The influence of task difficulty on the freely-moving thoughts dimension of mind wandering

Nicholaus P. Brosowsky[1], Anna P. Smith[1], Jonathan Schooler[2], & Paul Seli[1]

[1] Department of Psychology and Neuroscience, Duke University, Durham, NC 27708, USA
[2] Department of Psychological and Brain Sciences, University of California Santa Barbara, Santa Barbara, CA, USA

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Mind wandering, from a family-resemblances perspective, is a complex, multi-dimensional phenomenon best described as a natural category with graded membership. Three dimensions of prototypicality are often endorsed: *intentionality*, *task relatedness*, and the most recent addition, the *freely-moving thoughts dimension* (constrained versus unconstrained thoughts). In the current study, we examined whether changes in task-difficulty would influence the rate of self-reported freely-moving thoughts. Prior work has shown that mind wandering varies with task-difficulty and has been interpreted as an executive resource trade-off. That is, participants tend to engage in mind wandering when there are free resources to do so. Here, we had participants complete either an easy (0-back) or hard (2-back) task and intermittently presented thought probes to gauge how constrained their thoughts were throughout the task. We found that participants engaged in freely-moving thoughts significantly more in the easy task (20% difference) and increased in freely-moving thoughts over the experiment. These results suggests, that when given the resources to do so, participants will engage in more freely-moving thoughts.

Keywords: mind wandering, freely moving thoughts, task-difficulty
Word count: X

Over the last decade, "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). However, the recent surge of interest has brought with it some uncertainty about how best to define mind wandering as a construct. Historically, mind wandering has been treated as a unitary construct (e.g., as task-unrelated thought). These exclusive definitions however, have had difficulty capturing the rich phenomology of mind wandering (Seli, Kane, Smallwood, et al., 2018). More recently, it has been posited that mind wandering is a graded, natural category and as such, should be considered from a family-resemblance perspective (Seli, Kane, Metzinger, et al., 2018; Seli, Kane, Smallwood, et al., 2018).

Under the family-resemblance view, mind wandering is a graded, heterogeneous construct where prototypical exemplars of mind wandering are characterized by several overlapping, but ultimately dissociable, dimensions or features. Whereas highly prototypical members are those that share many overlapping features with other exemplars, low-prototypical members share very few overlapping features. For instance, the most frequently endorsed dimensions of mind wandering are *intentionality* and *task-relatedness*. Intentionality refers to the extent that the thoughts we engage in are intentional or unintentional–Highly-prototypical mind wandering tends to include unintentional streams of thought (Giambra, 1995; Seli et al., 2016a, 2016b). Task-relatedness refers to the extent that our thoughts are related to the current, focal task–highly-prototypical mind wandering tends to include thoughts that are task-unrelated (Barron, Riby, Greer, & Smallwood, 2011; Smallwood & Schooler, 2006).

More recently however, a third dimension has been proposed. This dimension characterizes mind wandering on the basis of whether thoughts are constrained or unconstrained (i.e., freely moving from thought-to-thought; Christoff et al., 2016; Mills, Raffaelli, Irving, Stan, & Christoff, 2018). For instance, unconstrained mind wandering could lead you from thinking about which wine you should you buy for dinner, to a memory of a trip to Italy, to rehashing an argument you had with a co-worker earlier in the day. Although, the string of thoughts might be loosely associated or thematically related, they tend to arise relatively freely with little constraint in their direction. To contrast, constrained mind wandering might consist of thoughts about a particularly challenging problem at work, considering alternative routes to solving the problem, visualizing yourself solving the problem,and/or considering the cir-

Correspondence concerning this article should be addressed to Nicholaus P. Brosowsky, Duke University, 417 Chapel Dr, Durham, NC 27708, USA. E-mail: nicholaus.brosowsky@duke.edu

cumstances when problem might arise again; In other words, highly constrained to a single topic or stream of thoughts.

