A Wandering Mind Cannot Resolve Conflicts in Displayed Information

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Human minds often wander around while performing a task. When the mind wanders, attention drifts away from task-relevant perceptual information, leading to deteriorated performance on the task at hand. The current study aims to examine how mind-wandering is associated with different aspects of attentional functions that are critical for perceptual processing of displayed information. Participants completed the Attention Network Task that assessed efficiencies of alerting, orienting, and executive functions of attention. During this task, participants reported their state of mind (focusing on the task or mind-wandering). The results showed that mind-wandering was particularly associated with impairments on executive function, which suggests that an ability to resolve conflicts in displayed information can be impaired when a mind wanders. Our findings suggest that, in work environment where mind-wandering is more likely to occur, tasks requiring conflict resolution in displayed information may be significantly impacted. Mechanisms of mind-wandering and implications in practical settings were discussed.

Our minds often leave the present experience or task at hand and wander around self-generated thoughts and feelings. Mind-wandering can be defined as attention drifting away from the ongoing task to task-unrelated thoughts (Smallwood & Schooler, 2006). These task-unrelated thoughts, such as thinking about past events, on-going concerns, and fantasies, are disconnected from the present moment. Our minds can wander almost at all times during various daily activities. For example, previous research suggested that adults experience mind wandering as much as 30%-50% of their waking time (Bixler & D'Mello, 2014; Killingsworth & Gilbert, 2010).

Mind wandering can severely impact task performance. For example, mind-wandering while driving is one of the most deadly types of driver distractions. According to an analysis of a nationwide census of fatal crashes in 2010 and 2011, 62% of distracted driving involved in fatal car crashes was associated with distraction due to internally-generated thoughts, or "lost in thought" (Erie Insurance, 2012). Other studies showed that mind-wandering significantly impairs reading comprehension (Feng, D'Mello & Graesser, 2013), working memory capacity and fluid intelligence (Mrazek et al., 2012). In general, mind-wandering has been categorized as a state in which attention is decoupled from the perceptual stimuli, and instead coupled with internally generated thoughts that are irrelevant to the task (Jha, Krompinger & Baime, 2007; Schooler et al., 2011). As a result, perceptual stimuli that are critical to the task at hand are not processed sufficiently, leading to deteriorated performance on the task.

Many tasks such as baggage screening and supervisory monitoring of a power plant require efficient processing of visual perceptual stimuli. Targets such as potential objects of interest inside luggage or a safety-critical warning message on the display panel are in general very infrequent during these tasks. Mind-wandering could become more frequent during such tasks. If an operator mind-wanders, it would decrease the likelihood of successfully processing perceptual information critical for task completion. Understanding the impacts of mind-wandering on the processing of displayed information can provide valuable guidelines on display design such as a monitoring display for TSA (Transportation Security Administration) baggage screening.

Although previous research has demonstrated potentially detrimental effects of mind-wandering on task performance (Mooneyham & Schooler, 2013), and mind-wandering was found to associate with attentional processes (Smallwood, McSpadden, & Schooler, 2008; Risko et al., 2012), very little has been examined about what specific attentional processes are affected by mind-wandering. It is possible that mind-wandering impacts all aspects of attentional functions; or it might affect particular types of attentional functions but not others.

Human attention is considered as a complex and multi-faceted construct, consisting of three important functions performed by distinct neural networks in the brain: alerting, orienting, and executive attention (Posner & Peterson, 1990; Raz & Buhle, 2006; Fan et al., 2002). The alerting function maintains a state of high sensitivity to incoming stimuli. Tonic alertness, or vigilance, is defined as an ability to maintain attention over an extended period of time, and phasic alerting is increased readiness to respond after a cue or a warning signal. In particular, phasic alerting function is necessary to make use of warnings or cues preceding a target. For example, drivers need to maintain alertness to be ready for the upcoming events when they encounter road warning signs relating to advance traffic control (e.g., Stop ahead, Traffic signal ahead, etc.). The orienting function is to switch attention toward a sensory signal to select relevant information among sensory input. Tasks involved in dynamic and complex information display such as stock trading often place information at multiple locations across the screen. Completing these complex tasks often requires orienting and changing attention and eye fixations across the display to process necessary information. Drivers must also be able to direct their attention to the most relevant area or objects during driving. The executive control of attention resolves conflicts among stimuli (Posner & Rothbart, 2007). This function is critical for tasks such as air traffic control, which require an accurate and fast resolution when there is conflicting or competing information in the display. In the context of driving, executive function often resolves conflicts, such as when a driver notices a pedestrian jaywalking against the traffic light that is green for traffics. It is important to understand how mind-wandering affects these distinct attentional functions which are primarily utilized in various perceptual processing of displayed information.

