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The Persistence of Thought: Evidence for a Role of Working Memory in the Maintenance of Task-Unrelated Thinking

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Abstract

Tasks that tax working memory (WM) have consistently been found to decrease mind wandering. These findings may indicate that maintenance of mind wandering requires WM resources, such that mind wandering cannot persist when WM resources are being consumed by a task. An alternative explanation for these findings, however, is that mind wandering persists without the support of WM but is nonetheless decreased during any demanding task because good task performance requires that attention be restricted from task-unrelated thought (TUT). The present study tested these two competing theories by investigating whether individuals with greater WM resources mind-wander more during an undemanding task, as would be predicted only by the theory that WM supports TUT. We found that individuals with higher WM capacity reported more TUT in undemanding tasks, which suggests that WM enables the maintenance of mind wandering.

Keywords

attention, cognition, cognitive ability, divided attention, individual differences

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The average mind wanders during half of daily life, often thinking quite spontaneously about personal priorities unrelated to the task at hand (Giambra, 1995; Killingsworth & Gilbert, 2010; Klinger & Cox, 1987–1988). Such task-unrelated thought (TUT) presents a paradox: Although the spontaneous nature of TUT suggests that it is a resource-free process, its priority-driven nature suggests that it is a resource-intensive process (Smallwood & Schooler, 2006). Indeed, priority-driven attention that maintains and manipulates information not present is classically considered to require working memory (WM) resources (Baddeley & Hitch, 1974), and WM-related brain areas are active during TUT (Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; Stawarczyk, Majerus, Maquet, & D'Argembeau, 2011). The tension between the spontaneous and goal-directed features of TUT has stimulated debate on whether mind wandering consumes WM resources.

One perspective suggests that TUT requires WM resources in order to persist. According to this view, a fragment of TUT can occur spontaneously, but elaboration of such a fragment into a train of TUT requires WM resources (Smallwood & Schooler, 2006; Teasdale, Proctor, Lloyd, & Baddeley, 1993). This theory rests on findings that TUT increases when WM resources are available, such as during tasks that place few demands on WM resources (Mason et al., 2007; Teasdale et al., 1993). Conversely, TUT decreases when WM resources are scarce, such as during tasks that do place a high demand on WM resources (Teasdale et al., 1995). Further, when TUT does occur during tasks relying on WM, performance can decline (Cheyne, Solman, Carriere, & Smilek, 2009; Smallwood et al., 2004), which suggests that maintaining TUT may divert cognitive resources needed for tasks (Smallwood, Beach, Schooler, & Handy, 2008; Teasdale et al., 1995).

An alternative perspective suggests that TUT does not require WM resources. According to this view, TUT occurs spontaneously and persists in a resource-free manner, entering awareness only when WM fails to restrict attention to a task (McVay & Kane, 2009, 2010). This theory can likewise explain why TUT decreases during WM-demanding tasks, as good task performance requires WM to unfailingly restrict attention from TUT. Perhaps the strongest evidence for this theory comes from studies of individual differences in WM

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capacity (WMC). A recent laboratory study indicated that individuals who possess greater WM resources report less TUT during a go/no-go task commonly used to study mind wandering (the Sustained Attention to Response Task, or SART; McVay & Kane, 2009).

This evidence that WM may inhibit mind wandering seemingly contradicts any role for WM in maintaining TUT. However, to conclude that WM solely inhibits TUT is premature. The low frequency of trials that refresh task goals in the SART (11% no-go trials in McVay & Kane, 2009) encourages using WM resources to proactively maintain no-go-relevant task goals in order to overcome the habitual go response reinforced by the large majority of trials. Thus, the SART places demands on WM resources that otherwise might have facilitated TUT.

In contrast, tasks with a high frequency of trials that refresh task goals (50% or 100%) relieve WM from proactively maintaining these goals (Kane & Engle, 2003). Such contexts are well suited for exploring whether greater WM resources, when free, support greater TUT. Therefore, to evaluate the two competing models of TUT, we gave participants with a range of WMCs tasks that place low demands on WM and are permissive to mind wandering. In Experiment 1, we used a visual search task (50% incongruent targets); in Experiment 2, we asked participants to press a key in time with their normal breathing (100% targets). We then examined whether participants with greater WMC mind-wandered more in these contexts placing low demands on WM, as predicted only by the theory that WM can support TUT.

