Attenuated Face Processing during Mind Wandering

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Abstract

■ Mind wandering (MW) has been recently investigated in many studies. It has been suggested that, during MW, processing of perceptual stimuli is attenuated in favor of internal thoughts, a phenomenon referred to as perceptual decoupling. Perceptual decoupling has been investigated in ERP studies, which have used relatively simple perceptual stimuli, yet it remains unclear if MW can impact the perceptual processing of complex stimuli with real-world relevance. Here, we investigated the impact of MW on behavioral and neural responses to faces. Thirty-six participants completed a novel sustained attention to response task with faces. They were asked to respond to upright faces (nontargets) and withhold responses to inverted faces (targets) and to report intermittently if they were "On task" or "Off task." Behavioral analyses revealed greater intraindividual coefficient of variation for nontarget faces preceding Off task versus On task. ERP analyses focused primarily on the N170 component associated with face processing but also included the P1 and P3 components. The results revealed attenuated amplitudes to nontarget faces preceding Off task versus On task for the N170, but not for the P3 or P1. These findings suggest decoupled visual processing of faces during MW, which has implications for social neuroscience research. ■

INTRODUCTION

The topic of mind wandering (MW) has garnered immense interest in cognitive psychology and neuroscience in the last 15 years (Callard, Smallwood, Golchert, & Margulies, 2013). The prevalence of MW research continues to escalate with the goal of disentangling multiple aspects of MW and achieving a fine-grained understanding of its underlying neurocognitive mechanisms (Kucyi, 2017; Christoff, Irving, Fox, Spreng, & Andrews-Hanna, 2016; Mittner, Hawkins, Boekel, & Forstmann, 2016; Smallwood & Schooler, 2015). One concept that has been consistently supported from a growing number of MW studies is perceptual decoupling (Kam & Handy, 2013). "Perceptual decoupling" refers to the attenuated processing of external events when one's attention drifts away from the task at hand and is directed toward internal thoughts (Smallwood, 2013; Smallwood & Schooler, 2006). Evidence for perceptual decoupling comes from behavioral and neural investigations showing decreased accuracy and increased RT variability (Bastian & Sackur, 2013; Seli, Cheyne, & Smilek, 2013; McVay & Kane, 2009) along with reduced neural signal (Baird, Smallwood, Lutz, & Schooler, 2014; Kam et al., 2011; Smallwood, Beach, Schooler, & Handy, 2008) in response to external stimuli when the mind wanders away from the ongoing task.

Attenuated neural processing of external stimuli during MW has been primarily evidenced using the ERP method (Baird et al., 2014; Kam, Nagamatsu, & Handy, 2014; Kam et al., 2011; Smallwood et al., 2008). Because the ERP method can reliably detect rapid neural changes due to its high temporal resolution on the scale of milliseconds, it is particularly well suited to precisely track the effects of MW on different stages of information processing: from early sensory processing, indexed by P1 and N1, to later cognitive processing, indexed by the P3 component. The ERP effects of MW have been primarily explored using the sustained attention to response task (SART; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997) or variants of it. Typically, the SART, which has been frequently used in the MW research (Seli, 2016; Smilek, Carriere, & Cheyne, 2010), consists of responding to frequent nontarget stimuli and withholding responses to infrequent target stimuli. Failure to inhibit responses to target stimuli, referred to as target errors or commission errors, has been primarily considered as an objective behavioral index of MW (Smilek et al., 2010; Cheyne, Carriere, & Smilek, 2006; but see Head & Helton, 2013). In addition, SART allows sampling self-reports of MW via probe questions presented intermittently throughout the task and asking participants whether their attention is focused on the ongoing task or away from it (on task vs. off task). Based on this past research, the SART appears to be a particularly well-suited task to elucidate the underpinnings of both objectively and subjectively assessed MW at both the behavioral and neural levels.

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Journal of Cognitive Neuroscience 30:11, pp. 1691–1703
doi:10.1162/jocn_a_01312

Using the SART, Smallwood et al. (2008) found attenuated P3 to nontarget stimuli immediately preceding both commission errors and subjective reports of MW. This result was taken as evidence for reduced cognitive processing of external stimuli, not only when participants are making target errors but also when they self-reported that their attention was off task. Intriguingly, some subsequent studies did not consistently find a significant reduction in the P3 as a function of MW reports (Kam et al., 2011, Experiments 2 and 3; Kam et al., 2016). In a similar vein, inconsistencies were also reported for early sensory components, such as the P1. Smallwood et al. (2008) failed to observe attenuation in the P1 with MW, whereas Kam et al. (2011) found this pattern (see also Baird et al., 2014). It is important to note that the stimuli to which the P1 was time-locked differed across these studies. Whereas Smallwood et al. (2008) examined P1 responses to task-relevant nontargets preceding MW reports, Kam et al. (2011) examined the P1 to task-irrelevant, "to-be-ignored" stimuli presented between nontargets and targets. Thus, inconsistencies across these studies may be, in part, due to subtle differences in stimulus parameters. In line with this suggestion, an emerging line of research proposes that factors such as the meaningfulness of the stimuli can influence the occurrence of MW (Maillet & Schacter, 2016).

Virtually all of the ERP studies of MW, to date, use perceptually simple stimuli (i.e., digits and letters). Hence, it remains unclear how MW impacts the neural processing of perceptually complex stimuli that are more representative of what is encountered frequently in the real world. Human faces are considered ecologically relevant stimuli with a key role in various aspects of daily life; hence, face perception research can be situated at the intersection of cognitive, social, and affective neuroscience (Amodio, Bartholow, & Ito, 2014; Ito, 2011; Todorov, 2011; Bartholow & Amodio, 2009). This research has greatly contributed to advancing our understanding of the neural underpinning of face perception and the factors that can modulate it.

Specifically, face perception has been consistently associated with the N170 ERP component, whose amplitude response is larger for faces than other stimuli (Rossion & Jacques, 2011; Bentin, Allison, Puce, Perez, & McCarthy, 1996). In addition, recent studies showed that the N170 can be sensitive to manipulations of attention (Navajas, Nitka, & Quian Quiroga, 2017; Sreenivasan, Goldstein, Lustig, Rivas, & Jha, 2009), and this highlights the importance of the top–down influence of attention on face perception. In the same vein, the N170 appears to be sensitive to variations related to social and motivational aspects (Senholzi & Ito, 2013), and it has been considered a crucial ERP component for the study of social interactions (Ito, 2011; Bartholow & Amodio, 2009). Despite an extensive research effort to achieve a better understanding of the factors that can influence face perception, as indexed by N170, it remains unclear how face perception is affected by MW, which is a topic at the intersection of attention research (Thomson, Besner, & Smilek, 2015) and social neuroscience research (Mrazek et al., 2011).