Importantly, recent work has shown that the freely-moving thoughts dimension is dissociable from task-relatedness and intentionality. Mills, Raffaelli, Irving, Stan, and Christoff (2018) examined the relationship between the task-relatedness and freely moving thoughts dimensions using experience-sampling. In their study, they had participants respond to thought probes presented via their cellphones intermittently over a ten-day period. Among the questions asked, was a question to gauge the task-relatedness of their thoughts ("Were you thinking about something other than what you were doing?") and a question to gauge how constrained their thoughts were ("Was your mind moving about freely?"). The goal of the study was to determine whether the freely moving thought dimension is redundant with task-relatedness. It is possible, for instance, that off-task thoughts are inherently freely moving and on-task thoughts are inherently constrained. If so, you would expect good correspondence between off/on-task reports and freely moving/constrained reports. However, what they found was that only 28% of reported thoughts were on-task and constrained, and only 29% of thoughts were off-task and freely moving. This result suggests that task-relatedness and freely moving thoughts are indeed dissociable dimensions of mind wandering.

O'Neill, Smith, Smilek, and Seli (2019) examined the relationship between intentionality and freely moving thoughts. In their study, they used the mind wandering clock task (Seli Carriere) where participants view an analogue clock and press a button every time the clock is in the 12 o'clock position. Intermittently, participants were presented thought probes to assess their current thoughts along the three dimensions: task-relatedness, intentionality, and freely-moving thoughts. O'Neill et. al. replicated prior work showiing that participants engage in less intentional mind wandering the closer the clock-hand is to the critical, to-be-responded-to event. The critical question however, was whether self-reports of freely moving thoughts varied in the same manner. Their results showed that, unlike intentionality, participants engaged in the same rate of freely-moving thoughts regardless of when the probe was presented. This result suggests that the freely-moving thoughts dimension of mind wandering can also be dissociated from the intentionality dimension.

Together, this work demonstrates that freely moving thought is a theoretically important, and dissociable, dimension of mind wandering. However, most of the prior work on mind wandering has focused on the task-relatedness dimension and there is little known about this relatively new dimension. One common finding, for example, is that mind wandering generally decreases as task difficulty increases (e.g., Smallwood et al., 2013; Thomson, Besner, & Smilek, 2013). This is often interpreted as an executive resource trade-off between performing the focal task and engaging in off-task thoughts (Smallwood & Schooler, 2006). For instance, performance tends to suffer when people are engaged in task-unrelated thoughts suggestive of a resource-dependency (e.g., McVay & Kane, 2009; Schooler, 2004; Smallwood et al., 2004; Smallwood, McSpadden, & Schooler, 2007; Smallwood, Obonsawin, & Heim, 2003). Similarly, participants tend to report more mind wandering as they gain more practice with the primary task (Brosowsky, Smilek, & Seli, 2019; Mason et al., 2007; Teasdale et al., 1995). This is thought to reflect automatization of the primary task through practice reducing the resource demands of the primary task and making more resources available for mind wandering (Smallwood & Schooler, 2006). When contrasting task-relatedness and intentionality, Seli et al. (2016b) found differential effects of task difficulty. Specifically, they found intentional mind wandering decreased as difficulty increased, but unintentional mind wandering increased.

In the current, we examined how (or whether) the rate of freely moving thoughts change under different task demands. From a methodological perspective, it is important to know to what degree the freely moving thoughts dimension of mind wandering can be manipulated experimentally. Many researchers are interested in the function and consequences of mind wandering (see Mooneyham & Schooler, 2013, for a review). It is not unreasonable to expect that those consequences differ according to how mind wandering is characterized along the three dimensions (Smallwood & Andrews-Hanna, 2013).

However, the degree to which freely moving thoughts change as a function of task demands is also theoretically important. Namely because it is not clear whether the degree of freely moving thought *should* vary with task-difficulty, or in which direction. The influence of task difficulty, as noted earlier, is often characterized as influencing resource-allocation: in an easy task participants have more resources to allocate towards mind wandering, and tend to do so. The primary question is: how does the limitation of resources influence how constrained or freely moving our thoughts are? Or to put it another way: when there are available resources, do people prioritize one type of thinking over another?

Methods

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.

