the individual variations in attentional fluctuations. This is crucial to understanding how and what types of personal characteristics may affect the prevalence of this phenomenon. First, certain personalities may be more prone to mind wandering than others. For example, previous research has shown that individuals with higher levels of schizotypal personality traits process information to a lesser extent compared to those with lower levels of schizotypal personality traits. This mirrors the sensory attenuation during periods of mind wandering as reported in this study. Therefore, the similar pattern of sensory attenuation evident in this population and during off-task attentional states perhaps suggest a relationship exists between the two. Second, identifying demographic characteristics associated with the tendency to mind wander would be equally important. For instance, there may be cultural and gender differences, or differences in intelligence and socioeconomic status affecting the frequency of mind wandering. Revealing the cognitive processes underlying task-related attention proves to be an important first step, which will hopefully facilitate future research in understanding all aspects of this omnipresent phenomenon.

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APPENDIX A: UBC Clinical Research Ethics Board Certificate of Approval

The University of British Columbia
Office of Research Services
Clinical Research Ethics Board – Room 210, 828 West 10th Avenue, Vancouver, BC V5Z 1L8

ETHICS CERTIFICATE OF EXPEDITED APPROVAL: RENEWAL

PRINCIPAL INVESTIGATOR:	DEPARTMENT:	UBC CREB NUMBER:
Todd Handy	UBC/Arts/Psychology, Department of	H05-70344

INSTITUTION(S) WHERE RESEARCH WILL BE CARRIED OUT:

Institution	Site
UBC	Vancouver (excludes UBC Hospital)

Other locations where the research will be conducted:
N/A

CO-INVESTIGATOR(S):
Julia Kam

SPONSORING AGENCIES:
- Michael Smith Foundation for Health Research - "Control of Visual Attention by the Demands of Locomotion - Implications for Movement Disorders and their Clinical Diagnosis"
- UBC Internal Grant - "Control of Visual Attention by the Demands of Locomotion - Implications for Movement Disorders and their Clinical Diagnosis"

PROJECT TITLE:
Control of Visual Attention by the Demands of Locomotion - Implications for Movement Disorders and their Clinical Diagnosis

EXPIRY DATE OF THIS APPROVAL: July 14, 2011

APPROVAL DATE: July 14, 2010

CERTIFICATION:
In respect of clinical trials:
1. The membership of this Research Ethics Board complies with the membership requirements for Research Ethics Boards defined in Division 5 of the Food and Drug Regulations.
2. The Research Ethics Board carries out its functions in a manner consistent with Good Clinical Practices.
3. This Research Ethics Board has reviewed and approved the clinical trial protocol and informed consent form for the trial which is to be conducted by the qualified investigator named above at the specified clinical trial site. This approval and the views of this Research Ethics Board have been documented in writing.

The Chair of the UBC Clinical Research Ethics Board has reviewed the documentation for the above named project. The research study, as presented in the documentation, was found to be acceptable on ethical grounds for research involving human subjects and was approved for renewal by the UBC Clinical Research Ethics Board.

Approval of the Clinical Research Ethics Board by one of:

Dr. Peter Loewen, Chair
Dr. James McCormack, Associate Chair