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Different efficiencies of attentional orienting in different wandering minds

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ABSTRACT

This study examined the relations between properties of attentional networks and Mind Wandering (MW) across individuals. For the attentional networks, we measured three components of attention, known as alerting, orienting, and executive control, using the Attention Network Test (ANT). To investigate MW, we measured thought probes embedded in the Sustained Attention to Response Task (SART). Moreover, four performance characteristics of the SART were calculated as behavioral indices of MW. Three of them showed significant associations with probed MW. Most research regarding MW focused on its relation to executive functions, while the present study revealed that MW, as indexed by self-reports and RT variability, was negatively correlated with orienting, specifically the exogenous orienting system. Furthermore, there was a positive association between RT variability and executive control. Our results suggest that individuals with higher tendency of MW are less sensitive to irrelevant external stimuli, supporting the decoupling hypothesis of MW.

1. Introduction

The mind tends to flit, often when there is a lack of demands for concentration, but even when processing a demanding task. This is a ubiquitous phenomenon referred to as Mind Wandering (MW) (Smallwood & Schooler, 2006) and has been investigated in many kinds of tasks, including signal detection tasks (Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; Smallwood, Fitzgerald, Miles, & Phillips, 2009), reading tasks (Sayette, Schooler, & Reichle, 2010; Smallwood, McSpadden, & Schooler, 2008), encoding tasks (Smallwood, Riby, Heim, & Davies, 2006) and also in normal classroom activities (Cameron & Giuntoli, 1972; Smallwood, Fishman, & Schooler, 2007). Like many other cognitive functions, there are individual differences in MW. It has been shown that MW rates are reliable over different tasks and daily life, as well as in test–retest analyses (Giambra, 1995; McVay, Kane, & Kwapil, 2009), indicating it is a stable cognitive characteristic.

MW was suggested to be viewed as a state of decoupled attention, that attention is divided between external task processing and internal thoughts and feelings when the mind wanders (Schooler et al., 2011; Smallwood, Baracaia, Lowe, & Obonsawin, 2003; Smallwood, Brown, Baird, & Schooler, 2011; Smallwood, O'Connor, Sudbery, & Obonsawin, 2007; Smallwood & Schooler, 2006). This idea has intuitive appeals as well, but in what way is MW related to attention? Given the complexity of attention and multiple components of the attentional system, a natural and important question to ask is: how do individual differences in the tendency toward MW associate with different attentional components?

Posner and Petersen (1990) proposed that the attentional system can be divided into three networks: alerting, orienting and executive control. *Alerting* is defined as the ability to achieve and maintain a state of high sensitivity to incoming stimuli.

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An internal state changes to prepare for perceiving a stimulus. While tonic or intrinsic alerting means wakefulness and arousal, phasic alerting represents the ability to increase response readiness for a short time following an external warning cue (Fan et al., 2009; Sturm & Willmes, 2001). *Orienting* is defined as the ability to select information from numerous sensory inputs. While exogenous orienting refers to attention direction triggered by abrupt stimuli, endogenous orienting represents a voluntary direction of attention to a certain location. *Executive control* function is defined as the ability to resolve conflicts among thoughts, feelings and responses, which is always assessed by introducing conflicts. Many neuroimaging and neurochemical studies also support the presence of these attentional networks (Fan, McCandliss, Fossella, Flombaum, & Posner, 2005; Fan, McCandliss, Sommer, Raz, & Posner, 2002; Fan et al., 2007, 2009; Marrocco & Davidson, 1998).

A number of recent studies have examined the relationships between MW and executive functions. Some researchers (Kane et al., 2007; McVay & Kane, 2009) demonstrated that working memory capacity (WMC), which can be used to predict the ability of executive control (Engle, 2002), is negatively correlated with the frequency of MW during attention-demanding activities, both in and out of the laboratory. Evidence from clinical studies also supports such a relationship. For example, students who have been diagnosed with attention-deficit/hyperactivity disorder (ADHD) in childhood and subjects with dysphoria (both groups with deficits in executive control) reported higher frequencies of task-unrelated thoughts (TUTs) when finishing tasks, compared to healthy controls (Shaw & Giambra, 1993; Smallwood, O'Connor, & Heim, 2005). These results suggest that a higher proneness of MW may be related to a lower ability of executive control.

However, it is worth noting that "executive functions" is an umbrella term involving many functions (Chan, Shum, Toulopoulou, & Chen, 2008). Braver, Gray, and Burgess (2007) put forth a theory termed 'dual mechanisms of control (DMC)', generalizing two distinct operating modes of executive control: proactive control and reactive control. Proactive control represents the active maintenance of internally represented goal-related information, allowing it to bias the processing of following information in accordance with this maintained information; reactive control is engaged after the occurrence of some imperative events and is usually triggered to resolve conflict. Kane and Engle (2003) used a Stroop task to distinguish individual differences in goal maintenance from competition resolution. The former is a form of proactive control whereas the latter is a form of reactive control. McVay and Kane (2009) tested the relations among WMC, MW, and goal neglect in a go/no-go task. They found that MW rates varied with WMC and predicted WMC-related variation in task performance, whereas fast and erroneous responding still occurred even when on-task states were reported, so MW rates might only partially mediate the relationship between WMC and task performance. They suggested that the predictive power of MW rates lies in its correlation with proactive control rather than reactive control, which was reflected in WMC's MW-independent prediction of task performance. In Posner's definition, executive control mainly represents the ability of conflict resolution. Therefore, one might not expect to see a correlation between MW rates and the executive network.

To our knowledge, few studies have examined the link between MW and the alerting or orienting component of attention. It would not be unreasonable to expect a relationship between MW and these attentional networks. Thus we set out to investigate potential relationships between MW and functions of attentional networks. To do so we need effective ways of measuring MW and the attentional components.

