

Mind Wandering and the Adaptive Control of Attentional Resources

Julia W. Y. Kam¹, Elizabeth Dao², Maria Stanciulescu¹, Hamish Tildesley³, & Todd C. Handy^{1,2}

¹Department of Psychology, University of British Columbia

²Department of Neuroscience, University of British Columbia

³Department of Psychology and Brain Sciences, Dartmouth College

October 31st, 2012

Correspondence:

Julia W. Y. Kam

julia@psych.ubc.ca

Department of Psychology

2136 West Mall

Vancouver, B.C.

Canada, V6T 1Z4

Abstract

Mind wandering is a natural, transient state wherein our neurocognitive systems become temporarily decoupled from the external sensory environment as our thoughts drift away from the current task at hand. Yet despite the ubiquity of mind wandering in everyday human life, we rarely seem impaired in our ability to adaptively respond to the external environment when mind wandering. This suggests that despite widespread neurocognitive decoupling during mind wandering states, we may nevertheless retain some capacity to attentionally monitor external events. But what specific capacities? In Experiment 1, using traditional performance measures, we found that both volitional and automatic forms of visual-spatial attentional orienting were significantly attenuated when mind wandering. In Experiment 2, however, event-related potentials revealed that during mind wandering states, there was a relative preservation of sensitivity to deviant or unexpected sensory events, as measured via the auditory N1 component. Taken together, our findings suggest that while some selective attentional processes may be subject to down-regulation during mind wandering, we may adaptively compensate for these neurocognitively-decoupled states by maintaining automatic deviance-detection functions.

1
2
3
4
5
6 One of the odd quirks of human cognition is that we frequently get lost in our own
7
8 trains of thought, even when doing attention-demanding tasks. When driving, for example,
9
10 many people have had that unsettling experience of suddenly realizing that they've been
11
12 completely tuned out for the past few miles, with little recollection of the traffic and terrain
13
14 that's been navigated in the interim. But this raises a striking question regarding our
15
16 natural propensity to have our thoughts drift off-task--how is it that our minds can
17
18 regularly wander like this during on-going tasks, yet we still seem to retain some capacity
19
20 to monitor and respond to the external environment? Is some ability to selectively attend
21
22 to salient events in the outside world actually preserved when in mind wandering states?
23
24
25
26
27
28
29

30 The question is all the more perplexing given what we know about the effect of
31
32 mind wandering on stimulus processing in cortex. When in mind wandering states, there is
33
34 a significant reduction in the extent to which we cognitively analyze or process task-
35
36 relevant events, relative to when in "on-task" attentional states (e.g., Barron, Greer, &
37
38 Smallwood, 2011; O'Connell et al., 2009; Smallwood, Beach, Schooler, & Handy, 2008).
39
40 Likewise, the initial sensory-evoked cortical activity engendered by task-irrelevant events
41
42 also decreases, an effect observed in both the visual and auditory domains (e.g., Braboszcz
43
44 & Delorme, 2011; Kam et al., 2011). Such evidence has suggested that mind wandering
45
46 facilitates the production and maintenance of internal trains of thought by transiently
47
48 "decoupling" neurocognitive systems from external stimulus inputs (e.g., Barron et al.,
49
50 2011; Schooler et al. 2011; Smallwood et al., 2003; 2011). But if our thoughts become
51
52 decoupled when mind wandering, do our attentional systems decouple as well?
53
54
55
56
57
58
59
60

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Given this question, the goal of our study was to examine whether controlled or more volitional attentional functions change as we drift in and out of mind wandering states, and if so, how this compares to the possible effect of mind wandering on more automatic or reflexive attentional functions. In our first experiment we thus asked participants to perform two different visual-spatial cuing tasks that required making manual responses to lateralized targets. One task involved volitional spatial orienting (e.g., Posner, 1980) and the other task involved reflexive spatial orienting (e.g., Friesen & Kingstone, 1998; Tipper, Handy, Geisbricht, & Kingstone, 2008). The volitional orienting of spatial attention involves individuals voluntarily shifting their attention elsewhere, whereas reflexive spatial orienting involves an external stimulus that attracts one's attention involuntarily. At unpredictable intervals during task performance we stopped participants and asked them to report on their task-related attentional state--either "on-task" or "mind wandering." We then examined the reaction times (RTs) to targets as a function of whether they were in cued or uncued spatial locations, and whether they immediately preceded an "on-task" vs. "mind wandering" report. If mind wandering disrupts visual selective attention, it is predicted that RTs should be faster for cued vs. uncued targets just prior to "on-task" reports, but not just prior to reports of "mind wandering." We predicted that these effects would be observed in both volitional and reflexive spatial orienting.

Experiment 1

Methods

Participants

A total of 32 individuals participated (17 females; $M = 20.83$ years, $S.D. = 1.42$), with 17 subjects completing the volitional spatial orienting task and 15 subjects completing the reflexive spatial orienting task. All were right handed, and had normal or corrected-to-normal vision. They all gave written informed consent, and were given course extra-credit for their participation. This study was approved by the UBC Behavioral Review Ethics Board.

Stimuli and Procedure

Stimuli were presented on an 18 in. color monitor, placed 80 cm away from the subjects. In both tasks, a fixation dot first appeared in the center of the screen for 2000 ms. Following this, a cue was presented at fixation, and remained on the screen for 1300 ms. The target, which was an X ($1.1^\circ \times 0.9^\circ$), appeared either in the left or right visual field (5.2° from the left/right edge of the screen). It was presented 800 ms after the onset of the cue, and lasted for 100 ms. The inter-trial interval was randomly jittered between 1500-1700 ms, during which a response was made. For both tasks, subjects were instructed to press a designated button as quickly and accurately as possible when the target appeared, regardless of its location.

