DIFFERENTIATING FREELY-MOVING FROM TASK-UNRELATED THOUGHT:

THE EFFECTS OF MOTIVATION

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Abstract

Freedom-of-movement in thought (the degree to which thought is constrained in its variety as opposed to being free to change) can be empirically dissociated from other well-studied dimensions of thought such as its task-unrelatedness in everyday life setting, but has yet to be studied in a controlled experimental environment. While there are several proposed mechanisms by which thought can become constrained (and therefore less freely moving), none have been explored empirically. The present study set out to uncover which constructs associated with thought’s task-relatedness were also related to its freedom-of-movement and to test potential mechanisms of constraint. Motivation was within-subjects through a variable-value time-sensitive task and administered experience sampling probes asking participants to self-report the level of freely-moving thought, task-unrelated thought, deliberate control, arousal, and valence they were experiencing. Electrodermal activity and pupillometry were used as an index of physiological arousal in addition to self-reports. When participants were more highly motivated they reported having more constrained and more task-related thoughts, and having greater control over their thoughts. Control fully mediated motivation’s impact on freedom-of-movement of thought, but only partially mediated motivation’s impact on task-unrelated thought. Neither self-report or physiological measures of arousal were impacted by the manipulation, but high levels of both task-unrelated and freely-moving thought were associated with high ratings or self-reported arousal, higher pupillary responses to stimuli and smaller average pupil size, with freely-moving thought being uniquely associated with reduced skin conductance. Additionally, high freely-moving thought ratings were uniquely associated with slower responses, while high task-unrelated thought ratings were uniquely associated with low valence.
ratings. Overall, these findings support and further extend the previously identified dissociation between task-unrelatedness and freedom-of-movement as two separable dimensions of thought. They indicate that a person’s degree of control over their own thoughts is a crucial determinant of the content and especially the dynamics of that thought, but further work needs to be done to explore what nonconscious factors constrain thought movement.
Lay Summary

The current study was conducted to better understand how motivation affects the movement of thoughts and their subject. One-hundred forty participants completed a task and were told that they could leave early if they earned enough points, so that they would be more motivated to do well during blocks that were worth many points vs. blocks that were worth almost nothing. It was found that when participants were completing the sections worth more points, they felt more in control of their thoughts, they were less likely to be thinking about anything other than the task, and there is some evidence that their thoughts were stable and slowly moving compared to the low-point sections. The results also indicate that people’s thoughts were more stable when their motivation was high only because they were more in control of their thoughts, suggesting that they were using this control to purposely suppress their thoughts’ movement.
Preface

The research project described in this thesis was the product of the joint efforts of Dr. Kalina Christoff, Dr. Caitlin Mills, and myself, Gabriel King Smith. KC and myself came up with the idea of studying the relationship between arousal and freely-moving thought; CM and myself came up with the idea of studying the effect of a motivation manipulation on freely-moving thought. I devised the manipulation, designed the experiment, wrote the E-Prime presentation script, obtained ethical approval, and presided over data collection. I decided upon the analysis plan and interpretation of the results with input from KC and CM and wrote the analysis script myself.

Ethical approval for the research presented in this thesis was obtained from the University of British Columbia Behavioural Research Ethics Board (certificate number: H18-00125).
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α: Alpha, the theoretical Type I error rate of a statistical test, used as the value below which a $p$-value indicates that its accompanying effect is statistically significant (i.e., at $\alpha = .05$, $p$-values below .05 are deemed statistically significant, which theoretically means that if no effect exists, a false-positive will be produced 5% of the time).
List of Abbreviations

EDA: Electrodermal Activity
LC-NE: Locus-Coeruleus Norepinephrine System
OSF: Open Science Framework
RT: Reaction Time
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My dog Digby: you came of age with this thesis, which is the only reason I have mixed feelings about letting it go.

Lastly, the love of my life, Kate. It’s been a privilege, and I’m so proud of you, what you’ve done, and of what you’re doing.
Dedication

This thesis is dedicated to Caitlin Mills, without whom I might not be graduating. You’ve been a better mentor than I could have asked for, and a great friend besides. While I’m sad that you’re leaving, I know you’ll be a fantastic professor and that you’ll shine in New Hampshire!
Chapter 1: Introduction

The last decades have seen an explosion in the number of studies investigating the topic of mind wandering (Callard, Smallwood, & Margulies, 2012; Marchetti, Koster, Klinger, & Alloy, 2016; Mills, Raffaelli, Irving, Stan, & Christoff, 2017; Valdez, Ramírez, & García, 2014). One issue that researchers in the field are currently grappling with is the fact that there is no agreed-upon definition of mind wandering (Christoff, Irving, Fox, Spreng, & Andrews-Hanna, 2016; Christoff et al., in press; Irving, 2016; Seli et al., 2018; Seli, Risko, Smilek, & Schacter, 2016); instead, there are a number of dimensions of thought that are currently being investigated for their presumed connection to mind wandering. The majority of studies so far have focused on the dimensions of task-unrelatedness and stimulus-independence (i.e., cognition with little/no relation to external events; Schooler et al., 2011), either explicitly or implicitly through their operationalization of mind wandering (Mills, Raffaelli, et al., 2017; Seli et al., 2018). More recent, however, research has pointed out that both of these dimensions are content-based: they reflect solely what we are thinking about, while ignoring the dynamics of thought, or how thoughts unfold over time (Christoff et al., 2016; Mills, Raffaelli, et al., 2017). A new dimension, freedom of movement in thought, has been proposed by Christoff et al. (2016) and has since been shown to be empirically dissociable from task-unrelatedness and stimulus-independence (Mills, Raffaelli, et al., 2017; Smith, Mills, Paxton, & Christoff, in press).

The previously common approach of equating mind wandering to task-unrelated thought is increasingly becoming obsolete, as researchers recognize that further work is required to establish the relationship between mind wandering and various dimensions of thought such as its task-unreladness, stimulus-independence, and freedom-of-movement (Christoff et al., in press;
Seli et al., 2018). While debate over the best way to define the term ‘mind-wandering’ continues, it is clear both that the previously identified dimensions of thought are distinct (Mills, Raffaelli, et al., 2017) and that each has implications and connections to real-world behaviour that make each of them an important object of study.

One of the key strengths of freely-moving thought as a construct is that it distinguishes between constrained streams of thought (such as rumination) and spontaneously unfolding streams of thought (which mind wandering is often intuitively considered to be). The Dynamic Framework of Thought (Christoff et al. 2016), proposes two sources of constraint: automatic (e.g., habits, affect, salient distractors) and deliberate (e.g., goal-directed focus). This model categorizes mind wandering as one variety of spontaneous thought, with other types of spontaneous thought such as nighttime dreaming (less constrained) and creative thinking (more constrained). This model distinguishes between spontaneous thought (which is not subject to strong constraints), goal-directed thought (which is subject to strong deliberate constraints), and ruminative thought (which is subject to strong automatic constraints). This ability to discriminate between spontaneously unfolding thought and inflexible, fixated thought (which qualifies as rumination by definition; Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008) provides freely-moving thought with an advantage over the more commonly-used dimension of task-unrelatedness, and gives it particular relevance to cognition in everyday life where task-relatedness and stimulus-independence are harder to define than they are in the controlled environment of the lab.

1.1 Correlates and Influencers of Task-Unrelated Thought

While researchers have been able to dissociate freely-moving thought from the content-based dimensions of thought in the past (Mills, Raffaelli, et al., 2017; Smith, et al., in press), it is unclear
in what ways freely-moving thought can be related to the far-larger literature on task-unrelated thought. For example, off-task thought may be associated with better or worse performance depending on the metric and the task. Past research has established that the more participants engage in task-unrelated thought during learning and text reading tasks, the poorer they perform on subsequent tests of the material, which is likely a result of their impaired ability to integrate new information into existing knowledge (Frank, Nara, Zavagnin, Touron, & Kane, 2015; Mills, Graesser, Risko, & D’Mello, 2017; Pachai, Acai, LoGiudice, & Kim, 2016). Similarly, in sustained attention (also known as vigilance) tasks in which participants are required to respond to infrequent and/or unpredictable stimuli, such task-unrelated thoughts predict slower reaction times (RTs) when participants are eventually required to give a response (McVay, Meier, Touron, & Kane, 2013), though some studies fail to find such an effect (McVay & Kane, 2012).