Very few studies have attempted to examine how mind-wandering influences different functions of attention, yet large discrepancies exist in the findings. One study observed that individuals who have tendency to experience a higher frequency of mind-wandering tend to have poorer orienting functions, but not differential alerting or executive functions (Hu, He & Xu, 2012). Other studies suggested mind-wandering is generally associated with executive control (McVay & Kane, 2010; Smallwood & Schooler, 2006). However, a precise relation between mind-wandering and executive control of attention remains to be identified (Smallwood & Schooler, 2015). Furthermore, no previous study has yet directly examined the effect of state of mind on alerting, orienting, and executive functions of attention.

The present study aimed to examine the impact of mind-wandering on these three distinct attentional functions. Given each of the alerting, orienting, and executive attentional functions is utilized in particular aspects of processing displayed information, such understanding could provide useful insights for the design of information displays. Participants self-reported their state of mind (mind-wandering or on the task) during an attentional task. We compared the efficiencies of alerting, orienting, and executive functions of attention between periods when participants were mind-wandering and when participants were focused on the task.

Methods

Participants

Twenty-eight participants (15 males, 13 females) were recruited from a local university. The participants were undergraduate students enrolled in an introductory psychology course and received course credits for participation. Our analyses only included participants who had 80% or greater accuracy on the task trials when they reported that their minds were on the task (thus they were not mind-wandering). Given the task was a relatively easy two-choice task (judging whether an arrow pointed to the left or right), and the method to examine mind-wandering relied on retrospective introspection, reliable data could not be obtained when a participant was not devoted to the experiment. As a result, a total of 20 participants (14 males, 6 females; Age M = 19.55, SD =1.82) were included in the data analyses. There was no significant difference in mind-wandering frequency between excluded (M = 14.50, SD =5.86) and included (M = 14.25, SD =7.40) samples, $F(1,26) = .01$, $p = .93$.

Apparatus & Stimuli

Attention Network Task (ANT). The Attention Network Task (Fan et al., 2002) was used to assess functional efficiencies of three attentional functions. The ANT we used followed the general procedure described in Fan et al. (2012), with minor modifications on target presentation and response duration. An example trial of the task is illustrated in Figure 1. The task was developed and administered via E-Prime (Version 2.0, Psychology Software Tools, Pittsburgh, PA) on a PC with a 42-inch LED TV monitor (Vizio HDTV, 1080P, 120 Hz). Each trial began with a fixation cross, followed by a cue, with an exception in no-cue condition. A target appeared after the offset of the cue. There were three cue conditions (center cue, double cue, and spatial cue). The center cue and double cue did not provide information regarding the location of the following target stimuli, and the spatial cues indicated where