MW is commonly measured with thought sampling, which can be grouped into two broad categories: probe-caught MW and self-caught MW (for reviews see Smallwood & Schooler, 2006). For the former method, participants have to report whether or not their minds wandered at the time when a probe appeared; while the latter method requires participants to monitor their minds and report when they notice their minds wandering. Since probe-caught MW can collect self-reports in an online fashion while keeping cognitive demands constant, we chose this method to estimate the rate of MW.

To get supportive evidence for the self-reports, they were collected while participants were performing the Sustained Attention to Response Task (SART; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997), a simple go/no-go task requiring participants to inhibit responses to infrequent targets. In order to further simplify this task and thus facilitate MW, we displayed stimuli with a slow pace of one stimulus every 2 s, since MW decreases with the increase of stimulus presentation rate (Giambra, 1995; Smallwood et al., 2004). The SART is widely employed to study MW because of the sensitivity of task performance to MW. For example, errors on the SART have been proved to predict and be predicted by self-reported MW (Christoff et al., 2009; Manly, Robertson, Galloway, & Hawkins, 1999; McVay & Kane, 2009; Robertson et al., 1997). Response times (RTs) are also very informative markers to indicate MW. The finding that response latencies decrease on go trials preceding no-go errors (*pre-error speeding*) and increase immediately after those errors (*post-error slowing*) may reflect momentary lapses of attention and reengaging in task set after the detection of errors (Jackson & Balota, 2011; Robertson et al., 1997; Smallwood et al., 2004). This pattern of speeding and slowing would increase the variability of RT (Johnson et al., 2007) and several studies have demonstrated that RT variability could provide some useful information to identify states of MW (McVay et al., 2009; Smallwood, McSpadden, Luus, & Schooler, 2008). Recently the following three performance characteristics of the SART were identified to index different MW states: *RT variability*, variation within the normal range of RT; *anticipations*, extremely fast RTs which are presumably attributed to anticipations of go stimuli; and *omissions*, the failure to respond to go stimuli. Each of the three characteristics above was strongly correlated with one another, and significantly correlated with self-reported MW as well as with no-go errors (Cheyne, Solman, Carriere, & Smilek, 2009). All the aforementioned measures of SART performance can be used as behavioral indices of MW.

The efficiencies of the three attentional networks could be measured with an Attention Network Test (ANT), a combination of the cued reaction time task (Posner, 1980) and the flanker task (Eriksen & Eriksen, 1974) that can assess those networks simultaneously (Fan et al., 2002). In this test, different warning cues are presented prior to a target arrow that is flanked by congruent or incongruent arrows. The participants' task is to indicate the direction of the target arrow. The efficiency of each network is measured comparing performance in different cue-type conditions and flanker-type conditions. Thanks to its simplicity and reliability, the ANT has been widely used in adults, children, as well as neuropsychological patients (e.g. Rueda, Posner, & Rothbart, 2004; Wang et al., 2005). Several versions of ANT have been developed (Callejas, Lupianez, Funes, & Tudela, 2005; Fan et al., 2009; Greene et al., 2008). In the original version, the spatial cue was 100% predictive of target location, so the information value was combined with peripheral cueing, that is, when measuring the orienting effect (central minus spatial cue), endogenous and exogenous components were mixed up (Klein, 2004). Callejas et al. (2005) modified this version by using uninformative peripheral cues to define the orienting network, allowing the measurement of the pure effect of exogenous orienting.

By utilizing the SART embedded with thought probes and the ANT, we measured the MW rates and the efficiency of attentional networks, attempting to relate individual differences in MW tendency to one or more of the three attentional network components.

2. Methods

2.1. Participants

Sixty five students (36 males, 29 females) gave their informed consent to participate in this study, with a mean age of 23.17 (SD 1.90) ranging from 20 to 29 years. All participants had normal or corrected-to-normal vision. Two participants who did not follow SART instructions were excluded.

2.2. Apparatus and procedure

Participants were tested individually in quiet rooms. Stimuli were presented through E-Prime on a 17-in. CRT monitor. The viewing distance was approximately 80 cm for the SART and 53 cm for the ANT.

The experiment began at around 10:00 every morning, in case performance is affected by time-of-day (Matchock & Toby Mordkoff, 2009). Participants first completed a 1-h session of the SART, and then a 30-min session of the ANT was performed after a break of ~15 min.

2.2.1. SART

During the SART, participants were shown a string of letters (A–Z) in the center serially, with a low frequency (5%) of the target letter (C). Each letter was presented for 1000 ms or until the participant gave a response. A blank screen followed for a variable duration, so that every trial lasted for 2000 ms. Participants' task was to press the space bar as soon as they saw any letter except the letter C, and withhold their response when the letter C appeared. Both speed and accuracy were equally emphasized.

Thought probes were inserted into the SART to obtain subjective reports of MW. The thought probe was a question asking participants what they were thinking about just before the probe. Three options were listed below the question for them to

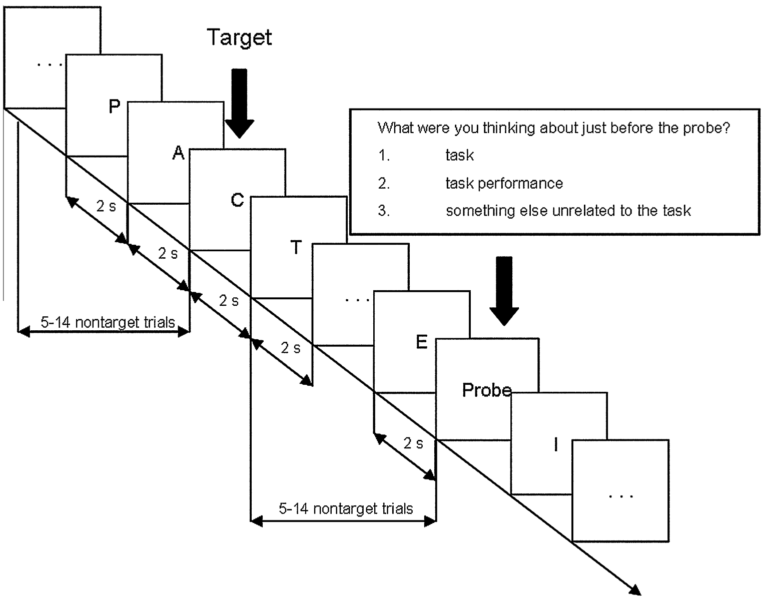

Fig. 1. Experimental procedure of the SART embedded with thought probes.

choose: 1. task; 2. task performance; and 3. something else unrelated to the task. All of these choices were elaborated in advance: "task" meant everything on the mind was about the stimulus letters or appropriate response; "task performance", just as the term suggested, meant evaluating their own performance; and "something else unrelated to the task" meant something irrelevant intruded, such as things that happened in the past, current state of being and plans after the experiment. Participants gave their answers by pressing corresponding numbers on the keyboard according to their thought contents.