However, in Go No-Go tasks such as the sustained attention to response task (SART) during which stimuli are presented regularly and most stimuli require the same response (e.g., press the “X” key to a 3, press the “O” key to any other digit), responses to the more frequent “Go” stimuli are faster during periods for which participants report having off-task thoughts at the expense of a greater proportion of errors to the less frequent “No-Go” stimuli (McVay & Kane, 2009, 2012; Smallwood et al., 2004; Wilson, Finkbeiner, Joux, Russell, & Helton, 2016). Higher frequency of task-unrelated thought seems to be a part of an automatic mode of responding in which conscious space is freed up for other mental processes and the prepotent response is given without proper evaluation, allowing for streamlined processing but causing the responses to be incorrect on the infrequent No-Go trials. This theory was supported more directly by Wilson et al. (2016) who found that the SART strategy participants adopted (fast-and-automatic versus slow-and-accurate) could be manipulated by changing the frequencies of Go and No-Go options (i.e.,
the more likely the No-Go option was, the slower and less prone to error participants were). This shift in strategies affected the occurrence of task-unrelated thought, which was highest in the low-frequency No-Go conditions when speed was high and accuracy was low.

Task-unrelated thought has also been related to affective valence. Killingsworth and Gilbert (2010) probed participants to answer questions about their happiness and the task-relatedness of their thoughts through the use of smartphones, and found that task-unrelated thoughts were associated with both concurrent and subsequent unhappiness. Research since has reinforced the often negative relationship between the two constructs but has called the causal nature of this effect into question. Ruby, Smallwood, Engen, and Singer (2013) found that the valence and temporal context of task-unrelated thought determined whether it resulted in unhappiness – for example, future-oriented thoughts resulted in improved mood. Smallwood, Fitzgerald, Miles, and Phillips (2009) and Stawarczyk, Majerus, and D’Argembeau (2013) both found the relationship in the opposite direction, with negative mood inductions resulting in increased frequency of task-unrelated and stimulus-independent thoughts. While the causal relationship between task-unrelated thought and negative affect appears to be uncertain, task-unrelatedness does seem to be associated with unhappiness in a simple correlational context.

The literature on arousal has been more contentious, and has focused on attention and task-relatedness of thoughts’ connection to the locus coeruleus, a brain region with far-reaching cortical connections that is believed to be the primary release point for norepinephrine in the brain (Aston-Jones & Cohen, 2005; Berridge & Waterhouse, 2003). This locus-coeruleus-norepinephrine system (LC-NE) exhibits two types of activity, tonic (consistent release of NE, independent of stimulation) and phasic (spikes in NE release in response to stimuli), with both signals detectable through non-invasive physiological measurements. Researchers have found that damaging the LC-
NE’s ascending pathway blunts both the average level of electrodermal activity (EDA) and its stimulus-evoked response (Yamamoto, Arai, & Nakayama, 1990; Zimmer & Demmel, 2000); likewise, a sizeable body of literature supports the notion that pupil size is determined largely by LC-NE activity through behavioural (Gilzenrat, Nieuwenhuis, Jepma, & Cohen, 2010; Murphy, Robertson, Balsters, & O’Connell, 2011), pharmacological (Chapman, Bradshaw, Donaldson, Jacobson, & Nakamura, 2014), and neuroimaging methods (Clewett, Huang, Velasco, Lee, & Mather, 2018; Murphy, O’Connell, O’Sullivan, Robertson, & Balsters, 2014).

One issue with using physiological measurements to index arousal that does not come with self-reports is that the average (tonic) signal strength (be it pupil size or average EDA) is not a true indication of arousal, nor is the phasic response to stimuli; each represent different aspects of physiological activation. This is also arguably a strength of these methods as well, for unlike self-reported measures they do not conceptualize arousal as a single, unified concept but treat it as a collection of features that often but not always vary together. In the literature on thought dimensions, many researchers now believe that high phasic responses are linked to a focus on external stimuli (though experimental studies have failed to fully distinguish between external stimuli that are and are not task-related) and that task-unrelated thought is associated with reduced phasic activity (Konishi, Brown, Battaglini, & Smallwood, 2017; Unsworth & Robison, 2018). There is less agreement on how tonic signals relate to thought. Some studies suggest that an inverted U-curve function describes this relationship best, such that task-related thoughts may only be possible under conditions of intermediate tonic arousal (Murphy et al., 2011; Unsworth & Robison, 2018), while others propose a simpler negative relationship, paralleling the negative relationship between phasic and tonic signals themselves (Aston-Jones & Cohen, 2005; Gilzenrat
et al., 2010) in which small pupil sizes are indicative of task-focus and large pupils are indicative of off-task thought.

Lastly, one of the most reliable (not to mention intuitive) influencers of task-unrelated thought is motivation – across a wide variety of studies, higher motivation to complete a task is associated with a decreased propensity of thoughts to drift away from the task. In addition to decades of research showing that performance on tasks that rely on sustained attention and are impaired by attentional lapses improves by inducing greater motivation (Bonnefond, Doignon-Camus, Hoeft, & Dufour, 2011; Corkum, Schachar, & Siegel, 1996; Esterman et al., 2016; Esterman, Reagan, Liu, Turner, & DeGutis, 2014; Tomporowski & Tinsley, 1996), recent research has confirm that those who report greater motivation are also less likely to experience task-unrelated thoughts (Seli, Cheyne, Xu, Purdon, & Smilek, 2015; Unsworth & McMillan, 2013). Mrazek et al. (2012) showed causation as well as correlation; they found that participants who were promised a financial award for good performance on a working memory task reported fewer task-unrelated. This effect was extended to time-based incentives by Seli, Schacter, Risko, and Smilek (2017) who found that participants who were told that their performance on a sustained-attention task would determine whether or not they would be allowed to leave early experience off-task thought less than those in a control condition. Mills, D’Mello, and Kopp (2015) showed these results on a within-participant basis by informing all participants in a passage reading experiment that they would be allowed to leave early with sufficient performance on a comprehension test, but that some passages would be worth more than others. Their finding that participants reported having fewer task-unrelated thoughts while reading passages containing information that was more valuable to the final test showed that the effect of motivation on off-task thinking scales with the magnitude of the motivation in question.
1.2 Exploring Mechanisms of the Effect of Motivation on Thought

In addition to its well-supported relationship to task-unrelated thought, examining the effects of a motivation manipulation on freely-moving thought may help us to understand the different mechanisms at play in these two dimensions. While the Dynamic Framework proposes that freedom-of-movement in thought is influenced most proximally by deliberate and automatic constraints (Christoff et al., 2016), less is theorized about the mechanisms that determine the task-relatedness of thought. By manipulating motivation and measuring indices of both deliberate and automatic constraint, it would be possible to determine the extent to which these two mechanisms play a role in the casual chain leading from motivation to thought, and discover whether these roles different depending on whether the content or dynamics of thought are being examined.

While intuition would suggest that manipulating participants’ conscious perceptions of the rewards for their performance would affect their thought process through a conscious, top-down route (deliberate constraint), it is also possible that mechanisms outside of conscious control (automatic constraints) may partially mediate this relationship. For example, past studies have demonstrated that inducing motivation has the potential to increase participants’ arousal (Berridge & Arnsten, 2013; Riemer & Viswanathan, 2013), and arousal has been proposed to be a source of automatic constraint (Christoff et al., 2016), though this has yet to be shown empirically.

By measuring arousal and asking participants to self-report their level of perceived control over their own thoughts (deliberate constraint), we can test whether automatic and/or deliberate constraints mediate any relationship that might exist between motivation and freely moving thought. An alternate (but not mutually exclusive) hypothesis is that these constraints may explain the effect of motivation on task-unrelated thought.
Self-reports of arousal have been found to correspond to objective physiological measures of bodily activation quite well (Dermer & Berscheid, 1972; Rosebrock, Hoxha, Norris, Cacioppo, & Gollan, 2017), but as with many constructs, they can diverge from the physiological indications under certain circumstances (Balconi, Vanutelli, & Finocchiaro, 2014; Pilotti, Klein, Golem, Piepenbrink, & Kaplan, 2015; Rosebrock et al., 2017), an issue that is complicated by the two varieties of signals derived from physiological data (tonic and phasic). Particularly given that automatic constraints are inherently outside of our control and have the potential to be outside of our awareness, it is advisable to use physiological measures in addition to self-reports if we seek to use arousal as a proxy for automatic constraint.

1.3 The Present Study
The goal of the current study was to explore the differential correlates of task-unrelated and freely-moving thought, and chiefly, determine whether they are differentially affected by manipulating participant motivation. In order to manipulate motivation, I created a simple and novel gender-identification task in which participants were incentivized by being allowed to leave early provided they earned enough points. Points earned were proportional to the speed of the response, with the maximum number of points differing substantially between ‘high motivation’ and ‘low motivation’ blocks. Thoughts probes were given psuedorandomly throughout the experiment, asking participants to report their level of freely-moving thought, task-unrelated thought, deliberate control over their thoughts, arousal, and valence in the preceding trials. Pupillometry and EDA equipment were used to obtain physiological indicators of tonic and phasic LC-NE activity.
Based on the Dynamic Framework (Christoff et al., 2016), I hypothesized that participants will report lower ratings of freely-moving thought in the high motivation condition compared to the low motivation condition. I also hypothesized that participants would report lower ratings of task-unrelated thought and higher ratings of deliberate control in the high motivation condition. I also anticipated a positive correlation between ratings of task-unrelated and freely-moving thought based on past work that has shown that while they are independent, they do covary to an extent (Mills, Raffaelli, et al., 2017).