In the volitional spatial orienting task, participants were instructed to attend to the left visual field if the inner circles were green, and attend to the right visual field if the inner circles were red. The cue on each trial was predictive of the upcoming target location (left vs. right visual field) with 0.8 probability, thereby providing the incentive to volitionally

MIND WANDERING AND ATTENTIONAL CONTROL

6

1
2
3 orient attention to the cued location. The cue was two circles ($2^\circ \times 2^\circ$) stacked vertically on
4
5 top of each other, with two smaller inner circles ($0.7^\circ \times 0.7^\circ$) colored either in green or red.
6
7
8 In the reflexive spatial orienting task, an eye-gaze cue was made of two circles ($1.9^\circ \times 1.9^\circ$)
9
10 presented horizontally next to each other with small, black inner circles ($0.9^\circ \times 0.9^\circ$), to
11
12 mimic eyes. These “eyes” would either look to the left or to the right (see Figure 1). The
13
14 direction of eye gaze was non-predictive of the upcoming target location, in that the target
15
16 was only presented at the gazed-at location with 0.5 probability (across the trial block).
17
18
19 Our eye-gaze paradigm is a canonical one that has been previously used to elicit reflexive
20
21 orienting of attention (e.g., Friesen & Kingstone, 1997; Tipper et al., 2007, etc.). Participants
22
23 were not given instructions as to where to attend, as previous evidence suggests that
24
25 individuals reflexively orient their attention to the direction of others’ eye gaze (Friesen &
26
27 Kingstone, 1998).
28
29
30
31
32
33
34

Task-related Attention

35
36
37 To measure task-related attention, subjects were instructed to report their attention
38
39 state as either being “on-task” or “mind wandering” at the end of each trial block (c.f. Kam
40
41 et al., 2011; Smallwood et al., 2008). Subjects were provided with definitions of these two
42
43 attention states prior to starting the testing session. “On-task” states were defined as when
44
45 one’s attention was firmly directed towards the task, whereas “mind wandering” states
46
47 were described as when one’s attention was not focused on the task. At the conclusion of
48
49 each trial block, attentional reports were recorded by the investigator, who was in the
50
51 room with the subject throughout the experiment. These reports were then used to sort the
52
53 RT data based on “on-task” vs. “mind wandering” states. The block duration itself was
54
55
56
57
58
59
60

1
2
3 randomly varied between 30 and 90 seconds in order to minimize predictability of block
4
5 completion and maximize variability of attentional state at the time of block completion.
6
7 Given one trial lasted approximately 2900 ms, each block would have consisted between 10
8
9 and 30 trials.
10
11

12 13 14 15 *Statistical Analysis*

16
17 We conducted an omnibus ANOVA that had orienting condition (volitional vs.
18
19 reflexive) as a between-subjects factor and both selective attention (cued vs. uncued) and
20
21 task-related attention (on-task vs. mind wandering) as within-subject factors. The
22
23 behavioral data for both cued and uncued conditions were based on averaging together the
24
25 RT to the 4 targets preceding each of the two attentional state reports (on-task vs. mind
26
27 wandering). Our analyses were based on the assumption that the 12 seconds prior to each
28
29 report would on average reliably capture the reported attentional state (c.f. Kam et al.,
30
31 2011; Smallwood et al., 2008), given recent evidence suggesting that the time course of off-
32
33 task thinking approximates this time window (e.g. Christoff, Gordon, Smallwood, Smith &
34
35 Schooler, 2009; Sonuga-Burke & Castellanos, 2007). The number of events included in the
36
37 averages was an attempt to maximize the number of events per each average without
38
39 extending the window so far back in time as to consistently capture the preceding
40
41 attentional state.
42
43
44
45
46
47
48
49
50

51 **Results**

52 53 *Subjective Reports*

54
55
56
57
58
59
60

Participants completed an average of 30 trial blocks, of which 43.2% ended with an "on-task" report and 56.8% ended with a "mind wandering" report (SD=19.37).

Reaction Time Data

The RT data are shown in Figure 2, and suggest that attentional orienting effects were indeed attenuated when in "mind wandering" states in both orienting conditions. This pattern was confirmed statistically as we found significant main effects of selective attention ($F(1,30) = 15.38; p < 0.001$) and task-related attention ($F(1,30) = 5.87; p = .02$), and a significant interaction between the two ($F(1,30) = 6.33; p = .02$). There were no significant interactions involving orienting condition, nor a main effect of this factor (all $p > .10$).

Towards understanding precisely how attentional orienting was affected by mind wandering, we conducted two planned follow-up analyses for the significant selective attention x task-related attention interaction. The first examined whether selective attention effects were individually present under the "on-task" and "mind wandering" states. This analysis revealed a significant main effect of selective attention in "on-task" states ($t(31) = 6.65; p < .001$) but not in "mind wandering" states ($t(31) = 0.93, p = .36$). The second planned analyses examined whether RTs changed between "on-task" vs. "mind wandering" states for cued trials, uncued trials, or both. This analysis revealed that RTs were significantly faster during "on-task" states vs. "mind wandering" states for cued trials ($t(31) = -4.33; p < .001$) but not in uncued trials ($t(31) = -0.78; p = .44$).

Anticipatory Responses

We also examined the participants' anticipatory responses of targets preceding an on-task vs. mind wandering report. Across both tasks, we found that responses made within the cue-target interval during on-task periods (M: 3.56) did not significantly differ from those made during mind wandering periods (M: 2.62; $t(31) = 1.02$ $p = .32$). Similarly, responses made within 150 ms of target onset during on-task periods (M: 8.66) did not significantly differ from those made during mind wandering periods (M: 7.94; $t(31) = 0.58$, $p = .57$).

Discussion

Our findings from Experiment 1 indicate that visual-spatial attentional orienting attenuates during periods of mind wandering. This effect was observed in both volitional orienting elicited by arbitrary stimulus-response associations, as well as reflexive orienting elicited by social eyes-mimicking stimuli. Of relevance, this raises the question of how exactly mind wandering might disrupt attentional orienting, and whether this effect could be driven by sensory attenuation of the cue itself – a point to which we return in the General Discussion. Importantly, a key aspect of the data pattern suggest that this finding can not simply be dismissed as participants having a reduced will or motivation to orient their visual-spatial attention during mind wandering attentional states. That is, the attenuation in orienting during mind wandering states was observed for both volitional and reflexive orienting conditions. If the effect of mind wandering we found was solely an issue of decreased motivation, it's difficult to understand how that would affect reflexive orienting, which is presumably not under volitional control. As such, our data support the

1
2
3 hypothesis that both volitional and reflexive forms of top-down visual spatial orienting are
4
5
6 diminished when mind wandering.
7
8
9

10
11 That mind wandering attenuated volitional visual-spatial orienting is certainly
12
13 consistent with what is known about the cortical regions involved in both attentional
14
15 control and mind wandering. In particular, volitional spatial orienting engages left
16
17 dorsolateral prefrontal cortex (e.g., Corbetta, Miezin, & Dohmeyer, Shulman, & Petersen,
18
19 1991; Hopfinger, Bounocore, & Mangun, 2000), one of the key brain regions that has been
20
21 shown to up-regulate activity during periods of mind wandering (e.g., Christoff et al., 2009;
22
23 Mason et al., 2007). Likewise, neural areas involved in reflexive spatial orienting to eye
24
25 gaze cues, including temporoparietal junction and superior temporal sulcus (Hooker et al.,
26
27 2003; Tipper et al., 2008) are also activated during mind wandering (Christoff et al., 2009;
28
29 Mason et al., 2007). If mind wandering and spatial orienting do indeed engage a common
30
31 set of neural regions, then this would explain the absence of spatial orienting during off-
32
33 task attentional states--when mind wandering, the cortical areas necessary for visual
34
35 spatial orienting are unavailable to support that function.
36
37
38
39
40
41
42
43