After a 3-min practice including 5 thought probes, participants carried out a total of four experimental test blocks. 315 trials were presented in each block, including 285 nontarget letters, 15 target letters and 15 thought probes. Nontargets consisted of 19 letters chosen from the alphabet repeated 15 times in a random order. Targets and probes occurred pseudorandomly, inserted into nontargets separately every 5–14 trials, so that they distributed evenly across the whole block (Fig. 1).

As proposed by Cheyne et al. (2009), four performance characteristics of the SART were calculated: no-go error rates, RT variability, anticipations and omissions. Commissions of no-go targets ("C") were coded as no-go errors; coefficients of variability of nontarget RTs above 200 ms (RTCVs) were calculated as RT variability, by dividing the standard deviations of corresponding RTs with their average speeds across trials; nontarget RTs less than 100 ms were classified as anticipations; and the numbers of times participants made no response to nontarget letters were counted as omissions.

2.2.2. ANT

Participants performed a slightly modified version of the ANT (Fan et al., 2002), adding manipulation of the validity of the spatial cue to measure the ability of exogenous orienting attention (Callejas et al., 2005). The center-cue condition and the neutral-flanker condition in the original version were left out, similar to a revised design (ANT-R) by Fan et al. (2009).

A target arrow was presented 1.06° above or below the center fixation, flanked by two arrows on both sides. The length of the arrows was 0.55° and they were 0.06° away from each other. In the congruent condition, the flanker arrows had the same direction as the target arrow; while in the incongruent condition, the flanker arrows pointed in the direction opposite the target. Participants were required to identify the direction of the central arrow and respond as quickly and accurately as possible, by pressing the 'F' key with their left index finger and the 'J' key with their right index finger for the corresponding direction. Before the appearance of the target, asterisk cues were shown in some trials, in the form of double cue and spatial cue. These cues were used to indicate when or where the arrow might occur. In all, there were four cue conditions: no-cue, without any cue flashed ahead; double-cue, with two asterisks flashed one above and one below the center fixation; valid-spatial-cue, with one asterisk flashed at the target position; and invalid-spatial-cue, with one asterisk flashed at the opposite spot. Those spatial cues were not informative regarding the target location, as the target appeared with equal probability at the cued and uncued location.

A fixation cross was shown in the center throughout the entire test. In each trial, after a fixation period of a random variable duration between 400 ms and 1600 ms, a cue was presented for the cued conditions or the fixation remained unchanged for the no-cue condition for 100 ms. Then after a cue-to-target interval of 400 ms, the arrows were presented

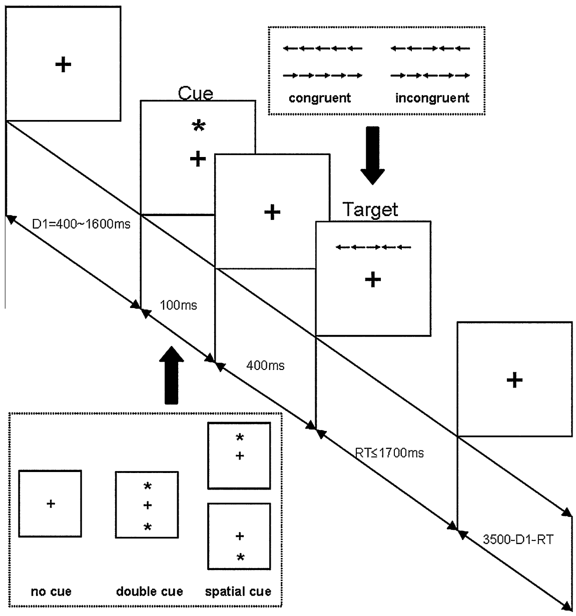

Fig. 2. Experimental procedure of the ANT. An example of the procedure in a valid-spatial-cue and incongruent condition, with all the cue types showing below and all the flanker conditions illustrated above.

Table 1
Correlations among Mind Wandering rates and performance measures on the SART.

	MW	No-go ER	RTCVs	Anticipations	Omissions
MW	–				
No-go ER	0.29*	–			
RTCVs	0.26*	0.35**	–		
Anticipations	0.35**	0.45**	0.40**	–	
Omissions	0.03	0.24	0.56**	0.04	–

Note: MW = Mind Wandering rates; RTCVs = nontarget response time coefficients of variation; No-go ER = No-go Error rates.
* $p < .05$.
** $p < .01$.

Table 2
Mean reaction times and accuracies for cue type and flanker condition.

Flanker Condition	Cue type			
	Double	No	Valid	Invalid
a. Mean reaction times (ms) and standard deviations				
Congruent	523.37 (56.66)	582.11 (60.74)	504.39 (52.76)	549.40 (57.96)
Incongruent	621.05 (69.87)	658.28 (69.10)	586.33 (67.39)	652.29 (72.96)
b. Mean error rate (%) and standard deviations				
Congruent	0.36 (1.03)	0.63 (1.33)	0.36 (0.96)	0.69 (1.63)
Incongruent	2.91 (3.77)	2.94 (3.86)	2.61 (3.87)	4.13 (4.12)

until the participant responded, with a limitation of 1700 ms. Finally, the duration between the offset of the stimuli and the onset of the next trial was manipulated to make the duration of the whole trial 4000 ms (Fig. 2).