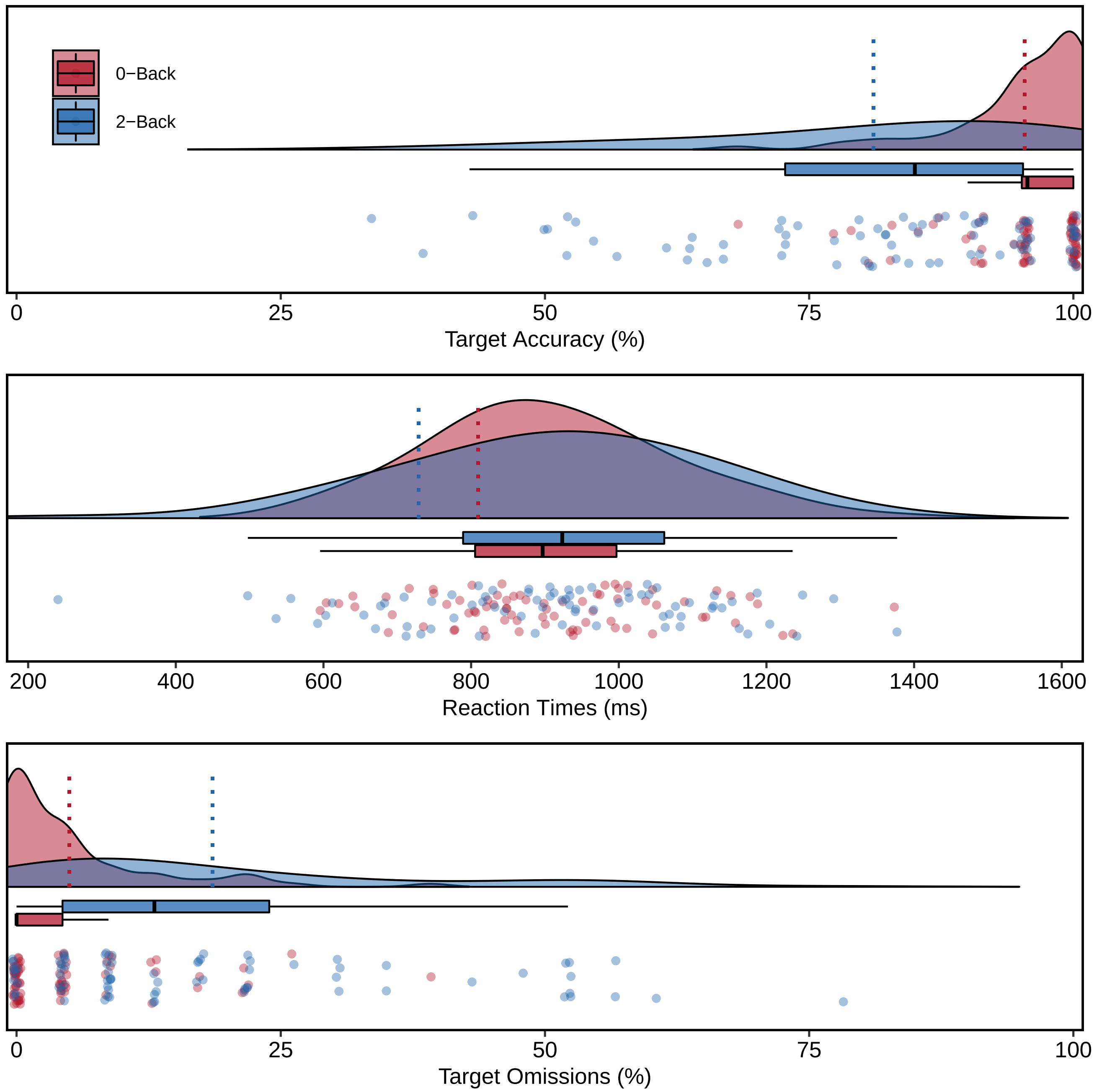

Figure 1. Results from the n-back tasks showing target accuracy (top), reaction times (middle), and target omissions (bottom). Dashed lines represent group means, except in the case of reaction times, where the dashed lines represent the estimated /textit{mu} for each group.

Materials

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. 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. Thought probes were randomly inserted once every 15 n-back trials, between trials 5 and 11 (on average, every 60 seconds).

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 ("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.

Results

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/????.

N-Back performance

Target accuracy and frequency of omissions. First, we compared target accuracy and the frequency of target omissions between n-back groups. Accuracy scores for targets were significantly better in the 0-back versus 2-back groups, $\Delta M = 14.31$, 95% CI [10.20, 18.42], $t(148) = 6.88$, $p < .001$, $d = 1.12$, 95% CI [0.78, 1.47]. Similarly, participants in the 0-back group had significantly fewer target omissions, $\Delta M = -13.57$, 95% CI [−18.13, −9.00], $t(148) = -5.88$, $p < .001$, $d = -0.96$, 95% CI [−1.3, −0.62].

