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Mind wandering and the attention network system

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ABSTRACT

Attention and mind wandering are often seen as anticorrelated. However, both attention and mind wandering are multi-component processes, and their relationship may be more complex than previously thought. In this study, we tested the interference of different types of thoughts as measured by a Thought Identification Task - TIT (on task thoughts, task related interference thoughts, external distractions, stimulus independent and task unrelated thoughts) on different components of the attention network system - ANT (alerting, orienting, executive). Results show that, during the ANT, individuals were predominantly involved in task related interference thoughts which, along with external distractors, significantly impaired their performance accuracy. However, mind wandering (i.e., stimulus independent and task unrelated thoughts) did not significantly interfere with accuracy in the ANT. No significant relationship was found between type of thoughts and alerting, orienting, or executive effects in the ANT. While task related interference thoughts and external distractions seemed to impair performance on the attention task, mind wandering was still compatible with satisfactory performance in the ANT. The present results confirmed the importance of differentiating type of "out of task" thoughts in studying the relationship between though distractors and attention.

1. Introduction

In absence of a specific task demand, minds tend to wander. Even with external attention demands, the mind periodically escapes into space and time travel (Corballis, 2013). In neuroimaging research, tasks that activate brain regions associated with attention are often referred as task positive while tasks responsible for the activation of mind wandering are labeled as task negative (Fox et al., 2005). Task negative and task positive conditions are associated with contrasting brain networks, respectively Default Mode Network (DMN) and Dorsal Attention Network (DAN). Switching from a mind wandering mode to an attention mode requires DMN deactivation and the concomitant activation of the DAN (Mason et al., 2007). Consistently, brain oscillatory rhythms show an increased activity of slow rhythms (Theta and Delta) and a decrease of fast rhythms (Alpha and Beta) when individuals start mind wandering, drifting away from a current task (Braboszcz & Delorme, 2011).

Attention and mind wandering are often seen as anticorrelated. This conclusion is based on data showing that mind wandering tends to recruit executive resources that are necessary for the performance of attention tasks (Smallwood & Schooler, 2006). Several studies have associated mind wandering with failures in executive control (Kane & McVay, 2012). However, there is now evidence that mind wandering does not affect equally different executive tasks. For example, Kam and Handy (2014) observed that mind wandering negatively affects performance in working memory and response inhibition but not set-shifting tasks. Each of those executive tasks involves distinct psychological mechanisms (working memory - capacity to hold and update information online; response inhibition - inhibitory control over a pre-potent response; set-shifting - cognitive flexibility for applying new rules to solve the same task).

Interestingly, a neuroimaging study by Christoff, Gordon, Smallwood, Smith, and Schooler (2009) showed that mind wandering tends to recruit not only the DMN but also brain networks associated with executive functioning. Therefore, it is possible that at least some types of mind wandering may not only compete but also facilitate some attention processes by recruiting complementary brain networks (e.g., DMN) that help with processes such as attention recycling, dishabituation or mood regulation (Smallwood & Schooler, 2015).

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Recent studies showed that the relationship between mind wandering and attention is more complex than previously thought and may require to approach both attention and mind wandering as multi-component processes (Peterson & Posner, 2012; Stawarczyk, Majerus, Catale, & Argembeau, 2014).

>30 years ago, Michal Posner introduced what is probably the most influential model of attention (Posner & Petersen, 1990). According to this model, there are at least three key functionally and anatomically distinct types of attention processes: alerting, orienting, and executive control. Alerting is defined as the process of reaching and maintaining a state of responsiveness to external stimuli. Orienting refers to the ability to select among multiple stimuli. Finally, executive control refers to the executive monitoring of performance and is mostly involved in goal-directed behaviors that requires, among others, decision making, error detection, and novel responses. These networks have been systematically assessed using the Attention Network Test (Macleod et al., 2010). Research shows that these three attentional components are supported by different neuroanatomical networks (Fan, McCandliss, Fossella, Flombaum, & Posner, 2005), and are associated with distinct genetic profiles (Fossella et al., 2002).