Experiment 1

Method

Ninety-three members of the University of Wisconsin–Madison community received $10 per hour to complete a 30-min visual search task followed by a WMC assessment, the Automated Operation Span (OSPAN) task. The OSPAN task is known to correlate well with established WMC assessments and to predict general fluid intelligence.

As is standard, participants were excluded for scoring below 85% on OSPAN's secondary math task ($n = 9$) and for performing at chance in visual search ($n = 10$). These exclusions left 74 participants (28 males, 46 females; age range = 18–61 years, $M = 24.7$, $SD = 8.9$), with OSPAN scores from 9 through 73 ($M = 58.9$, $SD = 13$). OSPAN scores were squared to yield a more normal distribution (skew = −0.81, kurtosis = −0.46).

Visual search task. For a detailed description of this task, see Forster and Lavie (2009, Experiment 4). In brief, on each trial of the visual search task, a central ring of six letters containing the target—either *X* or *N*—was presented for 100 ms with a peripheral distractor—either *X* or *N*—to the left or right. Participants pressed a key to indicate the target's identity as quickly and accurately as possible.

Trials varied on two dimensions, perceptual load (low, high) and distractor identity (congruent, incongruent). Each block of 48 trials presented a single load condition. In low-load blocks, nontarget letters in the central ring were small *O*s, which allowed the target to be easily distinguished. In contrast, in high-load blocks, nontarget letters (*H, K, M, V, W*, and *Z*) were angular and target sized, which made the target more difficult to perceive. There were eight blocks of each load condition, ordered ABBAABBAABBAABBA. Within each block, trials varied in distractor identity (50% incongruent). Target identity and the position of targets and distractors were counterbalanced across trials.

At the end of each block came the thought probe: "What were you thinking just now?" Participants pressed "0" if they had been thinking task-related thoughts, that is, thoughts "about the task you are doing at that exact moment" (example given in the instructions: "Where's the *X*? Oh, there it is."). Conversely, participants pressed "1" for TUTs (examples given in the instructions: "I must stop by the supermarket on the way home," "I made lots of mistakes at the beginning of the experiment"). The TUT score equaled the percentage of probes on which a participant reported TUT.

OSPAN task. The OSPAN task consisted of 15 trials. On each trial, the display alternated three to seven times between single letters, which were to be memorized and reported at the end of the trial, and math equations (e.g., $1 + (3/3) = ?$), which were to be verified before a response deadline. Deadlines were customized on the basis of the participant's latencies ($M + 2.5$ SD) on 15 math-only practice items. A participant's OSPAN score equaled the total number of letters recalled in correct sequence across the 15 trials (for a detailed task description, see Unsworth, Heitz, Schrock, & Engle, 2005).

Statistical analyses. TUT was analyzed using a general linear model with a within-participants categorical factor of perceptual load, WMC (a continuous quantitative factor of mean-centered $OSPAN^2$), and their interaction. When necessary, we included the following covariates in analyses of the low-load condition: response competition (RC) from distractors (i.e., the percentage increase in RT in incongruent relative to congruent trials, as in Forster & Lavie, 2009) in trials responded to correctly, error rate, and reaction time (RT) in trials responded to correctly.

Results

To test the theory that WM resources are necessary for mind wandering, we examined whether higher WMC predicted more TUT during low-perceptual-load visual search, a context permissive to mind wandering (Forster & Lavie, 2009). A true absence of a positive correlation between WMC and TUT would contradict the theory, but in fact, higher-WMC individuals reported greater TUT during low load, $r(72) = .28$, $p = .01$ (see Fig. 1). This pattern did not result from a general bias of