Past research has found associations between task-unrelated thought and arousal (Smallwood et al., 2011; Smallwood, O’Connor, Sudbery, & Obonsawin, 2007; Unsworth & Robison, 2018), valence (Killingsworth & Gilbert, 2010; Smallwood et al., 2009, 2007), and both accuracy and RT on laboratory tasks (McVay & Kane, 2012; Wilson et al., 2016). As discussed above, arousal is a potential instigator of automatic constraint (Christoff et al., 2016) and thus I expected freely-moving though ratings to be lower when both self-reported arousal and our two tonic physiological measures are high. Given that phasic responses are believed to index either stimulus-dependence or task-focus than they are bodily activation per se (Smallwood et al., 2011; Unsworth & Robison, 2018), I did not expect them to covary with freely-moving thought, but I did expect higher phasic responses to correspond to lower ratings of task-unrelated thought. I also anticipated that task-unrelated thought would be significantly associated with self-reported arousal and tonic pupil size/EDA, but given the heterogenous findings regarding physiological signals and off-task thought in the past (Grandchamp, Braboszcz, & Delorme, 2014; Konishi et al., 2017; Smallwood et al., 2011), I refrained from making hypotheses on the direction of the relationship. I hypothesized that phasic pupil responses would be greater when ratings of task-unrelated thought
were lower based on past findings of the phasic response relating to task/stimulus coupling (Smallwood et al., 2011; Unsworth & Robison, 2018).

Given the relationship found between task-unrelated thought and valence in the past (Killingsworth & Gilbert, 2010; Ruby et al., 2013; Stawarczyk et al., 2013), I expected participants to report more unpleasant feelings during periods of task-unrelated thought. As there was no reason to believe that freely-moving thought was associated with valence, I predicted that there would be no relationship between the two.

The associations between thought dimensions and performance were more difficult to predict given the ambiguous results across studies in the past (McVay & Kane, 2012; Wilson et al., 2016), but we expected higher levels of task-unrelated thought to either correspond to slower responses or to not be related to RT at all. It is possible that responses will be slower and more likely to be incorrect because attention is being taken away from the task at hand (McVay et al., 2013); it was also deemed possible that the 50/50 success probability of the two options in the task would dissuade participants from ever engaging in a fast-but-inaccurate strategy, and if task-unrelated thought was associated with strategy as opposed to RT and accuracy per se, it would be unrelated to either in such a task (Wilson et al., 2016). One possibility that I did believe to be unlikely was that responses would be sped up, as in McVay and Kane (2009) and Smallwood et al. (2004), since this speed seems to be a result of Go/No-Go task’s long streaks of Go stimuli, whether one believes that participants adopt a strategy or are unwillingly lulled off-task; similarly, it is difficult to imagine that off-task thoughts would improve accuracy. With no controlled laboratory research on the impact of freedom-of-movement in thought on task performance, I was agnostic about the relationship between freely-moving thought and both RT and accuracy.
Chapter 2: Methods

2.1 Participants

One-hundred forty (103 female) undergraduate students aged 17 to 61 ($M = 20.63$, $SD = 4.26$) at the University of British Columbia participated in the study in exchange for course credit. Inclusion criteria included fluency in English and no uncorrected visual impairments.

2.2 Materials and Measures

2.2.1 Stimuli

The task stimuli were a set of 38 pictures of faces, 19 female and 19 male, that were shown to participants in consistent male-female pairs. Face stimuli were taken from the MacBrain Face Stimulus Set, development of which was overseen by Nim Tottenham and supported by the John D. and Catherine T. MacArthur Foundation Research Network on Early Experience and Brain Development (Nim Tottenham at tott0006@tc.umn.edu can be contacted for more information concerning the stimulus set).

2.2.2 Thought Probes

Each thought probe was identical and began with a modified affect grid. The grid was adapted from a 9x9 grid (Russell, Weiss, & Mendelsohn, 1989) that prompts simultaneous self-report of valence (x-axis, Unpleasant Feelings to Pleasant Feelings) and arousal (y-axis, Sleepiness to High Arousal). The modified affect grid used in the current study differed in three ways which were all intended to increase intuitiveness, reduce visual clutter, and make answering easier on participants as they would be prompted to answer many times during the experiment: a) labels on the diagonals
(“Stress,” “Excitement,” “Depression,” and “Relaxation”) were shown during the instructions but removed during the probes, b) “High Arousal” was changed to “Alertness”, a term judged to be more easily understood by the participants but that still mapped on to the idea of physiological arousal, and c) sadness, happiness, alertness, and sleepiness emojis (cartoon faces representing emotions) were added to each side of the grid.

Following the affect grid, participants were given three statements, each accompanied by 6-point unnumbered Likert scales, with the leftmost option being labelled as “Strongly Disagree” and the rightmost option being labelled as “Strongly Agree.” The statements, assessing freedom of movement in thought, task-relatedness of thought, and deliberate constraint on thought respective, were: “My thoughts were moving freely,” “I was thinking about something other than the task at hand,” and “I was in control of my thoughts.”

2.2.3 EDA

A Biopac (Goleta, CA, USA) MP 150 with GSR100c attachment was used to collect EDA data. The module was set with a gain of 5 µmho (micromho/microsiemens) with a 10Hz low-pass filter and no high-pass filter. Disposable gel electrodes were placed on the finger pads of the index and ring fingers on participants’ left hand. Acqknowledge 5.0 software was used in conjunction with the Biopac system to record the data.

2.2.4 Pupilometry

An EyeTribe (Copenhagen, DK) portable eye tracker mounted at the base of the stimulus-presentation screen was used to gather pupil size information at a rate of 30Hz.
2.2.5 **Presentation Software**

The experimental procedure was presented and responses were collected with E-Prime 2 software created by Psychology Software Tools (Sharpsburg, PA, USA).

2.3 **Procedure**

Participants were given debriefing forms upon entering the lab, after which they were asked to wash their hands without soap to improve the fidelity of EDA readings. They were fitted with electrodes on their fingers at which point the Biopac system was calibrated. The EyeTribe tracker was calibrated to their eyes, with at least a three-out-of-five star accuracy rating required to continue onto the next step; calibration was redone as many times as needed to meet this threshold.

All instructions were presented on the screen in front of the participants and multiple-choice questions testing materials from previous screens were embedded throughout the instruction portion of the experiment to ensure participant comprehension. The task itself involved being presented with a male and a female face and pressing an arrow key corresponding to the side of the screen containing the female face within two seconds (participants were not told that the time limit was two seconds). Three seconds of white screen followed each trial (in order to better record phasic EDA and pupil dilation responses) before the next trial started with a fixation cross in the middle of the screen for 500ms prior to the presentation of the faces. The experiment consisted of four counterbalanced blocks of 75 trials (for a total of 300 trials), with five probes interspersed semi-randomly throughout each block (for a total of 20 probes). Each probe began with the word “STOP” appearing on screen in place of a fixation cross, followed by instructions to remember what the participant had just been thinking about and finally the affect grid and agreement statements.
In order to induce different levels of motivation across different blocks within-subjects, I adopted a technique based off of Mills, D’Mello, and Kopp's (2015) study in which participants were told to study passages in preparation for a comprehension test that would determine whether they could leave the experiment early. The experiment hinged on participants being told that certain passages contained the information needed to answer either a small or large number of the test questions, thus creating a value differential between passages. For the present study, participants were informed that they would be able to leave early (not have to complete the last two blocks of what they were told was a six-block experiment) if they earned enough points, which could be earned from correct answers. Participants were not informed of the cut-off point, which was set low enough (1000 points) so that none of the 140 participants had to complete the extra two blocks. The number of points earned from a correct answer was proportional to the speed of the answer (e.g., answering 500ms of the way through the 2000ms of available time would earn them three-quarters of the maximum number of points). This maximum differed between blocks, with two blocks (referred to as “Bonus Blocks”) granting up to 100 points per correct answer, and the other two blocks (referred to as “Regular Blocks”) granting only a five point maximum. Each block began by stating the maximum number of points, and the order of presentation was counterbalanced across participants.