Mind wandering, like attention, is a multidimensional process. According to Schooler et al. (2011), mind wandering involves decoupling from attention to external stimuli and engaging in thought flow. While most of the studies have relied on a dichotomic classification (attention versus mind wandering), several authors differentiate among several "out of task" thoughts usually subsumed under the concept of mind wandering. Stawarczyk et al. (2011a) suggested three different types of "out of tasks thoughts" during attention external demands: task-related interference thoughts (TRI), external distractions thoughts (ED), and stimulus independent and task unrelated thoughts (SITUT). TRI refers to thoughts that are associated with side aspects of the task being performed, and are therefore concerned with performance, duration, level of difficulty, etc. ED includes thoughts about environmental stimuli irrelevant for the task, namely: heat, noise, discomfort, hunger, etc. Finally, the typical mind wandering experience is constituted by SITUT in which the mind is dissociated from both the task and external stimuli. All these thoughts contrast with on task thoughts (OT - task-related and stimulus-dependent thoughts). Several studies suggest that these different type of thoughts can predict performance in a variety of cognitive tasks (Stawarczyk et al., 2014) and are characterized by distinctive neural networks (Stawarczyk, Majerus, Maquet, & D'Argembeau, 2011).

Several studies explored the relationship between attention and mind wandering, looking at different components of attention and mind wandering. For example, Hu, He, and Xu (2012) examined the relationship between the three components of the ANT (alerting, orienting and conflict) and mind wandering. In their study, mind wandering was directly measured through thought probes and, indirectly, by performance indexes in the Sustained Attention to Response Task (SART). More specifically, while responding to SART, participants were requested to report their thoughts during 15 pseudorandom probes by selecting one among three options: task (i.e., thoughts associated with the stimuli being presented and responses); task performance (i.e., thoughts regarding their own performance); something else unrelated to the task (i.e., irrelevant thought intrusions). Additionally, several SART measures were selected as indirect behavioral indexes of mind wandering: (e.g., reaction time variability, anticipations, and omissions). The authors found that mind wandering was negatively associated with the orienting network, as measured directly by the thought probes and indirectly by the correlation with SART indexes. No additional significant relationships were found between mind wandering and the other components of the ANT.

Stawarczyk et al. (2011a), on the contrary, looked at the relationship between different type of thoughts and attention as measured by the SART. In this study, each SART block was followed by thought probes requiring the participant to classify their thoughts in the previous block according to one of the thought categories described above (i.e., OT, TRI, ED, SITUT). The authors found that different types of thoughts have a different profile of impact on the attention task. SITUT, ED, and TRI significantly interfered on SART performance. However, the total number of TRI did not correlate significantly with SART performance and, contrary to ED and SITUT, frequency of TRI did not increase with task duration.

Unsworth and McMillan (2014) researched the relationship between two types of task unrelated thoughts (i.e., external distractions and mind wandering) and three cognitive variables (i.e., attention control, working memory, and fluid intelligence) as assessed by a variety of experimental tasks (e.g. SART, Arrow Flankers, Stroop, Operation Span, Reading Spam, and Raven Advanced Progressive Matrices). The results of latent variable analysis showed that external distractions and mind wandering (i.e., "I am zoning out/my mind is wandering") are different factors (even though correlated) and individuals with less attention control are more prone to both external distractors and mind wandering. Additionally, the authors found that lapses of attention, as expressed both by external distractions or mind wandering, were associated with individual differences in working memory capacity and fluid intelligence.

A more recent study by Robison and Unsworth (2015) confirmed that external distractions and mind wandering differentially impacts performance. While both types of thoughts negatively impact performance, individuals' executive abilities (e.g., working memory capacity) were found to mediate resistance to mind wandering in a silent condition (i.e., silent study environment) and resistance to external distraction in the noise condition (i.e., noisy study environment) during a reading comprehension task.

Studies with noninvasive brain stimulation techniques have also provided insights about the causal relationship between mind wandering and attention. Axelrod, Rees, Lavidor, Bar, and Corballis (2015) found that left dorsolateral prefrontal cortex (DLPFC) stimulation with transcranial direct current stimulation (tDCS) increased mind wandering. Interestingly, instead of a deleterious effect on external task performance, the authors found a small improvement on SART.

The results of the research reported above suggest a complex interaction between different types of mind of thoughts (e.g., ED, TRI, SITUT), type of task (e.g., inhibitory control, set-shifting), cognitive abilities (e.g. working memory, fluid intelligence), and contexts (e.g., silent versus noisy environments).

