Thought Dynamics Under Task Demands: Evaluating the Influence of Task Difficulty on Unconstrained Thought

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As research on mind wandering has accelerated, the construct's defining features have expanded and researchers have begun to examine different dimensions of mind wandering. Recently, Christoff and colleagues have argued for the importance of investigating a hitherto neglected variety of mind wandering: "unconstrained thought," or, thought that is relatively unguided by executive-control processes. To date, with only a few studies investigating unconstrained thought, little is known about this intriguing type of mind wandering. Across 2 experiments, we examined, for the first time, whether changes in task demand influence rates of constrained versus unconstrained thoughts. In both experiments, participants completed either an easy (0-back) or hard (2-back) task and responded to intermittently presented thought probes that gauged thought constraint throughout the task. In Experiment 1, we found that participants completing the easy task engaged in unconstrained thoughts more frequently than those completing the difficult task. In Experiment 2, we replicated this result and further demonstrated manipulations of unconstrained thought while also measuring task-relatedness (a common dimension of mind wandering). Finally, exploratory analyses showed associations between constrained thought and age, verbal intelligence, and an assessment of flow ('deep effortless concentration'), thereby adding further evidence to indicate a dissociation between task-relatedness and constraint. We discuss the methodological and theoretical applications of our findings to the burgeoning field of research on unconstrained thought. All data, analysis, article, and experiment code can be found at https://osf.io/wr2vk/

Public Significance Statement
In the current study, we established that task difficulty can be used to effectively manipulate rates of thought constraint. This study provides novel evidence that when resources are limited, participants engage in less unconstrained thought. These important theoretical contributions further refine thought constraint as a construct within the Dynamic Framework and narrow the candidate processes underlying (un)constrained thought.

Keywords: mind wandering, freely moving thoughts, task-demand, unconstrained thought, thought dynamics

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Over the past fifteen years, mind wandering has become a prominent topic of interest (e.g., Callard et al., 2013; Christoff et al., 2016; Esterman et al., 2013; Mills et al., 2015; Schooler et al., 2004; Wammes et al., 2016). Initially, researchers investigated mind wandering by examining when and why people have thoughts that are unrelated to a focal task (Murray et al., 2020). However, dissatisfaction with this "task-unrelated thought" view has recently led to new theoretical frameworks of mind wandering (Irving, 2016; Seli et al., 2018; Sripada, 2018). One notable (and now highly popular) departure from the task-unrelated thought view is the recently proposed Dynamic Framework of mind wandering, which defines mind wandering in terms of the dynamic transitions between different mental contents. Mind wandering consists in relatively unconstrained thinking (Christoff et al., 2016), where constraint is defined in terms of topical focus. Thus, highly constrained thinking consists of thoughts whose semantic content is closely related (e.g., thinking about how to build a birdhouse), while highly unconstrained thinking consists of thoughts whose semantic content is only loosely related—if at all (e.g., thinking about a birdhouse, then a past vacation, then an upcoming deadline, etc.). Constraints can be placed on thinking either by deliberate, top-down processes (e.g., cognitive control), or automatic, bottom-up processes (e.g., attentional capture by affective or sensory salience).

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The core thesis of the Dynamic Framework is that mind wandering is "a special case of spontaneous thought that tends to be more-deliberately constrained than dreaming, but less-deliberately constrained than creative thinking and goal-directed thought" (Christoff et al., 2016, p. 719). This is a significant departure from the task-unrelated thought view, which defines mind wandering in terms of the relation between some focal task and the content of thought. On the task-unrelated thought view, the dynamics of thinking are irrelevant to mind wandering. A student who is ignoring important lecture material by thinking intently about where to go for dinner later is thinking in a way that is unrelated to her focal task. This counts as mind wandering according to the task-unrelated thought view, but not according to the Dynamic Framework, because the student's thoughts are highly constrained by the goal of identifying a place to eat later. The task-unrelated thought view identifies mind wandering in terms of the content of thinking, while the Dynamic Framework identifies mind wandering in terms of how thinking unfolds over time. Because content and dynamics are distinct, these two views make different predictions about when people are mind wandering.

One consequence of this is that the Dynamic Framework distinguishes mind wandering from other, related cognitive phenomena that the task-unrelated thought view lumps together. Stimulus-independent thought is, like task-unrelated thought, a feature of the content of thinking rather than its dynamics. On the Dynamic Framework, then, some mind wandering might reflect stimulus-independent thought, but mind wandering need not be stimulus-independent. Rumination often consists of task-unrelated thoughts, but is also highly affectively-constrained, often involving replay of past events that elicit high regret or anxiety. Thus, mind wandering lacks the strong affective constraint that rumination exhibits. And, though dreaming shares many characteristics of mind wandering, the latter tends to be constrained by rules of logic and rationality that preclude some of the cognitive transitions experienced in dreaming.

Over the span of just four years, the foundational paper laying out the Dynamic Framework has become one of the most widely cited articles in the mind wandering literature, with over 535 citations already.[1] While the field has undoubtedly been receptive to Christoff et al.'s new framework, to date, only a few studies have investigated unconstrained thought (Mills et al., 2018; O'Neill et al., 2020; Smith et al., 2021), and much is left to be learned about this intriguing phenomenon. Here, to shed some light on this aspect of mind wandering, we sought to determine whether unconstrained thought varies as a function of task demand.

From a methodological perspective, it is important to understand whether (and how) we can experimentally manipulate various dimensions of mind wandering, including thought constraint. Indeed, research on task-unrelated thought frequently employs task-demand manipulations, and these have contributed significantly to our understanding of (a) the costs of mind wandering and (Brosowsky et al., 2021; b) how mind wandering responds to environmental changes (Randall et al., 2014). For instance, task-demand manipulations have been used to examine the effect of different rates of task-unrelated thought on reading comprehension (Forrin et al., 2019), visual processing (Smallwood et al., 2007), driving (Yanko & Spalek, 2014), and even whether people understand jokes (Zhang et al., 2020). To date, however, it is unclear whether rates of unconstrained thought are amenable to the same

experimental manipulations as task-unrelated thought; yet, in the same way that the literature on task-unrelated thought has benefited greatly from the ability to manipulate the relative frequency of task-unrelated thought, the growing literature on unconstrained thought will surely benefit from the identification of a method that can be used to indirectly manipulate thought constraint.

From a theoretical perspective, it is also important to understand the influence of task demand on thought constraint, since doing so could allow researchers to generate numerous testable hypotheses that could help to elucidate the nature of unconstrained thoughts. For instance, one prominent view in the mind-wandering literature is that engaging in task-unrelated thought requires executive resources (Smallwood & Schooler, 2006) and, consequently, task-demand effects are explained in terms of the availability of resources (Brosowsky et al., 2021). Under this view, the maintenance, updating, and manipulation of information in working memory depends on a limited pool of resources, which depletes and replenishes over time (e.g., Popov & Reder, 2020; see also, Oberauer et al., 2016). Completing difficult tasks require more resources, leaving fewer resources available for the maintenance of task-unrelated thoughts. Hence, increases in task-demand tend to produce decreases in task-unrelated thoughts.

The same effect might be observed for constrained thought. According to the Dynamic Framework (Christoff et al., 2016), constraints influence the variability of thought content and the transitions from one thought to another. In other words, thought constraint is defined in terms of temporal stability as determined by deliberate (i.e., cognitive control) and automatic (i.e., stimulus salience and attentional capture) processing. Whereas unconstrained thought is described as temporally unstable (i.e., having more variable content and less-predictable transitions between thoughts), constrained thought is described as temporally stable [that is, having more consistent content and fewer, predictable transitions; Mills et al., 2018]. This would suggest that temporal stability needs to be monitored and maintained in order to deliberately constrain one's thoughts (Sripada & Taxali, 2020). Because monitoring is a resource-demanding process (Smith & Bayen, 2005; Smith et al., 2007), more deliberately-constrained thought should consume more executive resources.

One plausible hypothesis, then, is that constraining thought—as opposed to permitting it to roam free—is a more resource-demanding process (Hypothesis A: Constraining thoughts is resource-demanding; see Figure 1). On this view, people ought to have less-constrained thoughts when resources are in low supply. Such a prediction could be empirically tested by varying task demands (and hence, the resources required to perform those tasks) and indexing rates of (un)constrained thinking during task completion: Given that easy tasks require fewer resources than hard tasks, Hypothesis A predicts higher rates of constrained thoughts (or lower rates of unconstrained thoughts) during an easy versus a hard task.