This study aims to bridge the gaps between the MW and face perception literatures by investigating how MW impacts the behavioral and neural responses to faces employed as stimuli in the SART.[1] At the behavioral level, the main goal is to examine RT performance via assessment of the RT variability to nontarget faces preceding subjective reports of MW as well as target errors. RT variability is known to be greater when there is lack of attentional stability, which coincides with the occurrence of MW (Bastian & Sackur, 2013). We expect to observe greater RT variability to nontarget faces when attention drifts away from the task at hand (i.e., intervals immediately preceding both self-reported MW and target errors). At the neural level, the primary goal is to examine the N170 response. Based on separate lines of evidence from the perceptual decoupling (e.g., Smallwood et al., 2008) and attention literatures (e.g., Sreenivasan et al., 2009), we expect to observe an attenuated N170 response to faces presented during intervals when attention has drifted away from the task at hand. The second goal is to examine the P1 and P3 responses to corroborate prior ERP findings in studies using the standard SART task design with simple stimuli (e.g., Smallwood et al., 2008), which was modified herein to employ complex perceptual stimuli. Based on Smallwood et al.'s study (2008), which used a variant of the SART that is the closest to the one used in this study, we expect to observe attenuated P3, but not P1, responses. Finally, an exploratory goal of this study is to determine if the behavioral and neural responses to faces preceding subjective reports of MW can be modulated by the level of confidence (LOC) participants have in these self-reports. Although confidence judgment has been primarily investigated in the perception and memory domains as indication of metacognitive ability (Fleming & Dolan, 2012), it appears to be an important-yet-understudied issue in the MW research (Seli, Jonker, Cheyne, Cortes, & Smilek, 2015).

METHODS

Participants

Thirty-six undergraduate students (18 women, M_{age} = 18.83 years, SD_{age} = 1.28 years, age range = 18–25 years) participated in the study. No participants reported a history of neurological disorder or head injury with loss of consciousness, and all had normal or corrected-to-normal vision. The study was approved by the institutional review board of the University of Miami, and participants provided written informed consent and received course credit for their participation. Data from eight participants were excluded from the analyses: one for incomplete data, one for low performance (more than 4 *SD*s below

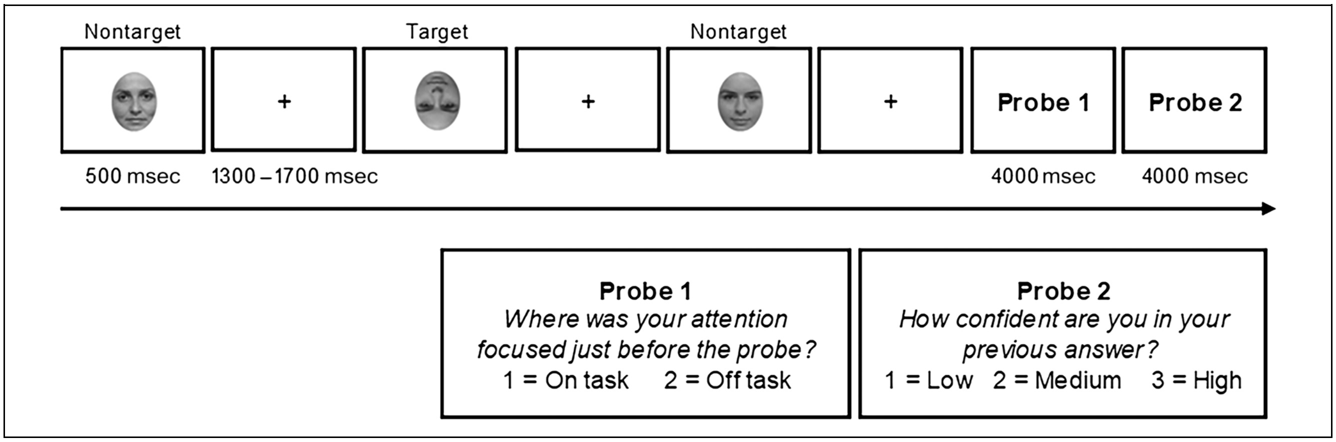

Figure 1. Schematic representation of F-SART. Participants were instructed to respond via button press to frequently occurring upright faces (nontargets) and withhold responses to infrequently occurring inverted faces (targets). They were also instructed to answer two probe questions: the first one assessing if their attention was On task or Off task (Probe 1) and the second one assessing their LOC in their Probe 1 response on a 3-point Likert scale (Probe 2).

the group accuracy mean), and six for insufficient number of trials per condition (<10) after artifact removal and exclusion of incorrect trials. As such, data from 28 participants (14 women, M_{age} = 18.86 years, SD_{age} = 1.41 years, age range = 18–25 years) were included in the present analyses. All but one participant were right-handed.[2]

Stimuli

The stimuli used in this study were 991 neutral face images. The faces were converted to grayscale and cropped with an oval template (length = 3.22 in., width = 2.49 in.) to remove hair and ears. Forty-nine upright faces were rotated 180° to form inverted faces. Each face (upright or inverted) was presented only once. All face images were adjusted to equate for luminance across faces. The processing of all face images was performed using Adobe Photoshop CC 2014.

Task: SART with Faces

To investigate the impact of MW on face processing, we adapted the SART (Robertson et al., 1997) by using facial stimuli rather than stimuli depicting digits, symbols, or letters. The SART is a widely used go/no-go task to study MW (Seli, 2016; Smilek et al., 2010; Smallwood & Schooler, 2006) and has also been adapted to the ERP context (Kam et al., 2011; Smallwood et al., 2008). The present version of the SART, referred to as Face SART (F-SART), consisted of a stream of facial stimuli presented visually one after the other in the center of a white screen. Each face was displayed for 500 msec and followed by a fixation cross of variable duration (*M* = 1501 msec, *SD* = 117 msec, range = 1300–1700 msec). Participants were instructed to respond via button press to frequently occurring upright faces (nontargets) and withhold their response to infrequently occurring upside-down faces (targets; see Figure 1). Responses were recorded while the face was displayed as well as during the fixation cross following the face offset. Because it has been demonstrated that low target occurrence can increase the probability of MW (Smallwood et al., 2004), targets were presented on ~5% of the trials. The presentation of targets was pseudorandomized with the restriction of at least six consecutive nontarget trials before target trials. This allows investigation of the behavioral and ERP responses to the six nontargets preceding targets as a function of the response to the target (correct withhold vs. commission error); this is akin to procedures used in prior ERP studies of MW (e.g., Smallwood et al., 2008).