In sum, there is evidence that interference of mind wandering in attention tasks can either be facilitative or detrimental (Randall, Oswald, & Beier, 2013; Smallwood & Schooler, 2006) dependent on the interaction between category of mind wandering thoughts (e.g., Stawarczyk's taxonomy) and type of attention task (e.g., Posner's ANT components). Therefore, the objective of this study is to test the relationship between different types of mind wandering thoughts and different components of the attention network system. More specifically, we aim to study if performance in the attention network test (alerting, orienting and executive) is associated with the predominant type of interfering thoughts reported online (On task - OT; Task related interference - TRI; External distractions - ED; Task-unrelated and stimulus-independent experience-SITUT).

2. Methods

2.1. Participants

The sample was constituted by 209 healthy college students (145 women, 64 men) with normal or corrected to normal vision. Their age ranged from 17 to 51 years, with a mean age of 20.94 years (SD = 4.99). All participants provided signed informed consent and the study was carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki).

2.2. Materials

2.2.1. Attention Network Test

The Attention Network Test (ANT) is a computerized task designed to assess the independent assessment of three attentional networks proposed by Michael Posner (Peterson & Posner, 2012; Posner & Petersen, 1990). During the entire procedure, participants are required to focus on a central fixation cross responding as quickly and accurately as soon as the target - a central arrow - appears either below or above a fixation cross. Participants are asked to identify if the arrow is pointing right or left by pressing the correspondent side of the mouse button. The targets are preceded by three cue conditions: a spatially informative cue announcing that the target will appear either above or below the fixation cross, a center cue or double cue condition (above and below the fixation cross) alerting that the target will be presented soon but without information about the spatial location, and, finally, a no cue condition. Additionally, the target arrow may be presented alone or accompanied by three types of flankers: other arrows pointing in the same direction of the target (congruent condition) in opposing direction of the target (incongruent condition) or no direction (neutral condition).

In the current version, ANT was programed and presented via E-Prime 2.10 (Psychology Software tools, Sharpsburg, PA, US) in desktop computers according to the following parameters: (1) a fixation cross appeared in the center of the screen all the time; (2) depending on the cue condition, a cue (none, center, double or spatial cue) appeared for 200 ms; (3) after a variable duration (300–1800 ms), the target (the center arrow) and flankers (congruent, incongruent or neutral flankers) were presented until the participant responds but with a time limit of 2000 ms (participants responses were provided by pressing either the right or the left side of the computer mouse); (4) after the response, the target and flankers were replaced by the central fixation cross (the time lapse between the onset of the target and the start time of the next trial is between 3000 and 15,000 ms).

A session consisted of five blocks: one full-feedback practice block and four experimental blocks without feedback. Each experimental block consisted of 24 trials (4 cue conditions $\times$ 2 target locations $\times$ 3 flanker conditions). Trials were presented in a random order.

The ANT allows the identification of three attention systems: alerting, orienting and executive control. Originally, the alerting effect was calculated by subtracting the mean Reaction Time (RT) of the double cue condition from the no-cue conditions. The orienting effect was calculated by subtracting the mean RT of the spatial cue conditions from the mean RT of the center cue. Finally, the executive control (i.e., conflict monitoring) effect was calculated by subtracting the mean RT of all congruent flanking conditions, from the mean RT of incongruent flanking conditions (Fan, McCandliss, Sommer, Raz, & Posner, 2002). There is still controversy regarding the independence of each attention system (Macleod et al., 2010), with evidence for cue x flanker interaction within each ANT system (McConnell & Shore, 2011). In the current study, we opted for a different method of computing the three ANT effects (alerting, orienting, and executive) that potentiates the independence of each attention system while taking into account the RT baseline (Wang et al., 2014). Before computing each ANT effect the following indexes were calculated: no-cue congruent (baseline), no-cue-incongruent (baseline + executive), center-cue congruent (baseline + alerting), center-cue incongruent (baseline + alerting + executive), spatial-cue congruent (baseline + alerting + orienting), spatial-cue incongruent (baseline + alerting + orienting + executive). The alerting effect was calculated by subtracting the RT for the center-cue congruent from the RT in the non-cue congruent condition, divided by the RT in the non-cue congruent condition. The orienting effect resulted from subtracting RT in the spatial-cue congruent from the RT in the center-cue congruent condition, divided by the RT in the center-cue congruent condition. Finally, the executive effect was computed by subtracting the RT in the non-cue incongruent from the RT in the non-cue congruent condition, divided by the non-cue congruent condition.