The task contained five blocks. A 32-trial practice block was followed by four 96-trial experimental blocks. Feedback regarding accuracy and reaction time was given during the practice block, but not during the experimental blocks. Each cue type was orthogonally crossed with 2 flanker conditions, and thus 8 combinations of cue type and flanker condition were formed, with 12 trials for each combination in an experimental block. The order of trials was randomized.

According to the established operational definitions (Callejas et al., 2005; Fan et al., 2002), we obtained efficiency scores for the attentional networks. The alerting effect was assessed by comparing the performance of the no-cue condition to the double-cue condition, since both conditions shared an attention–diffusion feature while the double-cue condition supplied alerting cues that accelerated the response. The orienting effect was measured as performance in the invalid-spatial-cue condition minus performance in the valid-spatial-cue condition, since they were the same in the form of alerting cue while the valid spatial cue provided correct spatial information that could benefit the response. The executive effect was calculated by subtracting the performance of the congruent condition from the performance of the incongruent condition, reflecting the ability to resolve conflict.

3. Results

3.1. Mind Wandering

Participants reported task-related thoughts and task-unrelated thoughts (i.e. MW) on 57% (SD = 21%) and 29% (SD = 20%) of thought probes. Thoughts about their own performance, namely task related interference (TRI; Sarason, Sarason, Keefe, Hayes, & Shearin, 1986), accounted for 14% (SD = 10%) of the probes. Responses of TRI were removed from future analyses in light of its ambiguous nature.

Mean error rate for target (no-go) trials was 32% (SD = 19%). Mean RTCV, anticipation and omission for nontarget (go) trials were 0.23 (SD = 0.06), 3.92 (SD = 15.21) and 0.87 (SD = 1.33), respectively. In concordance to previous studies (Robertson et al., 1997; Smallwood et al., 2004), mean RTs for the four nontarget trials before no-go errors (M = 328.80, SD = 41.87) were robustly shorter than those before no-go hits (M = 361.60, SD = 50.56), $t(62) = -11.86$, $p < .001$, so-called pre-error acceleration. And mean RTs after no-go errors (M = 340.34, SD = 63.54) were significantly longer than those before no-go errors, $t(62) = 2.25$, $p < .05$.

As can be seen in Table 1, three SART indices (no-go error rates, RTCVs, and anticipations) were significantly and strongly correlated with one another, and the fourth index (omissions) showed a significant correlation with RTCVs and a marginal correlation with no-go error rates ($p = .06$), but not with the others, basically consistent with the findings by Cheyne et al. (2009). Moreover, the first three indices were significantly correlated with probed MW rates, indicating the validity of the subjective reports.

Table 3
Mean scores and standard deviations of the three attentional networks and correlations among the scores on the SART and the ANT.

	Alerting	Orienting	Executive
Score	48.09 (21.21)	55.07 (28.14)	89.55 (26.31)
Alerting	–		
Orienting	−0.04	–	
Executive	−0.15	−0.09	–
MW	−0.17	−0.29*	0.15
No-go ER	0.05	0.02	0.20
RTCVs	0.00	−0.34**	0.30*
Anticipations	−0.04	0.09	0.08
Omissions	0.21	−0.21	0.17

Note: MW = Mind Wandering rates; RTCVs = nontarget response time coefficients of variation; No-go ER = No-go Error rates.
* $p < .05$.
** $p < .01$.

3.2. Attentional networks

3.2.1. Mean reaction times

Incorrect responses in the ANT were excluded first. Then statistical outliers of the remaining RTs more than three standard deviations from the mean were eliminated (1.4%). The mean RT data for each condition of the ANT are summarized in Table 2a. A four (cue type: double cue, no cue, valid spatial cue, invalid spatial cue) $*$ two (flanker condition: congruent, incongruent) repeated-measures analysis of variance (ANOVA) of the mean RTs was conducted.

In accord with previous studies, there were significant main effects of cue type, $F(3,186) = 194.66$, $p < .001$, and flanker condition, $F(1,62) = 732.17$, $p < .001$. The interaction between cue type and flanker condition was also significant, $F(3,186) = 27.22$, $p < .001$, suggesting some lack of independence among the networks (Fan et al., 2002, 2009). Post-hoc least-significant difference (LSD) test revealed that the RTs were faster in the valid-spatial-cue condition than in the invalid-spatial-cue condition ($p < .001$) and slower when no cue was presented than when the double cue appeared ($p < .001$). In addition, the RTs in incongruent trials were found to be longer than those in congruent trials ($p < .001$), reflecting a time cost to process conflict information in the incongruent condition. All of these results confirmed that the ANT is a usable method to measure the three attentional networks.

3.2.2. Error rates

Mean error rates are shown in Table 2b. A four (cue type) $*$ two (flanker condition) repeated-measures ANOVA revealed a main effect of cue type, $F(3,186) = 6.10$, $p < .001$, and flanker condition, $F(1,62) = 47.79$, $p < .001$. The interaction between cue type and flanker condition was not significant, $F(3,186) = 1.68$, ns. Pairwise comparisons showed that the error rates were higher in invalid-spatial-cue conditions than in valid-spatial-cue conditions ($p = .001$) and lower in congruent conditions than in incongruent conditions ($p < .001$). In general, the accuracy data were consistent with the RT data without the speed-accuracy tradeoff.

3.3. Efficiencies of the attentional networks and correlation analyses

Mean scores of the three attentional networks are displayed in Table 3. To examine the reliability of our measures of these networks, we collapsed the four blocks into two parts, and calculated the Pearson correlations between the two halves across subjects. Identical to the results from the study by Fan et al. (2002), estimates for all three networks produced significant reliability: the alerting network was the least reliable, $r = .54$, $p < .001$; the executive control network was the most reliable, $r = .80$, $p < .001$; and the orienting network was the intermediate, $r = .69$, $p < .001$.

