The Role of Mental Imagery in Spontaneous Thoughts of the Past and Future

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Abstract

Spontaneous thought refers to a mental state, or series of mental states, that are unconstrained by a specific task and move freely over time. Converging evidence suggests that spontaneous thoughts may contain mental imagery of scenes ('scene construction') when remembering the past and imagining the future ('mental time travel'). However, no research has directly examined the relationship between scene construction and mental time travel during spontaneous thought. We used experience sampling and multi-level modeling to obtain subjective reports from eighty participants during waking rest, and examined these reports along three dimensions: (1) freedom of movement (referring to the degree to which thoughts are deliberate or spontaneous), (2) mental imagery (including scene construction, inner speech, and isolated elements), and (3) temporal orientation (towards the past, present, and future). Our results showed that multiple types of mental imagery, including scene construction, inner speech, and isolated elements, were positively associated with spontaneous thoughts generated during waking rest. Furthermore, all forms of mental imagery were positively associated with past and future orientation. In contrast, deliberate thoughts generated during waking rest were negatively associated with mental imagery and present orientation. These data suggest that various forms of mental imagery, including scene construction, inner speech, and isolated elements, all support spontaneous thoughts of the past and future. This research advances our understanding of healthy, adaptive human thought patterns in everyday life, and provides a baseline for better understanding unhealthy, maladaptive thought patterns in clinical contexts.

Lay Summary

Spontaneous thought refers to a mental state, or series of mental states, that move freely over time. Research suggests that spontaneous thought may contain mental imagery of scenes ('scene construction') when remembering the past and imagining the future ('mental time travel'). However, no research has directly examined the relationship between scene construction and mental time travel during spontaneous thought. We used experience sampling and multi-level modeling to examine the role of scene construction in mental time travel during spontaneous thought. We addressed the following questions: i) What is the relationship between spontaneous thought and scene construction? ii) Is there a trade-off between visual and auditory imagery? iii) What is the relationship between scene construction and mental time travel? Our findings show that during spontaneous thought, scene construction, inner speech, and isolated elements help us to mentally travel away from the present to remember the past and imagine the future.

Preface

YG conceptualized and designed the study methods and conducted all data analyses for the research that forms the focus of this thesis. KC co-conceptualized and approved the study design and provided feedback on the manuscript. YG trained undergraduate research assistants EB, JC, AG, GL, and AW to carry out data collection under YG's guidance. YG built and programmed the E-Prime task for data collection and wrote the R scripts for data analysis. The research was approved by the UBC Research Ethics Board under Certificate # H18-01049.

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Dedication

This thesis is dedicated to my parents, Donna and Marc Graveline, who have supported me for as long as I can remember, and to three beloved humans, Kim Hicks, Kristin Hulvey, and Brian Felsen, who encouraged my scientific interests in their formative stages.

Chapter 1: Introduction

1.1 Theoretical Accounts of Mind-Wandering

Mind-wandering (Antrobus, Singer, Goldstein, & Fortgang, 1970; Christoff, Irving, Fox, Spreng, & Andrews-Hanna, 2016; Smallwood & Schooler, 2006) has been investigated under a variety of names, including daydreaming (Singer, 1966; Varendonck, 1921), fantasy (Klinger, 1971), task-unrelated thought (Giambra, 1989), stimulus independent mentation (Antrobus, 1968), and internally directed thought (Andrews-Hanna, 2012). A more recently introduced dimension of mind-wandering is freedom of movement, referring to the degree to which thoughts are constrained (exhibiting *low* freedom of movement) or spontaneously unfolding (exhibiting *high* freedom of movement) (Christoff et al., 2016). Freedom of movement is empirically dissociable from task-unrelatedness and stimulus independence (Mills, Raffaelli, Irving, Stan, & Christoff, 2018) and rates of freely moving thought fluctuate with time of day (Smith, Mills, Paxton, & Christoff, 2018), lending credibility to the efficacy of this measure for capturing the "forgotten dynamics" of mind-wandering (Christoff et al., 2016).

Until recently, mind-wandering had been primarily defined in relation to thought contents, such as when the mind "wanders" away from a task (Smallwood & Schooler, 2015), or perceptually decouples from the external environment (Schooler et al., 2011). In the typical paradigm for investigating mind-wandering, participants engage in the SART (sustained attention to response) task, which involves pressing a button in response to a target word as it appears on a computer screen. Meanwhile, thought probes are intermittently delivered to assess whether participants' thoughts were on-task or off-task during the preceding trial. At the end of the experiment, rates of mind-wandering are equated with the number of task-unrelated thoughts

(TUTS) that are generated throughout the task. This paradigm is rooted in the traditional framework of mind-wandering as an unintentional shift of attention away from some type of stimulus or content, be it a specific task or cue from the external environment.

