The influence of task difficulty on thought constraint

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Abstract

As research on mind wandering has accelerated, the construct's defining features have expanded and researchers have begun to appreciate different varieties of mind wandering. Recently, Christoff and colleagues argued for the importance of investigating a hitherto neglected variety of mind wandering: unconstrained thought. To date, with only a handful of studies investigating unconstrained thought, little is known about this intriguing type of mind wandering. In the current study, we examined, for the first time, whether changes in task difficulty influence rates of constrained versus unconstrained thoughts. Participants completed either an easy (0-back) or hard (2-back) and responded to intermittently presented thought probes that gauged thought constraint throughout the task. We found that participants engaged in unconstrained thoughts significantly more frequently in the easy than in the difficult task (~20% difference), and that rates of unconstrained thoughts increased across trial blocks. Finally, we found a small-to-moderate correlation between rates of unconstrained thought and scores on a trait-level assessment of flow, or "deep effortless concentration.

Keywords: mind wandering, freely moving thoughts, task-difficulty

Over the past fifteen years, "mind wandering" has become a prominent topic of interest (e.g., Christoff, Irving, Fox, Spreng, & Andrews-Hanna, 2016; Esterman, Noonan, Rosenberg, & DeGutis, 2012; Mills, D'Mello, & Kopp, 2015; Schooler, 2004; Schooler et al., 2011; Wammes, Boucher, Seli, Cheyne, & Smilek, 2016). Whereas researchers of mind wandering

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have tended to focus their investigations on task-unrelated thoughts, more recently, Christoff and colleagues have argued for the importance of studying a different, hitherto neglected variety of mind wandering: unconstrained thought. Although the field appears to have been receptive to Christoff et al.'s argument, to date, little is known about unconstrained thought. Here, to shed light on this newly identified variety of mind wandering, we sought to determine whether, like task-unrelated thought, unconstrained thought varies as a function of task difficulty.

From a methodological perspective, it is important to understand whether (and how) we can experimentally manipulate the various dimensions of mind wandering. Task difficulty manipulations have been frequently employed in research on the task-unrelated thought variety of mind wandering, and this has been helpful since such manipulations have allowed researchers to experimentally manipulate rates of task-unrelated thought and observe the consequences. For instance, task-difficulty manipulations have been used to examine relationships between task-unrelated thoughts and creativity (Baird et al., 2012), working memory (e.g., Rummel & Boywitt, 2014), and age (e.g., McVay, Meier, Touron, & Kane, 2013). To date, however, we do not know whether rates of unconstrained thought amenable to experimental manipulations. However, in the same way that it has been useful to manipulate rates of task-unrelated thought, it will be quite useful for the field to be able to manipulate unconstrained thought.

From a theoretical perspective, it is also important to understand the influence of task difficulty on thought constraint. Indeed, doing so could allow researchers to generate a variety of testable predictions that could help to elucidate the nature of (un)constrained thoughts. From one prominent view, for instance, engaging in task-unrelated thoughts requires attentional resources (Smallwood & Schooler, 2006) and, consequently, task-difficulty effects are explained in terms of the availability of resources: difficult tasks require more attentional resources, leaving little available for task-unrelated thoughts.

Considering thought constraint from this perspective, it seems plausible that the act of constraining our thoughts is an effortful, resource-demanding process (e.g., inhibition of unwanted thoughts, sustained attention, etc.). On this view, people ought to engage in more constrained thoughts when they have enough resources to do so. Such a prediction could be empirically tested by varying task demands (and hence, the resources required to perform well on those tasks) and indexing rates of constrained thinking during task completion: Given that good performance on easy tasks (compared to hard tasks) requires relatively few resources, here we might predict a higher frequency of constrained than unconstrained thoughts during an easy versus a hard task.