Measures of MW and attentional networks in the same individuals allowed us to explore their relationships. Table 3 also summarizes the correlations among the scores on the SART and the ANT. As in previous studies, there were no significant correlations between any combination of alerting, orienting and executive effects within the ANT. With respect to the associations between MW and the networks, we found that MW rates were negatively correlated with orienting attention (Fig. 3A), while not correlated with alerting or executive attention; RTCVs had a negative correlation with orienting and a positive correlation with executive attention (Fig. 3B and C), but no significant correlation with alerting attention. Despite the divergence of the significance between the MW – executive attention correlation and the RTCV – executive attention correlation, there was no significant difference between these two correlations, $t(60) = 1.004$, ns.

To further examine the correlation between MW and orienting attention, a median split on the MW rates was used to generate two groups of MW, and then the mean orienting scores were compared between these two groups. The median MW rate was 27%. Participants with MW rates higher than the median ($n = 31$, $M = 44\%$, SD = 15%) were assigned to the high-MW group; those whose MW rates were lower than the median ($n = 32$, $M = 13\%$, SD = 8%) were assigned to the

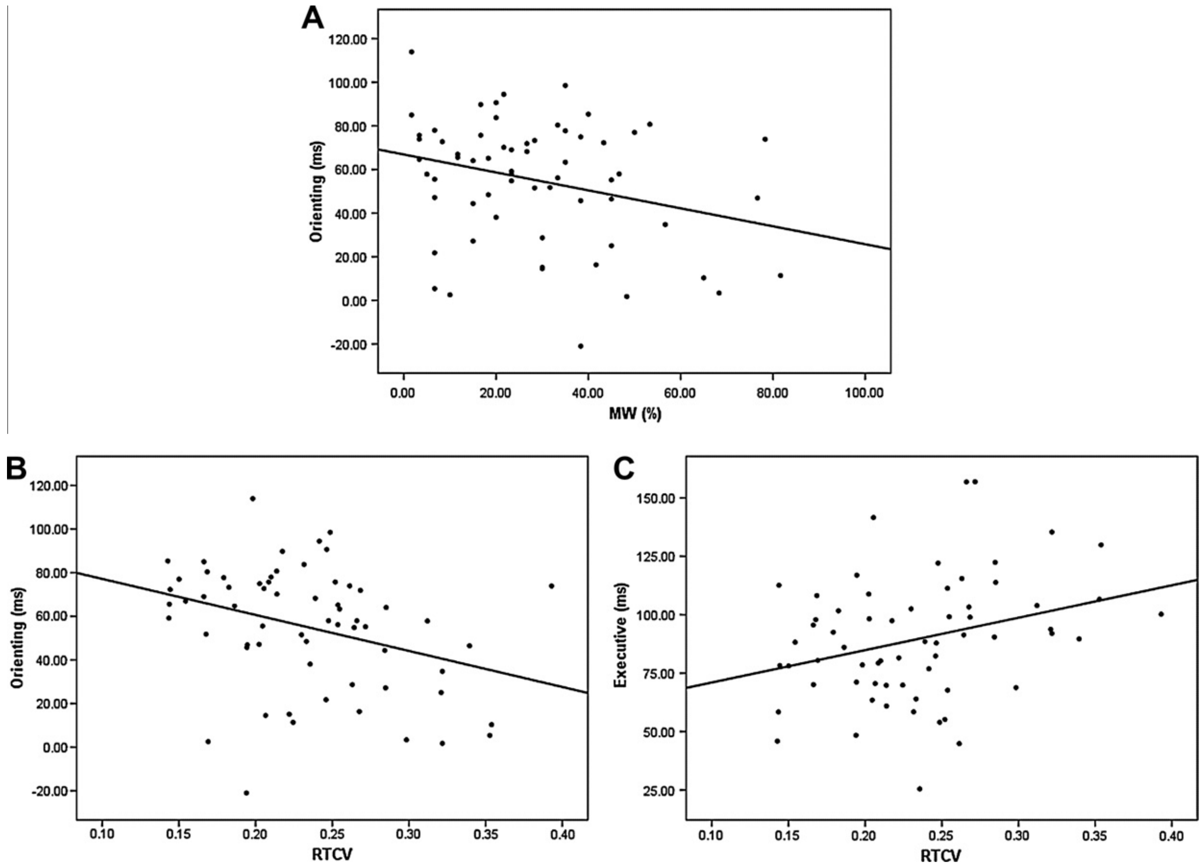

Fig. 3. Scatter plots for correlations between MW scores and efficiency measures of attentional networks that are statistically significant. (A) Correlation between individual's MW rates and orienting scores. (B) Correlation between RTCV in the SART and orienting scores. (C) Correlation between RTCV in the SART and executive control scores.

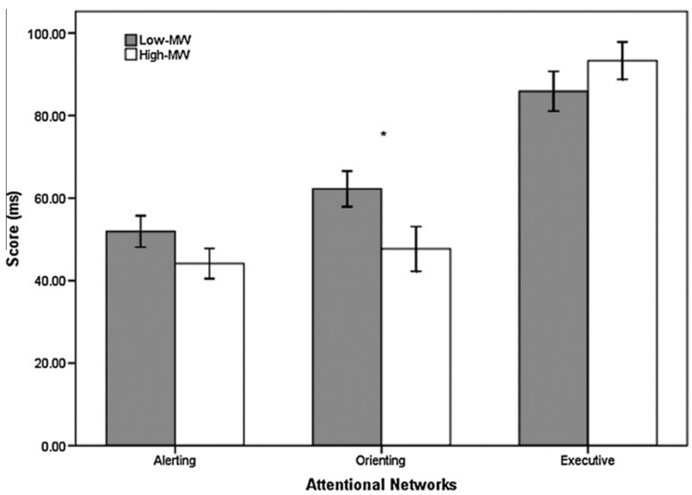

Fig. 4. The ANT scores for the high and low MW groups. Error bars represent one standard error of the mean; *Indicates significant differences at $p < .05$ level.

low-MW group. As can be seen in Fig. 4, the mean orienting score of the low-MW group was significantly higher than that of the high-MW group, $t(61) = 2.11$, $p < .05$. The same manipulations were also done to the scores of alerting and executive attention. In line with prior results, no significant differences were found between the two groups in alerting attention, $t(61) = 1.47$, ns, and executive attention, $t(61) = -1.12$, ns.