44
45 While these data suggest that mind wandering does in fact disrupt visual-
46
47 attentional orienting, one of the questions driving our study remained unanswered: Are
48
49 there any attentional functions that may be preserved during mind wandering, functions
50
51 that might allow us to adaptively respond to the outside environment despite our
52
53 "cognitively decoupled" state? In Experiment 2 we thus examined the impact of mind
54
55 wandering on a second form of attention that is qualitatively distinct from visual orienting--
56
57
58
59
60

1
2
3 -that of deviance detection.
4
5
6
7

8 Experiment 2

9
10 The occurrence of a stimulus that deviates from the prevailing situational context
11 unavoidably captures our attention. For example, when we hear a physically deviant sound
12 embedded in a sequence of repetitive, standard sounds, it automatically triggers a deviance
13 detection mechanism the activity of which is indexed by an event-related potential (ERP)
14 component known as the mismatch negativity (MMN; Escera, Alho, Winkler, & Näätänen,
15 1998; Escera & Corral, 2007; Näätänen, Gaillard, & Mantysalo, 1978; Näätänen, 1990).
16 Importantly, the major region that contributes to the generation of the MMN, namely
17 bilateral supratemporal cortex (Giard et al, 1995; Giard, Perrin, Pernier, & Bouchet, 1990;
18 Scherg, Vajsar, & Picton, 1989), has not been implicated in mind wandering nor stimulus-
19 independent thoughts (Christoff et al., 2009; Mason et al., 2007). Accordingly, in
20 Experiment 2 we examined the ERP responses to standard and deviant auditory tones as a
21 function of whether or not participants were in a mind wandering state. If deviance
22 detection is indeed preserved during mind wandering, it predicted that mind wandering
23 should differentially affect the ERP responses to the standard vs. deviant tones.
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45

46 Methods

47 *Participants*

48
49 20 participants (13 females, 7 males; M=24.6 years, S.D.=7.1) completed the
50 experiment in exchange for \$20 (Canadian dollars). They were all right handed, with no
51 history of neurological problems and had normal or corrected-to-normal vision.
52
53
54
55
56
57
58
59
60

1
2
3 Participants provided written informed consent to the experimental procedure, according
4
5 to the guidelines of the UBC Behavioral Review Ethics Board.
6
7
8
9

10 *Stimuli and Paradigm*

11
12 Participants were presented auditory stimuli while they read a book, which is a part
13
14 of the MMN protocol commonly used as a control condition (Escera et al., 1998; Näätänen,
15
16 Paavilainen, Tiitinen, Jiang, & Alho, 1993; Sussman, Winkler, & Wang, 2003). The book that
17
18 each participant read was Francis Bacon's "Essays". This book presented the author's
19
20 theory on various topics and participants were allowed to read whichever chapter
21
22 interested them. They were told to concentrate on reading the book and to ignore the tones
23
24 presented throughout the experimental session.
25
26
27
28
29
30
31

32 Each trial consisted of an auditory stimulus that was either a standard or deviant
33
34 tone with duration of 200ms, and presented at 80dB SPL through headphones. The inter-
35
36 trial interval was randomly jittered between 500-700ms, thus stimulus onset asynchrony
37
38 was approximately 800ms. Standard tones were 600Hz and deviant tones were 800Hz,
39
40 both presented in a random order with probabilities of 0.8 and 0.2, respectively.
41
42
43
44
45
46

47 Our measure of task-related attention is identical to the methods used in
48
49 Experiment 1. Specifically, participants were asked to report their attention state as either
50
51 being "on-task" or "mind wandering" at the end of each trial block. Given that each trial
52
53 lasted approximately 800ms, and that each block lasted 30 s to 90 s, each trial block
54
55 consisted between 38 and 112 trials. Each subject was tested in a single session lasting
56
57
58
59
60

1
2
3 approximately two hours in total. The EEG setup and the experimental task each lasted
4
5 about 60 minutes. There were no official breaks during the task, however participants were
6
7 allowed to rest briefly if they had requested.
8
9

10 11 12 *Electrophysiological Recording and Analysis*

13
14
15 During task performance, electroencephalograms (EEGs) were recorded from 64
16
17 active electrodes using a Biosemi Active-Two amplifier system. Two additional electrodes
18
19 located over medial-parietal cortex (Common Mode Sense and Driven Right Leg) were used
20
21 as ground electrodes. All EEG activities were amplified with a band-pass filter of 0.1 – 30
22
23 Hz, digitized on-line at a sampling rate of 256 samples-per-second. To ensure proper eye
24
25 fixation and allow for the removal of events associated with eye movement artifacts,
26
27 vertical and horizontal electrooculograms (EOGs) were also recorded – the vertical EOGs
28
29 from an electrode inferior to the right eye, and the horizontal EOGs from two electrodes on
30
31 the right and left outer canthus. Offline, computerized artifact rejection was used to
32
33 eliminate trials during which detectable eye movements and blinks occurred. These eye
34
35 artifacts were detected by identifying the minimum and maximum voltage values on all
36
37 recorded EOG channels from -50 to 600 ms post-stimulus for each event epoch, and then
38
39 removing the trial from subsequent signal averaging if that value exceeded 150 μ V, a value
40
41 calibrated to capture all blinks, saccades and other eye movements exceeding
42
43 approximately 1 degree of visual angle. An average of 17% of the total number of trials
44
45 across participants were rejected due to these signal artifacts. The percentage of trials
46
47 rejected in the on-task vs. mind wandering condition did not significantly differ from each
48
49 other ($t(19) = 0.53, p = .70$). For each participant, ERPs for each condition of interest were
50
51
52
53
54
55
56
57
58
59
60

1
2
3 averaged into 3000 ms epochs, beginning 1500 ms before stimulus onset. Subsequently, all
4
5 ERPs were algebraically re-referenced to the average of the left and right mastoid signals,
6
7 and filtered with a low-pass Gaussian filter (25.6 Hz half-amplitude cut-off) to eliminate
8
9 any residual high-frequency artifacts in the waveforms. The resulting ERPs were used to
10
11 generate grand-averaged waveforms.
12
13
14
15
16