Alternatively, it also seems plausible that unconstrained thought may depend on available resources, which, if true, would lead to a different set of predictions. Indeed, allowing our thoughts to "move freely" from one to the next might be a relatively controlled exploratory process–perhaps more in line with creativity or idea generation (e.g., Beaty, Benedek, Silvia, & Schacter, 2016). That is, to move from one loosely associated thought to the next might require executive control processes to generate, evaluate, and select and/or reject thoughts. Thus, from this view, unconstrained thinking could be as, or perhaps even more, resource-demanding than constrained thinking, albeit for different reasons. Furthermore, disengaging from constrained thoughts might be more resource-demanding than maintaining them. For instance, ruminative and obsessive thoughts are highly constrained, yet, to disengage from those thoughts to attend to a focal task, or to allow one's thoughts to move freely, would likely be effortful and resource-demanding. On this basis, one could predict more, or as much, unconstrained thought in a difficult versus easy task.

To the best of our knowledge, to date, no research has examined the influence of task-difficulty on (un)constrained thoughts, and it is therefore unclear whether changes in task difficulty influence rates of thought constraint and, if so, in which direction. To shed light on this issue we manipulated task difficulty via working memory load using an n-back task (e.g., Baird et al., 2012; Konishi, McLaren, Engen, & Smallwood, 2015; Smallwood et al., 2011). Participants viewed a series of numbers indicating whether a target was even or odd. In the "easy" group, participants would indicate whether the currently presented number was even or odd (0-back) and in the "hard" task, participants had to indicate whether the number presented two trials ago was even or odd (2-back). Periodically throughout the task we asked participants to indicate whether their thoughts were currently freely-moving or not (Mills, Raffaelli, Irving, Stan, & Christoff, 2018).

In addition to examining the possible influence of a task-difficulty manipulation on rates of (un)constrained thought, for exploratory purposes, we also sought to determine whether rates of unconstrained thought correlated with scores on a trait-level assessment of flow, or "deep effortless concentration" (Marty-Dugas & Smilek, 2019). The rationale for this decision follows from recent work by O'Neill et al. (under review). They had participants complete a mind wandering clock task (e.g., Seli et al., 2018) and respond to intermittently presented thought probes gauging task-relatedness and constraint. One interesting result was the relatively high proportion of probe responses that were both on task and unconstrained (see Mills et al., 2018 for a similar result using an experience-sampling procedure). This is perhaps surprising given that constraint was conceived as a measure of topical shifts in the content of one's thoughts, which is somewhat incompatible with being on task. O'Neill et al. suggested that perhaps constraint probes were not measuring topical shifts, but instead measuring the effortfulness of thoughts; where "unconstrained" thoughts are those that feel effortless. As such, unconstrained thoughts—particularly, on task unconstrained thoughts—might be related to the concept of a "flow state" (Csikszentmihalyi, 1988; Nakamura & Csikszentmihalyi, 2014) or "deep effortless concentration" (Marty-Dugas & Smilek, 2019). We, therefore, included a brief survey at the end of the experiment to determine whether rates of unconstrained thoughts correspond with reports of effortless concentration or "flow". If O'Neill et al. are correct, we would expect to observe a positive correlation between rates of on task unconstrained thoughts and scores on the flow questionnaire.

Current Study

Method

Participants

Participants were 150 individuals who completed a Human Intelligence Task (HIT) posted on the Amazon Mechanical Turk (www.mturk.com). All participants provided informed consent and were treated in accordance with guidelines approved by the ethics committee at Duke University. Participants were paid $2.00 (U.S. dollars) for completing the HIT, which lasted approximately 20 minutes.

Materials

N-back. Instructions and stimuli were displayed in the center of the screen. Stimuli were presented in a 72px black font on an off-white background (#f4f4f4). Participants completed 20 practice n-back trials, 188 experimental n-back trials, and 12 thought probe trials. Stimuli consisted of the numbers 1 through 8 (4 even and 4 odd). Non-target stimuli were presented in black font and target stimuli were presented in red font. Target stimuli were randomly inserted between the second and 8th trial of each block of 8 n-back trials.