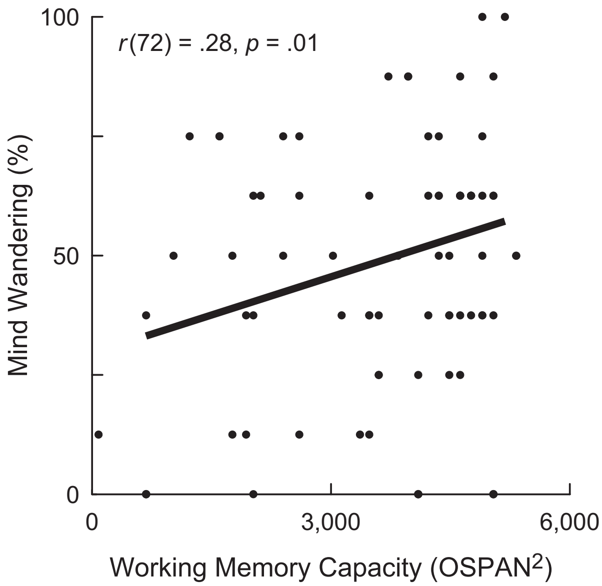

Fig. 1. Results from Experiment 1: scatter plot (with best-fitting regression line) showing the relation between working memory capacity and mind wandering during a low-perceptual-load visual search task that placed minimal demands on working memory. Mind wandering was indexed as the percentage of task blocks that ended with participants engaged in task-unrelated thought. Working memory capacity was indexed by how many letters participants could remember in sequence while simultaneously solving math problems in the Automated Operation Span (OSPAN) task.

higher-WMC individuals to report greater TUT. TUT did not depend on WMC during high-perceptual-load blocks, $r(72) = -.03$, $p = .83$, a result consistent with the significant Load × WMC interaction, $F(1, 72) = 9.3$, $p < .01$, $\eta_p^2 = .11$, and with theory that high load induces low TUT regardless of an individual's WM resources by exhausting limited perceptual capacity in task-relevant processing (Forster & Lavie, 2007, 2009; Lavie, 2005; Lavie, Hirst, de Fockert, & Viding, 2004). In sum, participants with more WM resources reported more mind wandering in an undemanding context.

Although we propose that higher-WMC participants mind-wandered more because they had more WM resources to mind-wander with, an alternative explanation is that higher-WMC participants found the low-load task easier. Indeed, task ease is known to increase TUT (McKiernan, D'Angelo, Kaufman, & Binder, 2006), and under certain conditions, WMC may facilitate visual search performance (Kane, Poole, Tuholski, & Engle, 2006; Poole & Kane, 2009; Sobel, Gerrie, Poole, & Kane, 2007). To explore this alternative explanation, we conducted planned comparisons of the correlation between WMC and performance in the low-load condition. These analyses revealed that WMC was not correlated with either error rate or RT, *p*s > .1, but higher WMC was associated with less RC due to distractors, $r(72) = .29$, $p = .01$. None of these performance measures correlated with TUT, however, *p*s > .2. Nonetheless, we reanalyzed the correlation between WMC and TUT while controlling for the three performance measures. Higher WMC still significantly predicted greater TUT, semipartial $r(69) = .25$, $p = .04$. This analysis suggests that our finding that higher-WMC participants mind-wandered more was not simply due to differences in task difficulty.

Experiment 2

In an attempt to replicate the positive association between WMC and TUT and to further rule out task difficulty as an explanation of our findings, we designed a breath-awareness task that placed minimal demands on WM and produced no detectable WMC-related performance differences. We then tested whether participants with greater WMC mind-wandered more while performing this task.

Method

Forty-five members of the University of Wisconsin–Madison community received $10 per hour to complete this experiment, which consisted of a 6-min resting baseline, a 20-min breath-counting task, a 9-min breath-awareness task, questionnaires, and the OSPAN. Only breath-awareness and OSPAN data are discussed here.

As is standard, participants were excluded for scoring below 85% on OSPAN's secondary math task ($n = 3$). This left 42 participants (17 males, 25 females; age range: 18–65 years, $M = 26.5$, $SD = 10$), with OSPAN scores from 16 through 75 ($M = 57.7$, $SD = 13.4$). OSPAN scores were squared to yield a more normal distribution (skew = −0.28, kurtosis = −0.81).

For the breath-awareness task, participants were instructed, "Be aware . . . of the movement of breath . . . breathe normally . . . [with] each exhale, press the letter *L*." Participants were also instructed to catch themselves mind wandering: "If you suddenly realize that your attention was completely off task, that's ok. Press the CONTROL button, and gently bring the attention back to your breath." For each participant, we calculated the self-caught TUT score as the number of times the participant pressed the control button.