17 All ERP data analyses were based on mean amplitude measures using repeated-
18
19 measures ANOVAs, with specific time-windows of analyses identified below as per each
20
21 reported ANOVA. These analysis time-windows were centered on the peak of the relevant
22
23 component as identified at each electrode site in the grand-averaged waveform. Statistical
24
25 quantification of ERP data was based on mean amplitude measures relative to a -200 to 0
26
27 ms pre-stimulus baseline. The ERP waveforms for each condition of interest were based on
28
29 averaging together the EEG epochs for the 15 tones preceding each of the two attentional
30
31 state reports (on-task vs. mind wandering). Our analyses were based on the same
32
33 assumption we made in Experiment 1 that the 12 seconds prior to each report would
34
35 reliably capture the given attentional state (c.f. Kam et al., 2011; Smallwood et al., 2008).
36
37
38
39
40
41
42

43 Results

44 *Subjective Reports*

45
46 Participants completed an average of 41 trial blocks, of which 61% ended with an
47
48 "on-task" report and 39 % ended with a "mind wandering" report (SD=10.1).
49
50
51
52

53 *Electrophysiology*

54
55
56
57
58
59
60

MIND WANDERING AND ATTENTIONAL CONTROL

15

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Analysis of the ERP data focused on two issues a priori. First, we wanted to determine how, if at all, mind wandering affected the automatic detection of deviant auditory signals, as measured via the MMN. Second, in order to assess whether participants were in fact reliably reporting their on-task vs. mind wandering states, we wanted to examine the amplitude of the sensory-evoked auditory N1 component, a component known to attenuate in amplitude during mind wandering states (Kam et al., 2011). To address these issues, we conducted repeated-measures ANOVAs that included factors of attention state (on task vs. mind wandering) as well as electrodes and subjects; however, for brevity, no main effects or interactions involving electrode or subjects are reported. The ANOVA examining the N1 component also included a within-subject factor of tones (standard vs deviant).

Mismatch Negativity. The main focus of ERP data analysis was to assess the effects of task-related attention on deviance detection, as indexed by the MMN elicited by deviant tones. ERP waveforms for "on-task" and "mind wandering" states were based on averaging standard/deviant tones presented within the last 12 s of each trial block, as described above. As such, we first derived difference waveforms by subtracting the standard tones averaged waveforms from the deviant tones averaged waveforms (e.g., Escera et al., 1998; Näätänen et al., 1993; Sams, Paavilainen, Alho, & Näätänen, 1985) for the on-task and mind wandering conditions. Next, the MMN mean amplitude of the difference waveforms was then statistically compared between on-task and mind wandering conditions. The MMN of the difference waveforms as a function of attentional state was examined at midline fronto-central scalp electrode sites, Fz and Cz, where the amplitude of the MMN is typically

1
2
3 maximal (e.g., Escera et al., 1998; Sams et al., 1985). In examining the difference waveform,
4
5 we observed that the peak of the MMN (90-150 ms) coincided with the peak of N1 (95-115
6
7 ms). That our MMN peaked earlier than the typical MMN at 150-250ms is consistent with
8
9 past studies that suggested peak latency does get shorter with greater magnitude of
10
11 stimulus change (Tiitinen et al., 1994; Näätänen et al., 1989; Amendo & Escera, 2000). That
12
13 is the case for our standard (600Hz) and deviant (800Hz) stimuli, whereas in other studies,
14
15 the difference in tones is around 100Hz (e.g. Escera et al., 1998). Nevertheless, given the
16
17 overlap in time window, and owing to the fact that in subtraction waveforms like the MMN,
18
19 the variance of the waveform is the sum of the variance in the two parent waveforms (e.g.,
20
21 Picton et al., 2000), we elected to focus our analysis on the N1 waveforms.
22
23
24
25
26
27
28
29

30 *N1.* We wanted to examine whether there was a normal sensory attenuation of the auditory
31
32 stimuli during mind wandering periods, as would be predicted by our previous finding
33
34 (Kam et al., 2011). As such, we compared the N1 component to both tones during on-task
35
36 vs. mind wandering states. Specifically, we conducted repeated-measures ANOVAs that
37
38 included factors of attentional state (on-task vs. mind wandering) and tones (standard vs.
39
40 deviant) to examine the interaction between the two. The N1 elicited by both standard and
41
42 deviant tones as a function of attentional state are shown in Figure 3a and 3b, and was
43
44 examined at midline fronto-central scalp electrode sites, Fz and Cz, where the amplitude of
45
46 the N1 is typically maximal (e.g., Woldorff, & Hillyard, 1991). The N1 mean amplitudes and
47
48 standard errors of the mean are shown in Table 1. Mean amplitude measures were taken
49
50 across a 95-115 ms post-stimulus time window. While the main effect of attention was not
51
52 significant ($F < 1.00$), the main effect of tones was significant ($F(1,19) = 38.24, p < .001$).
53
54
55
56
57
58
59
60

MIND WANDERING AND ATTENTIONAL CONTROL

17

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Importantly, we found a significant interaction between attention state and tones ($F(1,19) = 5.06, p = .037$). Separate analyses revealed a significant main effect of attention state for standard tones ($F(1,19) = 10.84, p < .005$), but not deviant tones ($F(1,19) = 0.19, p = .669$). Specifically, while the N1 elicited by standard tones was significantly greater during “on-task” states relative to mind wandering states, this difference was absent for deviant tones.

Control Analyses. Given the results reported above, we wanted to examine an additional control issue concerning our findings. Specifically, we observed residual noise in the pre-N1 portion of the ERP waveforms, and the waveforms for the deviant tones in particular, which may have impacted the reliability of our results. As such, we bootstrapped our current findings with 20 subjects to empirically create more samples in order to establish the reliability of our data. Bootstrapping is a nonparametric approach to analyzing ERP data without assuming normality of the sampling distribution (e.g. Keselman et al., 2003; Wasserman & Bockenholt, 1989). This procedure requires resampling of data with replacement, and leads to more accurate inferences (Fox, 2002).

First, we determined the average N1 amplitude at both electrodes (ie: Fz and Cz) in the specified time window used in our analyses for each subject, for both standard and deviant tones during both on-task and mind wandering conditions. Subsequently, we computed the difference between on-task and mind wandering states to represent the attentional difference for both standard and deviant tones. We then performed a bootstrap simulation that involves resampling our subjects’ data with replacement for both the

1
2
3 standard and deviant tones difference scores. This process involves creating a large
4
5 number of “bootstrap samples” of 20 data points, with each data point chosen randomly
6
7 and independently from the original set of 20 data points with replacement. Each subject’s
8
9 data has an equal chance of being chosen at each random draw, and each data point can be
10
11 selected more than once in each bootstrap sample dataset (Wilcox, 2001).
12
13
14
15
16
17