2.2.2. Thought Identification Task

After each ANT block, participants went through a Thought Identification Task (TIT) requiring the identification of which type of thought (derived from Stawarczyk et al., 2014′s classification) was predominant during the block by choosing one among the following four options: (1) OT - task-related and stimulus-dependent experience (i.e., on-task reports): participant was completely focused on the task (i.e., cues and direction of the arrows); (2) TRI - task related interference: participant thoughts were focused on side aspects of the task such as task duration, concerns about overall performance, rumination over a mistake, etc.; (3) ED - external distractions: participant was focused on stimuli from the current environment but not related to the experimental task, such as overall exteroceptive conditions (light, temperature) or interoceptive conditions (physical sensation, hunger, thirsty, etc.); (4) SITUT - task-unrelated and stimulus-independent experience: the participant wandered through thoughts dissociated either from the task or current exteroceptive or interoceptive conditions (past experience; future plans, etc.).

Given the nature of the ANT task (i.e., all conditions are present in each block), the thought probe encompassed the whole block and not only the preceding trial.

2.3. Procedure

After providing signed informed consent and before the experimental trials, participants underwent the following process: (1) instructions about the overall procedure; (2) instructions about the TIT (with examples and a quiz on the identification of the four types of thoughts); (3) a practice block of the ANT-TIT procedure with full feedback.

2.4. Statistical analysis

In order to carry out a repeated measures linear mixed analysis and given that most of the participants did not exhibit all categories in the TIT, data from the ANT task was arranged in stacked format. In those participants, repeated TIT results were averaged in order to estimate their performance on a given TIT category. For comparing the effect of TIT conditions in the ANT, a linear mixed model was used, with TIT categories as a fixed and also as a repeated effect and participant as a random effect. Significant effects were further analyzed with pairwise post-hoc comparisons with Bonferroni corrections.

A one-way ANOVA was used to test differences in the amount of responses across TIT conditions. Finally, we performed Spearman correlation analyses to examine the relationships between mean percentages for the TIT categories, Accuracy Scores (AS), RT and ANT systems. For all statistical tests a confidence level of $\alpha = 0.05$ was adopted.

3. Results

Before statistical analysis we excluded trials with RT <200 ms or above 1200 ms (4.17% of total data). RT, Alert, Orienting, and Executive components were computed only for correct responses. Nine participants were excluded from further analysis because of missing data necessary to compute at least one of the ANT components (Alert, Orienting or Executive).

3.1. Thought Identification Task - overall results

In the TIT, participants reported predominantly TRI thoughts (33.25%) followed by ED (24.87%), OT (22.34%) and SITUT (19.54%) thoughts. A repeated measures ANOVA showed significant difference between TIT conditions [$F(3, 556.62) = 7.41$, $p < 0.001$]. Bonferroni post-hoc tests indicated significant difference between TRI and all the others conditions: OT ($p = 0.003$), ED ($p = 0.021$) and SITUT ($p < 0.001$).

3.2. Accuracy scores, reaction times and alert, orienting and executive effects in ANT responses across TIT conditions

The AS (percentage of correct responses) and RT for each TIT condition are presented in Table 1. The linear mixed model showed significant differences in accuracy scores across TIT conditions [$F(3, 263.55) = 4.65$, $p = 0.003$]. Post-hoc pairwise comparisons confirmed the existence of significant increase in AS for OT when compared with TRI ($p = 0.008$) and with ED ($p = 0.003$). No significant differences were found in RT across TIT [$F(3, 257.97) = 0.28$, $p = 0.84$].

Next we look at each of three ANT components (alerting, orienting and executive) across all the TIT conditions (OT, TRI, ED, SITUT). Each of the effects was calculated with the procedure referred above (see Table 2). Negatives values in the alert and the orienting networks are evidence for effective alerting (i.e., RT to "no cue" was larger than RT to "central cue") and orienting effects (RT to "central cue" was larger than RT to "spatial cue") while positive values for the executive network confirm the existence of a conflict effect (RT for the "incongruent cue" was larger than RT to the "congruent cue"). (See Table 3.)