Alternatively, it also seems plausible that engaging in unconstrained thinking (i.e., exploratory thought with frequent topical shifts) may be more resource demanding than constraining them (Hypothesis B: Engaging in unconstrained thought requires executive resources; see Figure 1). Maintaining unconstrained thought over time may require suppressing salient, competing task representations

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Figure 1
Predicted Patterns of Unconstrained Thought as a Function of Task Demand

A Hypothesis A **B** Hypothesis B **C** Hypothesis C
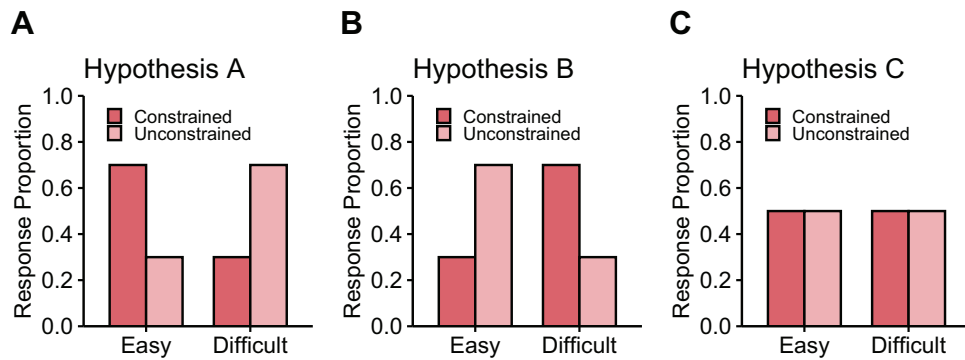
Note. According to Hypothesis A, the act of constraining our thoughts is resource-demanding; thus, Hypothesis A predicts fewer constrained and more unconstrained thought when resources are reduced (i.e., in a difficult task). According to Hypothesis B, the act of engaging in unconstrained thought is resource-demanding; thus, according to this hypothesis, we should observe fewer unconstrained and more constrained thoughts when resources are reduced (i.e., in a difficult task). Finally, according to Hypothesis C, constraint/unconstraint is automatic and resource-free; hence, this hypothesis predicts no systematic change in rates of thought constraint as a function of task demand. See the online article for the color version of this figure.

and frequent switching between representations; both of which can be effortful and costly (for a review, see Koch et al., 2018). Moreover, exercising metacontrol over control states, like constrained versus unconstrained states, might be more difficult when executive resources are unavailable (Dreisbach & Fröber, 2019). At the neural level, this might consist of processes that keep thoughts unconstrained by adaptively downregulating task-relevant networks to maintain mind wandering (McKiernan et al., 2006). On this basis, Hypothesis B would predict the opposite outcome of Hypothesis A: We should observe lower rates of constrained thoughts (or higher rates of unconstrained thoughts) during an easy versus a hard task.

Finally, task-demand manipulations might not influence thought constraint because these constraints operate independently of executive resources (Hypothesis C: Engaging constraint/unconstraint is automatic and resource-free; see Figure 1). The Dynamic Framework (Christoff et al., 2016) suggests that the constraints operating on thinking might be rooted in two different networks. One, located in frontoparietal control networks, reflects deliberate constraint, whereas the other, located in the dorsal attentional network and core regions of the default mode network, reflects automatic constraints (Christoff et al., 2016, pp. 724–25). These automatic constraints operate independently of available executive resources. As such, according to Hypothesis C, manipulations that reduce the availability of resources (e.g., task-demand manipulations) should have no influence on rates of thought constraint.

To the best of our knowledge, no research has yet examined the influence of task-demands on thought constraint. It is therefore unclear whether changes in task demand influence rates of thought constraint and, if so, in which direction. To shed light on this issue, here, across two experiments, we manipulated task demand via working memory load using an n-back task (e.g., Baird et al., 2012; Konishi et al., 2015; Seli et al., 2018; Smallwood et al., 2011).

In Experiment 1, we adopted modified 0-back and 2-back tasks for the low and high demand conditions, respectively–adapted from Smallwood et al. (2009; Experiment 1). Unlike a typical 0-back task, which involves continuous responding, responses were

dependent on the presence of an infrequent cue. In the 0-back, participants viewed a series of digits, and when an infrequent red digit was presented, indicated whether the digit was even or odd. For the 2-back condition, participants responded only when a red question mark was presented, indicating whether the digit presented two trials ago was even or odd (e.g., Konishi & Smallwood, 2016; Smallwood et al., 2009). Periodically throughout the task, we asked participants to indicate whether their thoughts were currently freely moving or not, adapting the thought-probe procedure from Mills et al. (2018; see also, Smith et al., 2021).

We chose these particular tasks because they both require sustained attention and include similar goals and instructions. The 0-back task, however, is relatively nondemanding compared to the 2-back in that it requires very little information maintenance and no working memory updating. There is little agreement across studies regarding the operationalization of the degree of cognitive demand and, in most cases, demand is relatively defined within individual studies. However, the 0-back task is routinely used as a low-demand comparison to a 1- or 2-back task in the mind wandering literature (e.g., Baird et al., 2012; Ho et al., 2020; Ju & Lien, 2018; Kam & Handy, 2014; Konishi & Smallwood, 2016; Smallwood et al., 2009; Smith et al., 2021; Steindorf et al., 2020) and, as such, suitable for our purposes in the current study.

Finally, given recent speculations (O'Neill et al., 2020) that unconstrained thinking might be an instance of a "flow state" (Csikszentmihalyi, 1988; Nakamura & Csikszentmihalyi, 2014) or "deep effortless concentration" (Marty-Dugas & Smilek, 2019), for exploratory purposes, we included an assessment of flow (Marty-Dugas & Smilek, 2019) to determine whether rates of unconstrained thought were associated with this measure.

In Experiment 1, we adapted the thought probes used in Experiment 1 to include a measure of task-relatedness (i.e., "on task" or "off task") in addition to thought constraint. Constraint and task-relatedness, although seemingly dissociable (Mills et al., 2018; O'Neill et al., 2020; Smith et al., 2021), are closely related in that off-task thought tends to be more unconstrained and on-task

thought tends to be more constrained (Mills, Raffaelli, et al., 2018; O'Neill et al., 2020; Smith et al., 2021). Therefore, the aims of Experiment 1 were to (a) determine whether thought constraint varies as a function of task demand, when task-relatedness is also measured, (b) further evaluate the relationship between flow and constraint, and (c) attempt to conceptually replicate the results of previous work showing dissociations of task-relatedness and thought constraint (Mills et al., 2018; O'Neill et al., 2020).

Experiment 1

Method

Participants

Participants were 150 individuals (no demographic information was collected in study 1) who completed a Human Intelligence task (HIT) posted on Amazon Mechanical Turk (MTurk). The sample size was determined by estimating the power to detect a range of effect sizes using a Monte-Carlo simulation approach (e.g., Brosowsky et al., 2021; Brosowsky & Crump, 2021) and assuming a mean response proportion of .5 and standard deviation of .3 (e.g., Ju & Lien, 2018). We estimated that, with 150 participants, our design could reliably detect differences in response proportions as low as .17 with 81% power and as high as .2 with 89% power. 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. Only workers who had completed more than 5000 HITs with 98% approval rating could participate in the study.

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. Participants completed 20 practice n-back trials, 188 experimental n-back trials, and responded to 12 thought probes. Stimuli consisted of the numbers 1 through 8 (4 even and 4 odd). Nontarget 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 for a total 23 targets and 165 nontargets. Each trial consisted of a fixation (1000 ms) followed by the stimulus (1500 ms duration) with 500 ms interstimulus intervals (for a total duration of 4000 ms).

In the 0-back group, participants were instructed to respond to the red digits (and not the black digits), and to indicate whether the red digits were 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 to indicate whether the digit presented two trials ago was even or odd using the keyboard (again, with 'e' for even and 'o' for odd).