18 In generating 4999 bootstrap samples (Fox, 2002) and computing a mean of the
19
20 scores from each sample, a bootstrapped sampling distribution is formed and the 95th
21
22 percentile confidence intervals allow one to make inferences about the statistic at hand. In
23
24 our case, we wanted to determine whether the difference between on-task and mind
25
26 wandering states is significant for the standard tone, as well as the deviant tone. Since we
27
28 created bootstrap samples on a difference score, a confidence interval that includes 0
29
30 suggests that the difference between the two attention states can be 0 thereby leading to
31
32 the conclusion of retaining the null hypothesis. On the other hand, if the confidence interval
33
34 does not include 0, then the two attention states is significantly different from each other,
35
36 and thus one can reject the null hypothesis.
37
38
39
40
41
42
43

44 The 95th percentile confidence interval for standard tones is [-1.2236, -0.1407] at
45
46 Fz, and [-1.0417, -0.3600] at Cz, whereas the 95th percentile confidence interval for deviant
47
48 tones is [-0.9383, 1.2428] at Fz, and [-0.4845, 0.8545] at Cz. That the confidence intervals at
49
50 both electrodes for standard tones do not include 0 suggest there is a significant difference
51
52 in the N1 amplitude between on-task and mind wandering conditions. On the other hand,
53
54 the confidence intervals for deviant tones do include 0, suggesting the difference in N1
55
56
57
58
59
60

1
2
3 between the two attentional states was not significant at either Fz or Cz. Both conclusions
4
5 are consistent with our omnibus N1 ANOVA and follow up analyses.
6
7
8
9

10 **Discussion**

11
12
13 In Experiment 2 we found that there was an increase in the relative saliency of
14
15 deviant events regardless of attention state, and a decrease in sensory-related processing
16
17 of standard events during mind wandering, as measured in the N1 ERP component. This
18
19 suggests that despite the characteristic down-regulation of sensory processing in auditory
20
21 cortex during mind wandering (Kam et al., 2011), there is a preserved ability to detect
22
23 deviant events. We support and expand on these conclusions in the General Discussion.
24
25
26
27
28
29

30 **General Discussion**

31
32 The present study examined whether some ongoing attentional functions are
33
34 preserved while we are mind wandering. In Experiment 1, using traditional performance
35
36 measures, we found that mind wandering appears to disrupt the strategic orienting of
37
38 visual spatial attention, both volitionally and reflexively. In Experiment 2, however, using
39
40 ERP-based measures, we found that mind wandering maintained the salience of
41
42 unexpected or deviant auditory events but decreased the sensory responses to standard
43
44 tones, as measured via the N1 ERP component. Taken together, what our data suggest is
45
46 that our attentional systems adaptively respond to mind wandering, such that under
47
48 conditions leading to a down-regulation of strategic spatial orienting, there is a
49
50 preservation of more automatic deviance detection. Given our conclusion, several key
51
52 issues and questions arise.
53
54
55
56
57
58
59
60

1
2
3
4
5
6 First, to what extent is the task-related attention effect in Experiment 1 due to
7
8 sensory and/or cognitive attenuation of the cue during mind wandering, as opposed to a
9
10 direct impairment of attentional orienting per se, as we would prefer to conclude?
11
12 Specifically, if mind wandering did attenuate sensory processing of the cue, the disruption
13
14 in attentional orienting could be a result of the cue not being processed sufficiently at a
15
16 sensory (e.g., Kam et al., 2011) and/or cognitive (e.g., Smallwood et al., 2008) level. Two
17
18 lines of evidence suggest, however, that this may be a less than complete account of our
19
20 behavioral findings. For one, the fMRI-based findings of Mason et al. (2007) and Christoff et
21
22 al. (2009) indicate that periods of mind wandering are also associated with a down-
23
24 regulation of activity in the same left prefrontal cortical regions consistently associated
25
26 with the top-down control of selective visual attention (e.g., Corbetta et al., 1993; Hopfinger
27
28 et al., 2000). This indicates that mind wandering has the capacity to directly impact the
29
30 top-down control of attention itself, regardless of any concomitant effects on the sensory
31
32 and/or cognitive processing of external stimuli. Second, the sensory attenuation reported
33
34 in Kam et al. (2011) was found specifically for task-irrelevant stimuli in the upper visual
35
36 periphery, whereas Smallwood et al. (2008) found no sensory attenuation for task-relevant
37
38 stimuli at fixation. Given that our attention-directing cues were presented at fixation, this
39
40 would appear to mitigate at least purely sensory-level accounts of our Experiment 1
41
42 findings. Regardless of these specific possibilities though, the broader implication is that
43
44 mind wandering is likely able to exert an impact on attentional orienting in both ways—via
45
46 reducing the extent to which attentionally-imperative stimuli are processed, as well as
47
48 directly down-regulating activity in attentional control regions of left prefrontal cortex.
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3
4
5
6 Second, our finding of an attenuation of automatic attention orienting during mind
7
8 wandering may be limited to the specific stimulus set used in our study. In order to
9
10 facilitate automatic spatial orienting, we used cues that mimic eyes. This particular set of
11
12 orienting stimulus have successfully elicited eye gaze orienting in past studies (e.g., Friesen
13
14 & Kingstone, 1997; Tipper et al., 2007). Notably, such reflexive orienting can arise along a
15
16 number of other dimensions and can be elicited by various types of stimuli, whether it be
17
18 visual (e.g. arrows) or auditory (e.g. loud sounds). Therefore, future studies are needed to
19
20 elucidate the effects of mind wandering of these other types of stimuli.
21
22
23
24
25
26
27

28 A third issue concerns what our findings specifically reveal about the adaptive
29
30 nature of attentional control during mind wandering. Our data may shed light on why our
31
32 minds can frequently wander, and yet we are still capable of monitoring and responding to
33
34 the external environment. In particular, that deviance detection is preserved during mind
35
36 wandering suggests that we seem to be designed to operate on autopilot during mind
37
38 wandering, but become more automatically vigilant for things out of the ordinary. This
39
40 would imply, for example, that when mind wandering while driving, we would continue to
41
42 mind wander so long as the traffic patterns and behaviors of other drivers remain
43
44 somewhat normal and expected. However, if something unusual were to happen, such as a
45
46 driver suddenly veering ahead, our data predict that such events should be readily
47
48 detected, thereby allowing us to emerge out of our state of automaticity and instead
49
50 adaptively respond to the deviant event.
51
52
53
54
55
56
57
58
59
60

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Fourth, we found that the N1 to deviant events was preserved during mind wandering, whereas Braboszcz and Delorme (2011) reported an attenuation of the MMN to deviant events during mind wandering compared to breath focus. While this appears to stand in contrast with our finding of a preserved N1 during mind wandering, there are several reasons that can account for this difference. First, various differences between our studies may have contributed to the potential differences observed. For example, while innovative, the authors considered data occurring both before and after an attention report. Following the interruption of the actual report of one's attention, it would be difficult to determine whether the subject is still in the reported attention state, or whether that interruption would put the subject back in focus even if temporarily. In contrast, we only examined the data immediately preceding an attention report. Further, the condition of mind wandering was compared to the condition of 'breath focus'. Subjects were instructed to count their breath cycles with their eyes closed and to ignore the auditory tones. On the other hand, we were comparing between conditions of attention directed towards the main task, reading, and attention away from the task. In other words, our main task required attention to an external, visual stimulus, whereas the 'breath focus' condition required attention to an internal, non-visual stimulus.