On occasion and in a pseudorandom fashion to limit participant expectation, two probe questions related to MW and confidence were presented in succession. The first question (Probe 1) asked “Where was your attention focused just before the probe?” and participants responded by choosing between (1) “On task” or (2) “Off task” responses. Before the experiment, On task was explained to the participants as the instances when attention is orientated completely and uniquely toward performing the task. Off task was explained as the instances when attention is on something unrelated to the task, such as upcoming exams, plans for the weekend, or more personal experiences. The second question (Probe 2) assesses the participants’ confidence regarding their Probe 1 response. The question asked “How confident are you in your previous answer?” and participants rated their confidence on a 3-point scale: 1 = *low*, 2 = *medium*, and 3 = *high*. The probes were presented one after the other (each for 4000 msec), and responses were recorded throughout the entire duration of each probe. The second probe was followed by a fixation cross of variable duration (*M* = 1487 msec, *SD* = 115 msec, range = 1313–1693 msec). Based on prior studies suggesting that a 1-min interval between probes can lead to ~50% MW reports during a task (Seli, Carriere, Levene, & Smilek, 2013), the average interval between probe trials was ~50 sec (range = 12–83 sec). The presentation of probes was pseudorandomized with the restriction of at least six consecutive nontarget trials before probe trials. This allows investigation of the behavioral and ERP responses to the six nontargets preceding probe trials as a function of the response to Probe 1 (On task versus Off task); this is akin to procedures used in prior ERP studies of MW (Baird et al., 2014; Kam et al., 2011; Smallwood et al., 2008).

E-Prime 2.0 software (Psychology Software Tools, Inc.) was used for stimulus presentation and recording of behavioral responses. In a sound-attenuating booth, participants sat approximately 28 in. away from a 23.5-in. LED computer screen to complete the task. They used the number pad of a computer keyboard to make their responses.

The experimental procedures were as follows: First, participants were given detailed instructions about the task and completed a 123-trial practice block with feedback to familiarize themselves with the task and ensure that they understood the instructions. Then, they completed 923 experimental trials, including 833 nontargets, 45 targets, and 45 probes. These trials were divided into three experimental blocks, each including the same number of probes and targets and lasting approximately 13 min. A quick break of approximately 2 min was given between blocks.

EEG Data Acquisition and Preprocessing

Continuous EEG data were recorded throughout the three experimental blocks of the F-SART from 64 Ag-Cl electrodes located according to the 10–20 International System (American Electroencephalographic Society, 1991) using BioSemi ActiveTwo system. In addition to the scalp electrodes, three electrodes were placed on the outer canthi and below the left eye to record horizontal and vertical electrooculograms, and two additional electrodes were placed on the left and right mastoid bones to record muscle artifacts from the jaw and neck. Data were recorded at a sampling rate of 256 Hz and bandpass filtered online at 0.16–100 Hz.

Data were preprocessed offline using EMSE Data Editor Version 5.5.1 (Source Signaling, Inc.). Recordings were first rereferenced to a common average of all 64 scalp electrodes and were then filtered with a bandpass filter of 0.1–30 Hz. Artifacts from ocular movements and blinks were corrected using a method of independent component analysis (Jutten & Herault, 1991). Facial stimuli data were segmented into 600-msec epochs, beginning 100 msec before stimulus onset and ending 500 msec after stimulus onset. Epochs were baseline-corrected with the 100 msec prestimulus time period. Epochs containing artifacts from any scalp channels with voltage magnitude greater than ±100 μV were excluded from further analyses.[3]

Data Analyses

The present analyses focused on the behavioral and ERP responses to the six nontarget faces preceding probes and targets. The six nontargets preceding probes were classified into On task or Off task conditions according to participants' subjective responses to the first probe question (Probe 1). The six nontargets preceding targets were classified into "Correct" or "Error" condition according to whether participants correctly withheld their response to the target or made an error of commission, respectively. This resulted in two "subjective" Probe conditions (On task and Off task) and two "objective" Target conditions (Correct and Error). The procedure to use the six preceding nontargets was based on prior ERP studies of MW and was considered optimal because it can capture differences in attentional states while also maximizing the number of trials included in analyses (Baird et al., 2014; Kam et al., 2011; Smallwood et al., 2008). Nontarget trials were excluded if incorrect or with excessive voltage magnitude. The Probe 2 responses was also explored using correlation analyses (see below Exploratory Correlation Analyses section).

Behavioral Analyses

Behavioral analyses focused on the intraindividual coefficient of variation (ICV) of RT to the six nontargets preceding probes and targets. ICV was calculated as the standard deviation of RT for the six nontargets divided by the mean RT for the six nontargets (i.e., for each participant: standard deviation RT/mean RT). Prior research has suggested that greater ICV reflects more variable responding and has been linked to greater MW; hence it has been proposed as a viable objective index of MW (Bastian & Sackur, 2013; Seli, Cheyne, et al., 2013). Average ICV was calculated for each of the Probe (On task and Off task) and Target (Correct and Error) conditions. We used paired t tests to compare average ICV for On task versus Off task and Correct versus Error. Of note, overall accuracy, RT, and probe responses throughout the task were collected and are reported in Table 1.