Thought Probes. Thought probes consisted of a single question gauging thought constraint ("The thoughts I was experiencing were freely moving: YES/NO"). Unconstrained thoughts or 'freely-moving thoughts' were characterized as having relatively low guidance or constraints (see Appendix A for verbatim instructions). Thought probes were adapted from Mills et al. (2018) who assessed

and validated this thought-probing procedure using an experience-sampling method (see also Kam et al., 2021). Conventionally, mind wandering is measured using a dichotomous thought probe (e.g., on-task vs. off-task, Smallwood & Schooler, 2006). As such, we adopted a dichotomous approach to remain consistent in our methodology (e.g., Weinstein, 2018). Importantly, however, the usage of the dichotomous freely-moving thought probe has been further validated in other contexts and shown to successfully dissociate constraint and task-unrelated thought (e.g., O'Neill et al., 2020; Smith et al., 2021).

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).

Flow-State Questionnaire. At the end of the experiment, participants completed a short, four-item questionnaire (adapted from Marty-Dugas, 2020) asking them to report on their thoughts during the task. Participants provided a response to each of the four items using a 5-point likert scale (strongly disagree, disagree, neutral, agree, strongly agree). The items included in this questionnaire were:

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 randomly assigned to either the 0-back or 2-back condition and were then given a general overview of the tasks and instructions on how to respond. Before moving on to the experimental trials, participants had to complete a block of 20 practice trials with 4 targets and respond correctly to 3/4 of the targets. If they failed to do so, they were required to repeat the practice trials. After completing the n-back tasks, participants completed the flow questionnaire.

Data Analysis and Article Preparation

This article was prepared using R (R Core Team, 2019). A variety of notable R packages were used for data analysis (Bates et al., 2015; Fox & Weisberg, 2019; Kuznetsova et al., 2017; Singmann et al., 2019; Wickham et al., 2019; Wickham & Henry, 2019), data visualization (Fox & Weisberg, 2018; Kassambara, 2019; Wickham, 2016; Wilke, 2019), and general article preparation (Aust & Barth, 2018). All data, analysis and article preparation code can be found at https://osf.io/wr2vk/.

Results

We supplemented the null hypothesis tests with corresponding Bayesian analyses (Rouder et al., 2009). It is not possible to

quantify the evidence for a null effect using conventional frequentist testing. A Bayes Factor, however, is a continuous measure of the relative strength of evidence and can quantify the degree to which the data are compatible with the null over the alternative hypothesis (Dienes, 2014; Rouder et al., 2009). All Bayesian analyses were performed using the R package BayesFactor and Bayes Factors (BFs) were calculated using its default settings (Morey & Rouder, 2018). BF_{10} indicates evidence in favor of the alternative hypothesis whereas BF01 indicates evidence in favor of the null hypothesis. To simplify the interpretation, we report the Bayes Factor in the direction the data supports (for example, BF_{01} when there is more evidence in favor of the null over alternative hypothesis). As per previous recommendations, we refer to a BF > 3 as "moderate" and BF > 10 as "strong" evidence (Jeffreys, 1961; Rouder et al., 2009). To test for interaction effects, we contrasted the best model with the same model including/excluding the interaction effect.

N-Back Performance

First, we compared sensitivity (d-prime) and bias (c) scores between n-back groups. Sensitivity was significantly better in the 0-back compared to the (see Table 1) 2-back group, $\Delta M = 1.13$, 95% CI [.63, 1.63], $t(148) = 4.45$, $p < .001$, $d = .73$, 95% CI [.39, 1.06], $BF_{10} = 1.06 \times 10^3$. Additionally, there was significantly lower response bias (c) in the 0-back versus the 2-back group, $\Delta M = -.33$, 95% CI [−.59, −.07], $t(148) = -2.50$, $p = .013$, $d = -.41$, 95% CI [−.73, −.08], though there was only anecdotal evidence in favor of the alternative, $BF_{10} = 3.00$.

Next, we compared reaction times for accurate target responses across groups. We found no significant differences between group reaction time (RT) means, $\Delta M = -6.52$, 95% CI [−66.09, 53.05], $t(148) = -.22$, $p = .829$, $d = -.04$, 95% CI [−.36, .29], $BF_{01} = 5.57$. In addition to the standard RT analysis, we also performed an ex-Gaussian analysis. This approach estimates three parameters that correspond to different characteristics of the RT 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 significantly larger mu in the 0-back compared to the 2-back ($\Delta M =$

80.06, 95% CI [19.50, 140.61], $t(148) = 2.61$, $p = .010$, $d = .43$, 95% CI [.1, .75], $BF_{10} = 3.88$); and significantly smaller 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], $BF_{10} = 1.30 \times 10^{12}$) 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], $BF_{10} = 3.17 \times 10^{15}$).

Counterintuitively, we found that participants in the 2-back responded faster in terms of mu, but were more variable (sigma), with higher frequency and magnitude of exceedingly long reaction times (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 would know the correct response prior to the target presentation, which would presumably decrease 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 demand.

The results of the n-back analysis confirm that the 2-back task was indeed more difficult than the 0-back. Participant performance was notably worse in terms of target discrimination and bias. The RT analyses corroborate this interpretation by showing increased variability, and higher frequency and magnitude of exceedingly long reaction times.

Thought Probes

To determine whether rates of unconstrained thoughts were influenced by task demand, we compared rates of self-reported thought constraint across n-back groups (see Figure 2 and Table 1). Here, we observed significantly higher rates of unconstrained in the 0-back as compared to the 2-back group, $\Delta M = .22$, 95% CI [.10, .34], $t(148) = 3.71$, $p < .001$, $d = .61$, 95% CI [.28, .94], with strong evidence in favor of the alternative, $BF_{10} = 80.93$.

Flow Questionnaire

We found no differences between mean flow-state responses across n-back groups, $\Delta M = .04$, 95% CI [−.32, .39], $t(148) = .20$, $p = .840$, $d = .03$, 95% CI [−.29, .36], $BF_{01} = 5.59$ (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, $\chi^2(1) = .01$, $p = .922$.

Additionally, we were interested in how responses to the flow-state questionnaire compared to the reported rates of unconstrained thoughts (see Figure 2). Using a Pearson correlation found a significant, small-to-moderate, positive correlation, $r = .19$, 95% CI [.03, .34], $t(148) = 2.37$, $p = .019$, $BF_{10} = 2.67$, indicating some overlap between these two constructs.

Discussion

In Experiment 1, we examined the influence of a task-demand manipulation on thought constraint. To manipulate task demand, we used two versions of the n-back task, throughout which we periodically presented thought probes to determine whether participants' current thoughts were constrained or unconstrained. Results across performance measures confirmed that the 2-back was significantly more difficult than the 0-back. More importantly, we found that participants engaged in significantly higher rates of unconstrained thought in the easy (0-

Table 1
Descriptive Statistics From Experiment 1 (N = 150)

Measure	0-Back M	0-Back SD	2-Back M	2-Back SD
Unconstrained thought	0.68	0.32	0.46	0.40
Flow	0.28	1.08	0.25	1.14
N-back performance				
d-prime	3.64	1.40	2.51	1.70
RT (ms)	905.59	159.75	912.11	206.45
Mu (ms)	809.19	155.05	729.13	215.38
Sigma (ms)	96.17	39.32	172.93	64.80
Tau (ms)	96.40	42.60	182.98	60.55

Figure 2
Results From Experiment 1
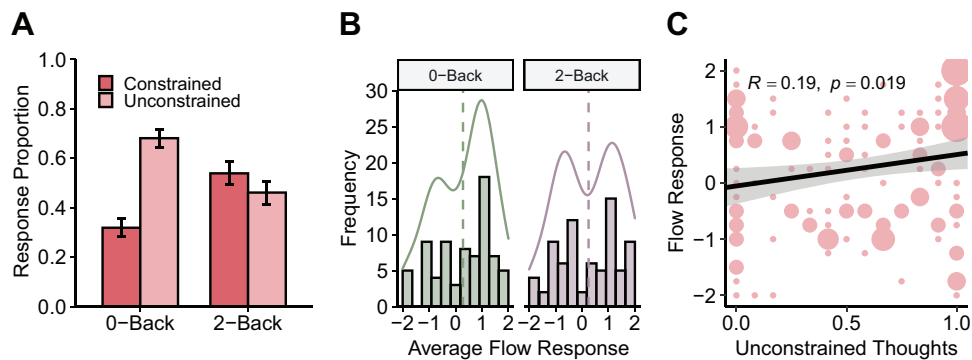
Note. Thought constraint response proportions are plotted as a function of n-back task (A). Frequencies of the average flow-state responses are plotted as a function of n-back task (B), and the average flow-state responses are plotted as a function of proportions of unconstrained thought (C). Error bars represent standard error of the mean. See the online article for the color version of this figure.

back) than the hard (2-back) task. Consistent with Hypothesis B, this preliminary evidence suggests that unconstrained thought is indeed resource dependent. That is, when the focal task required fewer executive resources, people tended to engage in more unconstrained thought. This suggests that varying task demand is an effective method with which to manipulate the proportion of unconstrained thoughts.