Reaction times. Second, we compared reaction times for accurate target responses across groups. We found no significant differences between group reaction time means, $\Delta M = -6.52$, 95% CI [−66.09, 53.05], $t(148) = -0.22$, $p = .829$, $d = -0.04$, 95% CI [−0.36, 0.29]. In addition however, 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 *mu* ($\Delta M = 80.06$, 95% CI [19.50, 140.61], $t(148) = 2.61$, $p = .010$, $d = 0.43$, 95% CI [0.1, 0.75]), *sigma* ($\Delta M = -76.76$, 95% CI [−94.06, −59.47], $t(148) = -8.77$, $p < .001$, $d = -1.43$, 95% CI [−1.79, −1.07]), and *tau* parameters ($\Delta M = -86.58$, 95% CI [−103.47, −69.68], $t(148) = -10.13$, $p < .001$, $d = -1.65$, 95% CI [−2.03, −1.28]). Counter-intuitively, we found participants in the 2-back responded faster on average, but were more variable, with a particularly longer reaction time tail. The difference in *mu* likely reflects the foreknowledge of the correct response in the 2-back group. That is, participants should know the correct response prior to the target onset, likely speeding reaction times on those trials. Differences in *sigma* and *tau*, in contrast, likely reflect the relative increase in difficulty between the tasks[1].

Freely moving thoughts

Next, we compared rates of freely moving thoughts across n-back groups. Here, we observed significantly higher rates of freely moving thoughts in the 0-back as compared to the 2-back group, $\Delta M = 0.22$, 95% CI [0.10, 0.34], $t(148) = 3.71$, $p < .001$, $d = 0.61$, 95% CI [0.28, 0.94]. We further examined how rates of freely moving 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, $F(1, 148) = 13.75$, $MSE = 0.53$, $p < .001$, $\hat{\eta}^2_p = .085$, 90% CI [0.03, 0.16], and a significant effect of block, $F(2.63, 389.57) = 10.59$, $MSE = 0.06$, $p < .001$, $\hat{\eta}^2_p = .067$, 90% CI [0.03, 0.11], but no significant interaction between n-back task and block, $F(2.63, 389.57) = 0.96$,

[1]Removing the conspicuously low reaction time has no bearing on the significance or direction of the reported effects.

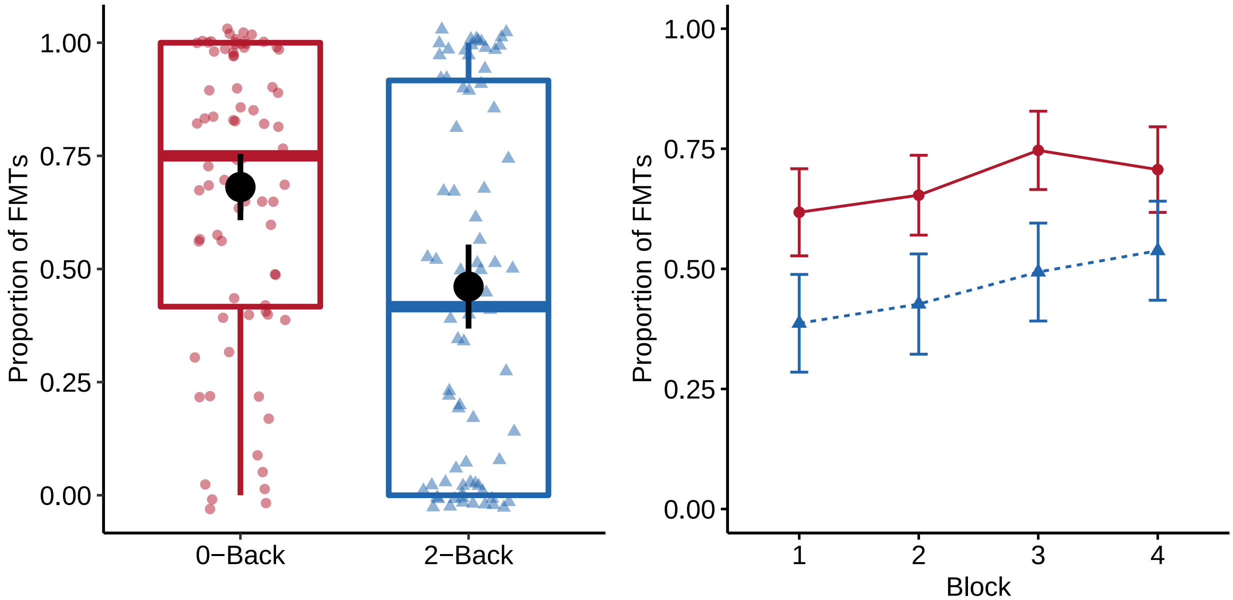

Figure 2. Results of the throught-probe trials as a function of n-back task (left) and plotted across trial blocks (right). Error bars represent 95% confidence intervals around the mean.