ERP Analyses

The EEG epochs of the six nontargets were averaged to create the ERP waveforms for each of the Probe (On task and Off task) and Target (Correct and Error) conditions. Although the main focus of this study was on the N170, we also examined the P1 and P3 because they were investigated in prior ERP studies of MW without always yielding consistent results (Kam et al., 2011, 2016; Baird et al., 2014; Smallwood et al., 2008). The selection of

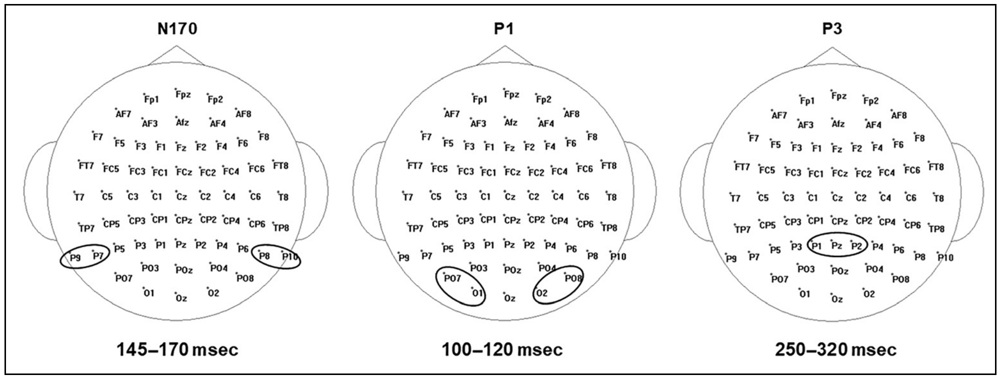

Figure 2. Topographic maps depicting electrode sites and time windows for the N170 (P9, P7, P8, P10), P1 (PO7, O1, O2, PO8), and P3 (P1, Pz, P2).

electrode sites for each component was guided by prior research and based on the overall waveform collapsing together all nontargets ("collapsed localizers approach"; Keil et al., 2014). Namely, examination of the timing and topographical map of each component from the collapsed waveform allowed us to select the most representative electrode sites and time window.

N170. Consistent with prior ERP studies using faces (Rossion & Jacques, 2011; Bentin et al., 1996), visual inspection of the collapsed waveform revealed a bilateral posterior negativity peaking around ~158 msec after face onset, which we identified as the N170. Amplitude data from the most representative electrode sites (P9, P7, P8, P10) in the 145–170 msec time window following face onset were used in the analyses (Figure 2A).

P1. Consistent with prior P1 studies of MW (Baird et al., 2014; Kam et al., 2011; Smallwood et al., 2008), visual inspection of the collapsed waveform revealed a bilateral occipital positivity peaking around ~110 msec after face onset, which we identified as the P1. Amplitude data from the most representative electrode sites (PO7, O1, O2, PO8) in the 100–120 msec time window following face onset were used in the analyses (Figure 2B).

P3. Consistent with prior P3 studies of MW (Kam et al., 2011; Smallwood et al., 2008), visual inspection of the collapsed waveform revealed a midline parietal positivity peaking around ~280 msec after face onset, which we identified as the P3. Amplitude data from the most representative electrode sites (P1, Pz, P2) in the 250–320 msec time window following face onset were used in the analyses (Figure 2C).

To investigate ERP modulation as a function of subjective reports of MW, we used Probe conditions (Probe) × Electrode sites (Site) repeated-measures ANOVA separately for each component. To investigate ERP modulation as a function of objective responses to targets, we used Target conditions (Target) × Electrode sites (Site) repeated-measures ANOVA separately for each component. Although the primary focus of this study is on the effect of Probe and Target conditions, we also report all main effects and interactions for completeness; however, we did not further follow up significant main effects of Site or interactions between Probe/Target and Site (e.g., Kam et al., 2011; Smallwood et al., 2008). Effects with more than two factors that violated assumptions of sphericity were adjusted using the Greenhouse–Geisser (if $\varepsilon < .75$) or Huynh–Feldt (if $\varepsilon > .75$) procedures. ERP analyses were based on the following averaged numbers of EEG epochs for each condition of interest: 110.14 ($SD = 65.75$) for On task, 74.32 ($SD = 57.24$) for Off task, 123.25 ($SD = 45.77$) for Correct, and 90.00 ($SD = 41.26$) for Error.

Exploratory Correlation Analyses

Probe 2 responses were collected on a Likert scale, and the number of responses at each level (low, medium, high) was not sufficient to perform categorical analysis comparing low versus high confidence Off task reports.

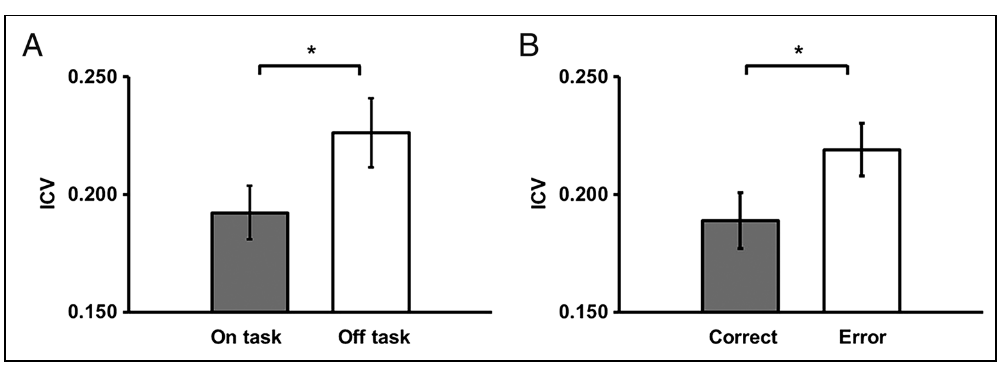

Figure 3. Behavioral results showing greater ICV for the six nontargets preceding Off task versus On task Probe 1 responses (A) and Error versus Correct target responses (B). *$p < .01$.

Table 1. Descriptive Statistics and Pearson Correlations for Behavioral SART Outcomes

SART Outcomes	*Mean (SD)*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
1 Off task reports (%)	40.61 (24.13)		.00	−.16	.38*	.66**	−.16	−.27	.12
2 Target accuracy (%)	58.33 (13.05)			.28	.18	−.19	.88**	−.04	.28
3 Nontarget accuracy (%)	98.53 (1.55)				−.26	−.45*	.36	.20	−.23
4 Nontarget RT (msec)	325.63 (40.05)					.74**	−.28	.00	.30
5 ICV	0.30 (0.09)						−.53**	−.16	.11
6 Skill Index	0.18 (0.04)							.00	.18
7 LOC On task	2.43 (0.41)								−.29
8 LOC Off task	2.33 (0.30)								

The correlations are reported for completeness only and should be treated with caution as the sample size in this study is relatively small (n = 28) compared with prior behavioral studies using the SART (N > 45; e.g., Seli, 2016; Seli, Cheyne, & Smilek, 2012).