We also compared self-reported rates of unconstrained thoughts with responses to the flow-state questionnaire. Replicating a recently reported finding (Smith et al., 2021), here, we found a small-to-moderate correlation between measures. Although the magnitude of the observed correlation was modest, finding some correspondence between rates of unconstrained thoughts and flow is heartening. Indeed, at face value, it seems sensible that these conceptually similar constructs should overlap to some degree. However, the relatively low correspondence suggests that the constraint dimension of mind wandering is distinct from the concept of a "flow state" (Csikszentmihalyi, 1988; Marty-Dugas & Smilek, 2019; Nakamura & Csikszentmihalyi, 2014).

One potential limitation of Experiment 1 was that we only measured general rates of (un)constrained thoughts and did not measure the task-relatedness of those thoughts. Although prior work suggests that the thought-constraint and task-relatedness dimensions of mind wandering are dissociable (e.g., Mills et al., 2018; O'Neill et al., 2020; Smith et al., 2021), they are not entirely independent. Mills et al. (2018)\., for instance, found that off-task thoughts were more likely to be unconstrained than constrained, and, conversely, that on-task thoughts were more likely to be constrained than unconstrained. Moreover, task demand is known to influence rates of off-task thought, with decreases in task-demand leading to increased rates of off-task thought (e.g., Giambra, 1989; Smallwood et al., 2011; Teasdale et al., 1995; Thomson et al., 2013).

Given that (a) off-task thoughts tend to increase during easy tasks (e.g., Giambra, 1989), and (b) off-task thoughts tend to be unconstrained (e.g., Mills et al., 2018), one possibility is that participants conflated off-task thought with unconstrained thought. That is, without the option to specify whether their thoughts were on- or off-task, participants were more likely to indicate unconstrained whenever their thoughts were off-task (see Smith et al., 2021).

Another potential limitation of Experiment 1 was that, because we did not index the task-relatedness of participants' thoughts, we may not have adequately tested the hypothesis that unconstrained thoughts are positively associated with flow. It could, for instance, be that the hypothesized positive relation between flow and unconstrained thoughts is qualified by the task-relatedness of thoughts. Along these lines, in recent work, O'Neill et al. (2020) observed the surprising finding of relatively high rates of probe responses that were both on-task and unconstrained. This finding is surprising given that the recent proposal that goal-directed, on-task thoughts are highly constrained (Christoff et al., 2016). To explain this finding, O'Neill et al. proposed that the Mills et al. (2018) constraint probes (those used in the present experiments) may not measure topical shifts, but instead the effortfulness of thoughts (where unconstrained thoughts are those that feel relatively effortless). Indeed, if one is on-task and engaging in unconstrained thoughts, it appears that such thoughts could not involve topical-shifts (else they would not be on-task), so they may instead consist of thoughts that reflect a goal-directed flow state (Csikszentmihalyi, 1988; Nakamura & Csikszentmihalyi, 2014) or a state of "deep effortless concentration" (Marty-Dugas & Smilek, 2019). At the same time, because flow states reflect deep effortless concentration on a focal task, one might not expect off-task thoughts (whether constrained or unconstrained) to be positively associated with flow. Thus, if O'Neill et al.'s hypothesis is correct, we should expect to observe a significant positive correlation with flow only when examining rates of on-task, unconstrained thoughts (and perhaps negative correlations with flow when examining off-task thoughts, whether constrained or unconstrained).

Experiment 2

Having established that rates of unconstrained thought can be manipulated via changes in task demand, the primary aim of Experiment 2 was to determine whether variations in task demand influence rates of thought constraint for both on- and off-task thought. As noted above, research has found that (a) decreases in task demand lead to increased rates of off-task thought (e.g.,

Giambra, 1989; Smallwood et al., 2011; Teasdale et al., 1995; Thomson et al., 2013), and (b) whereas off-task thoughts are more likely to be unconstrained than on-task thoughts, on-task thoughts are more likely to be constrained than off-task thoughts (Mills et al., 2018; Smith et al., 2021). One concern, then, is that participants conflate unconstrained thought and off-task thought because they had no option to indicate on or off task. Therefore, in Experiment 1, we sought to determine how thought-probe responses varied under a task-demand manipulation when both task-relatedness and thought constraint were measured.

A secondary aim of Experiment 1 was to better evaluate the relationship between constraint and flow by testing O'Neill et al.'s (2020) hypothesis that the concept of a "flow state" or "deep effortless concentration" is closely associated with both on-task and unconstrained thought. The third and final aim of Experiment 1 was to conceptually replicate the work of Mills et al. (2018) using a laboratory task. Mills et al. used a time-consuming and costly experience-sampling procedure for which they examined task-relatedness and thought constrained in daily life, via probes sent to participants' smartphones. Methodologically, it is important to know whether a simple, online task would produce the same pattern of thought-probe responses as the Mills et al. experience-sampling procedure. If so, this would suggest that researchers who are interested in testing hypotheses about thought constraint and task-relatedness could forgo the lengthy experience-sampling procedure and instead use the much simpler online task.

We again used the n-back tasks to manipulate task demand. Extending our design in Experiment 1, here we included thought probes that gauged both thought constraint (constrained, unconstrained) and task-relatedness (on-task, off-task). We also included a demographics survey, as well as the Wordsum test [a brief vocabulary test that correlates well with full-scale measures of intelligence; Huang and Hauser (1998)]. We included these measures to explore how rates of thought constraint might be related to age (Maillet & Schacter, 2016) and/or verbal intelligence (e.g., Mrazek et al., 2012), respectively. We ran two samples, both preregistered prior to data collection (Sample 1: https://osf.io/2djqf; Sample 2: https://osf.io/guq7j).[2]

Because no other studies have examined on- and off-task (un)constrained thought under task-demand manipulations, it was not possible to conduct an a priori power analysis. Thus, we decided to collect data from a relatively large sample (N = 150, 75 per group, the same as Experiment 1), with the intention of attempting to replicate any significant findings we observed. In Sample 1, we found a significant difference in unconstrained thought between groups ($p < .05$. To improve our confidence in this result and the exploratory analyses, we collected data from an additional 300 participants (150 per group) to augment those from our initial sample. Below, we report the results of an analysis combining data from both samples; however, individual sample analyses can be found in the online supplementary material and, critically, both samples converged on the same general conclusions. As in Experiment 1, we supplemented the null-hypothesis tests with corresponding Bayesian analyses.

Method

Participants

Sample 1 consisted of 150 individuals (43.7% women, mean age = 40 (SD = 12.5) who completed a HIT on Amazon Mechanical Turk;

Sample 2 consisted of 300 individuals (46.8% women, mean age = 40.2 (SD = 12.5; see Table 2). All participants provided informed consent and were treated in accordance with guidelines approved by the ethics committee at Duke University. Participants were paid $2.50 (U.S. dollars) for completing the HIT, which lasted approximately 25 minutes.

Materials

N-Back. The n-back tasks were identical to those used in Experiment 1.

Thought Probes. Instructions and stimuli were identical to those from Experiment 1. However, in addition to asking participants to report whether their thoughts were unconstrained or not (identical to Experiment 1), we also asked whether their current thoughts were on- or off-task ("Just prior to seeing this screen, I was: (a) on-task (b) thinking task-unrelated thoughts"). Verbatim instructions are reported in Appendix B.

Wordsum Test. The Wordsum Test (Huang & Hauser, 1998) is a verbal intelligence test fpr which participants are asked to identify which of five words comes closest in meaning to a target word. For example, one of the target words is accustom, and the five options are disappoint, customary, encounter, get used to, or business (here, the correct answer is "get used to"). The traditional version consists of 10 target words. In the version presented here, we included two additional target words, audacious (options: smart, daring, brave, loud, or outgoing) and encumber (options: oppress, gather, impede, press, or encompass). The Wordsum is commonly used as a proxy for intelligence in many psychological, sociological, and political science studies (e.g., Malhorta et al., 2007; Pennycook et al., 2012), and included in the 16 General Social Surveys (Davies & Smith, 1994).