After the last block, the final score was shown on screen and the experimenter let the participant know that they had met the threshold to leave early without completing the extra blocks (provided the score was over 1000, which it was in all cases). Participants were given a short form to fill out which asked about their age, gender, and ethnicity, as well as three manipulation check questions: “Were you motivated to get a high score so that you could leave early?” “If you answered no above, why?” and “Did you try harder or were you more concerned with your success
in the bonus blocks (max: 100 points) compared to the regular blocks (max: 5 points)?”. The options for the first and third question were “Yes,” “Only a little,” and “No.” The second question was open-ended. Finally, participants were given a debriefing form explaining the purpose of and hypotheses for the study.

2.4 Details of Data and Analysis

2.4.1 Design

The unit of analysis for the experiment were the probe-sets: consecutive sets of 10-20 trials followed by a thought probe. Phasic values for physiological data were calculated for each trial, and averaged across all trials in a probe-set to create a single value; all other variables were collected/determined at the probe level (or the block level, as was the case with motivation). This resulted in a maximum of 20 data points per person.

2.4.2 Physiological Data

Pupil size information from the left eye was used for all analyses; data from the right eye was recorded and is included in the data file accessible online. Tonic and phasic measures were derived from the continuous EDA and pupillometric datasets. Tonic measures were created by averaging conductivity/pupil diameter across the time course for each probe-set (beginning at the first trial, ending at the thought probe). A phasic response was created for each trial by subtracting the average baseline value (the 500ms prior to trial onset) from the maximum value recorded in the three seconds following stimulus onset, and the phasic response value for each probe set was calculated as the average phasic response across all trials in that probe-set. Visual exploration of the data indicated that the three-second window between the response on a given trial and the
presentation of the fixation cross for the following trial was insufficient to allow for the resolution of a phasic EDA response in the majority of cases; thus, the phasic skin response variable was dropped from further analyses.

2.4.3 Statistical Analyses

To capture the multilevel nature of the data, mixed effects tests were used to conduct all analyses with the exception of the mediation analyses. As is recommended for mixed effects analyses, all test were initially run using the fixed effects of interest and a maximal random effects structure (West, Welch, & Galecki, 2014; Winter, 2013), including by-subject random intercepts and slopes that are allowed to correlate with one another. In the event that the model failed to converge, the plan in place was to reduce the random effect structure sequentially until the model converged. The sequence of models used in each case was, a) the maximal (full) model, b) a model with uncorrelated random intercepts and slopes, and finally, c) a model without the random effect of slope. This proved to be unnecessary as the model converged in all cases. In all models, conclusions were based off t-tests evaluating the significance of the fixed effects of the model using Satterthwaite’s approximations to estimate degrees of freedom.

One disadvantage of nonexperimental tests (here, all test besides those of the effects of motivation on other variables) is the inability to separate out subject-level relationships (e.g., people who drink more alcohol might be more likely to have higher intelligence scores) with observation-level relationships (e.g., consuming alcohol immediately before an intelligence test might impair your performance). The conflation of two levels of effects with different magnitudes or even directions, sometimes known as Simpson’s Paradox (Kievit, Frankenhuis, Waldorp, & Borsboom, 2013), has been observed before in the mind wandering literature: Wilson et al. (2016)
found that task-related thoughts (as opposed to task unrelated thoughts) corresponded to faster responses when analyzing within-subjects, but that there was a nonsignificant trend towards participants who reported more task-related thoughts overall being slower to answer than the participants who reported less. To account for these two possible sources of variance within the data, each mixed effects model was run with two predictors: a mean score for the participant (the same score for all observations belonging to the same person), and a deviation score that corresponded to that participant’s mean subtracted from the observation’s raw score. The presence of a statistically significant effect of the mean variable indicates that a participant’s overall level on variable X is predictive of their ratings on variable Y; an effect of the deviation score indicates that scores on X at any given moment are predictive of scores on Y at that same moment in time. The random effect structure used is identical between the experimental and nonexperimental analyses; random effects are meaningful only for nested observation-level variables, and thus no random effect of the slope of the within-subject mean was added.

A coding issue with the E-Prime software resulted in a portion of incorrectly coded responses for the arousal component of the affect grid; as such, data were transformed into a binary variable in which ‘0’ represented negative or below average arousal on the scale (0-4) and ‘1’ represented positive or above average arousal (6-9) with neutral scores of 5 being discarded. This transformation corrected for the misclassification of responses error by ensuring that the intended and recorded responses were both categorized into the same bin. Tests were performed with both the continuous and binary data. As the results did not change, only the results of the binary tests are reported here.

For tests of mediation, the mediation package in R (Tingley, Yamamoto, Hirose, Keele, & Imai, 2014) was used to create 10,000 bootstrapped samples for the purpose of obtaining an
average indirect effect estimate and constructing a 95% confidence interval value for it, producing an accompanying p-value. To ensure replicability of bootstrapping results, a seed state of 999 was set prior to running each mediation test.

2.5 Preregistration and Confirmatory vs. Exploratory Analyses

Prior to the collection of data, I preregistered the methods, main hypotheses, and preliminary analysis scripts on the Open Science Framework (OSF) where they are freely available at https://osf.io/hjvsz/ along with all data files.

In order to limit the number of confirmatory tests, the only analyses for which I made preregistered a-priori hypotheses were for the effects of motivation on each of the three measured thought variables (suppression of task-unrelated and freely-moving thought, enhancement of deliberate control), the correlational analyses between task-unrelated and freely-moving thought (positive relationship), and the mediation analyses (significant indirect effects of motivation on the thought variables through the mediating variables). The analyses associating freely-moving and task-unrelated thought with other non-manipulated variables were intended to fully compare the association profiles of thought contents and dynamics and identify avenues for future research, do not correspond to preregistered hypotheses, and were conducted on an exploratory, post-hoc basis.

It should also be noted that the analysis script changed significantly from the initial preregistered version to the latest version due to: a) the inclusion of post-hoc tests, b) the inclusion of figure/plot-generating code, c) adjustments/improvements to the analysis made on the basis of information regarding best practices (particularly as they pertain to mixed effects analyses) gleaned after the preregistration. A full list of changes and their accompanying justifications is available in the OSF repository.
Chapter 3: Results

3.1 Data Loss

An experimenter error resulted in the lost of the demographic and manipulation check information from one participant. Equipment failures resulted in the loss of eye-tracking data from five participants and the loss of EDA data from two participants. These participants were included in all analyses that did not require the missing modality of data, meaning that different analyses contained slightly different samples. Lastly, given the close-to-100% accuracy rates in the experiment across participants (a histogram of the accuracy score distribution can be found in Appendix B), I elected to remove the 30 probe-sets for which accuracy was below 60% and thus at or below chance, as such chance answering indicates that participants were giving route responses and were unlikely to have been putting deliberate thought into their answers during the ensuing thought probe. This exclusion criterion meant that all probe-sets from one participant were excluded; thus, the final sample size for the analyses was 139.

3.2 Motivation Manipulation Check

51.8% of participants gave a definitive “Yes” to the question of whether or not they were motivated to try harder during the high motivation blocks compared to the low motivation blocks, although an additional 32.4% said that they were motivated “a little”, leaving only 15.8% who reported being completely unconcerned with the difference between blocks. A one-proportion z-test was performed on the manipulation check information to derive a 95% confidence interval of 77.2%-89.3% for the percentage of participants who reported being at least somewhat more motivated to perform well during the high as opposed to low motivation blocks, giving us some confidence that
the experimental manipulation influenced most participants’ motivation to complete the task in the expected direction.

All analyses below that involve the effect of motivation on a second variable (the three thought variables and the four arousal variables) were rerun with a subsample that excluded all of those who answered “No” to the manipulation check question and the results, with the expectation that the magnitude of some of the effects might increase when only participants who reported truly experiencing a difference in motivation between the two conditions were analyzed. However, all effects failed to reach statistical significance in this subsample ($p_s >= .072$), indicating that the absence of certain effects below cannot likely be explained by the manipulation being ineffective or unconvincing for a portion of the sample. The full results can be found in Appendix A.