*p < .05.

**p < .01.

Hence, the relationship between confidence and behavioral and neural responses was examined using correlation analyses. Namely, in a series of Pearson correlations, we explored if the LOC reported on Probe 2 can be linked to the modulation of the behavioral (ICV) and ERP responses as a function of subjective reports of MW.

RESULTS

Behavioral Results

Behavioral analyses revealed greater ICV for Off task (M = .226, SD = .078) versus On task (M = .192, SD = .061), $t(27)$ = 2.821, p = .009, Hedges' g_{av} = .479, 95% CI [−.059, −.009] (Figure 3A). ICV was also greater for Error (M = .218, SD = .058) versus Correct (M = .189, SD = .062), $t(27)$ = 3.496, p = .002, Hedges' g_{av} = .476, 95% CI [−.047, −.012] (Figure 3B).

Although the behavioral analyses focused primarily on the ICV on the six nontarget trials preceding probe and target responses, for completeness, descriptive statistics for each of the commonly used SART outcomes and the correlations among these outcomes are presented in Table 1. In addition to the standard SART outcomes, Table 1 includes the Skill Index, which takes into account both target accuracy and nontarget RT (Target accuracy/nontarget RT) to control for the speed–accuracy trade-offs (Seli, 2016; Jonker, Seli, Cheyne, & Smilek, 2013).

ERP Results

Table 2 displays the mean amplitudes and standard deviations for each component at each electrode for each condition.

N170

Probe (On task, Off task) by Site (P9, P7, P8, P10) repeated-measures ANOVA revealed a significant main effect of Probe, $F(1, 27)$ = 6.827, p = .014, η^2 = .202, with attenuated N170 amplitude for Off task (M = −3.962, SE = 0.479) versus On task (M = −4.805, SE = 0.575; Figure 4A). There was a significant main effect of Site, $F(2.20, 59.43)$ = 17.103, p < .001, η^2 = .388, but no

Table 2. Means (μV) and Standard Deviations (μV) at Each Electrode Site for Each Condition

	On Task	*Off Task*	*Correct*	*Error*
N170				
P9	−6.36 (4.07)	−5.32 (3.73)	−5.49 (3.20)	−5.95 (3.51)
P7	−2.90 (2.63)	−2.05 (3.35)	−2.72 (2.82)	−3.13 (2.90)
P8	−3.40 (4.77)	−2.70 (3.08)	−3.28 (3.82)	−2.38 (3.21)
P10	−6.55 (3.95)	−5.78 (3.15)	−6.14 (3.43)	−6.53 (3.86)
P1				
PO7	3.90 (2.28)	4.48 (2.44)	4.14 (2.42)	3.98 (1.97)
O1	3.79 (2.43)	4.25 (2.59)	3.88 (2.52)	3.82 (2.55)
O2	3.65 (2.75)	3.58 (2.94)	3.56 (2.84)	3.20 (3.36)
PO8	5.58 (2.68)	5.33 (3.06)	5.16 (2.97)	5.28 (3.37)
P3				
P1	4.73 (2.25)	4.23 (2.87)	4.81 (2.41)	4.07 (2.28)
Pz	4.99 (2.57)	4.28 (2.69)	4.82 (2.56)	4.00 (2.70)
P2	5.26 (2.66)	4.88 (3.19)	5.33 (2.31)	4.22 (2.43)

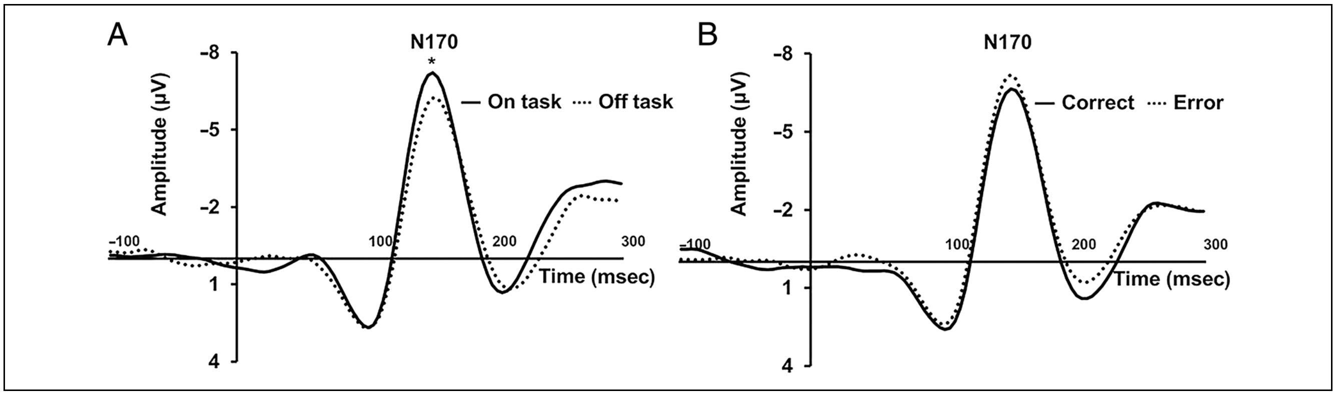

Figure 4. N170 waveforms at P10 electrode showing attenuated N170 for Off task versus On task (A) and no significant N170 difference between Correct versus Error (B). * denotes significance.

significant interaction between Probe and Site, $F(2.18, 58.93) = .106, p = .914, \eta^2 = .004$. Target (Correct, Error) by Site (P9, P7, P8, P10) repeated-measures ANOVA revealed no significant main effect of Target, $F(1, 27) = .087, p = .770, \eta^2 = .003$ (Figure 4B). There was a significant main effect of Site, $F(2.62, 70.82) = 18.010, p < .001, \eta^2 = .400$, but no significant interaction between Target and Site, $F(1.63, 43.91) = 1.827, p = .179, \eta^2 = .063$.

P1

Probe (On task, Off task) by Site (PO7, O1, O2, PO8) repeated-measures ANOVA revealed no significant main effect of Probe, $F(1, 27) = .369, p = .548, \eta^2 = .013$ (Figure 5A). There was a significant main effect of Site, $F(2.55, 68.97) = 4.985, p = .005, \eta^2 = .156$, but no significant interaction between Probe and Site, $F(1.41, 38.09) = .975, p = .359, \eta^2 = .035$. Target (Correct, Error) by Site (PO7, O1, O2, PO8) repeated-measures ANOVA revealed no significant main effect of Target, $F(1, 27) = .640, p = .431, \eta^2 = .023$ (Figure 5B). There was a significant main effect of Site, $F(2.10, 56.82) = 4.707, p = .012, \eta^2 = .148$, but no significant interaction between Target and Site, $F(1.58, 42.74) = .598, p = .517, \eta^2 = .022$.