Flow State and Demographics Questionnaires. Following the Wordsum, participants completed the same flow-state questionnaire completed in Experiment 1, and an optional demographics questionnaire.

Procedure

The procedure was identical to that from Experiment 1. After the n-back task, participants completed the flow questionnaire, followed by the Wordsum, then the demographics survey.

Results

N-Back Performance

Sensitivity (d-prime) was significantly better in the 0-back versus 2-back groups, $\Delta M = .67$, 95% CI [.41, .93], $t(448) = 5.09$, $p < .001$, $d = .48$, 95% CI [.29, .67], $BF_{10} = 2.22 \times 10^4$. Additionally, there was significantly lower response bias (c) in the 0-back versus 2-back group, $\Delta M = -.42$, 95% CI [−.54, −.30], $t(448) = -7.00$, $p < .001$, $d = -.66$, 95% CI [−.85, −.47], $BF_{10} = 7.65 \times 10^8$. We found no significant differences between group RT means,

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[2] We diverged from our original preregistered analysis plan. Due do concerns over ipsativity, we no longer use an ANOVA and instead analyze the overall rates of task-unrelated thought and constraint, followed with individual response contrasts. Importantly, these results converge on the same result as our planned analyses. We thank the reviewers for these suggestions.

Table 2
Descriptive Statistics From Experiment 2 (N = 450)

Measure	0-Back		2-Back	
	M	*SD*	*M*	*SD*
Age	39.51	11.51	40.66	12.07
Flow	0.23	1.01	0.12	1.04
Wordsum accuracy	0.67	0.19	0.69	0.18
Unconstrained thought	0.56	0.35	0.45	0.36
Off-task thought	0.36	0.29	0.20	0.21
Individual response rates				
Constrained off-task	0.07	0.12	0.05	0.10
Unconstrained off-task	0.30	0.26	0.16	0.18
Constrained on-task	0.37	0.35	0.50	0.37
Unconstrained off-task	0.27	0.33	0.30	0.36
N-back performance				
d-prime	3.58	1.47	2.91	1.31
Mean RT (ms)	894.42	173.13	886.26	194.65
Mu (ms)	787.17	179.03	709.14	203.74
Sigma (ms)	101.80	43.73	170.84	63.98
Tau (ms)	107.25	47.51	177.12	63.59

$\Delta M = 8.16$, 95% CI $[-25.96, 42.28]$, $t(448) = .47$, $p = .639$, $d = .04$, 95% CI $[-0.14, 0.23]$, $BF_{01} = 8.59$. However, we did observe significant differences in the mu ($\Delta M = 78.02$, 95% CI $[42.50, 113.55]$, $t(448) = 4.32$, $p < .001$, $d = .41$, 95% CI $[0.22, 0.59]$, $BF_{10} = 749.84$), sigma ($\Delta M = -69.03$, 95% CI $[-79.18, -58.89]$, $t(448) = -13.37$, $p < .001$, $d = -1.26$, 95% CI $[-1.46, -1.06]$, $BF_{10} = 1.44 \times 10^{31}$), and tau parameters ($\Delta M = -69.87$, 95% CI $[-80.26, -59.47]$, $t(448) = -13.21$, $p < .001$, $d = -1.25$, 95% CI $[-1.45, -1.04]$, $BF_{10} = 3.10 \times 10^{30}$). These results are consistent with those from Experiment 1: Participants in the 2-back group were quicker in terms of mu but showed greater variability sigma and a longer tail tau. The differences in mu again likely reflect the foreknowledge of the correct response prior to the target stimulus, whereas the differences in sigma and tau likely reflect the increase in general task demand.

Thought Probes

First, we examined whether the overall rate of task-unrelated thoughts and unconstrained thoughts differed across groups (see Figure 3 and Table 2). We found that participants in the 0-back group reported significantly more off-task thoughts ($M = 0.36$) than the 0-back group ($M = 0.20$), $\Delta M = 0.16$, 95% CI $[0.11, 0.21]$, $t(411.80) = 6.81$, $p < .001$, $BF_{10} = 2.30 \times 10^8$. Replicating the results from Experiment 1, we also found that participants in the 0-back group reported significantly more unconstrained thoughts ($M = 0.56$) than the 2-back group ($\Delta M = 0.11$ $M = 0.45$), 95% CI $[0.04, 0.17]$, $t(446.66) = 3.23$, $p = .001$, $BF_{10} = 15.65$.

Next, we were interested in how individual response rates differed between groups. To that end, we calculated a proportion for each of the four possible thought-probe responses–unconstrained off-task, constrained off-task, unconstrained on-task, and constrained on-task–and, using a Bonferroni correction ($\alpha = .0125$), tested for differences between N-back groups. Here, we found that the 0-back group reported a higher rate of unconstrained off-task thought ($M = 0.30$) than the 2-back group ($M = 0.16$), $\Delta M = 0.14$, 95% CI $[0.10, 0.18]$, $t(401.54) = 6.62$, $p < .001$, $BF_{10} = 7.12 \times 10^7$; and the 0-back group also reported a lower rate of constrained on-task thought

($M = 0.37$) than the 2-back group ($M = 0.50$), $\Delta M = -0.13$, 95% CI $[-0.19, -0.06]$, $t(445.83) = -3.80$, $p < .001$, $BF_{10} = 106.75$. However, there was no significant differences between groups in terms of constrained off-task thought (0-back group: $M = 0.07$; 2-back group: $M = 0.05$), $\Delta M = 0.02$, 95% CI $[0.00, 0.04]$, $t(441.05) = 1.87$, $p = .062$, $BF_{01} = 1.77$; and unconstrained on-task thought (0-back group: $M = 0.27$; 2-back group: $M = 0.30$), $\Delta M = -0.03$, 95% CI $[-0.10, 0.03]$, $t(444.54) = -1.03$, $p = .306$, $BF_{01} = 5.74$.

Finally, we examined the relationship between rates of off-task and unconstrained thought using Pearson correlations. There was a significant correlation between rates of off-task and unconstrained thought for both the 0-back, $r = .33$, 95% CI $[.21, .44]$, $t(224) = 5.28$, $p < .001$, $BF_{10} = 5.63 \times 10^4$, and the 2-back group, $r = .20$, 95% CI $[.07, .32]$, $t(222) = 3.07$, $p = .002$, $BF_{10} = 13.74$. Further, these correlations did not significantly differ from one another (Fisher's z, $p > .05$).

Flow Questionnaire

Using a *t* test, we found no significant difference between mean flow-state responses across n-back groups (see Figure 4 and Table 2), $\Delta M = 0.12$, 95% CI $[-0.08, 0.31]$, $t(448) = 1.19$, $p = .235$, $d = 0.11$, 95% CI $[-0.07, 0.3]$ $BF_{01} = 4.82$, and no significant difference using the Kruskal-Wallis Test, $\chi^2(1) = 1.89$, $p = .169$.

Next, we used a linear regression model to predict flow-state responses using rates of off-task thought, rates of unconstrained thought, and N-back group as predictors. We fit three models: (1) all main effects, all two-way interactions, and the three-way interaction,

Figure 3
Thought-Probe Responses From Experiment 2
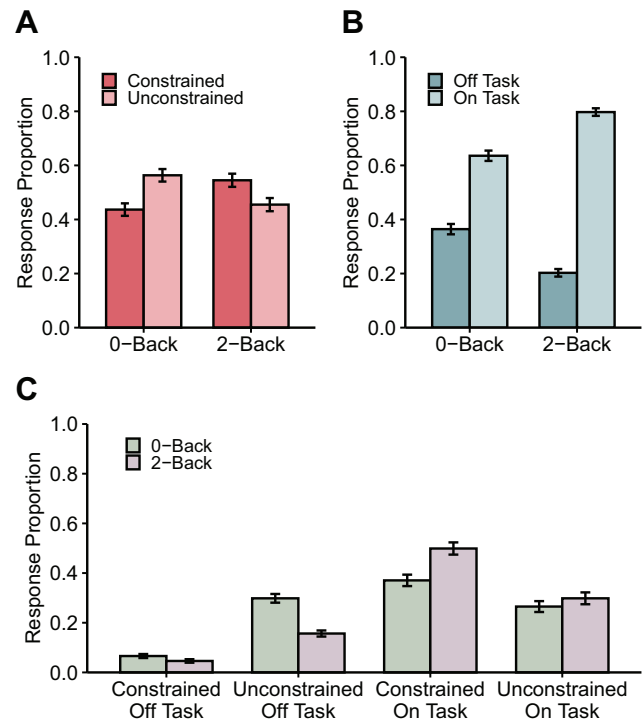
Note. Plotted are the overall rates task-relatedness responses (A), thought constraint responses (B), and individual thought probe responses (C). Error bars represent 95% confidence intervals around the mean. See the online article for the color version of this figure.