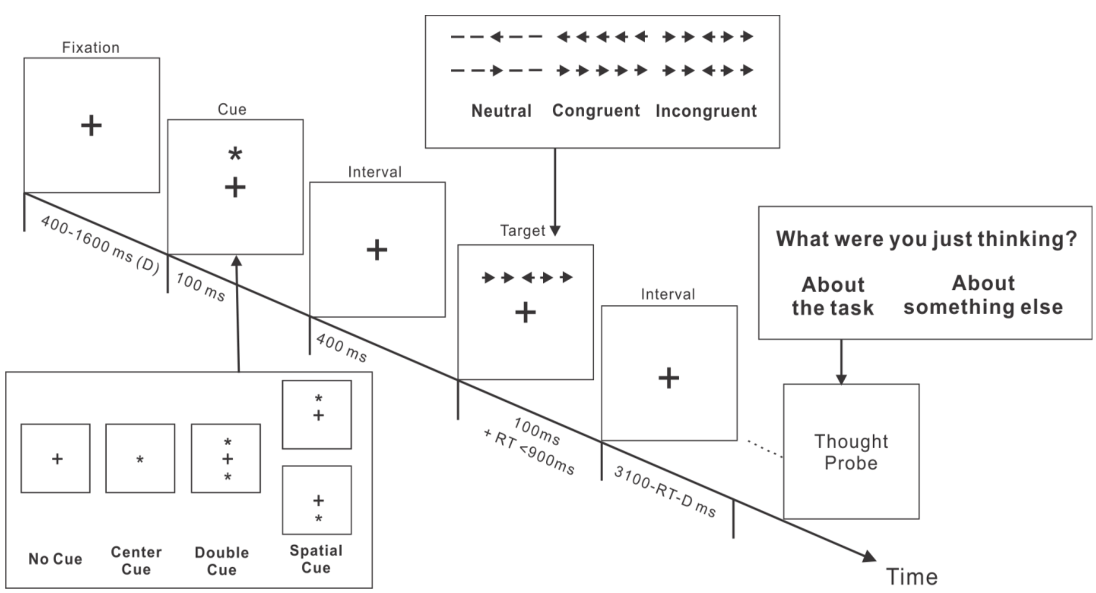

Figure 1. An illustration of the Attentional Network Test (ANT) with thought probes (There were four cue conditions - no cue, center cue, double cue, and spatial cue- and three target conditions - neutral, congruent, and incongruent; for each direction of left and right. There were total 12 cue X target combinations).

the target will appear (above or below the fixation cross). The target stimulus consisted of five objects in a row either above or below the fixation. The center object was the target (an arrow pointing to the left or right), accompanied by two flankers on each side. The flankers were either arrows pointing to the same direction as the target (congruent condition), or the opposite direction (incongruent condition); or horizontal bars that do not contain any directional information (neutral condition). The target was displayed for 100 ms and response could be made until 1000 ms from the onset of the target. Participants reported the direction of the target arrow by pressing one of the two mouse buttons with either thumb (they were instructed to hold the mouse using both hands, with each thumb rested on the left or right button). Participants were instructed to respond as quickly and accurately as possible.

We used the standard method of calculating the efficiency of the alerting, orienting and executive attentional functions (Fan et al., 2002). Median RT for each of the 12 cue × target combinations were obtained from correct trials. Estimates of the efficiency in three functions of attention were computed as:

Alerting efficiency = RTno-cue − RTdouble-cue
Orienting efficiency = RTcenter-cue − RTspatial-cue
Executive efficiency = RTincongruent − RTcongruent

Alerting and orienting efficiency scores represented the benefits (decreased RT) of the cues, while executive efficiency score represented the cost (increased RT) due to incongruent flankers.

Measure of Mind Wandering during ANT: Thought Probes. We used the probe-caught thought -unrelated thought (TUT) method (Seli et al., 2013; Smallwood et al., 2004) to measure participant's mind-wandering during the ANT. Thought probes were presented at randomly selected intervals during the ANT to obtain self-reported state of mind. A thought probe explicitly asked participants to indicate whether their minds were on the task or not during a brief period before the probe was displayed. Participants needed to retrospectively introspect and report whether they were focusing on the task, or task-unrelated thoughts. Before beginning the task, participants were given a list of examples of task-unrelated thoughts such as thinking about recent or impending events, current conditions (e.g., hunger or sleepiness), daydreams, and fantasies disconnected from reality (similar to response options provided in McVay et al., 2013).

Measure of General Tendency of Mind Wandering in Everyday Life: Mind-Wandering Questionnaire. The Mind-Wandering Questionnaire (MWQ; Mrazek et al., 2013) was used to assess an individual's general level of mind-wandering tendency. The questionnaire consists of 5 items asking how often participants experience: 1) having difficulty maintaining focus on simple or repetitive work, 2) While reading, finding they haven't been thinking about the text and must therefore read it again, 3) doing things without paying full attention, 4) finding themselves listening with one ear, thinking about something else at the same time, and 5) mind-wandering during lectures or presentations, in a 6-point Likert scale (from almost never to almost always).

Procedure

Participants first signed the consent forms and were instructed about the overall procedure of the experiments. Before an experiment started, participants were informed that they would be asked about their state of mind (mind-wandering) during the task. They were told that they should try to focus on the task, but it would be natural to mind-wander periodically, and that they should honestly report mind-wandering. Participants were then given a short practice of the ANT task consisting of 24 trials, followed by three experimental blocks. Each block included 12 repetitions of a set of 12 trials (1 trial for each combination of task conditions) in addition to a random number (between 1 to 6) of trials. The random numbers of trials were added in order to present the thought probe in a varying interval. Only performance on sets of 12 trials was included for analysis. As a result, out of an average of 557.85 trials, 432 trials were included in the analysis. Each of three experiment blocks had 12 thought probes, with varying intervals between adjacent probes (12 trials plus a random number of 1 to 6 trials; between 40.3 seconds and 55.8 seconds). Feedback on accuracy and reaction time was given during the practice, but not during the experiment. Participants took a short break after each block. The Mind Wandering Questionnaire was administered at the end of participation. Performance on the ANT task was calculated separately for mind-wandering and focused-on-the-task condition based on self-reports in the following thought probe.