3.3 Descriptive Statistics

Table 1 contains the means and standard deviations for each measured variable, averaged over all participants and broken down by motivation condition. Both freely moving ($M = 3.75, SD = .94$) and task-unrelated thought ($M = 3.61, SD = 1.03$) ratings tended toward the middle of their 6-point Likert scales. As for performance outcomes, the mean RT was 657.03ms ($SD = 54.64ms$), and the mean accuracy rate was 96.6% ($SD = 3.4\%$). Visual inspection of the data indicates a ceiling effect for accuracy, with accuracy rates in excess of 90% in the majority of probe-sets (see Appendix B).
<table>
<thead>
<tr>
<th></th>
<th>Low Mean (SD)</th>
<th>High Mean (SD)</th>
<th>df</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freely-Moving Thought</td>
<td>3.82 (1.10)</td>
<td>3.70 (1.04)</td>
<td>137.17</td>
<td>-1.698</td>
<td>.092</td>
</tr>
<tr>
<td>Task-Unrelated Thought</td>
<td>3.66 (1.23)</td>
<td>3.49 (1.08)</td>
<td>136.82</td>
<td>-2.495</td>
<td>.014</td>
</tr>
<tr>
<td>Deliberate Control</td>
<td>3.34 (1.04)</td>
<td>3.47 (1.15)</td>
<td>137.19</td>
<td>2.243</td>
<td>.027</td>
</tr>
<tr>
<td>Self-Reported Arousal*</td>
<td>6.04 (1.71)</td>
<td>5.84 (1.97)</td>
<td>124.08</td>
<td>-1.524</td>
<td>.130</td>
</tr>
<tr>
<td>Phasic Pupil Dilation</td>
<td>4.23 (3.00)</td>
<td>4.07 (2.69)</td>
<td>116.33</td>
<td>-1.153</td>
<td>.251</td>
</tr>
<tr>
<td>Tonic Pupil Size</td>
<td>14.15 (3.94)</td>
<td>14.22 (3.97)</td>
<td>134.57</td>
<td>-.050</td>
<td>.960</td>
</tr>
<tr>
<td>EDA</td>
<td>6.01 (4.24)</td>
<td>5.96 (4.18)</td>
<td>133.69</td>
<td>1.105</td>
<td>.271</td>
</tr>
<tr>
<td>Valence</td>
<td>5.38 (1.61)</td>
<td>5.44 (1.58)</td>
<td>109.76</td>
<td>-.481</td>
<td>.632</td>
</tr>
<tr>
<td>Accuracy</td>
<td>96.5% (4.0%)</td>
<td>96.7% (3.2%)</td>
<td>137.40</td>
<td>1.016</td>
<td>.311</td>
</tr>
<tr>
<td>RT</td>
<td>660.3ms (59.2ms)</td>
<td>654.2ms (55.3ms)</td>
<td>136.63</td>
<td>-1.792</td>
<td>.075</td>
</tr>
</tbody>
</table>

Table 1. Descriptive statistics for each of the two motivation conditions, and test statistics for the effect of motivation on each. p-values in bold represent effects of motivation that are significant at α = .05.

*1-9 numeric values for self-reported arousal that produced the mean and standard deviation in the above table are not used in the analyses themselves due to coding issues; the test statistics above correspond to the analyses using binarized data (see below).
3.4 The Impact of Motivation on Thought Dimensions

Two maximal mixed effect models with motivation level as the predictor and freely-moving and task-unrelated thought ratings as the respective outcomes were constructed to test whether or not ratings on these two dimensions of thought were influenced by the motivation manipulation. The fixed effect of motivation on freely-moving thought was found to be statistically insignificant, though trending towards a negative relationship, $t(137.17) = -1.698$, $p = .092$, whereas the effect of motivation on task-unrelated thought was found to be statistically significant, $t(136.82) = -2.495$, $p = .014$.

The absence of a motivational effect on freely-moving thought seemed worth exploring further, particularly because the hypothesis was confirmatory and explicitly directional; I predicted that participants would report less freely-moving thought in the high motivation “bonus” block, which was indeed the case in the present sample, regardless of statistical significance status. While the regression family of statistical tools does not allow for the explicit use of one-tailed versus two-tailed hypothesis tests unlike families such as t-tests, if a one-tailed test had been performed the p-value would have been half, making it $p = .046$, significant at $\alpha = .05$. Similarly, a post-hoc one-tailed paired-samples t-test found the effect of motivation on freely-moving thought to be significant, $t(138) = 1.750$, $p = .041$ (mimicking the mixed effects results, the corresponding two-tailed test did not quite reach statistical significance, $p = .082$). As well, post-hoc exploratory analyses found that the effect became significant when a random effect structure without a random slope was used, $t(2589.5) = -2.582$, $p = .010$, meaning that the random slope added enough variance to the fixed effect of motivation on freely-moving thought to render it nonsignificant, without reducing the magnitude of the raw effect. Altogether, the data show numerous indications of an
effect of motivation on freedom-of-movement in thought, but cannot be said to provide conclusive support for such a relationship.

In addition, I created a similar mixed effects model to determine whether or not deliberate control over thoughts differed between conditions. The effect of motivation on control was significant and positive, $t(137.19) = 2.243, p = .027$, indicating that participants reliably rated their control over their own thoughts as being higher during the high motivation “bonus” blocks compared to the low motivation “regular” blocks.

Though they were not relevant to the primary goal of differentiating freely-moving and task-unrelated thought, statistics from the tests examining the effect of motivation on the other seven variables in a similar fashion to the tests performed above can be found in Table 1. All effects were nonsignificant, though the speeding of RTs in the high motivation block came close to significance ($p = .075$).

### 3.5 Association Profiles of Freely-Moving and Task-Unrelated Thought

In order to explore whether or not freely-moving thought exhibited similar relationships to task-unrelated thought with other variables such as components of affect and performance, I performed a number of mixed effects regression with the two thought dimensions as the predictors and the other measured variables of the study as the outcomes. These results are summarized in Table 2. As observation-level effects were of primary interest to our goals, these results are reported first and in individual sections, followed by a single section summarizing the subject-level effects.
Table 2. Results of mixed effects regression of the two dimensions of thought on arousal, valence, and performance variables. p-values in bold represent effects of motivation that are significant at $\alpha = .05$.

<table>
<thead>
<tr>
<th></th>
<th>Freely-Moving Thought</th>
<th></th>
<th>Task-Unrelated Thought</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>df</td>
<td>t</td>
<td>p</td>
<td>df</td>
</tr>
<tr>
<td>Self-Reported Arousal</td>
<td>119.08</td>
<td>5.747</td>
<td>.001</td>
<td>122.82</td>
</tr>
<tr>
<td>Phasic Pupil Dilation</td>
<td>36.57</td>
<td>2.955</td>
<td>.005</td>
<td>54.62</td>
</tr>
<tr>
<td>Tonic Pupil Size</td>
<td>73.76</td>
<td>-3.335</td>
<td>.001</td>
<td>50.17</td>
</tr>
<tr>
<td>EDA</td>
<td>484.2</td>
<td>-2.045</td>
<td>.041</td>
<td>66.07</td>
</tr>
<tr>
<td>Valence</td>
<td>122.28</td>
<td>-0.855</td>
<td>.394</td>
<td>120.33</td>
</tr>
<tr>
<td>Accuracy</td>
<td>96.10</td>
<td>.120</td>
<td>.905</td>
<td>93.94</td>
</tr>
<tr>
<td>RT</td>
<td>105.09</td>
<td>2.506</td>
<td>.014</td>
<td>96.53</td>
</tr>
</tbody>
</table>

3.5.1 Correlation Between the Dimensions

There exists strong evidence that while separable, the dimensions of freedom-of-movement and task-unrelatedness of thought are highly correlated (Mills, Raffaelli, et al., 2017), and I expected this correlation to be elevated in an experimental context in which the “task” that task-unrelatedness is judged against is well-defined and controlled by the experimenters. A mixed effects model with both participant means and within-participant deviations on task-unrelated thought as predictors and freely-moving thought as the outcome showed a significant effect at the level of the observation, $t(125.40) = 14.44, p < .001$. A post-hoc Pearson’s paired samples correlation test indicated that the correlation coefficient between the two measures was $r = .56$. 

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3.5.2 Arousal

I conducted four mixed effects analyses with mean and deviation scores of freely-moving thought as the predictors and the four indicators of arousal (self-report, phasic pupil dilation, tonic pupil size, tonic EDA) as the outcomes in each. Within-subjects, both the binary transformation of self-reported arousal, t(104.03) = 5.857, p < .001, and phasic pupil dilation, t(106.31) = 2.413, p = .018, showed positive relationships with freely-moving thought. The tonic measures of pupil size, t(106.18) = -2.176, p = .032, and EDA, t(603.20) = -1.982, p = .048, both displayed negative relationships with freely-moving thought.

Four additional analyses were conducted with task-unrelated thought as the outcome and the four arousal measures as predictors. Within-subjects, task-unrelated thought showed a near-identical pattern of associations with the measures of arousal, with the exception of tonic EDA ratings which appeared to have no association to task-unrelated thought, t(75.64) = .884, p = .380. Reports of off-task-thoughts were associated with higher ratings of self-reported arousal, t(106.91) = 7.381, p < .001, larger phasic pupil dilations, t(86.33) = 2.986, p = .004, and smaller tonic pupil size, t(55.85) = -3.531, p = .001.

3.5.3 Valence

Two mixed effects models with freely-moving and task-unrelated thought as outcomes and both means and deviations of self-reported valence as the predictor were constructed to determine whether happiness was associated with different types of thought. As predicted, reports of higher-than-average levels of off-task thought were associated with higher happiness ratings within-subjects, t(108.46) = -3.332, p = .001. On the other hand, there was no such relationship
between participants’ valence and the freedom-of-movement of their thoughts, $t(105.00) = -1.005, p = .317$.