In both the 0-back and 2-back conditions, participants were instructed to withhold responses to black-colored digits and only respond when a red target appeared. In the 0-back condition, participants indicated whether the red digit was even or odd. In the 2-back condition, participants were presented a red question mark and indicated whether the digit presented two trials ago was even or odd.

Thought probes. Participants were presented 12 thought probes throughout the experiment. Thought probes were randomly inserted once every 15 n-back trials, between trials 5 and 11 (on average, every 60 seconds). Thought probes consisted of a single question gauging thought constraint ("The thoughts I was experiencing were freely moving: YES/NO"). At the beginning of the experiment, participants received the following instructions:

> Your thoughts are considered "freely moving" when they seem to wander around on their own, flowing from one thing to the other, when there is no overarching purpose or direction to them, when it seems like your thoughts could land on pretty much anything, and when images and memories easily come to mind
>
> You will be presented the prompt: "The thoughts I was experiencing were moving freely:" and respond by clicking (a) YES (b) NO

Flow state questionnaire. At the end of the experiment, participants completed a short questionnaire about their thoughts during the task. They reported their response on a 5-point likert scale (strongly disagree, disagree, neutral, agree, strongly agree):

> Below are five questions that ask about your state of mind while you completed the n-back activity. Please select the response option that most accurately reflects your mental state while you completed this activity.
>
> 1. I was able to focus on the task without straining to pay attention
> 2. I seemed to reach a level of deep focus almost effortlessly
> 3. I got in the zone and didn't have to force myself to concentrate on the task
> 4. I easily paid deep attention to the task for extended periods of time.

Procedure

Participants were first given a general overview of the tasks and instructions on how to respond. In the 0-back group, participants were instructed to respond to the red digits (and not the black digits), indicating whether the digit was even or odd using the keyboard

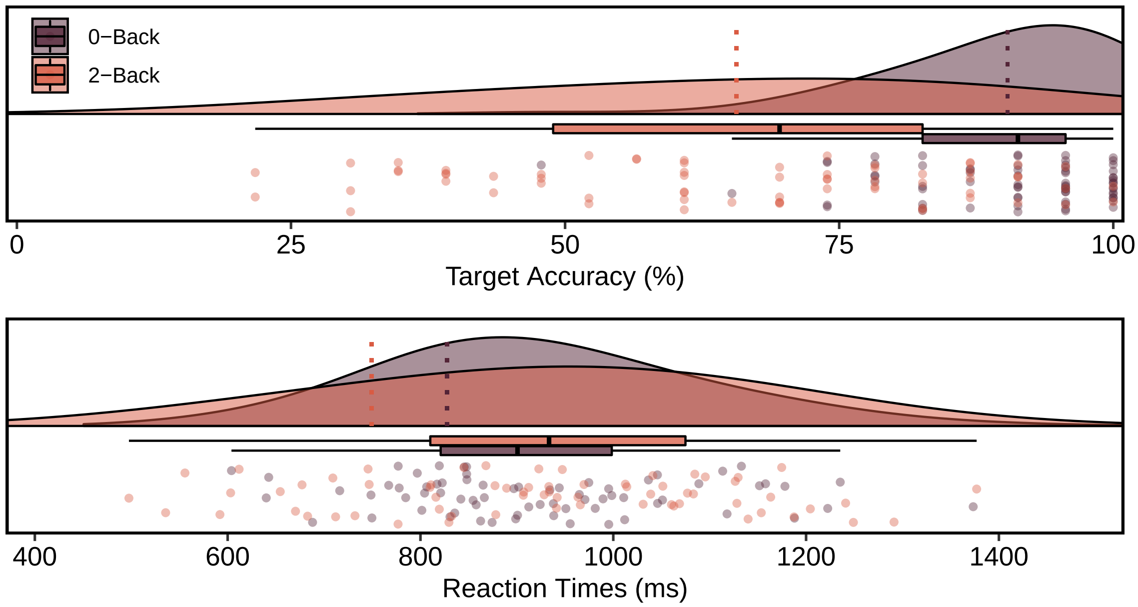

Figure 1. N-back task performance in Experiment 1. Target accuracy (%) and reaction times (ms) for correct responses are plotted across n-back groups. Dashed lines represent group means in the target accuracy plot and estimated mu for the reaction time plot.