A fifth issue concerns whether mind wandering differentially modulates processing of stimuli presented in different modalities. In Experiment 1, mind wandering disrupted spatial orienting to the visual stimuli, whereas in Experiment 2, mind wandering preserved the detection of the deviant auditory stimuli. At first glance, this may seem to suggest visual and auditory processing are differentially altered by mind wandering. Nevertheless,

1
2
3 previous evidence has suggested that mind wandering attenuates sensory processing in the
4
5 same manner whether the stimuli were presented in the visual or auditory modality (Kam
6
7 et al., 2011). Perhaps the crucial factor modulating stimulus processing does not lie in the
8
9 modality of stimulus, but whether the external stimulus was more worthy of our attention
10
11 than our internal thoughts at any given time. In particular, it has been suggested that our
12
13 minds generally shield us from mundane sensory events to facilitate internal thoughts
14
15 (Barron et al., 2011; Schooler et al., 2011). This is consistent with findings from Experiment
16
17 1, where processing of the anticipated stimuli was attenuated. However, when a change
18
19 occurs in the environment, for example an unexpected stimulus that is potentially harmful
20
21 or dangerous, we may automatically shift attention from our internal thoughts to the
22
23 external environment, as observed in Experiment 2 in our response to the deviant stimuli.
24
25 Together, this suggests that our minds may engage in this ongoing automatic evaluation of
26
27 the importance of both external and internal stimuli, at which point our attention is then
28
29 allocated accordingly.
30
31
32
33
34
35
36
37
38
39

40 Lastly, our findings from Experiment 1 raise an important issue concerning the
41
42 interaction between mind wandering and selective attention. Canonical models of both
43
44 spatial- (e.g., Posner et al., 1980; Corbetta & Shulman, 2002) and object-based (e.g.,
45
46 Desimone & Duncan, 1995; Duncan, Humphreys, & Ward, 1997) attentional selection
47
48 implicitly assume that we are always selecting *something* from the external environment
49
50 for higher levels of cognitive analysis. But if mind wandering disrupts selective attention, it
51
52 would suggest that there are systematic periods of time when we select *nothing* from the
53
54 external environment. This is consistent with our previous finding that mind wandering
55
56
57
58
59
60

MIND WANDERING AND ATTENTIONAL CONTROL

24

1
2
3 attenuates initial level sensory processing of stimuli (Kam et al., 2011). Our study furthers
4
5 this idea in two ways. First, we demonstrated that we don't simply shut down sensory
6
7 processing per se, but we do in fact shut down the spotlight. Second, we also showed that
8
9 we compensate for this dampened spotlight by preserving our sensitivity to the unusual
10
11 events. That is, we don't deliberately select for anything to process, but we maintain
12
13 vigilance instead.
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

For Review Only

References

- 1
2
3
4
5
6 Barron, E., Riby, L., Greer, J., Smallwood, J. (2011). Absorbed in thought: The effect of
7
8 mind wandering of the processing of relevant and irrelevant events. *Psychological*
9
10 *Science*, *22*(5), 596-601.
- 11
12
13 Braboszcz, C., & Delorme, A. (2011). Lost in thoughts: neural markers of low alertness
14
15 during mind wandering. *Neuroimage*, *54*, 3040-3047.
- 16
17
18 Christoff, K., Gordon, A. M., Smallwood, J., Smith, R., & Schooler, J. W. (2009).
19
20 Experience sampling during fMRI reveals default network and executive system
21
22 contributions. *Proceedings of the National Academy of Sciences*, *106* (21), 8719-
23
24 8724.
- 25
26
27 Corbetta, M., Miezin, F. M., Dobmeyer, S., Shulman, G. L., & Petersen, S. E. (1991).
28
29 Selective and divided attention during visual discriminations of shape, color, and
30
31 speed: Functional anatomy by positron emission tomography. *Journal of*
32
33 *Neuroscience*,
34
35 *11*, 2383-2402.
- 36
37
38 Corbetta, M., & Shulman, G. L. (2002). Control of goal-directed and stimulus-driven
39
40 attention in the brain. *Nature Review Neuroscience*, *3*, 201-215.
- 41
42
43 Desimone, R. & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual*
44
45 *Review of Neuroscience*, *18*, 193-222.
- 46
47
48 Duncan, J., Humphreys, G., & Ward, R. (1997). Competitive brain activity in visual
49
50 attention. *Current Opinions in Neurobiology*, *7*, 255-261.
- 51
52
53
54 Escera, C., Alho, K., Winkler, I., & Näätänen, R. (1998). Neural mechanisms of
55
56
57
58
59
60

1
2
3 involuntary attention to acoustic novelty and change. *Journal of Cognitive*
4
5
6 *Neuroscience*,

7
8 10, 590-604.

9
10 Escera, C., & Corral, M. J. (2007). Role of mismatch negativity and novelty-P3 in
11
12 involuntary auditory attention. *Journal of Psychophysiology*, 21, 251-264.

13
14
15
16 Fox, J. (2002). *An R and S-Plus Companion to Applied Regression*. Sage Publications,
17
18 Thousand Oaks, CA.

19
20 Friesen, C. K., & Kingstone, A. (1998). The eyes have it! Reflexive orienting is triggered by
21
22 nonpredictive gaze. *Psychonomic Bulletin and Review*, 5, 490-495.

23
24
25 Giard, M. H., Lavikainen, J., Reinikainen, K., Perrin, F., Bertrand, O., et al. (1995).

26
27 Separate representation of stimulus frequency, intensity, and duration in auditory
28
29 sensory memory: An event-related potential and dipole-model analysis. *Journal of*
30
31
32 *Cognitive Neuroscience*, 7, 133-143.

33
34
35 Giard, M. H., Perrin, F., Pernier, J., & Bouchet, P. (1990). Brain generators implicated in
36
37 processing of auditory stimulus deviance. A topographic ERP study.
38
39
40 *Psychophysiology*, 27, 627-640.

41
42 Hooker, C. I., Paller, K. A., Gitelman, D. R., Parrish, T. B., Mesulam, M. M., Reber, P. J.

43
44 (2003). Brain networks for analyzing eye gaze. *Cognitive Brain Research*, 17, 406-
45
46
47 418.