### 3.5.4 Performance

Two maximal mixed effects models with freely-moving and task-unrelated thought as predictors and accuracy (as a percentage of the trials in a probe-set answered correctly) as the outcome revealed that neither freely-moving, $t(94.71) = .475, p = .636$, nor task-unrelated thought, $t(99.70) = -.477, p = .634$, could be significantly predicted from accuracy within-subjects. As discussed above, this is likely due to a ceiling effect in the data (see Appendix B for a histogram the accuracy data).

More informative as a measure of performance was RT. Within-subjects, the freely-moving thought model was significant, revealing that slower responses corresponded to thoughts that were more freely-moving, $t(105.09) = 2.506, p = .014$, whereas the model predicting task-unrelated thought was not, $t(96.53) = .585, p = .629$.

### 3.5.5 Subject-Level Effects

Including a term that represented the participant’s mean score on the predictor variable in addition to a term representing the raw value’s deviation from that mean allowed us to examine effects at the level of individual-differences. While relationships at the observation level were of key interest to the goal of understanding how freely-moving and task-unrelated thought are connected to mental and physical constructs as well as task features, better understanding these subject-level relationships lets us know whether individual’s propensity to ‘mind wander’ by either dimension of thought is predictive of their outcomes on other variables.
Firstly, the observation-level relationship between freely-moving and task-unrelated thought did not come close to bearing out at the subject-level, $t(2580) = .100, p = .921$, suggesting that the people who were more likely to engage in task-unrelated thought were no more or less likely to engage in freely-moving thought. This finding adds to the body of work differentiating the two constructs (Mills, Raffaelli, et al., 2017; Smith, et al., in press) by indicating that even though they are predictive of each other at any given point in time, the predispositions to experience each of these dimension of thought are utterly unrelated.

The only arousal measure to demonstrate a subject-level effect with a dimension of thought was self-reported arousal: ratings of self-reported arousal tended to be higher for participants with high average freely-moving thought scores, $t(143.22) = 2.861, p = .005$. Average levels of freely-moving thought were not associated with any of the three physiological scores ($ps > .157$), nor were average levels of task-unrelated thought associated with any of the four arousal variables ($ps > .356$). Both variables were similarly unrelated to valence ($ps > .267$) and accuracy ($ps > .835$) on a subject-level, indicating that the relationship between task-unrelated thoughts and happiness cannot be explained as happier people being less likely to drift off-task or vice versa.

Finally, although average levels of both thought dimensions were unrelated to accuracy scores ($ps > .835$), participants who reported more freely-moving thought also reported answering slower, $t(138.75) = 2.764, p = .006$, mirroring the observation-level effect. As well, whereas there was no evidence of a relationship between task-unrelated thought and RT on the observation-level, there was a nonsignificant trend towards higher mean task-unrelated thought scores predicting slower responses $t(138.40) = 1.889, p = .061$. 

3.6 Mediation Analyses

In order to explore the mechanisms behind motivation’s effects on thought, a series of mediation analyses testing whether or not the variables believed to represent deliberate constraint (deliberate control) and automatic constraint (arousal) accounted for the relationship between motivation and thought were conducted.

I used the package ‘mediate’ in R (Tingley et al., 2014) was used to estimate the direct and indirect effects of motivation on each of the two thought variables with the five candidate mediators: deliberate control and the four arousal measures. The ‘mediate’ function of the package uses constructs bootstrapped samples from the data and estimates each of these two effects (in addition to the total effect) along with a 95% confidence interval and accompanying p-value. A significant p-value indicates that the effect in question was found in the same direction in 95% of the bootstrapped samples. Analyses involving bootstrapping depend on randomness and thus the same test may return different results if performed twice; to counter this, the number of bootstrapped iterations was set to 10,000 (to decrease the odds of finding an uncommon result by chance) and the random seed was set to 999 prior to each analysis (to ensure the exact same results can be found by anyone). The p-values associated with both the indirect and direct effects for each test can be found in Appendix C. Within-subject centered scores were used instead of raw scores to ensure that observation-level effects were captured by the analysis, not subject-level effects. Mediations were also conducted with raw scores, with no changes in the significance statuses of any of the indirect effects (see Appendix C for test statistics).

While some guidelines state that mediation should not be conducted unless a total effect between the independent and dependent variables has been found significant (Baron & Kenny, 1986; Judd & Kenny, 1981), the ambiguous evidence for an effect of motivation on freely-moving
thought prompted me to continue with the tests of control and arousal’s mediation of this relationship.

Figure 1 and Figure 2 contain diagrams of the relationships involved in the control mediation analyses for freely-moving and task-unrelated thought respectively. The relationship between control and the dimensions of thought ($p < .001$ in both cases) was determined by creating a mixed effects model with each of the dimensions as outcomes and both control (deviations and subject means) and motivation as predictors, using the deliberate control deviation score to estimate the relationship between the mediator (control) and the outcome when controlling for motivation. Deliberate control was found to significantly mediate the relationships between motivation and both task-unrelated thought, $p < .001$, and freely-moving thought, $p = .001$, despite the lack of a clear relationship found between motivation and freely-moving thought above. In line with this, the mediation analysis indicated that there was no direct effect of motivation on freely-moving thought when control was taken into account, $p = .206$, while on the other hand, there was still a significant direct effect of motivation on task-unrelated thought even when the indirect effect was included, $p < .001$. 
Figure 1. Mediation model and resulting p-values for control’s mediation of the relationship between motivation and freely-moving thought. The p-value for the relationship between control and freely-moving thought represents the p-value associated with the mixed effects regression of freely-moving thought onto control, holding motivation constant. * = significant at α = .05.
Next, I tested whether or not there was an effect of motivation on the four arousal measures. Four mixed-effects models with motivation as the predictor and each of the four arousal measures (self-reported, phasic and tonic pupil size, and EDA) were constructed, maximal models converged in all cases, and indicated an absence of effect of motivation on any of the indicators of arousal ($p\,s > .123$; see Table 1). Mediation analyses indicated a complete absence of indirect effects of motivation on either of the thought variables through any of the physiological measures ($p\,s > .160$), but found significant indirect effects of motivation through self-reported arousal on both freely-moving ($p = .020$) and task-unrelated thought $p = .020$).

Figure 2. Mediation model and resulting p-values for control’s mediation of the relationship between motivation and task-unrelated thought. The p-value for the relationship between control and task-unrelated thought represents the p-value associated with the mixed effects regression of task-unrelated thought onto control, holding motivation constant. * = significant at $\alpha = .05$. 

\[ p = .027^* \quad \text{Direct:} \quad p = .003^* \quad \text{Indirect:} \quad p < .001^* \]

**Task-Unrelated Thought**
Chapter 4: Discussion

The current study was designed to explore the mediated and unmediated impact of motivation on two different thought dimensions: freely-moving thought and task-unrelated thought. Participants engaged in a simple gender-discrimination task in which their performance was motivated by the goal of being allowed to leave early, with performance in half of the blocks counting significantly more to this goal, and half of the blocks contributing far less. At intervals during the task, participants responded to thought probes asking about the content (task-relatedness) and dynamics (freedom-of-movement) of thought, as well as perceived thought control, arousal, and affective valence; physiological measures of arousal (pupillometry and EDA) were also recorded.

As predicted, participants reported less task-unrelated thought during the high-motivation blocks. However, there was no direct effect between motivation and freely-moving thought; instead the deliberate control variable mediated this relationship such that higher motivation produced greater control, which in turn suppressed freely-moving thought. On the other hand, self-reported control only partially mediated the relationship between motivation and task-unrelated thought – while an indirect effect through control was found, the direct effect remained in the presence of control.

This partial mediation is puzzling on the surface – one might expect that motivation’s suppression of task-unrelated thought would be accounted for entirely by control (i.e., motivation gives you conscious control over your thoughts, which in turn allows you to prevent mind wandering). Considering the intentionality of off-task thinking makes these results more understandable: while many of our task-unrelated thoughts fall into the category of unintentional and counterproductive drifts of thought away from what is important to us, a large portion may be
intentional. A body of literature exists differentiating the impact and influence of intentional versus unintentional task-unrelated thoughts (Seli et al., 2015; Seli, Risko, et al., 2016; Seli, Wammes, Risko, & Smilek, 2016), and researchers have long pointed out the folly of assuming that participants consider the often-monotonous tasks used in psychological studies to be more important than their own internal musings and plans (Baars, 2010). Many of our participants may have been purposefully disregarding the task at hand to focus on internal matters they deemed more important, but these types of thoughts would be categorized as task-unrelated the same as accidental slips.