MSE = 0.06, p = .402, $\hat{\eta}^2_p$ = .006, 90% CI [0, 0.02]. Finally, we tested for a linear contrast, confirming that rates of freely moving thoughts increased across trial blocks similarly for both groups, $F(1, 447)$ = 28.70, MSE = 0.05, p < .001, $\hat{\eta}^2_p$ = .060, 90% CI [0.03, 0.1].

Flow questionnaire

Finally, we compared responses from the flow questionnaire and found no differences between mean responses,ΔM = 0.04, 95% CI [−0.32, 0.39], $t(148)$ = 0.20, p = .840, d = 0.03, 95% CI [−0.29, 0.36]. Given the non-normal distribution of responses we also tested for difference using the Kruskal-Wallis Test, and found no differences between response distributions, $Kruskal - Wallis\chi^2(1)$ = 0.01, p = .922.

We were also interested in how the response in the flow questionnaire compared to the reported rates of freely-moving thoughts. Using a Pearson correlation we found a significant, small to moderate, positive correlation between average flow responses and reported rates of freely-moving thoughts, r = .19, 95% CI [.03, .34], $t(148)$ = 2.37, p = .019.

Effects of outlier removal procedures

In the above results, we retained all the participant data to give us a general overview of participant performance. However, it is typical for researchers to remove participants who fail to meet some performance criteria (). To determine the influence of outlier removal procedures on our results, we re-ran the analyses using two additional performance criteria. In the first, we removed participants who had either (a) more than 50% target errors, (b) more than 48% target omissions (11/23 targets), or (c) erroneously responded to more than 50% of non-target stimuli. This outlier removal procedure removed 7 participants from the 0-back group and 12 participants from the 2-back group. Results of the n-back performance analysis remained the same as the original analysis (for the complete results, see Appendix A). Similarly, the 0-back group reported higher rates of freely moving thoughts than the 2-back group, ΔM = 0.22, 95% CI [0.10, 0.35], $t(120)$ = 3.46, p = .001, d = 0.63, 95% CI [0.26, 1]

For the second cut-off criteria, we removed participants who had either (a) more than 25% target errors, (b) more than 22% target omissions (5/23 targets), or (c) erroneously responded to more than 25% of non-targets. This procedure removed 8 participants from the 0-back group and 39 participants from the 2-back group. Again, we find the n-back performance results to be the same as previous analyses (for complete results, see Appendix A), and again, we observe a significant difference in rates of freely moving thoughts across groups, ΔM = 0.21, 95% CI [0.07, 0.35], $t(101)$ = 2.90, p = .005, d = 0.6, 95% CI [0.18, 1.02].

Differences between groups, therefore, appear to be robust across outlier removal procedures. However, we note that these outlier procedures removed a considerable amount of data—particularly from the 2-back group. We would suggest that researchers intending to use a performance criterion for outlier removal should plan accordingly and increase their sample size to compensate for the loss of participant data.