48
49 Hopfinger, J. B., Buonocore, M. H., & Mangun, G. R. (2000). The neural mechanisms of
50
51
52 top-down attentional control. *Nature Neuroscience*, 3, 284-291.

53
54 Kam, J. W. Y., Dao, E., Farley, J., Fitzpatrick, K., Smallwood, J., et al. (2011). Slow
55
56
57
58
59
60

MIND WANDERING AND ATTENTIONAL CONTROL

27

- 1
2
3 fluctuations in attentional control of sensory cortex. *Journal of Cognitive*
4
5
6 *Neuroscience*,
7
8 23, 460-470.
9
- 10 Keselman, H. J., Wilcox, R. R., & Lix, L. M. (2003). A generally robust approach to
11
12 hypothesis testing in independent and correlated group designs. *Psychophysiology*,
13
14 40, 586-596.
15
16
- 17
18 Mason, M. F., Norton, M. I., Van Horn, J. D., Wegner, D. M., Grafton, S. T., & Macrae,
19
20 C. N. (2007). Wandering Minds: The default network and stimulus-independent
21
22 thought. *Science*, 315, 393-395.
23
24
- 25 Nätänen, R. (1990). The role of attention in auditory information processing as revealed
26
27 by event-related potentials and other brain measures of cognitive function.
28
29 *Behavior and Brain Science*, 13, 201-288.
30
31
- 32 Nätänen, R., Gaillard, A. W. K., & Mantysalo, S. (1978). Early selective attention effects
33
34 on the evoked potential reinterpreted. *Acta Psychologica*, 42, 313-329.
35
36
- 37 Nätänen, R., Paavilainen, P., Tiitinen, H., Jiang, D., & Alho, K. (1993). Attention and
38
39 mismatch negativity. *Psychophysiology*, 30, 436-450.
40
41
- 42 O'Connell, R. G., Dockree, P. M., Robertson, I. H., Bellgrove, M. A., Foxe, J. J., et al.
43
44 (2009). Uncovering the neural signature of lapsing attention: Electrophysiological
45
46 signals predicts errors up to 20 s before they occur. *Journal of Neuroscience*, 29,
47
48 8604-8611.
49
50
- 51 Picton, T. W., Bentin, S., Berg, P., Donchin, E., Hillyard, S. A., Johnson, R., et al. (2000).
52
53 Guidelines for using event-related potentials to study human cognition: Recording
54
55 standards and publication criteria. *Psychophysiology*, 37, 127-152.
56
57
58
59
60

MIND WANDERING AND ATTENTIONAL CONTROL

28

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, 32,

3-25.

Sams, M., Paavilainen, P., Alho, K., & Näätänen, R. (1985). Auditory frequency discrimination and event-related potentials. *Electroencephalography and Clinical Neurophysiology*, 62, 437-448.

Scherg, M., Vajsar, J., & Picton, T. W. (1989). A source analysis of the late human auditory evoked potentials. *Journal of Cognitive Neuroscience*, 1, 336-355.

Schooler, J.W., Smallwood, J., Christoff, K., Handy, T., Reichle, E., & Sayette, M. A. (2011). Meta-awareness, perceptual decoupling and the wandering mind. *Trends in Cognitive Science*, 15, 319-326.

Schröger, E., Giard, M. H., & Wolff, C. (2000). Auditory distraction: Event-related potential and behavioral indices. *Clinical Neurophysiology*, 111, 1450-1460.

Smallwood, J., Beach, E., Schooler, J. W., & Handy, T. C. (2008). Going AWOL in the brain: Mind wandering reduces cortical analysis of external events. *Journal of Cognitive Neuroscience*, 20, 458-469.

Smallwood, J., Obonsawin, M.C., & Heim, D. (2003) Task Unrelated Thought: the role of distributed processing. *Consciousness and Cognition*. 12(2), 169-189.

Smallwood, J., Brown, K. S., Tipper, C., Giesbrecht, B., Franklin, M. S., et al. (2011). Pupillometric evidence for the decoupling of attention from perceptual input during offline thought. *PLoS ONE*, 6, e18298. doi:10.1371/journal.pone.0018298

Sonuga-Barke, E. J., & Castellanos, F. X. (2007). Spontaneous attentional fluctuations in impaired states and pathological conditions: A neurobiological

MIND WANDERING AND ATTENTIONAL CONTROL

29

1
2
3 hypothesis. *Neuroscience and Biobehavioral Reviews*, 31, 977-986.

4
5
6 Sussman, E., Winkler, I., & Wang, W. (2003). MMN and attention: Competition for
7
8 deviance detection. *Psychophysiology*, 40, 430-435.

9
10
11 Tipper, C. M., Handy, T. C., Giesbrecht, B., & Kingstone, A. (2008). Brain responses to
12
13 biological relevance. *Journal of Cognitive Neuroscience*, 20, 879-891.

14
15
16 Wasserman, S., & Bockenholt, U. (1989). Bootstrapping: applications to psychophysiology.
17
18 *Psychophysiology*, 26, 208-221.

19
20
21 Wilcox, R. R. (2001). *Fundamentals of Modern Statistical Methods*. New York: Springer.

22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
Woldorff, M. G., & Hillyard, S. A. (1991). Modulation of early auditory processing during
selective listening to rapidly presented tones. *Electroencephalography and Clinical
Neurophysiology*, 79, 170-191.

MIND WANDERING AND ATTENTIONAL CONTROL

30

Table 1. Mean amplitudes of N1 component (95-115ms) from Experiment 2. Amplitudes and standard errors of each component at electrode sites Fz and Cz are presented below as a function of attention states (on-task vs. mind wandering).

Tones	Electrodes	Attentional State	
		On Task	Mind Wandering
Standard Tones	Fz	-1.93 (0.20)	-1.20 (0.35)
	Cz	-1.87 (0.16)	-1.30 (0.19)
Deviant Tones	Fz	-2.91 (0.32)	-3.11 (0.46)
	Cz	-2.44 (0.28)	-2.61 (0.29)

Figure Legends

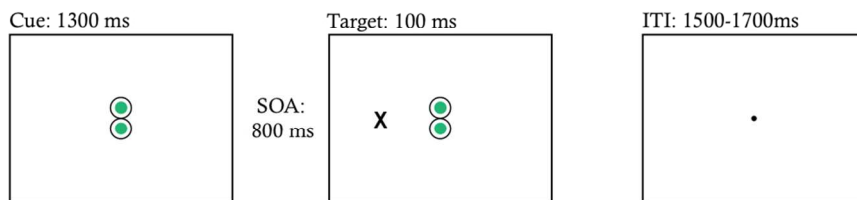
Figure 1. Task paradigm of Experiment 1. The stimulus and timing of the (a) volitional orienting task and (b) reflexive orienting task are shown.