4. Discussion

The predicted effects of MW rates on the three mutually associated SART indices supported the validity of the subjective self-reports. Omissions only had a significant association with RT variability and a marginal correlation with no-go error rates, though. The significant effects of cue type and flanker condition, the non-significant correlations among alerting, orienting, and executive attention, and the high test–retest reliability in the ANT supported the fact that the ANT can measure the three relatively independent attentional networks efficiently. Across participants, different frequencies of MW as well as RT variability negatively correlated with the efficiency of orienting attention, specifically the exogenous orienting system. No significant correlations were found between MW rates and the other two attentional networks, while RT variability showed a positive correlation with executive attention.

The most intriguing result in the present study was that participants with more wandering minds, as indexed by higher MW rates and RT variability, showed impaired exogenous orienting attention. It suggests that the uninformative peripheral cues cause less automatic shifts of attention for the high-MW group. Participants in this group are less responsive to irrelevant external stimuli, and hence benefit less from the valid spatial cue. The result is in accordance with several recent studies documenting that sensory processing was dampened during TUT, regardless of whether it was task-relevant or task-irrelevant. Kam and colleagues (2011) adapted the SART by adding a task-irrelevant stimulus interspersed between each target/nontarget stimulus, either a visual grating or an auditory beep, and recorded the event-related potentials (ERPs) to these irrelevant stimuli. They found that both visual and auditory sensory responses in the cortex were attenuated during TUTs relative to during on-task states. Barron, Riby, Greer, and Smallwood (2011) lowered the frequency of the task-irrelevant stimuli, so that they were as rare as the target. A reduction in ERPs to both task-relevant stimuli and novel distractors was observed to associate with high levels of TUT. Unlike the direct examination of the cortical responses to task-irrelevant events during MW, the present study investigated the ability of attentional orienting attracted by abrupt cue stimuli in individuals with different MW tendencies. A similar result was obtained in this study revealing that the exogenous orienting could not work efficiently for high-MW individuals. All these findings corroborate the decoupling hypothesis suggesting that engaging the internal stream of thought would prevent detailed processing of external stimuli (Barron et al., 2011; Schooler et al., 2011; Smallwood, 2010; Smallwood et al., 2003, 2011), even when they are abrupt and irrelevant.

Consistent with previous studies, we found no statistically significant correlation between reported MW and the executive control network. As in McVay and Kane (2009), who demonstrated MW's predictive efficacy for goal maintenance, a form of proactive control (Braver et al., 2007), and suggested MW's independence to competition resolution, a form of reactive control (Braver et al., 2007), our result also suggests that MW rates are not related to reactive control, since executive attention measured here reflects the reactive component of executive control. So, although the ability to resist interference from TUTs could be responsible for the frequency of goal neglect, it might not be associated with the ability to resolve conflict.

However, RT variability in the SART was positively correlated with the executive network, indicating its relation to competition resolution. This result corresponds to WMC's non-MW prediction of SART variance in the study by McVay and Kane (2009), further manifesting that the ability of proactive control and reactive control both contribute to performance variability. In addition, RT variability has been widely introduced as a marker of executive dysfunction. People with ADHD, old age or brain damage in the frontal lobe, all of which are associated with some sort of executive deficit, exhibit increased intra-individual RT variability in previous studies (Bunce et al., 2010; Epstein et al., 2011; Hultsch, MacDonald, Hunter, Levy-Bencheton, & Strauss, 2000). Therefore, it is not surprising that individual variations in RT variability were predictive of executive control.

As we can see above, the executive network was significantly correlated with the objective index but not with the subjective reports of MW. Nevertheless, these two relations did not significantly differ from each other. This finding may result from the methodological issue which is one of the key problems in the investigation of MW (Riby, Smallwood, & Gunn, 2008). As the most common method for measuring MW, verbal reports have been found to be valid in a great deal of research (e.g., McVay & Kane, 2009; Smallwood et al., 2004), as well as in the current study. However, they still have some inherent limitations and barriers (Smallwood & Schooler, 2006). For example, one's reports of MW may be biased by the understanding of MW or the belief regarding the purpose of the research (Smallwood & Schooler, 2006). Such influence would weaken the reliability of the measures of MW. So a possible explanation of this result, as has been suggested by one of the reviewers of a previous version of this article, is that the thought-probe responses may be less reliable than the RTCV to index MW, such that the reported MW could not reveal the possible MW – executive network association. Accordingly, to clarify the relationship between MW and the efficiency of competition resolution, it would be helpful to test the differences in the reliability of the subjective and objective measures of MW.

With respect to the relationship between MW and alerting attention, our data indicate that the phasic alertness is not significantly different among individuals with different rates of MW. Yet, as the frequency of MW varies with arousal (Giambra, 1995) and alcohol consumption (Sayette, Reichle, & Schooler, 2009), we suspect that the tonic or intrinsic alertness will be more likely to vary with different MW rates.

This study examined the efficiencies of the three attentional networks and their relations to the MW rates across individuals. Results show that individuals who are more prone to MW are less sensitive to abrupt external stimuli. These data are in line with the decoupling hypothesis of MW. On the one hand, external task processing suffers during the period of MW; on the other hand, the suppression of processing of the external world when the mind wanders prevents internal mentation from distraction, so that more important personally relevant problems can be solved without interruption (Klinger, 1999; Smallwood & Schooler, 2006). Baars (2010) argued that we were being misled by such tendentious labels of MW as TUTs, cognitive failures, absent-minded and so on to regard MW in a negative way. He insisted that even if MW appeared arbitrary, irrelevant, unwanted or intrusive, it might still play an important adaptive role. The present empirical study revealed a less susceptible orienting system for individuals with more MW, supporting the decoupling hypothesis and suggesting an important positive role of MW.