P3

Probe (On task, Off task) by Site (P1, Pz, P2) repeated-measures ANOVA revealed no significant main effect of Probe, $F(1, 27) = 1.582, p = .219, \eta^2 = .055$ (Figure 6A) or Site, $F(2, 54) = 2.740, p = .074, \eta^2 = .092$, and no significant interaction between Probe and Site, $F(2, 54) = .444, p = .644, \eta^2 = .016$. Target (Correct, Error) by Site (P1, Pz, P2) repeated-measures ANOVA revealed a significant main effect of Target, $F(1, 27) = 9.941, p = .004, \eta^2 = .269$, with attenuated P3 amplitude for Error ($M = 4.098$, $SE = 0.429$) versus Correct ($M = 4.988$, $SE = 0.437$; Figure 6B). There was no main effect of Site, $F(2, 54) = 1.391, p = .258, \eta^2 = .049$, nor a significant interaction between Target and Site, $F(1.57, 42.48) = .803, p = .428, \eta^2 = .029$.

Exploratory Correlation Analyses

Exploratory analyses used LOC responses on Probe 2 as a continuous variable in a series of Pearson correlations

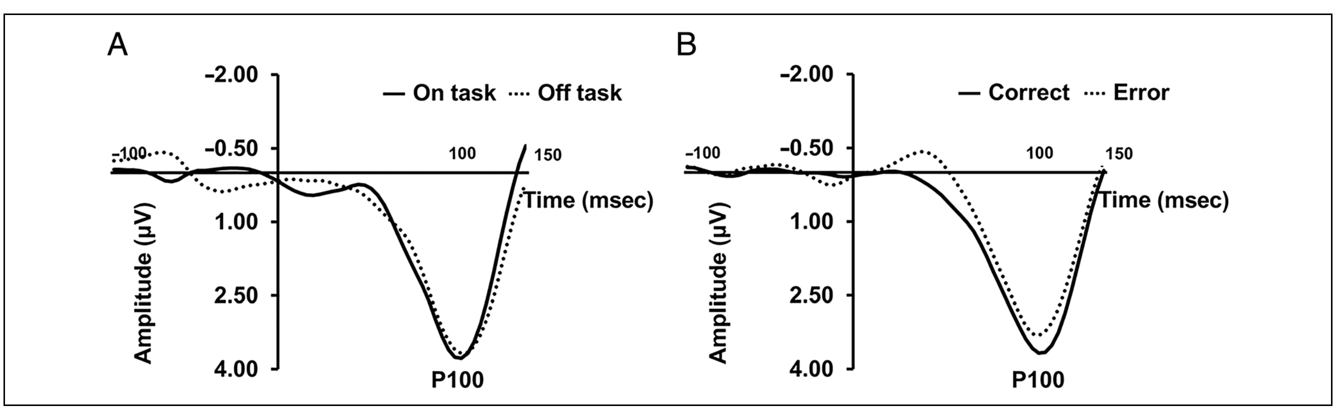

Figure 5. P1 waveforms at O2 electrode showing no significant difference between On task versus Off task (A) and between Correct versus Error (B).

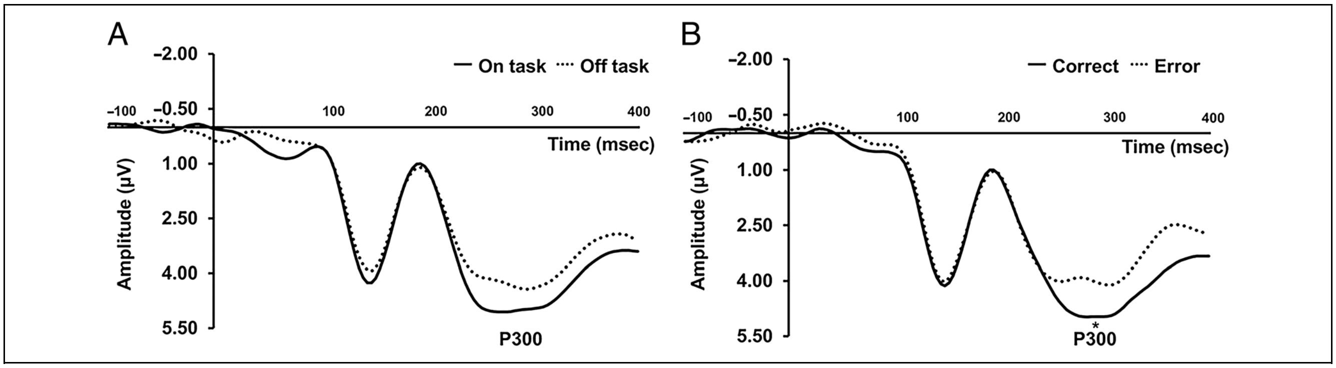

Figure 6. P3 waveforms at Pz electrode showing no significant difference between On task versus Off task (A) and attenuated P3 for Error versus Correct (B). * denotes significance.

focusing on the relationship between LOC[4] and the outcomes showing significant differences between On task versus Off task, namely the ICV and the N170. These analyses were all based on difference scores (On task minus Off task) for LOC, ICV, and N170. Analyses revealed no significant correlation between LOC and ICV ($r = .047$, $p = .811$). There was also no significant correlation between LOC and N170 response at any of the electrode sites (P9: $r = .190, p = .332$; P7: $r = -.114, p = .563$; P8: $r = .293, p = .130$; P10: $r = .048, p = .808$).

DISCUSSION

This study yielded three main findings regarding the behavioral and neural indices of subjective reports of MW and objective attentional errors. First, behavioral results revealed greater variability in RTs, signaling a diminished attentional stability for nontarget faces preceding both MW reports and target errors. Second, ERP data revealed an attenuated N170 response to nontarget faces preceding subjective reports of MW, but not to those preceding target errors. Third, the P3 response was attenuated to nontarget faces preceding target errors, but not to those preceding subjective reports of MW. Of note, no differences were observed in the P1 response as a function of subjectively reported MW or objective attentional performance. These findings, discussed in detail below, may help fill in gaps between the MW and face perception literatures. They may also motivate new paradigms to investigate the role of MW in socially relevant, real-life situations, such as those involving face perception during social interactions.