Figure 2. Reaction times for both volitional and reflexive spatial orienting tasks in Experiment 1. Reaction times and standard errors to cued and uncued targets are shown as a function of on-task and mind wandering attentional states. Reaction times to cued targets were significantly faster than uncued targets during the on-task condition only (* $p > .05$).

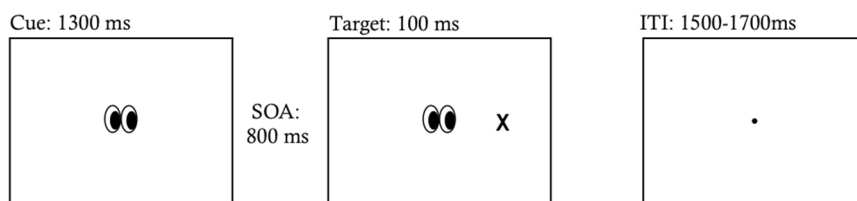
Figure 3. ERP waveforms in response to (a) standard tones and (b) deviant tones as a function of on-task and mind wandering states at electrode sites Fz and Cz. While the amplitude of N1 to standard tones was significantly greater during on-task relative to mind wandering states, this difference was not observed in the N1 to deviant tones.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

a) Task 1: Volitional Spatial Orienting



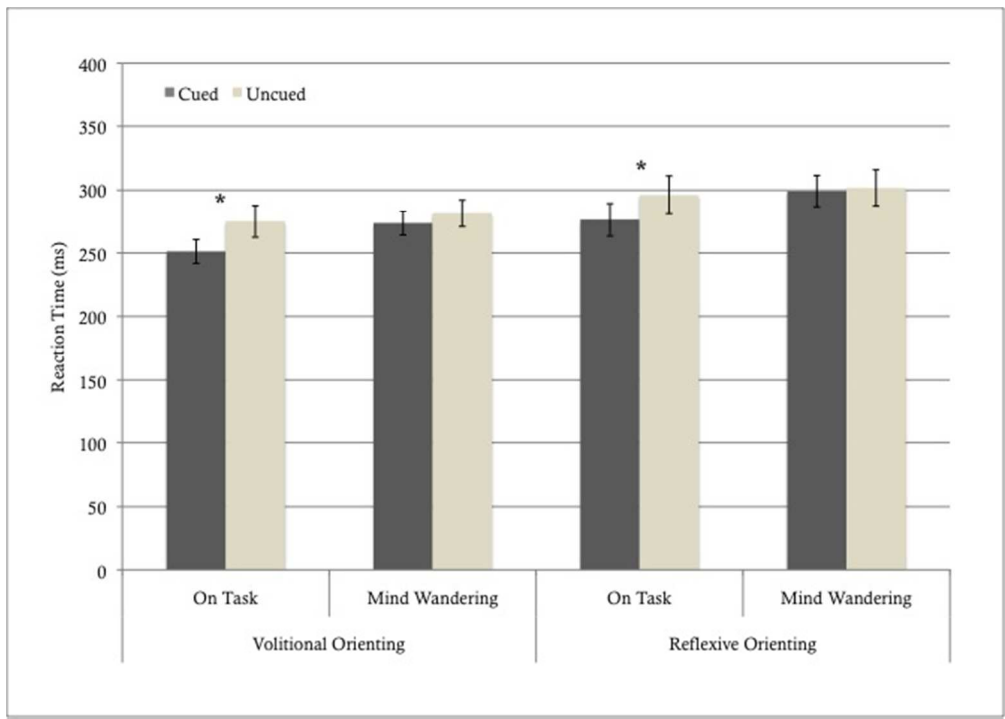
b) Task 2: Reflexive Spatial Orienting



195x118mm (150 x 150 DPI)

View Only

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60



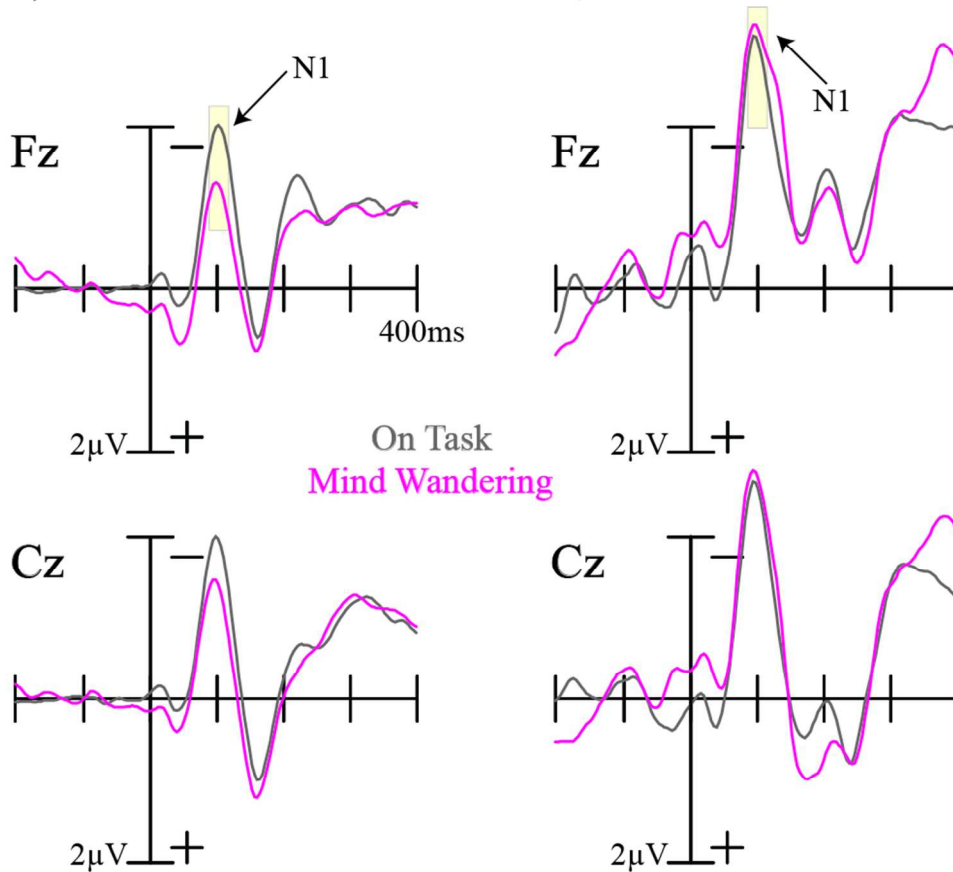
235x167mm (72 x 72 DPI)

View Only

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

a) Standard Tones

b) Deviant Tones



87x82mm (300 x 300 DPI)