These two types of task-unrelated thoughts may explain the observed partial mediation effect. The variable of control was negatively associated with task-unrelated thought, but perhaps it was only associated with unintentional task-unrelated thought. Heightened ability to control one’s thoughts would theoretically result in fewer accidental episodes of cognition drifting away from the task, but control itself should not reduce instances of intentional task-unrelated thought (i.e., if a participant is purposefully planning out their commute home as opposed to focusing on the task, their degree of control should not matter – thinking off-task by planning the commute is still the priority). However, motivation does more than heighten control over thoughts, it also restructures priorities by its very nature. Independent of their level of control, participants should be less likely to engage in task-unrelated thoughts during the high motivation blocks – they have a conscious choice between purposefully staying on task and purposefully diverting attention away, and when incentives to do well on the task are higher they can be expected to choose the task more of the time.

In this way, motivation directly impacts intentional task-unrelated thought without the need for control as a mediating variable, but it also indirectly suppresses unintentional task-unrelated
thought through its bolstering of deliberate control, producing the mixed, partial mediation seen in the present data. Whether or not motivation also directly affects unintentional as well as intentional task-unrelated thought is unclear, but either answer is compatible with the results at hand. This explanation has interesting implications for freely-moving thought, as well. An indirect effect of motivation through deliberate control (thought to correspond to deliberate constraint on thought; Christoff et al., 2016) would support Christoff et al.’s (2016) idea that under certain situations people are able to consciously suppress the freedom of their thoughts’ movement in order to focus on a narrow set of topics and/or stimuli. At the same time, accepting the shifting priorities explanation of the partial mediation on task-unrelated thought in conjunction with the lack of a direct effect of motivation on freely-moving thought would lead one to the conclusion that motivation levels and personal priorities by themselves have no direct impact on the freedom-of-movement in thought; the only effect is that which is transmitted through thought control. To give an example, two people with the same amount of control over their thoughts would be expected to display roughly the same degree of freely-moving thought, even if they had vastly different levels of motivation to do well on a task, and even if that task required constrained thought. This raises the interesting possibility that while freely-moving thought is amenable to top-down influences, it is not possible for people to consciously dampen it in the same way that task-unrelated thought can be dampened.

While the indirect effect of motivation on freely-moving thought through thought control is supportive of the Christoff et al. (2016) Dynamic Framework which posited that deliberate constraints could restrict freedom of movement in thought, the present results pertaining to automatic constraints are less straightforward. While the Dynamic Framework proposed that arousal was a form of automatic constraint and would therefore predict that arousal would be
negatively associated with freely-moving thought, higher ratings of freely-moving thought were associated with both higher self-reports of arousal and larger pupillary dilation responses. On the other hand, average levels of both EDA and pupil size were smaller during probe-sets with high freely-moving thought ratings, contradicting the self-report results. The simplest answer to this unpredicted pattern of findings is simply that arousal, independent of the cognitive variables that often accompany it, does not constitute automatic constraint. While arousal was predicted to be one form of automatic constraint by Christoff et al. (2016), other (not mutually-exclusive) candidates such as habit and rumination – cognitive constructs with more intuitive relationships to thought dynamics – were also proposed, and a lack of evidence of an effect of arousal on freely-moving thought is not particularly damaging to either the framework or the concept of automatic constraint. The current results undermine the belief that arousal is a reliable index of automatic constraint, a finding that echoes that of psychologists in recent years who have found that affect may not be related to cognitive variables as once thought (Gable & Harmon-Jones, 2013).

This account of an absence of a negative relationship nonetheless does not explain the positive relationship between freely-moving thought and self-report and phasic measures of arousal. The finding is not unprecedented, however: support for the idea that arousal may co-occur with freely-moving thought comes from Smith et al. (in press) who found that in an everyday life experience sampling study, ratings of freely-moving thought peaked around noon and were lowest at the beginning and end of the day. This pattern of change mirrors that of core body temperature, which has previously been related to a host of cognitive abilities and outcomes (Carrier & Monk, 2000; Fimm, Brand, & Spijkers, 2016; Giambra, Rosenberg, Kasper, Yee, & Sack, 1989; Valdez et al., 2005; Valdez, Reilly, & Waterhouse, 2008; Wright, Hull, & Czeisler, 2002). Smith et al. (in press) proposed that general bodily arousal could be the common mechanism behind the rise and
fall of freely-moving thought, which could account for why it showed diurnal rhythms similar to that of attentional performance, a seemingly opposing construct. An alternate account is that causality flowed in the reverse direction, with freely-moving thought producing aroused states (either an inherent, hereto unexplored feature of freely-moving thought or an indirect effect through another construct), or that a third variable causes both. Ultimately the directionality question can only be solved with experimental manipulation of one of these two variables.

Another possibility is simply that the self-report information received from participants is not a reliable index of their actual bodily arousal state, but that average pupil size and EDA are. If so, the negative relationship between these tonic physiological measures and freely-moving thought supports the notion of automatic constraints such as arousal suppressing the movement of thought and enforcing stability. While the inverse relationship between self-reported arousal and arousal as measured by both pupil size and EDA is puzzling and will require further work to illuminate, a likely explanation for the pattern of results relating to the phasic pupillary response is that physical constraints can cause it to be anticorrelated with tonic pupil size. Because there is a ceiling on how large the pupil can grow within the iris, pupils closer to that ceiling due to large tonic expansion are necessarily limited in how large their stimulus-evoked responses can be. Such an interpretation is supported by the duel findings that phasic pupil dilation and tonic pupil size are anticorrelated and that only the tonic signal retains its explanatory power when they are both included as predictors of freely-moving thought in the same model, indicating that phasic responses were unrelated to thought dynamics when average pupil size was taken into account.

While thought content (task-relatedness) and dynamics (freedom-of-movement) showed similar association profiles with arousal, the two were differentiated by valence and performance. Participants who were off-task were more likely to feel unpleasant than their task-focused
counterparts, replicating a frequently observed finding in the literature. While some maintain that it is off-task thought that results in unhappiness (Killingsworth & Gilbert, 2010), others suggest that unhappiness itself may cause us to drift away from the task at hand (Smallwood et al., 2009), or that task-unrelated thought causes unhappiness but only for certain people (e.g., those with depression: Stawarczyk, Majerus, & D’Argembeau, 2013) or for certain off-task thoughts (e.g., negative thoughts about the past: Ruby, Smallwood, Engen, & Singer, 2013).

Participants did not seem to be less happy while their thoughts were freely-moving, but the speed of their answers suffered nonetheless. The finding that participants who’s thoughts were freely-moving were slower to answer on a task that presumably required focused attention is not terribly surprising, but does raise the question of why task-unrelated thought and RT were unrelated when past research has often found them to be highly correlated (McVay & Kane, 2012; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997; Smallwood et al., 2004). The reason may lie with the context of the task itself. The experiment in question involved motivating participants to answer as quickly as possible, and moreover, the task itself was quite easy with correct responses given 96.6% of the time on average, inducing a ceiling effect on accuracy that likely accounted for the lack of an association with any other variable. Several studies in the past have shown that high task-unrelated thought rates correspond to faster and less accurate answers (McVay & Kane, 2012; Robertson et al., 1997; Smallwood et al., 2004), and some have suggested that as opposed to a mere performance failure, task-unrelated thought is indicative of a strategy that prioritizes speed over accuracy (Peebles & Bothell, 2006; Wilson et al., 2016), a strategy that may or may not be conscious. Participants completing our task would benefit most by answering as fast as possible, both because of the ease of the task and because speed is particularly incentivized (not only could they finish the four main blocks earlier if their speeds were higher, but they could earn a higher
score and thus avoid the two extra blocks). If they were able to switch between strategies and favour the strategy that benefited them the most, one would expect them to keep to the fast-and-loose strategy for the entire experiment, or close to. If task-unrelated thought is indeed a consequence and not a cause of performance strategy as suggested by Peebles and Bothell (2006) and Wilson et al. (2016), then one would expect no relationship between RT and task-unrelated thought in situations in which strategy is relatively fixed. If true, this explanation would serve to distance freely-moving and task-unrelated thought further, as the relationship between freely-moving thought and reaction time (on both observation and subject-levels) would lead to the conclusion that thought dynamics are not a part of such a strategy-shifting mechanism.

### 4.1 Limitations

One problem inherent to using a relatively new variable such as freely-moving thought is the absence of a large body of literature to support its measurement validity. It is possible that participants did not fully understand the meaning of this concept, and unlike previous studies on freely-moving thought that involved extended training sessions in which participants were taught what the concept was and asked to generate their own examples to be verified by the experimenters (Mills, Raffaelli, et al., 2017), the current study was designed to be shorter and had to forgo such training. However, with this in mind, the initial instructions both stressed the importance of asking any questions regarding the definitions that might come to mind (the experimenter remained in the room throughout the experiment to facilitate this) and included multiple-choice questions designed to test participants’ understanding of the concepts. In the event that participants failed a multiple-choice question, the experimenter re-explained the relevant concept (e.g., freely-moving thought). This meant that even participants who mindlessly clicked through the instructions would be
stopped 75% of the time (there were four multiple-choice options) to have the concept explained to them directly by the experimenter, decreasing the chance that someone would begin the study without a solid grasp of freely-moving thought.