Figure 4
Results From the Flow Questionnaire in Experiment 2
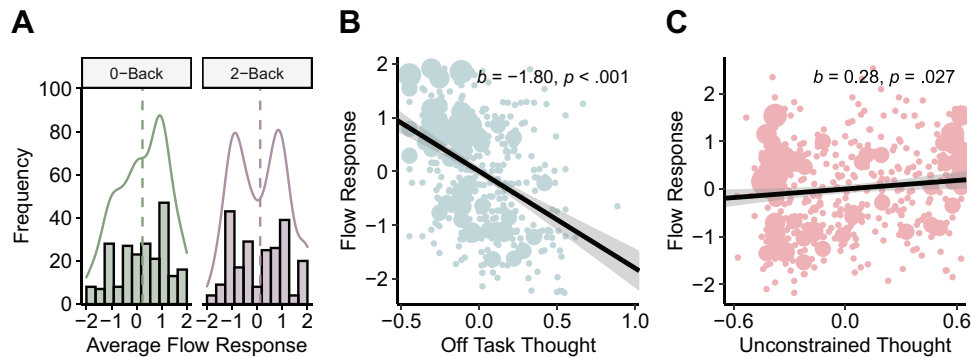
Note. Frequency of average flow responses are plotted as a function of n-back task (A). Error bands represent 95% confidence intervals. B. and C contain partial regression plots estimated from the linear regression model predicting flow responses using rates of off task thought (B) and unconstrained thought (C) as predictors. See the online article for the color version of this figure.

(2) all main effects and two-way interactions between off-task thought and N-back group, and unconstrained thought and N-back group, and (3) only main effects. The best fitting model according to the Akaike information criterion (AIC) was the main effects-only model ($R^2 = .18$, 90% CI [0.13, 0.24], $F(3, 446) = 33.52$, $p < .001$; $BF_{10} = 2.07 \times 10^{16}$). Within this model, we found that whereas rates of off-task thought negatively predicted flow-state responses, $b = -1.80$, 95% CI [−2.16, −1.45], $t(446) = -9.93$, $p < .001$, rates of unconstrained thought positively predicted flow-state responses, $b = 0.28$, 95% CI [0.03, 0.54], $t(446) = 2.22$, $p = .027$. Interestingly, N-back group was also a significant predictor, with lower flow rates estimated for the 2-back versus 0-back group, $b = 0.28$, 95% CI [0.03, 0.54], $t(446) = 2.22$, $p = .027$.

Finally, we were also interested in how responses in the flow-state questionnaire compared to each of the individual response types (i.e., constrained off-task, unconstrained off-task, constrained on-task, and unconstrained on-task). We found no significant differences between the N-back groups for any of the correlations ($p > .05$). We, therefore, collapsed across N-back groups and compared each using a Pearson correlation to the flow state responses. we found a small, nonsignificant correlation between rates of constrained on-task thought and flow responses, $r = .08$, 95% CI [−.01, .17], $t(448) = 1.66$, $p = .099$, $BF_{01} = 2.36$; a significant positive correlation between unconstrained on-task thought and flow responses, $r = .21$, 95% CI [.12, .29], $t(448) = 4.50$, $p < .001$, $BF_{10} = 1.92 \times 10^3$; a significant negative correlation between constrained off-task thought and flow responses, $r = -.21$, 95% CI [−.30, −.12], $t(448) = -4.54$, $p < .001$, $BF_{10} = 2.32 \times 10^3$; and a significant negative correlation between unconstrained thought and flow responses, $r = -.32$, 95% CI [−.40, −.23], $t(448) = -7.13$, $p < .001$, $BF_{10} = 2.35 \times 10^9$.

We also tested for differences between these correlations and found the correlation with unconstrained off-task thought differed significantly from unconstrained on-task and constrained on-task correlations ($ps < .001$) but did not differ from the constrained off-task correlation ($p > .05$). The constrained on-task correlation differed significantly from the constrained off-task ($p < .001$) but not the unconstrained on-task ($p > .05$) correlations. And finally, the unconstrained on-task correlation significantly differed from the constrained off-task correlation ($p < .001$).

Exploratory Analyses

In addition to the primary analyses, we were also interested in the associations between thought-probe responses and age, verbal intelligence, and flow. For each of the following analyses, we adopted the same approach: We fit regression models including the predictor of interest (e.g., age) and N-back group to determine the best fitting model using the Akaike information criterion. This approach allows us to estimate the associations between our variables of interest while, at the same time, taking the N-back manipulation into consideration. The candidate models included (a) the full model with the predictor of interest (e.g., age), N-back group, and their interaction, (b) the main-effects-only model with the primary predictor of interest and N-back group, or (c) the predictor-only model. We used this same approach to determine how each of our predictors of interest were associated with rates of off-task thought, unconstrained thought, and flow state responses (see Figure 5). The age analyses included 377 participants who completed the optional demographics survey.

Age

Off-Task Thought and Age. Predicting rates of off-task thought, the best fitting model was the main-effects model containing age and N-back group as predictors ($R^2 = .10$, 90% CI [0.05, 0.15], $F(2, 374) = 20.49$, $p < .001$, $BF_{10} = 5.22 \times 10^8$). Within this model, age was negatively associated with rates of off-task thought, $b = -0.36$, 95% CI [−0.57, −0.16], $t(374) = -3.45$, $p = .001$, and N-back group negatively predicted off-task thought, $b = -12.94$, 95% CI [−17.82, −8.06], $t(374) = -5.21$, $p < .001$.

Unconstrained Thought and Age. Predicting rates of unconstrained thought, the best fitting model was the main-effects model containing age and N-back group as predictors ($R^2 = .07$, 90% CI [0.03, 0.11], $F(2, 374) = 13.91$, $p < .001$, $BF_{10} = 5.18 \times 10^8$). Within this model, age was negatively associated with rates of off-task thought, $b = -0.65$, 95% CI [−0.95, −0.35], $t(374) = -4.25$, $p < .001$, and N-back group negatively predicted off-task thought, $b = -10.54$, 95% CI [−17.65, −3.42], $t(374) = -2.91$, $p = .004$.

Figure 5
Results From the Exploratory Analyses in Experiment 2
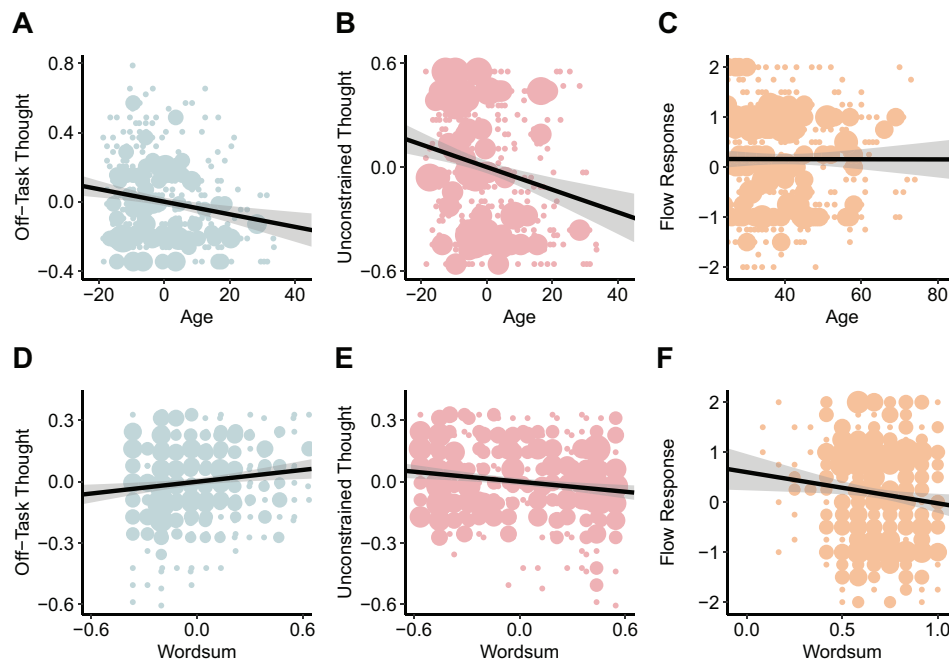
Note. A, B, and C contain partial regression plots predicting off-task thought, unconstrained thought, and flow-state responses as a function of age. D, E, and F. contain partial regression plots predicting off-task thought, unconstrained thought, and flow-state responses as a function of verbal intelligence (wordsum scores). Error bands represent 95% confidence intervals. See the online article for the color version of this figure.