The linear mixed model did not show significant difference between TIT conditions on alerting [$F(3, 364.65) = 0.96$, $p = 0.41$], orienting [$F(3, 370.39) = 1.90$, $p = 0.12$] and executive [$F(3, 356.26) = 1.95$, $p = 0.12$] ANT networks .

Finally, Spearman correlation analysis shown in Table 3 revealed significant positive correlation between OT and accuracy performance in the ANT, contrasting with a negative correlation between ED and accuracy. No significant correlations were found between any of the TIT categories and ANT components.

4. Discussion

The objective of this study was to test the relationship between different types of thoughts and the Attention Network Test. Overall we found that: (1) while performing the ANT, participants were predominantly involved in TRI thoughts; (2) TRI and ED significantly impaired performance accuracy in the ANT when compared with OT; (3) there was no significant relationship between type of TIT thoughts and alerting, orienting and executive networks; (4) a significant positive correlation was found between OT and ANT accuracy contrasting with a negative correlation between ED and ANT accuracy.

The finding that participants were involved in TRI thoughts for about 1/3 of time deserves additional discussion. We remind that TRI refers to thoughts on side aspects of the task, such as task duration, overall performance or rumination over a mistake. It is interesting to note that, even though using a different attention task (i.e., SART), Stawarczyk et al. (2011a) found an identical predominance of TRI thoughts (30.34%). However, when compared with their study, our participants seem to be more prone to external distractions (ED - 25.37% versus 20,78%) and less focused on the task (OT - 22.03% versus 27.28%). It is possible that the length and level of difficulty of the current ANT version, when compared with Stawarczyk version of the SART, facilitates external distraction. Additionally, as shown in a recent study by Stawarczyk et al. (2014), different characteristics of the sample may also be associated with a distinct TIT profile. For example, adolescents reported significantly less OT thoughts and significantly more ED reports than young adults. Similarly, McVay, Meier, Touron, and Kane (2013) found that older adults reported more TRI and less task unrelated thoughts when compared with younger adults in several cognitive tasks (e.g., SART, go/no-go, n-back)

A second important finding is that task related interference and external distractions, but not stimulus independent and task unrelated thoughts, significantly decreased performance accuracy in the ANT. This is further confirmed by the existence of a significant negative correlation between the percentage of external distractors and accuracy, contrasting with a positive correlation between on task thoughts and ANT accuracy. Similar findings were reported in studies using other attention tasks. For example, Stawarczyk et al. (2011a) found a significant positive correlation between OT and SART accuracy and a significant negative correlation between ED, SITUT and SART accuracy. However, in the present study, SITUT, the category most typically associated with mind wandering (thoughts dissociated either from the task or current exteroceptive or interoceptive stimuli) did not interfere significantly with either reaction time or accuracy in the ANT.

Several authors suggested that mind wandering interferes with some cognitive processes, such as attention, but not with others (Kam & Handy, 2014). It is possible that the level of processing required for ANT performance is compatible with mind wandering (SITUT) but not with task related and external thought distractors. However, contrary to OT, data from our correlation analyses did not show a facilitative effect of SITUT on ANT performance accuracy. On the contrary, while not reaching statistical significance, there was still a modest but negative correlation between SITUT and accuracy.

This data confirms the importance of differentiating type of out of task thoughts in studying the relationship between though distractors and attention. While task related interference thoughts and external distractions seemed to impair attention processes, mind wandering (i.e. SITUT) was still compatible with satisfactory performance with certain attention tasks (e.g., ANT's performance in our study versus SART's performance in Stawarczyk et al., 2011b). A possible interpretation is that mind wandering, while sharing resources from executive networks, also recruits the DMN (Christoff et al., 2009). A neuroimaging study by Stawarczyk et al. (2011b) showed that SITUT is associated with higher levels of DMN recruitment, and OT with lower levels of DMN activation. Both ED and TRI are associated with intermediate levels

Table 1
Descriptive statistics for Accuracy Score (AS) and Reaction Time (RT) for each Thought Identification Task (TIT) condition, reporting mean, standard error (inside parentheses) and 95% confidence interval for the mean (inside square brackets).