However, recent theoretical developments have begun to challenge this unitary approach to mind-wandering (Christoff et al., 2018; Seli et al., 2018), with mind-wandering being increasingly acknowledged as a dynamic (Christoff et al., 2016) and heterogeneous construct (Seli et al., 2018), that has so far resisted a one-to-one mapping with any particular dimension of thought (Christoff et al., 2018). While there is no consensus on how best to define mind-wandering, a rich literature nevertheless suggests that all of the dimensions considered so far, including stimulus independence (Singer, 1970), task-unrelatedness (Giambra, 1989), perceptual decoupling (Schooler et al., 2011), internal directedness (Andrews-Hanna, 2012), and freedom of movement (Christoff et al., 2016), are relevant for understanding mind-wandering and its real-world implications.

1.2 Mental Imagery

On the topic of mental imagery, William James once wrote: "Fantasy, or Imagination, are the names given to the faculty of reproducing copies of originals once felt" (James, 1890). Echoing James's perspective is a more contemporary framework by Moulton and Kosslyn (2009), which suggests that mental imagery occurs "when a representation of the type created during the initial phases of perception is present but the stimulus is not actually being perceived" (Moulton & Kosslyn, 2009). Three central ideas about mental imagery are implicit in these assertions: 1) mental imagery originates from our experience with external stimuli, and as such, 2) inherits structural properties in common with perception, and yet 3) can occur regardless of those external stimuli being present. Thus, mental imagery is generally defined as the internal representation of

percept-*like* contents that are generated independently of cues in the immediate external environment.

Illustrating the connection between mental imagery and real-world experience, it has been argued that there are as many types of imagery as there are types of perception (Moulton & Kosslyn, 2009). Indeed, mental imagery has been observed in every modality, including visual (Bartolomeo, 2002; Dijkstra, Zeidman, Ondobaka, van Gerven, & Friston, 2017; Lee, Kravitz, & Baker, 2012; Lee et al., 2012), auditory (Hurlburt, Heavey, & Kelsey, 2013; Klinger, 2008), proprioceptive (Jeannerod, 1995; Kilteni, Andersson, Houborg, & Ehrsson, 2018), olfactory (Algom & Cain, 1991; Stevenson & Case, 2005), gustatory (Kobayashi et al., 2004), and tactile (Schmidt & Blankenburg, 2019; Schmidt, Ostwald, & Blankenburg, 2014; Yoo, Freeman, McCarthy, & Jolesz, 2003).

Visual and auditory modalities of imagery are by far the most commonly reported (Heavey & Hurlburt, 2008; Stawarczyk, Majerus, Maj, Van der Linden, & D'Argembeau, 2011), with one study finding visual imagery in 34% of thoughts, auditory imagery in 26% of thoughts, and other modalities reported at lower rates (Heavey & Hurlburt, 2008). Two separate studies found inner speech in 23% of all self-reports (Heavey & Hurlburt, 2008; Mihelic, 2008), while another study found inner speech in up to 74% of reports (Klinger, 2008), yielding an average rate of 40% across studies (Heavey & Hurlburt, 2008; Klinger, 2008; Mihelic, 2008). These widely varying estimates likely reflect the different criteria used by researchers (see Hurlburt et al., 2013 for discussion), but nevertheless demonstrate the overwhelmingly audiovisual nature of mental imagery in everyday thoughts.

Mental imagery can be further broken down into complex and simple categories with dissociable effects at psychological and neural levels (Hassabis, Kumaran, & Maguire, 2007;

Hegarty, 2004; Kanwisher, McDermott, & Chun, 1997; Kosslyn, Ganis, & Thompson, 2001; Kozhevnikov, Kosslyn, & Shephard, 2005; Moulton & Kosslyn, 2009; Sugiura, Shah, Zilles, & Fink, 2005). At the psychological level, complex imagery involves the integration of multiple elements into an overarching context, with a prime example being *scene construction.* Scene construction is defined as the ability to mentally integrate elements into a spatial setting (Hassabis, Kumaran, & Maguire, 2007). To illustrate, imagine a group of people sitting around a campfire in a forest with snow-capped mountains in the background. Simple visual imagery, on the other hand, would involve an isolated element, such as a campfire, without a surrounding spatial context. Beyond visual imagery, a complex form of auditory imagery is inner speech, which involves internally simulated self-talk and conversations (Hurlburt et al., 2013). In contrast, a simple form of auditory imagery would be an isolated auditory element, such as when replaying a word or phrase from a conversation.

William James (1890) and Sir Frederik Charles Bartlett (1932) were among the first to argue that individuals can be reliably classified as either *visualizers* or *verbalizers*. According to this view, some people rely on visual imagery when performing cognitive tasks, while others rely on a verbal-analytic strategy. At first, individuals were believed to rely on either a visual or verbal strategy, and not both. But by the 1970's, the idea of "pure" cognitive types had largely fallen out of favor due to the consistent failure of earlier studies to demonstrate that individuals rely on one strategy over another, and also due to the emerging evidence showing that most people experience varying degrees of mental imagery in all modalities (Paivio & Harshman, 1983; Phillips, 2014). These latter findings would eventually come to support a more tempered version of the visualizer-verbalizer argument which continues to generate research to this day (Kirby, Moore, & Schofield,

1988; Richardson, 1977; Riding & Cheema, 1991) albeit with mixed results (Alesandrini, 1981; Green & Schroeder, 1990; Paivio & Harshman, 1983).