("e" for even, "o" for odd). In the 2-back group, participants were instructed to respond to the red question mark ("?") and indicate whether the digit presented two trials ago was even or odd using the keyboard. Participants had to complete a block of 20 practice trials with 4 targets and respond correctly to 3/4 of the targets before moving on to the experimental trials. If not, they repeated the practice trials. After completing the n-back task, participants completed the flow questionnaire.

Data analysis and manuscript preparation

This manuscript was prepared using R (R Core Team, 2019). A variety of notable R packages were used for data analysis (Bates, Mächler, Bolker, & Walker, 2015; Fox & Weisberg, 2019; Kuznetsova, Brockhoff, & Christensen, 2017; Singmann, Bolker, Westfall, Aust, & Ben-Shachar, 2019; Wickham et al., 2019; Wickham & Henry, 2019), data visualization (Fox & Weisberg, 2018; Kassambara, 2019; Wickham, 2016; Wilke, 2019), and general manuscript preparation (Aust & Barth, 2018). All data, analysis and manuscript preparation code can be found at osf.io/????.

Results

Prior to all analyses, we removed any participants with a d' less than 0. This removed a total of 15 participants.

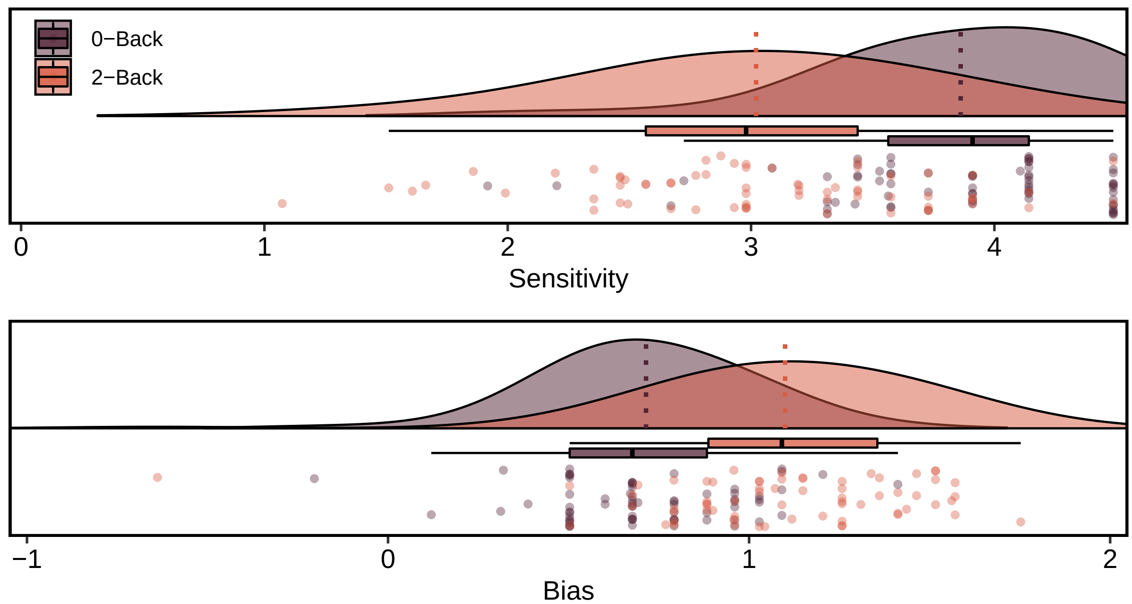

Figure 2. N-back task performance in Experiment 1. Distributions of sensitivity (d') and bias (c) estimates across n-back groups.