TIT	AS	RT
OT	95.74(0.63); [94.50, 96.98]	628.91(6.84); [615.45, 642.36]
TRI	93.80(0.52); [92.77, 94.83]	629.47(6.16); [617.34, 641.61]
ED	93.20(0.52); [92.11, 94.29]	633.10(6.32); [620.66, 645.55]
SITUT	93.84(0.66); [92.53, 95.15]	632.32(7.09); [618.36, 646.28]

Table 2
Descriptive statistics for each ANT effect (alerting, orienting, executive) by TIT condition, mean, standard deviation (inside parentheses) and 95% confidence interval for mean (inside square brackets).

	Alerting	Orienting	Executive
OT	−0.01(0.02)	−0.05 (0.02)	0.27(0.02)
	[−0.04, 0.02]	[−0.08, −0.03]	[0.22, 0.31]
TRI	−0.04(0.01)	−0.02 (0.01)	0.26(0.02)
	[−0.06, −0.01]	[−0.05, 0.002]	[0.22, 0.29]
ED	−0.04 (0.01)	−0.01 (0.01)	0.25(0.02)
	[−0.07, −0.02]	[−0.04, 0.01]	[0.21, 0.29]
SITUT	−0.025(0.017)	−0.047(0.016)	0.19 (0.02)
	[−0.06, 0.01]	[−0.08, −0.02]	[0.15, 0.24]

Table 3
Spearman correlation analyses between TIT (OT, TRI, ED, SITUT), Accuracy Scores, Reaction Time and ANT systems (alerting, orienting, executive).

	Accuracy score	Reaction time	Alerting	Orienting	Executive
OT	0.19**	−0.12	−0.02	−0.09	0.01
	$p = 0.008$	$p = 0.084$	$p = 0.809$	$p = 204$	$p = 0.180$
TRI	0.04	−0.11	0.03	−0.01	0.12
	$p = 0.628$	$p = 0.122$	$p = 0.635$	$p = 0.886$	$p = 0.100$
ED	−0.15*	0.13	−0.07	0.06	−0.09
	$p = 0.037$	$p = 0.061$	$p = 0.36$	$p = 0.413$	$p = 0.201$
SITUT	−0.10	0.10	0.03	0.04	−0.11
	$p = 0.172$	$p = 0.164$	$p = 695$	$p = 0.554$	$p = 0.126$

* $p < 0.05$.
** $p < 001$.

of DMN recruitment. This would help explain why, in mind wandering, some degree of interference on attention tasks is expected (recruiting other brain networks that may facilitate processes such as attention recycling or avoiding boredom) while maintaining a satisfactory performance (associated the recruitment of executive processes necessary for attention processing).

According to the context regulation hypothesis, nondemanding tasks facilitate mind wandering in individuals with good executive resources (Smallwood & Schooler, 2015). However, an increase in task demand requires an increment of executive control allowing fewer resources available for mind wandering.

The study of the interactions between TIT and the attention network effects may contribute to further insights on the relationship between different types of thoughts and specific attention task demands. In the present study, neither the mixed linear model nor the correlation analysis found evidence for any significant relationship between different type of thoughts and each of the ANT network effects. It is important to note that the computation of ANT network effects, only uses RT for the correct responses as dependent measure. Eliminating the trials with incorrect responses may have affected the RT variability and, consequently, decreased the probability of finding significant ANT network effects.