Increased Behavioral Variability to Faces Preceding Both MW Reports and Target Errors

Greater ICV for nontarget faces preceding both subjective reports of MW and target errors is consistent with prior findings linking increased variability in RTs with MW reports (Bastian & Sackur, 2013; Seli, Carriere, et al., 2013) and attentional errors (Rosenberg, Noonan, DeGutis, & Esterman, 2013; Cheyne, Carriere, & Smilek, 2009). Although prior investigations have demonstrated that RT variability is a valid objective indicator of fluctuations in the attentional states, almost all of these studies used very simple stimuli. One exception is the Rosenberg et al.'s (2013) study, which employed faces but did not gather self-reported MW data during the task. This study investigated the relationship between variability in RTs and errors (commission errors and omission errors). Hence, the present findings extend previous studies by showing within the same experiment that RTs to complex, socially relevant stimuli, such as faces, are more variable during intervals preceding subjective reports of Off task versus On task as well as Error versus Correct target trials. These findings provide evidence of a similar behavioral pattern of responses for the intervals preceding self-reported MW as well as those preceding objective performance errors.

Attenuated N170 to Faces Preceding MW Reports but Not Target Errors

Attenuated N170 response to faces preceding Off task versus On task suggests reduced early face processing when the mind is wandering. To our knowledge, this is the first ERP study to provide insight into the neural effects of subjectively reported MW on the early processing of meaningful, socially relevant stimuli, such as faces. This finding is consistent with the perceptual decoupling account, which postulates reduced perceptual processing of external input during internally oriented off-task thinking (Kam & Handy, 2013; Schooler et al., 2011; Smallwood, McSpadden, & Schooler, 2007). This account has been largely based on findings emerging from ERP studies that employed simple, meaningless stimuli. Hence, this study complements prior ERP investigations of MW and provides additional evidence in favor of the perceptual decoupling account by demonstrating that MW can be associated with an attenuated processing of faces.

In addition to enriching the MW literature, this study also informs the face perception literature by highlighting the need to consider the critical role of internally driven changes of attentional state in early face processing, indexed by N170. Historically, the face perception literature has been marked by several debates; the main one being the question of whether face processing is automatic or susceptible to top–down manipulation (Farah, Wilson, Drain, & Tanaka, 1998). ERP research examining N170 responses has provided conflicting results, with some studies (Cauquil, Edmonds, & Taylor, 2000) favoring the automatic face processing view, whereas other studies have favored the attention-modulated face processing view (Mohamed, Neumann, & Schweinberger, 2009).

On the one hand, some earlier ERP studies found that the N170 response is not modulated by task manipulations of attention suggesting that faces are, at least in the early stages of perceptual analyses, processed in an automatic, prioritized manner (Carmel & Bentin, 2002; Cauquil et al., 2000). Some studies reported a prioritized processing even when faces are not relevant to the task at hand (Sato & Kawahara, 2015; Lavie, Ro, & Russell, 2003). In contrast, several ERP studies have revealed reduced N170 response as a function of attentional manipulations suggesting top–down effects of attention on early face processing (Navajas et al., 2017; Sreenivasan et al., 2009; Crist, Wu, Karp, & Woldorff, 2007). Recently, it has been suggested that the discrepancies in these findings may have been due to bottom–up factors, such as the load of the display (Mohamed et al., 2009) and face discriminability (Sreenivasan et al., 2009). For instance, a reduced N170 response was observed under high but not low load (different vs. identical letters overlaid on a face; Mohamed et al., 2009) and low but not high face discriminability (low vs. high discriminability of the face in a face–scene overlay; Sreenivasan et al., 2009). The impact of load and discriminability seems broadly consistent with the perceptual load theory (Lavie, Beck, & Konstantinou, 2014), which posits that when the main task is taxing the bulk of available attentional resources, there are few available resources for processing of information outside the focus of attention. The perceptual load theory has been recently extended to encompass MW (Forster, 2013) by proposing that when the task demands are high, there are fewer available resources for the mind to wander (Levinson, Smallwood, & Davidson, 2012; Forster & Lavie, 2009), although this may depend on other factors, such as time-on-task (Krimsky, Forster, Llabre, & Jha, 2017) and individual difference in working memory capacity (McVay & Kane, 2012). However, these factors were not examined here. The time-on-task effect would be a fruitful target for future ERP studies specifically designed to have sufficient numbers of trials to allow for direct comparisons of MW rates at the beginning versus end of the task. Overall, although this study does not aim to test the perceptual load theory, it provides support for the view by identifying the impact of top–down effects of attention on early faces processing. Furthermore, it extends this view by showing that these top–down effects can be observed in cases of internally driven changes in the attentional state (i.e., MW) and not only in cases of external manipulations of attention (i.e., via manipulation of task instructions).

The current findings suggest that there may be a putative link between perceptual load theory and perceptual decoupling theory. Perceptual load theory suggests that the load of the main task influences how task-irrelevant information is processed. Perhaps, the notion of load should be expanded to refer to the current focus of attention, regardless of whether it is oriented toward external or internally generated input (i.e., MW). That is, if the concept of load is expanded to refer to the current focus of attention, regardless of whether it is task relevant or not, then the occurrence of MW would be considered as a transient episode of high load. During MW episodes, attentional resources may be pulled away from the task at hand and directed toward off-task thinking. The resulting paucity of attentional resources may lead to attenuated processing of task-relevant information. Indeed, this is consistent with the resource competition account of perceptual decoupling according to which MW consumes attentional resources leaving fewer resources available for processing of external input (Franklin, Mrazek, Broadway, & Schooler, 2013; Smallwood, 2013; see Thomson et al., 2015; McVay & Kane, 2010, for other accounts of MW).