Approximately every 90 s (range = 60–120 s), two probes appeared in succession: "Just now where was your attention?" and "How aware were you of where your attention was?" Only data for the first probe are reported here. Participants responded to this probe using a 6-point Likert scale ranging from *completely on task* to *completely off task*. The probe-caught TUT score equaled the percentage of these six probes that a participant rated 4 or higher. The instructions included the same examples of TUT that were given to participants in Experiment 1.

A subset of participants wore a respiration belt (Model MP150CE, BIOPAC, Goleta, CA), depending on its availability, as it was shared by multiple research studies.

Results

Compliance with the motor instructions was confirmed in the subset of participants who wore the respiration belt. Their mean key-press rate tracked their mean breath rate, $r(9) = .99$, $p < .01$. Across the entire sample, the mean key-press rate did not depend on WMC, $r(40) = .02$, $p = .91$.

Results were in line with the theory that WM resources are necessary for mind wandering: Higher WMC predicted more probe-caught TUT during breath awareness, $r(40) = .33$, $p = .03$ (see Fig. 2). Self-caught TUT did not correlate with WMC, $r(40) = −.05$, $p = .76$.

Discussion

This study establishes that TUT increases with increasing WMC when tasks make few demands on WM resources. These findings support the view that WM enables TUT to persist in situations permissive to mind wandering (Smallwood & Schooler, 2006; Teasdale et al., 1993). Conversely, these findings challenge claims that the sole influence of WM on TUT is inhibitory, restricting attention to the task at hand (McVay & Kane, 2009, 2010). Such a theory cannot easily explain why participants with more WM resources, though better at restricting attention, nonetheless mind-wandered more during the low-perceptual-load and breath-awareness tasks.

In light of existing data, we propose that WM enables a context-dependent moderation of TUT. In contexts that place few demands on WM and in which restricting attention to the task at hand is not prioritized, WM resources are free to maintain personal priorities and facilitate TUT. However, in WM-demanding contexts, if restricting attention to the task at hand is prioritized, WM resources can help maintain the goal to stay on task and inhibit TUT. Such a dual role of WM resources could explain both the positive correlation between WMC and TUT observed in the current study and the negative correlation between WMC and TUT observed in McVay and Kane's (2009) study of the SART. We propose, though, that even in the SART, when TUT does occur, WM resources are required to help it persist. This view is consistent with findings of increased activity in brain areas associated with WM during mind wandering in the SART (Christoff et al., 2009; Stawarczyk, Majerus, Maquet, & D'Argembeau, 2011).

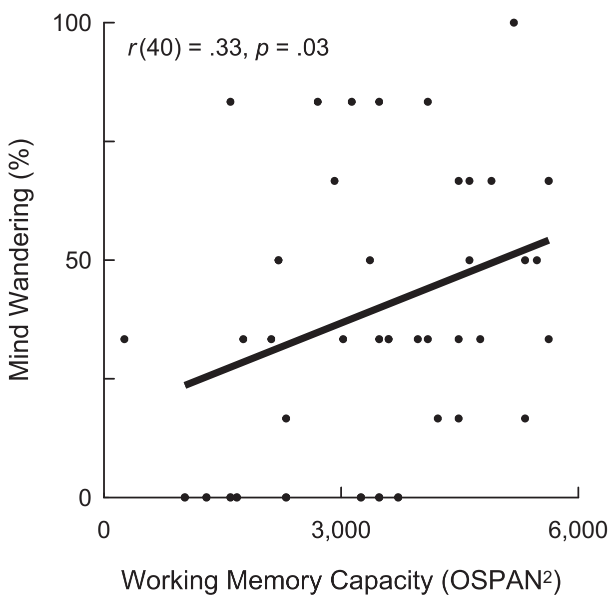

Fig. 2. Results from Experiment 2: scatter plot (with best-fitting regression line) showing the relation between working memory capacity and mind wandering during a breath-awareness task that placed minimal demands on working memory. Mind wandering was indexed as the percentage of probes to which participants responded that their thoughts were off task. Working memory capacity was indexed by how many letters participants could remember in sequence while simultaneously solving math problems in the Automated Operation Span (OSPAN) task.