Flow and Age. Predicting rates flow state responses, the best fitting model only included age as a predictor ($R^2 = .02$, 90% CI [0.00, 0.04], $F(3, 373) = 2.22$, $p = .085$, $BF_{10} = 5.97 \times 10^3$). However, age was not significantly associated with flow state responses, $b = 0.01$, 95% CI [0.00, 0.02], $t(373) = 1.39, p = .167$.

Verbal Intelligence

Off-Task Thought and Verbal Intelligence. Predicting rates of off-task thought, the best fitting model was the main-effects model containing wordsum accuracy and N-back group as predictors ($R^2 = .11$, 90% CI [0.07, 0.16], $F(2, 447) = 27.41$, $p < .001$, $BF_{10} = 4.38 \times 10^{10}$). Within this model, wordsum accuracy was positively associated with rates of off-task thought, $b = 0.18$, 95% CI [0.05, 0.31], $t(447) = 2.79$, $p = .005$, and N-back group negatively predicted off-task thought, $b = -0.16$, 95% CI [−0.21, −0.12], $t(447) = -6.98, p < .001$.

Unconstrained Thought and Verbal Intelligence. Predicting rates of unconstrained thought, the best fitting model was the main-effects model containing wordsum accuracy and N-back group as predictors ($R^2 = .05$, 90% CI [0.02, 0.08], $F(2, 447) = 11.08$, $p < .001$, $BF_{10} = 4.33 \times 10^{10}$). Within this model, wordsum accuracy was negatively associated with rates of unconstrained thought, and N-back group negatively predicted unconstrained thought, $b = -0.10$, 95% CI [−0.17, −0.04], $t(447) = -3.11$, $p = .002$.

Flow and verbal intelligence. Predicting rates flow state responses, the best fitting model only included wordsum accuracy as a predictor ($R^2 = .01$, 90% CI [0.00, 0.04], $F(1, 448) = 5.65$, $p = .018$, $BF_{10} = 37.03$). Within this model, wordsum accuracy was negatively associated with flow state responses, $b = -0.62$, 95% CI [−1.14, −0.11], $t(448) = -2.38$, $p = .018$.

Discussion

In Experiment 1, we examined the influence of a task-demand manipulation on thought-probe responses when both thought constraint and task-relatedness were measured. To manipulate task demand, we used two versions of the n-back task and periodically presented thought probes to determine whether participants' thoughts were constrained or unconstrained. Results across performance measures confirmed that the 2-back was significantly more difficult than the 0-back.

More importantly, we found that participants engaged in significantly higher rates of unconstrained thought in the easy versus the hard task. Replicating prior work, we also found lower rates of off-task thought in the hard task as compared to the easy task (e.g., Giambra, 1989; Smallwood et al., 2011; Teasdale et al., 1995; Thomson et al., 2013). Similarly, we found that, whereas off-task thoughts were more likely to be unconstrained than constrained, on-task thoughts were more likely to be constrained (Mills et al., 2018; Smith et al., 2021). Given that (a) the association between

constraint and task-relatedness and (b) the fact that task demand manipulations produced additive effects (i.e., increasing both task-unrelated thought and unconstrained thought independently), we suggest that future work using variations in task demand to manipulate thought constraint should also measure task-relatedness to determine how much of the change is due to a shift in off-task thought.

In Experiment 1, we found a small positive association between rates of unconstrained thought and measures of flow. This result was replicated in Experiment 1, where we also observed a significant negative association between off-task thought and flow. As for the individual response rates: we found that unconstrained on-task thought was positively correlated with flow, unconstrained off-task thought was negatively correlated with flow. The overall pattern of results suggests that flow states are not identical to unconstrained thought. However, flow might reflect a particular kind of on-task unconstrained thought, which fits well with the idea that a flow state is effortless concentration (Marty-Dugas & Smilek, 2019).

Turning to our exploratory analyses, we found that age was positively associated with constrained on-task thought, but negatively associated with unconstrained off-task thought. This aligns with prior work showing rates of task-unrelated thought tends to decrease with age (e.g., Jackson & Balota, 2012; Seli et al., 2020). It also suggests that constrained on-task reports may be capturing traditional measures of task-related thought, and that unconstrained off-task may be capturing traditional measures of task-unrelated thoughts. However, we also found that age was negatively associated with unconstrained on-task thought. This result is particularly interesting as it suggests that unconstrained on-task thought is more like mind wandering than constrained on-task thought and is consistent with the view that constraint and task-relatedness are dissociable (e.g., Mills et al., 2018; O'Neill et al., 2020).

We also examined the relationship between verbal intelligence, as indexed by the Wordsum, and thought-probe responses. To our knowledge, there is only one similar study that used the Wordsum test and results of this study indicated no association between rates of task-unrelated thought and verbal intelligence (Phillips et al., 2016). However, more generally, task-unrelated thought (i.e., mind wandering) has been shown to be negatively associated with measures of general intelligence (Mrazek et al., 2012). In this regard, our result is mixed. On the one hand, constrained on-task thought was positively associated with verbal intelligence. This is consistent with prior studies that have found a relationship between mind wandering and intelligence (e.g., Mrazek et al., 2012). On the other hand, we found a small, positive association between unconstrained off-task thought and verbal intelligence and a negative association between unconstrained on-task thought and verbal intelligence. Again, this suggests that unconstrained on-task thought more closely resembles traditional conceptualizations of mind wandering than it does on-task thought.

Finally, we examined the relationship between flow-state responses, age, and verbal intelligence. Previous work has indicated that the tendency to experience flow may actually increase across the life span (Marty-Dugas & Smilek, 2019; Ullén et al., 2012). However, despite having a large sample and a wide distribution of ages, here we found no association between age and flow-state responses. Looking at verbal intelligence we find a small, negative association between flow-state responses and WordSum scores. Prior work has found small, but inconsistent,

associations between intelligence and flow using much larger samples and concluded that they were essentially unrelated (Ullén et al., 2012).

General Discussion

The primary question addressed across these two experiments was whether manipulating task demand would influence thought constraint (Christoff et al., 2016; Mills et al., 2018; Smith et al., 2021). From the Dynamic Framework's perspective, we hypothesized that both unconstrained and constrained thought could be more or less resource demanding depending on the underlying assumptions. These hypotheses resulted in diverging predictions about how task demand should influence the rate of (un)constrained thought (see Figure 1 for a summary). In Experiment 1, we found lower rates of unconstrained thought in the more difficult 2-back condition as compared to the 0-back condition, suggesting that (a) constraint can be manipulated by varying task demand and (b) engaging in unconstrained thoughts is a resource-demanding process. In Experiment 1, we replicated the finding of lower rates of unconstrained thought in the more difficult condition, again providing evidence that thought constraint can be influence via a task-demand manipulation, and that unconstrained thoughts require executive resources. More importantly, in Experiment 1, we also determined that this manipulation did not depend on task-relatedness. Furthermore, we replicated prior findings that (a) participants engage in more off-task thought during easier tasks (e.g., Giambra, 1989; Smallwood et al., 2011; Teasdale et al., 1995; Thomson, Besner, & Smilek, 2013), and (b) off-task thoughts are more likely to be unconstrained than constrained, whereas on-task thoughts are more likely to be constrained than unconstrained (Mills et al., 2018; O'Neill et al., 2020; Smith et al., 2021). Together, these results were most consistent with Hypothesis B (i.e., engaging in unconstrained thought requires executive resources), and suggest that unconstrained thought is indeed resource dependent: When the focal task is demanding, and resources are restricted, people tend to engage in less unconstrained thought and more constrained thought.