This finding contrast with a previous study by Hu et al. (2012), reporting that mind wandering was negatively correlated with the orienting network. However, this study relied on the classical procedure for calculating each of the ANT effects and not the modified computation system used in our experiment (Wang et al., 2014). As discussed previously, ANT network effects as traditionally computed, fail to give a full account of the network interdependence and baseline performance. The lack of control for network interdependence tends to inflate the probability of significant interactions. Indeed, a preliminary analysis of our data using the traditional system for computing the ANT effects, showed a significant interaction between TIT and the orienting [$F(3, 382.53) = 2.89$, $p = 0.035$] and the executive networks [$F(3, 338.89) = 3.45$, $p = 0.017$]. However, there is now evidence that the computation of ANT network effects (based in RT for correct responses) may not be sensitive enough to capture the relationship between MW and ANT. Several studies have been questioning the reliability (both split-half and test-test) of the ANT. In an extensive review of the reliability of ANT, Macleod et al. (2010) alerted that, researchers looking at differential effects in ANT networks (particularly orienting and alerting), may be disappointed by the lack effects due to low reliability in network scores. While the modified ANT computation had proven to be more reliable (Wang et al., 2014) it still cannot provide pure network scores. More recently, Wang et al. (2015) suggested that a possible reason for undetected network effects is the event-related design used in ANT. In this design different networks are tested in the same run without controlling for inter-trial effects. The computation method used in the present study, while potentiating network independence it is still prone to the inter-network effects of an event-related design.

It is also possible that the inconstancy in findings results from the different thought probe methods used in Hu et al. (2012). While Hu et al. (2012) collected thoughts offline (during a SART task) correlating them to a subsequent ANT; in our study thoughts were collected online after each experimental block. This brings us to a core issue in mind wandering research - the timing/type of thought probes. Here we opted for a strategy that is, simultaneously, real time and retrospective (Gruberger, Ben-Simon, Levkovitz, Zangen, & Hendler, 2011). Thought probes were presented online during the course of the ANT experiment (real time probing). However, because we chose not to interrupt the sequence of trials within each block, the though probes were presented at the end of each ANT block (retrospective probing). As that probe inquires retrospectively about the whole block, we cannot be sure that there were no recency effects with participants biasing their reports towards the immediate trial preceding the thought probe. Future studies should clarify this by presenting pseudo-random thought probes across the ANT trials while assuring that all trial conditions are being probed. Another possibility would be to experimentally prime different types of mind wandering thoughts using task-embedded cues as suggested by McVay and Kane (2013).

Summing up, while overall AS scores seem to be sensitive to different types of interfering thoughts, the ANT design and the thought probed system used may be the responsible for the lack of significant findings on the relationship between attention networks and TIT. Future studies should further test this interaction by using a block design (each networks effect is tested in a distinct block) along with pseudo-random ITI probes across the ANT trials in each block.

A final note to comment some eventual methodological constrains present in this study. First, mind wandering was assessed by means of a single self-report task. Even though this is a direct measure for sampling real time mind wandering often used in research (Gruberger et al., 2011), other authors have opted for the use of indirect-cognitive load measures. For instances, in the study reported above Hu et al. (2012) used both a direct measure (thought probes) and an indirect cognitive load measure (START). We opted to restrict our study to a direct self-report measure due to the fact that TIT was already initially validated by Stawarczyk et al. (2011a) using the SART. However, it would be interesting, in future studies, to use both direct and indirect measures of mind wandering to test interference with attentional networks. Second, as shown by Thomson, Seli, Besner, and Smilek (2014), the relationship between MW and attention may be sensitive to temporal dynamics and a temporal analytic approach can further elucidate the relation between MWT and ANT. Finally, our research design does not allow the extrapolation of a causal relationship between TIT and ANT. Future studies should try to solve this by intentionally inducing different types of thoughts using priming strategies (McVay & Kane, 2013) or neuromodulation methods (Axelrod et al., 2015).

Concluding, the current study shows that during the ANT individuals are predominantly involved in task related interference thoughts and those thoughts, along with external distractors, tend to significantly impair their performance accuracy. On the contrary, mind wandering (i.e., stimulus independent and task unrelated thoughts) did not significantly interfere with accuracy in the ANT. No significant relationship was found between type of thoughts and alerting, orienting and executive effects in ANT. While task related interference thoughts and external distractions seemed to impair performance on the attention task, mind wandering was still compatible with a satisfactory performance in the ANT. The lack of association between ANT networks and TIT may call for the need to use more reliable methods for assessing both ANT networks and interfering thoughts. While the present study used an ANT computation system that potentiates network independence, the typical ANT event-related design seems particularly prone to inter-trial interference. Additionally, since our though probes were presented at the end of experimental block we were not able to tackle apart in real-time the interfering thoughts specifically associated with each attention network. Future studies should use an ANT block design interleaved with pseudo-random though probes.

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