N-Back performance

First, we compared target and non-target accuracy between n-back groups (see **??**). Accuracy scores for targets were significantly better in the 0-back versus 2-back groups, $\Delta M = 24.75$, 95% CI [19.17, 30.32], $t(133) = 8.78$, $p < .001$, $d = 1.51$, 95% CI [1.12, 1.9]. However, there was no evidence for a difference in non-target accuracy between groups, $\Delta M = 0.33$, 95% CI [−1.19, 1.85], $t(133) = 0.43$, $p = .669$, $d = 0.07$, 95% CI [−0.27, 0.41]. Next, we compared sensitivity (d') and bias (c) estimates across n-back groups (see **??**). We found that sensitivity was significantly higher in the 0-back versus n-back groups, $\Delta M = 0.84$, 95% CI [0.63, 1.06], $t(133) = 7.77$, $p < .001$, $d = 1.34$, 95% CI [0.96, 1.71], and bias was significantly lower in the 0-back versus 2-back group, $\Delta M = -0.39$, 95% CI [−0.49, −0.28], $t(133) = -7.14$, $p < .001$, $d = -1.23$, 95% CI [−1.6, −0.86].

Finally, we compared reaction times for accurate target responses across groups (see Figure 1). We found no significant differences between group reaction time means, $\Delta M = -6.27$, 95% CI [−66.57, 54.02], $t(133) = -0.21$, $p = .837$, $d = -0.04$, 95% CI [−0.38, 0.31]. In addition to the standard reaction time analysis, we also performed an ex-Gaussian analysis. This approach estimates three parameters that correspond to different characteristics of the reaction time distribution: mu, sigma, and tau. Mu corresponds to the mean of the normal component of the distribution, sigma, to the standard deviation of the normal component of the distribution, and tau to the tail of the ex-Gaussian distribution (i.e., the mean and standard deviation of the exponential component of the distribution). These parameters can provide additional information regarding changes in reaction times that the estimated mean cannot provide.

Contrasting the 0-back and 2-back groups, we observed significant differences in the

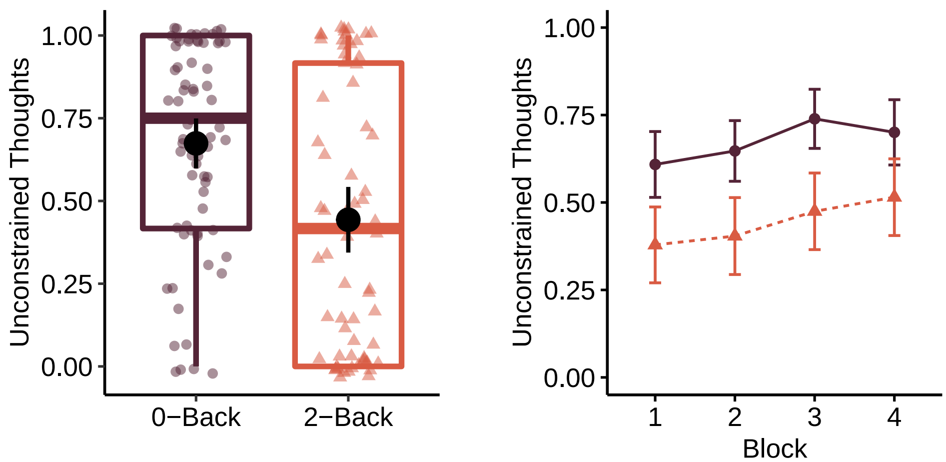

Figure 3. Results of the thought-probe trials from Experiment 1 plotted as a function of n-back task. Error bars represent 95% confidence intervals around the mean.