Results

Rates of Mind-Wandering

Of 36 probes, participants reported an average of 14.25 times as being engaged in task-unrelated thoughts (thus experiencing mind-wandering; ranged from 4 to 32 reports). As a result, mind-wandering occurred 39.58% (mind-wandering rate, $M = .39$, $SD = .21$) across the three blocks of the task. The frequency of mind-wandering was significantly higher in the second and the third blocks compared to the first block ($M = 3.85$, $SD = 2.68$ in the first block; $M = 5.00$, $SD = 2.73$ in the second block; $M = 5.50$, $SD = 2.86$ in the third block; Figure 2), $F(2,38) = 6.32$, $p < .01$, which indicates that the frequency of mind-wandering increased over time during the ANT.

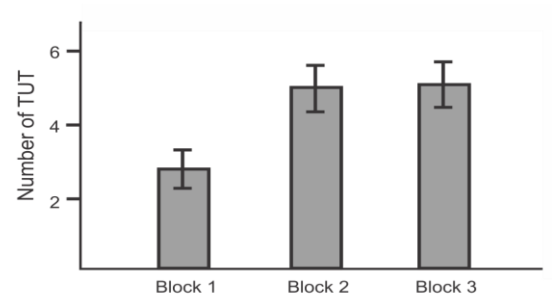

Figure 2. Task-unrelated thought frequency across three task blocks (total 12 probes included in each block).

Correlations were computed among five criteria; mind-wandering frequency during the ANT, overall ANT accuracy and reaction time, and trait-level mind-wandering tendency as measured by the Mind Wandering Questionnaire. The results revealed that overall accuracy, but not reaction time, was significantly correlated with mind-wandering frequency during the task. These correlations indicate that a greater frequency of mind-wandering during the task is associated with lower accuracies on the attentional task (r = -.54, p < .05). However, mind-wandering frequency during the attentional task was not significantly correlated with self-reported trait-levels of mind-wandering tendency (r = .40, p = .08), suggesting mind-wandering frequency during a relatively short-length task might not be highly reflective of trait-level everyday mind-wandering tendency.

Efficiency of Attentional Functions

Average across all ANT trials, mean efficiency scores were 42.61 (*SD* = 22.03) for alerting, 18.73 (*SD* = 16.20) for orienting, and 88.11 (*SD* = 33.02) for executive attention.

Impacts of Mind-Wandering on Alerting, Orienting, and Executive functions

Alerting, orienting, and executive attention efficiencies were compared between trials during mind-wandering vs. focused on task. Efficiency scores for three attentional functions were presented in table 1. Alerting efficiency did not differ between the two states of mind, $F(1,19)$ = .86, p = .37. Neither did orienting efficiency, $F(1,19)$ = .13, p = .72. However, the efficiency of executive attention was significantly different between mind-wandering and on-task states, $F(1,19)$ = 4.39, p = .05. Executive attention efficiency was significantly higher when participants reported they were on task-unrelated thoughts (i.e., mind-wandering), compared to when they reported being focused on the task. Because a higher score of executive attention represents a greater difference between when congruent or incongruent information was presented, the result indicates that participants became more impacted by information surrounding the target, which may be congruent or incongruent with the target.

Table 1.
Mean efficiency scores (standard deviations) of alerting, orienting, and executive attentional functions between when minds were focused on the task vs. on the task-unrelated thoughts (mind-wandering).

	Self-reported State of Mind	
	On-Task	**Mind-Wandering**
Alerting	40.15 (24.28)	46.41 (33.07)
Orienting	15.86 (16.57)	13.65 (25.14)
Executive	81.22 (31.90)	98.66 (46.59)

To further investigate the impacts of mind-wandering on the effects of congruent and incongruent flankers, we examined the differences between mind-wandering vs. on-task in benefits of congruent flankers (i.e., enhancement effects) and costs of incongruent flankers (i.e., interference effects). The enhancement effect of congruent flankers was computed using the difference between the mean reaction time from the neutral condition and the mean reaction time from the congruent condition. The interference effect of incongruent flankers was computed using the difference between the mean reaction time from the incongruent condition and the mean reaction time from the neutral condition. Comparing the sizes of enhancement and interferences effects in the wandering and on-task states of the mind, there was no difference between the two states of the mind in the enhancement effects (M = 5.77, SD = 13.67 in on-task condition; M = 9.91, SD = 24.36 in mind-wandering condition) , $t(19)$ = -.70, p = .49; however, the interference effects were significantly greater when mind wandered (M = 86.99, SD = 33.66 in on-task condition; M = 108.58, SD = 42.27 in mind-wandering condition) , $t(19)$ = -2.46, p < .05.