While the task was designed to be boring and monotonous so as to induce off-task thought, this brings up the issue of whether or not participants were giving rote responses. While the experiment was designed to motivate them, the juxtaposition of the point-earning trials with thought probes that were divorced from the reward system may have increased the rate at which participants answered as quickly as possible to thought probe questions in spite of the instructions, giving either imprecise or inaccurate answers. Fatigue as the task wore on may also have contributed to thoughtless-answering (anecdotally, many participants reported being especially bored towards the end), although the counterbalancing of the order of blocks will have prevented this from confounding the results of the motivation analyses.

A core limitation to any study on motivation is that motivation may be manipulated in numerous ways which may not be as equivalent as hoped. While past research has found that allowing participants to leave early with sufficiently good performance has motivated them to perform better (Mills et al., 2015), it is difficult to say whether or not this kind of motivation is functionally equivalent to the more commonly used financial incentives (Clewett et al., 2018; Esterman et al., 2016; Horne & Pettitt, 1985; Knutson, Westdorp, Kaiser, & Hommer, 2000; Tomporowski & Tinsley, 1996) or whether these types of external incentives can at all be compared to the literature that assess participants’ levels of intrinsic motivation (Kanfer, Ackerman, Murtha, Dugdale, & Nelson, 1994; Seli, Risko, et al., 2016; Unsworth & McMillan, 2013). Another drawback to this motivation manipulation is the lack of a control group – in order to ensure that both groups were as equivalent as possible, only the *intensity* of motivation was
manipulated, meaning that participants were never left without external incentives. This enabled a purer contrast between two levels of motivation as opposed to two different states of motivation, but prevents us from directly exploring how thought patterns differ between states of external motivation linked to present-tasks and states lacking in any kind of incentive. Another concern, that the difference between blocks was not sufficient to create a detectable motivational gap, can be addressed at least partly by the finding that the majority of people reported trying harder to succeed in the high-point blocks as compared to the low-point blocks.

4.2 Future Directions

The loss of significance for the effect of motivation on freely-moving thought when a random slope is included indicates substantial heterogeneity in the effect between individuals. Aside from conducting longer studies with more observations per person to stabilize the per-person slope estimates, future research may seek to find an explanation for this high level of heterogeneity. For instance, if the effect of the present motivation manipulation was highly depended on a person’s own intrinsic level of motivation (perhaps with high pre-existing intrinsic motivation crowding-out any new external sources), measuring intrinsic motivation might not only be useful in that it can be added as a control variable, but may also help us understand how intrinsic and extrinsic sources of motivation interact to influence thought patterns.

Though the present study has introduced motivation as a useful technique to manipulate deliberate constraints on thought, at least indirectly, the finding that self-report arousal was associated with freedom of movement in thought in the reverse of the predicted direction suggests that arousal may not be a reliable pathway through which to access and manipulate automatic constraints – or at the least, caution must be exercised when making inferences about arousal
levels. Automatic constraints are more difficult to control in laboratory experiments than deliberate ones since they are composed of a myriad of factors that are opaque not only to the experimenter but to the participant themselves. As such, future research in the area of thought dynamics would benefit from further exploring the nature of automatic constraints and testing the role of potential sources of such automatic constraints – for example, Christoff et al. (2016) proposed that particularly salient concerns may constrain thought without intention. This idea originates from the body of research on current concerns that highlights how having unattained goals primes the stream of thought to focus ruminatively on the corresponding goal states (Klinger, 2013; Marchetti et al., 2016). These concern-primed thought patterns are not necessarily within the realm of our control and often occur in situations in which there are no goal-relevant actions and rumination on the concern is unproductive, suggesting an automatic root. Supporting this idea, neuroimaging studies have found that activity in executive regions of the brain during task-unrelated thought is counterintuitively higher when meta-awareness is lower; the authors suggest that this could be the result of executive areas monitoring discrepancies between the current state and the goal state in the absence of meta-awareness of this line of thought. If this evaluation of the goal state corresponds to current concerns, it indicates that these fixated, ruminative processes are largely automatic and might be better candidates for sources of automatic constraint than physiological arousal. This prediction could be tested by priming participants with self-reported worries or concerns specific to their lives, either at the beginning of an experiment or subtle throughout the procedure, and testing whether such priming reduces ratings of freely-moving thoughts.

While behavioural research such as the present study provide an excellent way to explore relationships among thought dimensions, finding supporting neuroimaging evidence would solidify the findings and help us to better understand the basic mechanisms at play. In particular,
recent advances in functional connectivity analysis are allowing us to understand not only which brain regions become active during certain mental states, but also which areas appear to cooperate with or suppress one another (Allen et al., 2014; Biswal, Zerrin Yetkin, Haughton, & Hyde, 1995; Cole et al., 2013; Gonzalez-Castillo & Bandettini, 2017; Hutchison et al., 2013; Kucyi & Davis, 2014; Tagliazucchi et al., 2016; Taren et al., 2017; Yeo et al., 2011), providing unprecedented potential to explore particular cognitive mechanics (such as constraints on thought dynamics). For example, past studies have shown that approach motivation and action states are strongly connected to activity in the left prefrontal cortex (Harmon-Jones, Harmon-Jones, Fearn, Sigelman, & Johnson, 2008), and it has been suggested the source of variability that prompts freedom of movement in thought may be located in the medial-temporal subsystem of the default mode network (Ellamil et al., 2016). If motivation is truly a source of deliberate constraint, then one would expect the left prefrontal cortex to exhibit not only increased activity during a motivation induction but also enhanced functional connectivity with either the default mode network as a whole or the medial-temporal subsystem more specifically.

The mapping of constraints onto the brain may be even better suited to the study of automatic constraints, given how difficult they are to assess via self-report. Candidate manipulations such as the current concerns manipulation described above could be validated by testing whether they result in greater connectivity between regions that potentially instigate automatic constraints (such as the core subsystem of the default network; Christoff et al., 2016) and the medial-temporal subsystem of the default network.

While the past decade has seen a rapid increase in the number of studies dedicated to understanding the subject of our thoughts (Callard et al., 2012), it is my hope that the next decade will similarly bear witness to a renewed interest in the study of how exactly we think, and what
factors influence the transition from one thought to another. Furthering out understanding of both of these elements of the stream of consciousness, as well as of the neural mechanisms that underlie them, is the surest way to advance toward a unified theory of thought, one small step at a time.
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### Table A1. Test statistics for the effect of motivation on each of the other variables for the subsample of participants who reported being motivated to succeed more in the “bonus” blocks than the “regular” blocks.

<table>
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<th>Variable</th>
<th>df</th>
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<th>p</th>
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</thead>
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<tr>
<td>Freely-Moving Thought</td>
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<tr>
<td>Task-Unrelated Thought</td>
<td>116.06</td>
<td>-1.578</td>
<td>.117</td>
</tr>
<tr>
<td>Deliberate Control</td>
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<td>.072</td>
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<tr>
<td>Self-Reported Arousal</td>
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<td>-.869</td>
<td>.387</td>
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<tr>
<td>Phasic Pupil Response</td>
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<td>-.478</td>
<td>.634</td>
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<tr>
<td>Tonic Pupil Size</td>
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<td>.096</td>
<td>.924</td>
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<tr>
<td>Tonic EDA</td>
<td>111.67</td>
<td>1.036</td>
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<tr>
<td>Valence</td>
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<td>-.791</td>
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<tr>
<td>Accuracy</td>
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<td>1.393</td>
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<tr>
<td>RT</td>
<td>114.85</td>
<td>-1.541</td>
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Appendix B

Figure B1. Histogram plot of accuracy ratings across all probe-sets.
Appendix C

<table>
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<td>Indirect Effect</td>
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<tr>
<td>Tonic EDA</td>
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<td>.630</td>
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Table C1. p-values for direct and indirect effects of motivation on thought dimensions using deliberate control and arousal measures as mediators (centered values). p-values in bold represent effects of motivation that are significant at $\alpha = .05$. 


<table>
<thead>
<tr>
<th></th>
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<th>Task-Unrelated Thought</th>
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<td>Indirect Effect</td>
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<tr>
<td>Tonic EDA</td>
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Table C2. p-values for direct and indirect effects of motivation on thought dimensions using deliberate control and arousal measures as mediators (raw values). p-values in bold represent effects of motivation that are significant at $\alpha = .05$. 