mu ($\Delta M = 78.26$, 95% CI [19.02, 137.50], $t(133) = 2.61$, $p = .010$, $d = 0.45$, 95% CI [0.11, 0.79]); sigma ($\Delta M = -73.81$, 95% CI [-92.15, -55.47], $t(133) = -7.96$, $p < .001$, $d = -1.37$, 95% CI [-1.75, -0.99]); and tau parameters ($\Delta M = -84.53$, 95% CI [-101.61, -67.45], $t(133) = -9.79$, $p < .001$, $d = -1.69$, 95% CI [-2.08, -1.29]). Counter-intuitively, we found participants in the 2-back responded faster in terms of mu, but were more variable (sigma), with a particularly longer reaction time tail (tau). The difference in mu likely reflects the foreknowledge of the correct response in the 2-back group. That is, if participants were accurately tracking whether the digit presented two trials ago was even or odd, they will know the correct response prior to the target presentation, likely speeding reaction times on those trials. Differences in sigma and tau, in contrast, likely reflect performance when participants in the 2-back condition were uncertain of the correct response due to the increase in difficulty.

Thought probes

To determine whether rates of unconstrained thoughts were influenced by task difficulty, we compared rates of self-reported thought constraint across n-back groups (see **??**). Here, we observed significantly higher rates of freely moving thoughts in the 0-back as compared to the 2-back group, $\Delta M = 0.23$, 95% CI [0.11, 0.35], $t(133) = 3.72$, $p < .001$, $d = 0.64$, 95% CI [0.29, 0.99].

Additionally, we examined how rates of unconstrained thoughts change across the experiment using a mixed ANOVA with n-back task (0-Back versus 2-Back) as the between-subjects factor and trial block (1, 2, 3, and 4) as the within-subjects factor. The results of this analysis show a significant main effect of n-back task, $F(1, 133) = 13.83$, $MSE = 0.52$, $p < .001$, $\hat{\eta}^2_p = .094$, 90% CI [0.03, 0.18], and a significant effect of block, $F(2.63, 350.15) = 8.87$, $MSE = 0.06$, $p < .001$, $\hat{\eta}^2_p = .062$, 90% CI [0.02, 0.1], but no significant interaction between n-back task and block, $F(2.63, 350.15) = 0.74$, $MSE = 0.06$, $p = .513$, $\hat{\eta}^2_p = .006$, 90% CI [0, 0.02].

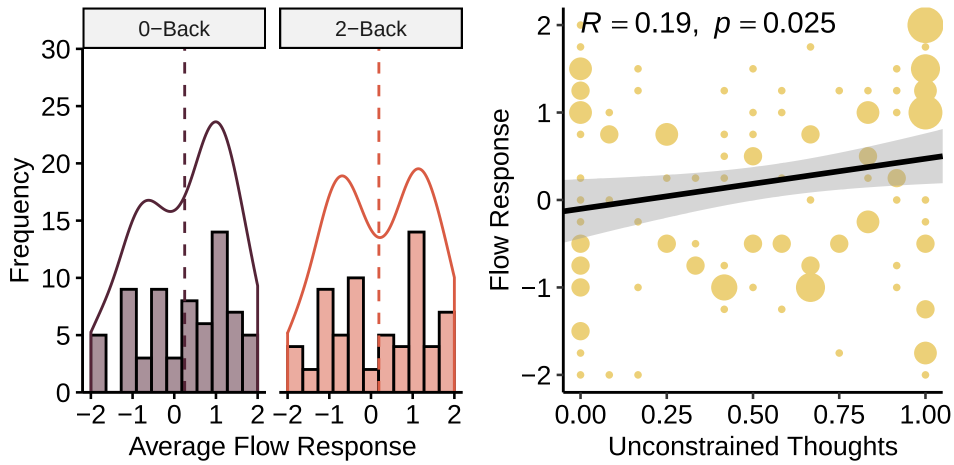

Figure 4. Results of the flow questionnaire from Experiment 1. Average flow responses are plotted as a function of response frequency (left) and proportion of unconstrained thoughts (right).