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References

Baars, B. J. (2010). Spontaneous repetitive thoughts can be adaptive: Postscript on "Mind Wandering". *Psychological Bulletin, 136*(2), 208–210.

Barron, E., Riby, L. M., Greer, J., & Smallwood, J. (2011). Absorbed in thought: The effect of mind wandering on the processing of relevant and irrelevant events. *Psychological Science, 22*(5), 596–601.

Braver, T. S., Gray, J. R., & Burgess, G. C. (2007). Explaining the many varieties of working memory variation: Dual mechanisms of cognitive control. In A. R. A. Conway, C. Jarrold, M. J. Kane, A. Miyake, & J. N. Towse (Eds.), *Variation in working memory* (pp. 76–106). New York, NY: Oxford University Press.

Bunce, D., Anstey, K. J., Cherbuin, N., Burns, R., Christensen, H., Wen, W., et al (2010). Cognitive deficits are associated with frontal and temporal lobe white matter lesions in middle-aged adults living in the community. *PloS One, 5*(10), e13567.

Callejas, A., Lupianez, J., Funes, M. J., & Tudela, P. (2005). Modulations among the alerting, orienting and executive control networks. *Experimental Brain Research, 167*(1), 27–37.

Cameron, P., & Giuntoli, D. (1972). Consciousness sampling in the college classroom or is anybody listening? *Intellect, 101*(2343), 63–64.

Chan, R. C. K., Shum, D., Toulopoulou, T., & Chen, E. Y. H. (2008). Assessment of executive functions: Review of instruments and identification of critical issues. *Archives of Clinical Neuropsychology, 23*(2), 201–216.

Cheyne, J. A., Solman, G. J. F., Carriere, J. S. A., & Smilek, D. (2009). Anatomy of an error: A bidirectional state model of task engagement/disengagement and attention-related errors. *Cognition, 111*(1), 98–113.

Christoff, K., Gordon, A. M., Smallwood, J., Smith, R., & Schooler, J. W. (2009). Experience sampling during fMRI reveals default network and executive system contributions to mind wandering. *Proceedings of the National Academy of Sciences, 106*(21), 8719–8724.

Engle, R. W. (2002). Working memory capacity as executive attention. *Current Directions in Psychological Science, 11*(1), 19–23.

Epstein, J. N., Langberg, J. M., Rosen, P. J., Graham, A., Narad, M. E., Antonini, T. N., et al (2011). Evidence for higher reaction time variability for children with ADHD on a range of cognitive tasks including reward and event rate manipulations. *Neuropsychology, 25*(4), 427–441.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics, 16*(1), 143–149.

Fan, J., Byrne, J., Worden, M. S., Guise, K. G., McCandliss, B. D., Fossella, J., et al (2007). The relation of brain oscillations to attentional networks. *Journal of Neuroscience, 27*(23), 6197–6206.

Fan, J., Gu, X., Guise, K. G., Liu, X., Fossella, J., Wang, H., et al (2009). Testing the behavioral interaction and integration of attentional networks. *Brain and Cognition, 70*(2), 209–220.

Fan, J., McCandliss, B. D., Fossella, J., Flombaum, J. I., & Posner, M. I. (2005). The activation of attentional networks. *Neuroimage, 26*(2), 471–479.

Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience, 14*(3), 340–347.

Giambra, L. M. (1995). A laboratory method for investigating influences on switching attention to task-unrelated imagery and thought. *Consciousness and Cognition, 4*(1), 1–21.

Greene, D. J., Barnea, A., Herzberg, K., Rassis, A., Neta, M., Raz, A., et al (2008). Measuring attention in the hemispheres: The lateralized attention network test (LANT). *Brain and Cognition, 66*(1), 21–31.

Hultsch, D. F., MacDonald, S. W. S., Hunter, M. A., Levy-Bencheton, J., & Strauss, E. (2000). Intraindividual variability in cognitive performance in older adults: Comparison of adults with mild dementia, adults with arthritis, and healthy adults. *Neuropsychology, 14*(4), 588.

Jackson, J. D., & Balota, D. A. (2011). Mind-wandering in younger and older adults: Converging evidence from the sustained attention to response task and reading for comprehension. *Psychology and Aging*. doi:10.1037/a0023933.

Johnson, K. A., Kelly, S. P., Bellgrove, M. A., Barry, E., Cox, M., Gill, M., et al (2007). Response variability in attention deficit hyperactivity disorder: Evidence for neuropsychological heterogeneity. *Neuropsychologia, 45*(4), 630–638.

Kam, J. W. Y., Dao, E., Farley, J., Fitzpatrick, K., Smallwood, J., Schooler, J. W., et al (2011). Slow fluctuations in attentional control of sensory cortex. *Journal of Cognitive Neuroscience, 23*(2), 460–470.

Kane, M. J., Brown, L. H., McVay, J. C., Silvia, P. J., Myin-Germeys, I., & Kwapil, T. R. (2007). For whom the mind wanders, and when. *Psychological Science, 18*(7), 614–621.

Kane, M. J., & Engle, R. W. (2003). Working-memory capacity and the control of attention: The contributions of goal neglect, response competition, and task set to stroop interference. *Journal of Experimental Psychology: General, 132*(1), 47–70.

Klein, R. M. (2004). On the control of visual orienting. In M. Posner (Ed.), *Cognitive neuroscience of attention* (pp. 29–44). New York: The Guilford Press.

Klinger, E. (1999). Thought flow: Properties and mechanisms underlying shifts in content. In J. A. Singer & P. Salovey (Eds.), *At play in the fields of consciousness: Essays in the honor of Jerome L. Singer* (pp. 29–50). Mahwah, NJ: Erlbaum.