The context-dependent effect of WM on mind wandering is likely to generalize beyond the laboratory. Experience sampling in daily life indicates that higher-WMC participants mind-wander more than low-WMC participants on tasks on which they report not trying to concentrate, but mind-wander less than low-WMC participants when they are concentrating (Kane et al., 2007). As our data provided concurrent measurement of TUT and behavior, we were able to verify that the positive WMC-TUT association was not simply a side effect of WMC-related differences in task performance, a finding with potential ecological validity given that TUT in the laboratory can predict TUT in life (McVay, Kane, & Kwapil, 2009).

Our data suggest that in circumstances conducive to mind wandering, WM resources can help maintain TUT. An unanswered question is how they do this. We suggest that if WM resources are maintaining personal priorities, then they will prime the elaboration of TUT fragments into coherent trains of TUT on the basis of those priorities. Supporting this view, research has shown that TUT forms more connected sequences when a context makes WM resources available than when WM resources are consumed by a task (Teasdale et al., 1993). TUT also becomes more future oriented in contexts that place minimal demands on WM (Smallwood, Nind, & O'Connor, 2009), especially for individuals with greater WMC (Baird, Smallwood, & Schooler, in press)—results in line with findings that future-oriented TUT increases when personal priorities are primed (Stawarczyk, Majerus, Maj, Van der Linden, & D'Argembeau, 2011).

However, free WM resources are not obligated to support TUT. As in the high-load condition of Experiment 1, task-relevant perceptual processing may cut off TUT—presumably at early perceptual processing stages (Lavie, 2005)—rendering it unavailable for elaboration by WM. Or task-unrelated personal priorities may be recognized as unhelpful and released from WM maintenance. Training in these and other strategies holds promise for reducing mind wandering associated with unhappiness (Killingsworth & Gilbert, 2010).

The relationship between WM and TUT merits more research. Given that half of daily life is typically spent mind wandering, opportunity abounds for exploring the way in which WM shapes and perpetuates people's internal worlds.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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References

Baddeley, A. D., & Hitch, G. J. (1974). Working memory. In G. A. Bower (Ed.), *Recent advances in learning and motivation* (pp. 47–89). New York, NY: Academic Press.

Baird, B., Smallwood, J., & Schooler, J. W. (in press). Back to the future: Autobiographical planning and the functionality of mind-wandering. *Consciousness and Cognition*.

Cheyne, A. J., 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*, 98–113. doi:10.1016/j.cognition.2008.12.009

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, USA*, *106*, 8719–8724. doi:10.1073/pnas.0900234106

Forster, S., & Lavie, N. (2007). High perceptual load makes everybody equal: Eliminating individual differences in distractibility with load. *Psychological Science*, *18*, 377–381. doi:10.1111/j.1467-9280.2007.01908.x

Forster, S., & Lavie, N. (2009). Harnessing the wandering mind: The role of perceptual load. *Cognition*, *111*, 345–355. doi:10.1016/j.cognition.2009.02.006

Giambra, L. M. (1995). A laboratory method for investigating influences on switching attention to task-unrelated imagery and thought. *Consciousness and Cognition*, *4*, 1–21. doi:10.1006/ccog.1995.1001

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: An experience-sampling study of working memory and executive control in daily life. *Psychological Science*, *18*, 614–621. doi:10.1111/j.1467-9280.2007.01948.x

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*, 47–70.

Kane, M. J., Poole, B. J., Tuholski, S. W., & Engle, R. W. (2006). Working memory capacity and the top-down control of visual search: Exploring the boundaries of "executive attention." *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *32*, 749–777. doi:10.1037/0278-7393.32.4.749

Killingsworth, M. A., & Gilbert, D. T. (2010). A wandering mind is an unhappy mind. *Science*, *330*, 932. doi:10.1126/science.1192439

Klinger, E., & Cox, W. M. (1987–1988). Dimensions of thought flow in everyday life. *Imagination, Cognition and Personality*, *7*, 105–128. doi:10.2190/7K24-G343-MTQW-115V