Flow questionnaire

We found no differences between mean flow state responses across n-back groups, $\Delta M = 0.06$, 95% CI $[-0.32, 0.44]$, $t(133) = 0.31$, $p = .755$, $d = 0.05$, 95% CI $[-0.29, 0.39]$ (see **??**). Given the non-normal distribution of responses, however, we also tested for difference using the Kruskal-Wallis Test, and found no differences between response distributions, $\chi^2(1) = 0.06$, $p = .806$.

Additionally, we were interested in how the response in the flow state questionnaire compared to the reported rates of unconstrained thoughts (see **??**). Using a Pearson correlation found a significant, small to moderate, positive correlation, $r = .19$, 95% CI $[.02, .35]$, $t(133) = 2.26$, $p = .025$.

Discussion

In the current study, we examined the influence of task difficulty on thought constraint. To manipulate difficulty, we used two versions of the n-back task and periodically presented thought probes to determine whether participants' current thoughts were constrained or unconstrained. Results across performance measures confirm that the 2-back was significantly more difficult than the 0-back. More importantly, however, we found that participants engaged in significantly higher rates of unconstrained thought in the easy versus the hard task and, for both groups, the proportion of unconstrained thoughts increased across trial blocks. This preliminary evidence suggests that unconstrained thought is indeed resource-dependent. That is, when the focal task requires less attentional resources, people tend to engage in more unconstrained thought. This suggests that such task difficulty could be a useful manipulation for studying (un)constrained thoughts. Additionally, it seems that when the primary task requires less controlled processing, and when participants have more executive resources available, they tend to engage in more unconstrained thought. This suggests the possibility that unconstrained thought is resource dependent.

We also compared self-reported rates of unconstrained thoughts with responses to the flow state questionnaire. Here, we found only a small-to-moderate correlation between measures. In any case, finding some correspondence between rates of unconstrained thoughts and flow is heartening. Indeed, on the surface, it seems sensible that these very similar constructs should overlap. However, the relatively low correspondence suggests that the constraint dimension of mind wandering is indeed distinct from the concept of a "flow state" (Csikszentmihalyi, 1988; Marty-Dugas & Smilek, 2019; Nakamura & Csikszentmihalyi, 2014). O'Neill et al. (2019) suggested that the constraint thought probes might not be measuring topical shifts in thought content, as others have posited (Mills et al., 2018), but instead a feeling of effort. The relatively low correspondence between the flow state questionnaire and rates of unconstrained thought, however, makes this unlikely.

Our result is somewhat at odds with O'Neill et al. (2019). They found that the frequency of unconstrained thoughts did not vary with changes in task demands. Specifically, they found intentional mind wandering varied according to task demands, but unconstrained mind wandering largely remained the same regardless of task demands. The difference in timescales however, could help explain this discrepancy. In their study, they manipulated task demands within 20-second trial windows–with the assumption that task demands are higher closer to the start/end of the trial. In our study we manipulated the overall level of task demands across groups. As such, it may be the case the rates of unconstrained thoughts fluctuate at a slower rate than the other dimensions of mind wandering. Indeed, the overall percentage of unconstrained thoughts in O'Neill et al. (2019) was 72%, closely resembling the 68% we observed in the easy task. This would suggest that overall task-wide difficulty was quite low in the clock task. The differences in fluctuation timescales would also reaffirm the claim that constraint is a theoretically important and dissociable dimension of mind wandering.

One noteworthy limitation is that we only measured general rates of (un)constrained thoughts and did not measure the task-relatedness of those thoughts. Although the prior work suggests that these two dimensions are dissociable (e.g., Mills et al., 2018, O'Neill et al., under review), it is possible that on- versus off-task thought constraint is differentially influenced by task difficulty. For instance, Mills et al. (2018) found off-task thoughts were more likely to be unconstrained than constrained and on-task thoughts more likely to be constrained than unconstrained. So it is possible that the task difficulty manipulation, rather than influencing constraint, could simply be increasing the overall rate of off-task thoughts, which in turn, results in higher overall proportions of unconstrained thought.

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