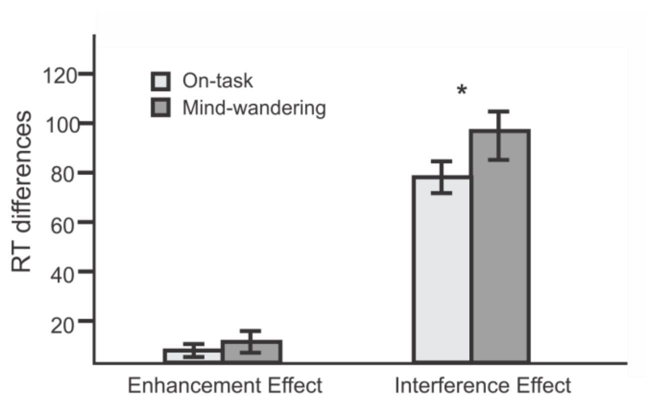

Figure 3. Effects of congruent and incongruent flankers when minds were focused on the task vs. on the task-unrelated thoughts (mind-wandering), * p < .05. (Enhancement effects = RTs for congruent condition – RTs for neutral condition; Interference effects = RTs for incongruent condition – RTs for neutral condition)

Discussion

This study examined the impact of mind-wandering on the alerting, orienting, and executive functions of attention. We found that mind-wandering was frequent while performing an attention task within an average duration of 30-40 minute. Participants reported mind-wandering for about 40% of the task time with an increasing frequency of mind wandering over time during the task, although with significant variations among individuals. Furthermore, it was also found that the task-specific mind-wandering frequency was not related to the trait-level mind-wandering tendency in everyday life. Mind-wandering was found to associate with lower accuracy on the task at hand. The results indicated that mind-wandering particularly impairs the executive control of attention, but not alerting and orienting functions of attention. Our results further revealed that interference increased from incongruent flankers during mind-wandering, which suggesting that an ability to resolve conflicts in displayed information can be impaired when mind wanders. It should be noted, however, that about a third of participants had to be excluded due to low task accuracy, and most of the excluded samples were female. Additional data collecting may need to confirm the results found in the current samples.

The ability to resolve conflicts is required to successfully perform various tasks. Multiple perceptual features can be presented in a single display in which some information is in conflict (e.g., not aligned or being congruent to other information or to background context). It might be particularly difficult to process task-relevant information successfully if users are mind-wandering. For example, drivers could be involved in safety critical situations in which conflicting perceptual cues and information must be resolved. Take the following scenario for example; a driver might encounter a sudden pedestrian who walks into the lane while following a car in front of them. The pedestrian cues an action of slowing down or stopping; but the moving vehicle at the front cues an action of continuing to move. If the driver was mind-wandering at that moment, their ability to resolve the conflicts in the information and quickly make a proper choice of action could be impaired. Similarly, when an operator was interacting with a large and complex display, if saliently displayed information (e.g., various colors and motions) is associated with different responses / actions, such conflicts in displays information would be more difficult to resolve when the operator's mind wanders. In particular, if a target does not occur very often in the task (e.g., baggage screening, monitoring a power plant, security monitoring), mind-wandering is highly likely at all times. Thus, conflicts in displayed information may significantly impact an operator's performance.

Both alerting and orienting functions of attention were intact even when participants were mind-wandering. However, the alerting function that was examined in the current study is a phasic type of alerting. Tonic alertness, or vigilance, might still be associated with mind-wandering states. Further studies may need to examine how mind-wandering might have different relations with tonic and phasic alertness. Unlike our results, orienting efficiency was found to associate with individual differences in mind-wandering tendency in a previous study (Hu, He, & Xu, 2012). In this study, executive function was not associated with frequency of mind-wandering. These inconsistent findings might be due to differences in trait-levels of mind-wandering and task-specific mind-wandering frequency. No correlation found between mind-wandering rate during ANT and self-reported mind-wandering tendency (MWQ response) also supports the assertion that these variables are independent. It is possible that individual differences in tendency of mind-wandering may associate more with orienting than executive function, whereas task-specific mind-wandering frequency may impact executive, but not orienting function. Future studies should investigate the precise relations between intra-individual and inter-individual mind-wandering experiences. Knowledge of attentional aspects of both task-specific and individual-specific mind-wandering can provide implications for display or environment designs. For example, it might allow predicting potential operators or users who have deficits in particular attentional functions are more or less likely to mind-wander depending on task or environment design.

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