Lavie, N. (2005). Distracted and confused? Selective attention under load. *Trends in Cognitive Sciences*, *9*, 75–82. doi:10.1016/j.tics.2004.12.004

Lavie, N., Hirst, A., de Fockert, J. W., & Viding, E. (2004). Load theory of selective attention and cognitive control. *Journal of Experimental Psychology: General*, *133*, 339–354. doi:10.1037/0096-3445.133.3.339

Mason, M. F., Norton, M. I., Van Horn, J. D., Wegner, D. M., Grafton, S. T., & Macrae, C. N. (2007). Wandering minds: The default network and stimulus-independent thought. *Science*, *315*, 393–395. doi:10.1126/science.1131295

McKiernan, K. A., D'Angelo, B. R., Kaufman, J. N., & Binder, J. R. (2006). Interrupting the "stream of consciousness": An fMRI investigation. *NeuroImage*, *29*, 1185–1191. doi:10.1016/j.neuroimage.2005.09.030

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*, 196–204. doi:10.1037/a0014104

McVay, J. C., & Kane, M. J. (2010). Does mind wandering reflect executive function or executive failure? Comment on Smallwood and Schooler (2006) and Watkins (2008). *Psychological Bulletin*, *136*, 188–197. doi:10.1037/a0018298

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*, 857–863. doi:10.3758/PBR.16.5.857

Poole, B. J., & Kane, M. J. (2009). Working-memory capacity predicts the executive control of visual search among distractors: The influences of sustained and selective attention. *Quarterly Journal of Experimental Psychology*, *62*, 1430–1454. doi:10.1080/17470210802479329

Smallwood, J., Beach, E., Schooler, J. W., & Handy, T. C. (2008). Going AWOL in the brain: Mind wandering reduces cortical analysis of external events. *Journal of Cognitive Neuroscience*, *20*, 458–469. doi:10.1162/jocn.2008.20037

Smallwood, J., Davies, J. B., Heim, D., Finnigan, F., Sudberry, M., O'Connor, R., & Obonsawin, M. (2004). Subjective experience and the attentional lapse: Task engagement and disengagement during sustained attention. *Consciousness and Cognition*, *13*, 657–690. doi:10.1016/j.concog.2004.06.003

Smallwood, J., Nind, L., & O'Connor, R. C. (2009). When is your head at? An exploration of the factors associated with the temporal focus of the wandering mind. *Consciousness and Cognition*, *18*, 118–125. doi:10.1016/j.concog.2008.11.004

Smallwood, J., & Schooler, J. W. (2006). The restless mind. *Psychological Bulletin*, *132*, 946–958. doi:10.1037/0033-2909.132.6.946

Sobel, K. V., Gerrie, M. P., Poole, B. J., & Kane, M. J. (2007). Individual differences in working memory capacity and visual search: The roles of top-down and bottom-up processing. *Psychonomic Bulletin & Review*, *14*, 840–845.

Stawarczyk, D., Majerus, S., Maj, M., Van der Linden, M., & D'Argembeau, A. (2011). Mind-wandering: Phenomenology and function as assessed with a novel experience sampling method. *Acta Psychologica*, *136*, 370–381. doi:10.1016/j.actpsy.2011.01.002

Stawarczyk, D., Majerus, S., Maquet, P., & D'Argembeau, A. (2011). Neural correlates of ongoing conscious experience: Both task-unrelatedness and stimulus-independence are related to default network activity. *PloS ONE*, *6*(2), e16997. doi:10.1371/journal.pone.0016997

Teasdale, J. D., Dritschel, B. H., Taylor, M. J., Proctor, L., Lloyd, C. A., Nimmo-Smith, I., & Baddeley, A. D. (1995). Stimulus-independent thought depends on central executive resources. *Memory & Cognition*, *23*, 551–559.

Teasdale, J. D., Proctor, L., Lloyd, C. A., & Baddeley, A. D. (1993). Working memory and stimulus-independent thought: Effects of memory load and presentation rate. *European Journal of Cognitive Psychology*, *5*, 417–433. doi:10.1080/09541449308520128

Unsworth, N., Heitz, R. P., Schrock, J. C., & Engle, R. W. (2005). An automated version of the operation span task. *Behavior Research Methods*, *37*, 498–505.