At the methodological level, the results of the present study are rather promising for future investigations on unconstrained thought because they demonstrate a method with which to indirectly influence rates of unconstrained thought. This could be useful for future work exploring the costs and benefits of unconstrained thought. For instance, experimental manipulations increasing unconstrained thought would surely be beneficial for examining whether unconstrained thought benefits creative idea generation (Baird et al., 2012), results in increases in topical shifts, and/or improves boredom management. Conversely, manipulating unconstrained thought would be useful for examining the negative consequences of thought constraint, such as rumination or fixation (Christoff, 2016). Just as the mind wandering literature has benefited from experimental manipulations of task-unrelated thought, our novel finding that task demand can influence unconstrained thought, will surely benefit the growing literature on unconstrained thought.

However, our study also identifies two caveats in using our experimental manipulations. First, although we clearly established that task demand can be used to manipulate rates of thought constraint, it is not clear whether this manipulation would scale linearly with increased demand. An important aspect of our task demand manipulation is that the low-demand task contains very

little, if any, working memory demand compared to the high-demand task. Therefore, one possibility is that the manipulation depends not on the degree of demand, but the presence/absence of working memory demands, such as information maintenance and updating. However, it is important to note that even if changes in unconstrained thought were sensitive to the degree of demand, it may not be linear. For instance, prior work has shown that task-unrelated thought tends to decrease as demands increase, but only to a point. When a task becomes too demanding, task-unrelated thought tends to increase, not decrease (e.g., Feng et al., 2013; Xu & Metcalfe, 2016). Thus, although we have demonstrated that increased task demands produce lower rates of unconstrained thought, more work is still needed to better define the relationship between task demands and unconstrained thought.

Second, our distribution of thought-probe responses was similar to, but not identical with, Mills et al.'s (2018), who used experience sampling. The main discrepancy concerns rates of constrained off-task thought. Whereas Mills et al. found ~20% of reports to be constrained and off-task, participants in our task only reported ~5%. Therefore, our laboratory task should be sufficient for those interested in the other thought-probe responses, but inappropriate if one were interested in reports of constrained off-task thought.

One additional point worth noting, however, is that although we clearly established that task demand can be used to manipulate rates of thought constraint, the results of Experiment 2 demonstrate the need to supplement assessments of constraint with measures of task-relatedness. Since both task-relatedness and thought constraint are influenced by task demand, it is possible that changes in task relatedness could appear as changes in constraint. Moreover, our distribution of thought-probe responses was similar, but not identical to Mills et al.'s (2018), who used daily-life experience sampling. The main discrepancy concerns rates of constrained off-task thought. Whereas Mills et al. found ~20% of reports to be constrained and off-task, participants in our task only reported ~5%. Therefore, our laboratory task should be sufficient for those interested in the other thought-probe responses, but inappropriate if one were interested in reports of constrained off-task thought.

In addition to examining the influence of a task-demand manipulation on rates of unconstrained thought, we also reported a number of exploratory analyses examining the relationships between thought-probe responses and flow, age, and verbal intelligence. Of those results, there were three key takeaways. First, lending further support to recent research (Kam et al., 2021; Mills et al., 2018; O'Neill et al., 2020; Smith et al., 2021), thought constraint and task-relatedness do not appear to be redundant. That is, relationships between thought-probe responses and other measures did not converge consistently along one dimension or the other as one would expect if they were redundant. Second, consistent with O'Neill et al.'s (2020) proposal, we found that unconstrained on-task thought was associated with flow. Although in Experiment 1, we found a small positive relationship between unconstrained thought and flow (similar to Smith et al., 2021), in Experiment 1, we found flow-state responses were positively associated with unconstrained on-task thought and negatively associated with unconstrained off-task thought. This result, though preliminary, is promising, as it suggests there is some relationship between unconstrained thought and the concept of a "flow state" (Csikszentmihalyi, 1988; Nakamura & Csikszentmihalyi, 2014) or "deep effortless concentration" (Marty-Dugas & Smilek, 2019). Third, and finally, unconstrained thought seems to behave differently when associated with on task versus off task thought. This was evidenced by the differential relationship between age, verbal intelligence, and flow measures. These differential patterns suggest that although unconstrained thought is always resource demanding, the role that it may play may differ depending on whether thoughts are currently on or off task. This distinction might be critical for understanding the costs and benefits of engaging in (un)constrained thought.

One interesting avenue for future research is to examine how motivation influences thought constraint. By manipulating task demand, we presumably restricted the number of attentional resources available in the difficult versus easy conditions and concluded—on that basis—that the restriction of resources influenced thought dynamics. However, motivation has also been shown to be a key moderator of thought content and dynamics (Brosowsky et al., 2020; Giambra, 1989; Smallwood et al., 2011; Teasdale et al., 1995; Thomson et al., 2013). Smith et al. (2021), for instance, found that increasing motivation increased constrained on-task thought and decreased unconstrained off-task thought. One possibility, then, is that increasing task demands decreases motivation, which consequently influences rates of (un)constrained thought. Notably, this alternative explanation would also apply to task-demand manipulations of task-unrelated thought (e.g., Giambra, 1989; Smallwood et al., 2011; Teasdale et al., 1995; Thomson et al., 2013) since motivation is also known to influence rates of task-unrelated thought (e.g., Brosowsky et al., 2021; Seli et al., 2018). In any case, further work is needed to tease apart the potentially interactive effects of task demands and motivation on both task-unrelated thought and (un)constrained thought.

Concluding Remarks

From a methodological perspective, our experiments establish that task demand can be used to effectively manipulate rates of thought constraint. In the same way that the literature on task-unrelated thought has benefited greatly from the ability to manipulate the relative frequency of task-unrelated thought, the growing literature on unconstrained thought will surely benefit from our novel finding that task demand can indirectly manipulate constraint in a brief online task. From a theoretical perspective, our results provide novel evidence that unconstrained thought is resource-dependent: When resources are limited, participants engage in less unconstrained thought. Moreover, we found additional evidence that constraint and task-unrelatedness are dissociable dimensions of mind wandering, and we observed a positive association between flow states and on-task constrained thought which helps to clarify prior reports of associations between unconstrained thought and flow. These important theoretical contributions further refine thought constraint as a construct within the Dynamic Framework and narrow the candidate processes underlying (un)constrained thought.

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Appendix A

Experiment 1 Thought-Probe Instructions

Throughout the even/odd number task, we will also periodically ask you about the content of your thoughts while you were performing the task.

In particular, we will ask you whether your thoughts were "freely moving" or not.

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.

Appendix B

Experiment 2 Thought-Probe Instructions

Throughout the even/odd number task, we will also periodically ask you about the content of your thoughts while you were performing the task.

While you are completing the task, you may find yourself thinking about something other than the task. These thoughts are referred to as "task-unrelated thoughts." Experiencing task-unrelated thoughts is perfectly normal, especially when one has to do the same thing for a long period of time.

We would like to determine how frequently you are focused on the task and how frequently you are thinking about thoughts that are unrelated to the task. To do this, throughout the task, you will be periodically presented a "thought-sampling screen" asking you to report whether you were ON TASK or experiencing TASK-UNRELATED THOUGHTS (TUTs) just before the thought-sampling screen was presented.

Being ON TASK means that, just before the thought-sampling screen appeared, you were focused on task. For instance, if you were thinking about your performance on the task or thinking about when you should make a button press, these thoughts would count as being ON TASK.

On the other hand, experiencing TASK-UNRELATED THOUGHTS (TUTs) means that you were thinking about something completely unrelated to the task. Some examples of TUTs include thoughts about what to eat for dinner, an upcoming event,

or something that happened to you earlier in the day. Any thoughts that you have that are not related to the task count as TASK-UNRELATED THOUGHTS.

When the thought-sampling screen is presented, we would like you to indicate whether, just prior to seeing the screen, your thoughts were ON TASK or TASK-UNRELATED.

The thought-sampling screen will look like this: "Just prior to seeing this screen, I was: (a) on task (b) thinking task-unrelated thoughts."

We will also ask you whether your thoughts were "freely moving" or not.

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.