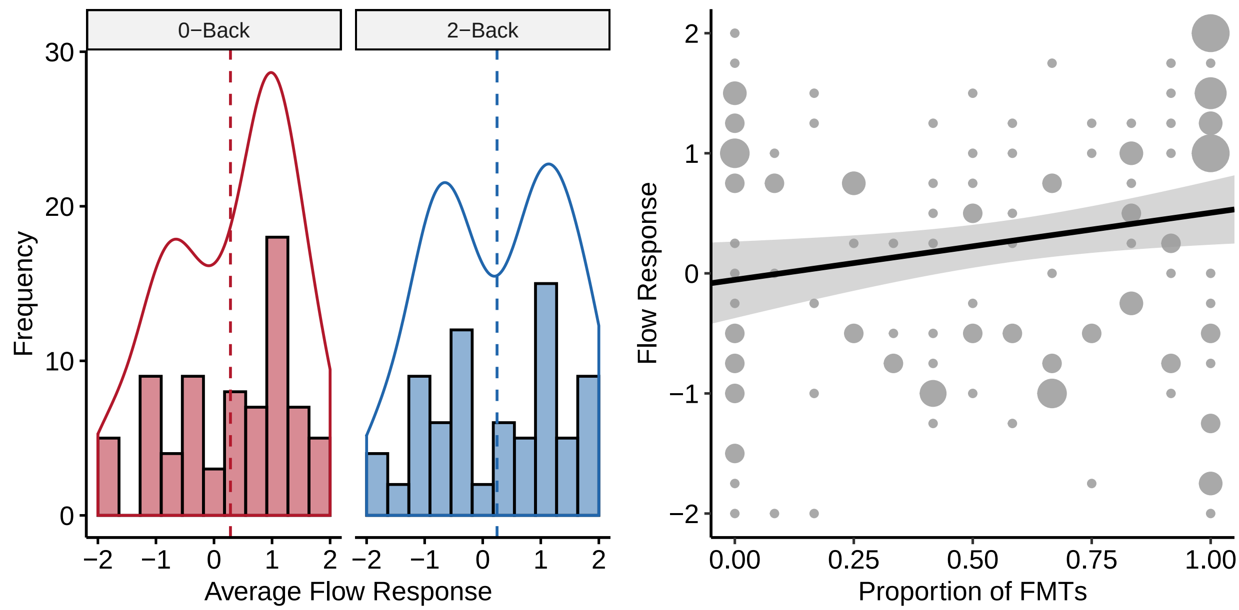

Figure 3. Results of the flow questionnaire. Average responses are plotted as a function of n-back task (left) and freely-moving thoughts (right).

Discussion

In the present study, we examined the influence of task difficulty on constrained versus unconstrained (or freely moving) thoughts; a relatively new, but theoretically important dimension of mind wandering (). In studies that manipulate task difficulty, a common finding is that people report more mind wandering when completing an easy versus hard task. This observation has been explained as a resource trade-off: under easier task demands there are more resources available to allocate towards mind wandering. The primary question of interest in the current study, was whether participants would prioritize constrained or unconstrained thoughts when more resources were available. We found that participants engaged in a significantly higher proportion of unconstrained thoughts in the easy task versus the hard task, suggesting that participants, when given the resources to do so, would more often engage in thoughts that were freely moving. Additionally, we found a linear increase in the proportion of freely moving thoughts across the task. This also tracks well with previous work and again, suggests as more resources become available (through the automatization of the primary task), participants devoted more time to thoughts that were freely moving. Finally, we found only a small to moderate correlation between between self-reports of freely-moving thoughts and responses on the flow questionnaire. This suggests that the freely-moving thoughts dimension of mind wandering, although related, is not entirely redundant with the "flow state" construct ().

Our result is somewhat at odds with O'Neill et al. (2019). They found that the frequency of freely moving thoughts did not vary with changes in task demands. That is, freely moving thoughts did not decrease when the task demands were about to increase. 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 freely moving thoughts fluctuate at a slower rate than the other dimensions of mind wandering. Indeed, the overall percentage of freely moving 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 freely moving thoughts is a theoretically important and dissociable dimension of mind wandering.

The results of our study also leave an open question: why do people prioritize freely moving thoughts over constrained thoughts? In one sense, this might be counter-intuitive. One proposed function of mind wandering is problem-solving (). Constraining our mind wandering to a single problem, would seem to better serve this function. Additionally, we might consider constrained mind wandering to be more resource-dependent, requiring cognitive control (e.g., inhibiting unwanted thoughts, dual-task management). Constrained thinking could be conceptualized as the engagement of control over our thoughts and unconstrained thinking, the disengagement or lack of control. Therefore, we might have reasonably expected that when more resources are available, people should engage in more constrained mind wandering–in a similar way that they engage in more intentional mind wandering (Seli et. al., 2016).

However, it may not be the case that unconstrained thinking is a resource-free process. Unlike its name suggests, "allowing" our thoughts to freely move from one to the next might be more of a controlled exploratory process–Perhaps more in line with creativity or idea generation (). That is, to move from one loosely associated thought to the next might require executive control processes to generate, select and/or reject thoughts. Unconstrained mind wandering could very well be as resource-demanding as constrained mind wandering, albeit for different reasons. People therefore might be prioritize unconstrained over constrained mind wandering for reasons other than resource-demands, like perceived effort or enjoyment. This however, remains an interesting question for future work.

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