Manly, T., Robertson, I. H., Galloway, M., & Hawkins, K. (1999). The absent mind: Further investigations of sustained attention to response. *Neuropsychologia, 37*(6), 661–670.

Marrocco, R. T., & Davidson, M. C. (1998). Neurochemistry of attention. In R. Parasuraman (Ed.), *The attentive brain* (pp. 35–50). Cambridge, MA: MIT Press.

Matchock, R. L., & Toby Mordkoff, J. (2009). Chronotype and time-of-day influences on the alerting, orienting, and executive components of attention. *Experimental Brain Research, 192*(2), 189–198.

McVay, J. C., & Kane, M. J. (2009). Conducting the train of thought: Working memory capacity, goal neglect, and mind wandering in an executive-control task. *Journal of Experimental Psychology: Learning, Memory and Cognition, 35*(1), 196–204.

McVay, J. C., Kane, M. J., & Kwapil, T. R. (2009). Tracking the train of thought from the laboratory into everyday life: An experience-sampling study of mind wandering across controlled and ecological contexts. *Psychonomic Bulletin & Review, 16*(5), 857–863.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32*(1), 3–25.

Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience, 13*(1), 25–42.

Riby, L., Smallwood, J., & Gunn, V. (2008). Mind wandering and retrieval from episodic memory: A pilot event-related potential study. *Psychological Reports, 102*(3), 805–818.

Robertson, I. H., Manly, T., Andrade, J., Baddeley, B. T., & Yiend, J. (1997). 'Oops!': Performance correlates of everyday attentional failures in traumatic brain injured and normal subjects. *Neuropsychologia, 35*(6), 747–758.

Rueda, M. R., Posner, M. I., & Rothbart, M. K. (2004). Attentional control and self-regulation. In R. F. Baumeister & K. D. Vohs (Eds.), *Handbook of self-regulation: Research, theory, and applications* (pp. 283–300). New York: Guilford Press.

Sarason, I. G., Sarason, B. R., Keefe, D. E., Hayes, B. E., & Shearin, E. N. (1986). Cognitive interference: Situational determinants and traitlike characteristics. *Journal of Personality and social Psychology, 51*(1), 215–226.

Sayette, M., Reichle, E., & Schooler, J. (2009). Lost in the sauce: The effects of alcohol on mind wandering. *Psychological Science, 20*(6), 747–752.

Sayette, M., Schooler, J., & Reichle, E. (2010). Out for a smoke. *Psychological Science, 21*(1), 26.

Schooler, J. W., Smallwood, J., Christoff, K., Handy, T. C., Reichle, E. D., & Sayette, M. A. (2011). Meta-awareness, perceptual decoupling and the wandering mind. *Trends in Cognitive Sciences, 15*(7), 319–326.

Shaw, G. A., & Giambra, L. M. (1993). Task-unrelated thoughts of college students diagnosed as hyperactive in childhood. *Developmental Neuropsychology, 9*(1), 17–30.

Smallwood, J. (2010). Why the global availability of mind wandering necessitates resource competition: Reply to McVay and Kane (2010). *Psychological Bulletin, 136*(2), 202–207.

Smallwood, J., Baracaia, S. F., Lowe, M., & Obonsawin, M. (2003). Task unrelated thought whilst encoding information. *Consciousness and Cognition, 12*(3), 452–484.

Smallwood, J., Brown, K., Baird, B., & Schooler, J. W. (2011). Cooperation between the default mode network and the frontal–parietal network in the production of an internal train of thought. *Brain Research*. doi:10.1016/j.brainres.2011.1003.1072.

Smallwood, J., Davies, J. B., Heim, D., Finnigan, F., Sudberry, M., O'Connor, R., et al (2004). Subjective experience and the attentional lapse: Task engagement and disengagement during sustained attention. *Consciousness and Cognition, 13*(4), 657–690.

Smallwood, J., Fishman, D. J., & Schooler, J. W. (2007). Counting the cost of an absent mind: Mind wandering as an underrecognized influence on educational performance. *Psychonomic Bulletin & Review, 14*(2), 230–236.

Smallwood, J., Fitzgerald, A., Miles, L. K., & Phillips, L. H. (2009). Shifting moods, wandering minds: Negative moods lead the mind to wander. *Emotion, 9*(2), 271–276.

Smallwood, J., McSpadden, M., Luus, B., & Schooler, J. W. (2008). Segmenting the stream of consciousness: The psychological correlates of temporal structures in the time series data of a continuous performance task. *Brain and Cognition, 66*(1), 50–56.

Smallwood, J., McSpadden, M., & Schooler, J. W. (2008). When attention matters: The curious incident of the wandering mind. *Memory & Cognition, 36*(6), 1144–1150.

Smallwood, J., O'Connor, R. C., & Heim, D. (2005). Rumination, dysphoria, and subjective experience. *Imagination, Cognition and Personality, 24*(4), 355–367.

Smallwood, J., O'Connor, R. C., Sudbery, M. V., & Obonsawin, M. (2007). Mind-wandering and dysphoria. *Cognition & Emotion, 21*(4), 816–842.

Smallwood, J., Riby, L., Heim, D., & Davies, J. B. (2006). Encoding during the attentional lapse: Accuracy of encoding during the semantic sustained attention to response task. *Consciousness and Cognition, 15*(1), 218–231.

Smallwood, J., & Schooler, J. W. (2006). The restless mind. *Psychological Bulletin, 132*(6), 946–958.

Sturm, W., & Willmes, K. (2001). On the functional neuroanatomy of intrinsic and phasic alertness. *Neuroimage, 14*(1), S76–S84.

Wang, K., Fan, J., Dong, Y., Wang, C., Lee, T., & Posner, M. I. (2005). Selective impairment of attentional networks of orienting and executive control in schizophrenia. *Schizophrenia Research, 78*(2–3), 235–241.