Although a modulation of the N170 response was observed as a function of subjective reports of MW, this effect was not reported in the case of objective performance on target trials. Why would this be? If target errors are driven by MW, such an attenuation would be expected. Yet, it is possible that the MW is not the singular driving reason of target errors, and as such, a clear pattern of attenuation may not systematically emerge. Indeed, prior studies have suggested that target errors in the SART may be driven by attentional lapses as well as motor-related factors (Head & Helton, 2013; Seli, Jonker, Cheyne, & Smilek, 2013; Seli et al., 2012). This is particularly relevant in the case of the standard SART instructions that ask participants to give equal emphasis to both speed and accuracy, which may induce tendencies toward speed–accuracy trade-offs (Seli et al., 2012). Although the standard instructions were employed in this study, target error rate was not significantly correlated with the nontarget RTs (see Table 1). Given that this study was not designed to disentangle the multitude of factors that may lead to target errors, further ERP investigations are necessary to more fully examine this issue. For example, future studies may consider integrating probe questions after target errors to examine if an MW episode contributed to the commission error; studies may also use instructions emphasizing accuracy alone (Seli et al., 2012) to reduce the tendency of the participants to engage in potential speed–accuracy trade-offs.

Overall, the present N170 findings allow us to bridge together MW and face perception literatures to advance our understanding of the vulnerabilities of face perception due to MW.

Attenuated P3 to Faces Preceding Target Errors but Not MW Reports

In a prior study by Smallwood et al. (2008) using simple digits as stimuli during the SART, attenuation of the P3 was found for both subjective reports of MW and target errors. Yet, herein, the P3 results demonstrated an attenuated response for faces preceding Error versus Correct target trials, but not for those preceding Off task versus On task reports. In the context of perception of unfamiliar faces, P3 has been attributed to conscious awareness of the presentation of faces in paradigms using factorial designs to disentangle the effects of attention and awareness (Navajas et al., 2017). Prior findings suggest that the modulation of the P3 response as a function of target performance observed in this study may be due to differences in the level of conscious awareness of face presentation before Error versus Correct target trials. These differences in levels of awareness could be due, in part, to MW.

If MW was driving the attenuation of the P3 response to faces preceding target errors, why did we fail to see significant attenuation of the P3 response to faces preceding Off task reports? It is important to note that, although the P3 response did not significantly differ for Off task versus On task, the pattern is similar to that reported for Error versus Correct target trials (see Figure 6). Hence, one potential explanation for this could be that the modulation of P3 for On task versus Off task is less robust because of variability in the level of awareness of being off task. In line with this view, Smallwood et al.'s (2008) study demonstrated that the difference in P3 response between On task and Off task reports was significant when off-task thinking was accompanied by conscious experience of MW ("tuned out") and only marginal when off-task thinking was not consciously experienced ("zoned out"). Although this study did not probe participants' awareness of MW, it did probe the LOC in participants' reporting of being on task or off task. The logic was that if a participant is highly confident of being off task, for example, they are likely to be more aware of his or her engagement in off-task thinking; however, due to limitations in trial numbers, we were unable to parse trials as a function of both MW and LOC (see Methods section). Overall, the lack of significant, albeit directional, P3 effect for Off task versus On task highlights the fragility of this effect, which has been also noted in prior ERP studies of MW (e.g., Kam et al., 2011). One prominent factor that may modulate P3 amplitude is the level of conscious experience of MW, and future studies should comprehensively aim to track the impact of awareness of MW on the P3 component.

The present findings lead to the speculation that differences in levels of awareness can account for the P3 pattern of response. However, the impact of levels of awareness on attentional lapses, linked to subjective MW reports or objective performance errors, remains poorly understood. Prior research has attempted to understand the neural mechanisms underlying the impact of awareness on MW reports (Christoff, Gordon, Smallwood, Smith, & Schooler, 2009) or attentional errors (Allen et al., 2013). Future research should consider examining concomitantly awareness of MW and awareness of objective errors.

It should be mentioned that the modulation of the P3 response according to target performance should be interpreted with caution, given that differences in the P3 response can be contaminated by motor-related factors (see Smallwood et al., 2008, for a similar discussion). Indeed, some investigations have proposed that target errors during SART can signal motor decoupling rather than perceptual decoupling (Head & Helton, 2013). Although recent evidence suggests that both accounts are not mutually exclusive and that the SART can be a valid measure of attentional lapses despite susceptibility to motor demands (Seli, 2016), this issue is still under debate (Wilson, Finkbeiner, de Joux, Russell, & Helton, 2016).

It is important to note that the patterns of responses for both N170 and P3 components do not appear to be driven by differences in the earliest stages of sensory processing based on the P1 results in this study. Although some prior ERP studies of MW have revealed reduced P1 response linked to subjective reports of off-task thinking (e.g., Kam et al., 2011), this may be constrained to tasks, which include task-irrelevant, "to-be-ignored" stimuli, which were not used in the present version of the SART.

In conclusion, the present findings reveal that off-task thinking can impact the behavioral and neural correlates of face processing. They underscore the importance of considering MW as a critical factor in face perception. These findings may contribute to a more comprehensive understanding of both typical and dysfunctional face processing. For instance, a reduced N170 response has been observed in psychopathology, such as depression (Feuerriegel, Churches, Hofmann, & Keage, 2015), which is also characterized by an increased vulnerability to MW (Hoffmann, Banzhaf, Kanske, Bermpohl, & Singer, 2016). Overall, understanding the relationship between MW and face perception can shed light on the vicious circle of rumination and social isolation in depression (Holt-Lunstad, Smith, Baker, Harris, & Stephenson, 2015) and suggest targeted interventions. One potential way to diminish the negative impact of MW on face processing could be through mindfulness training, which has been associated with a decrease in MW (Rahl, Lindsay, Pacilio, Brown, & Creswell, 2017; Zanesco et al., 2016; Morrison, Goolsarran, Rogers, & Jha, 2014).

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Notes

1. Of note, although there are still numerous debates around the functional role of perceptual decoupling during MW (Franklin et al., 2013; Smallwood, 2013; Christoff, 2012), those are beyond the scope of this study, in which the primary goal is to tackle whether MW is associated with attenuated perceptual processing of complex, ecologically valid and meaningful stimuli, such as human faces.
2. Data analyses were also performed without the left-handed participant and yielded nearly identical results. Therefore, this participant remained included in all analyses.
3. For one participant, a spatial interpolation filter was added to the P2 channel due to excessive noise. Because this electrode site was used in the P3 analyses, data analyses were performed also without this participant, and this did not change the results. Therefore, this participant remained included the analyses.
4. The LOC for On task (M = 2.43, SD = .41) was not significantly different from that for Off task (M = 2.33, SD = .30) reports, $t(27)$ = .965, p = .343.

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