A major challenge for research on so-called cognitive styles has been in choosing a task that reliably pinpoints the domains in question (see Kozhevnikov et al., 2005 for commentary). For instance, the majority of research on visual and verbal styles has relied primarily on questionnaires that probe self-knowledge retrospectively (Paivio, 1971; Richardson, 1977), or tasks that are presumed to involve visual or verbal imagery without probing for the presence of mental imagery in subjective experience. As such, it remains unclear whether the results of these studies might translate to internally generated mental imagery, externally oriented perception, or both.

If the visualizer-verbalizer distinction holds in our everyday mental lives as some proponents continue to claim (McEwan & Reynolds, 2007), it might be reflected as an inherent *trade-off* whereby individuals who tend to produce more of one type of imagery (e.g., visual-spatial scene construction) would tend to produce less of another type of imagery (e.g., auditory inner speech). Then again, it remains possible that visual and auditory modalities of imagery are not incompatible after all, and would instead be found to co-occur owing to the multi-modal nature of both real and simulated experience (Moulton & Kosslyn, 2009; Nanay, 2018). Regardless of the outcome, examining the putative trade-off between visual and verbal imagery in the absence of a task is worthwhile for assessing whether the visualizer-verbalizer distinction holds at *baseline*, even if simply for the sake of ruling out the possibility altogether.

1.3 Mental Time Travel

More than two decades have passed since Suddendorf and Corballis (1997) coined the phrase 'mental time travel' to describe a state of mind where we temporarily shift our focus away

from the present moment, to mentally reconstruct events in the past, and to mentally construct possible events in the future. Mental time travel is closely related to the concept of 'chronesthesia' referring to the subjective sense of time (Tulving, 1985; 2002), and it is also related to the concept of 'episodic constructive simulation,' as was more recently introduced in the hypothesis of the same name (Schacter & Addis, 2007).

Episodic memory is believed to be *constructive* in nature, meaning that it involves a cognitive system capable of resurrecting and flexibly integrating elements from memory into mentally simulated events and scenarios (Schacter, Norman, & Koutstaal, 1998; Hassabis & Maguire, 2009; Schacter & Addis, 2007; Schacter et al., 2012). The brain's constructive capacity enables us to form detailed and cohesive representations of real life experiences in their absence (Hassabis & Maguire, 2009), which is necessary for reflecting upon or recalling previously experienced events (Schacter, Norman, & Koutstaal, 1998; Tulving, 1985). Without the ability to simulate past events, we would be perpetually stuck in the present moment, operating at only the most basic level of conscious awareness (Edelman, 1989; 2003). As such, 'constructive simulation' is a core capacity underlying extended consciousness and the ability to toggle between the personal past and future.

Beyond episodic memory, episodic construction is believed to support the ability to mentally simulate future events and scenarios. According to the *episodic constructive simulation hypothesis*, a memory system capable of accessing and reconstructing the elements of remembered events should also be capable of accessing elements across multiple memory sources and constructing these into novel or hypothetical situations (Schacter & Addis, 2007). It is by now well established that brain systems critical for episodic memory are relied upon for future-oriented thinking (Addis, Wong, & Schacter, 2007; Hassabis, Kumaran, & Maguire, 2007; Hassabis,

Kumaran, Vann, & Maguire, 2007; Hassabis & Maguire, 2007; Klein, Loftus, & Kihlstrom, 2002; Kwan, Carson, Addis, & Rosenbaum, 2010; Okuda et al., 2003). For instance, lesion studies reveal that the MTL is as critical for remembering the past as it is for imagining the future (Andelman, Hoofien, Goldberg, Aizenstein, & Neufeld, 2010; Klein et al., 2002; Milner & Klein, 2016; Palombo, Keane, & Verfaellie, 2015; Penfield & Milner, 1958; Race, Keane, & Verfaellie, 2011, 2013; Scoville & Milner, 1957). Subsequently, neuroimaging studies reveal that the medial temporal lobe sub-system of the default network (of which the MTL is central) becomes similarly engaged when participants construct scenes and events of the past and future (Addis et al., 2007; Hassabis, Kumaran, Vann, et al., 2007). Together, these studies provide evidence at the neural level that memory and future-oriented imagination commonly rely on a core system specializing in construction.

Intimately tied to the concept of construction is *scene construction*, referring to a complex form of visual imagery whereby elements are mentally integrated within a spatial context (Hassabis & Maguire, 2009). Scene construction is hypothesized to play a central role in mental time travel due to its capacity for integrating the details of real life experiences into complex visual-spatial contexts (Hassabis & Maguire, 2009). In support, fMRI research reveals that brain regions involved in memory and future-thinking (Addis et al., 2007) are recruited in common when individuals remember past scenes, as well as future and fictitious scenes (Hassabis, Kumaran, & Maguire, 2007; Hassabis & Maguire, 2007, 2009).

Hassabis et al. (2007) examined brain activity in two separate conditions where participants either remembered real-life scenes that they had experienced one week prior to fMRI scanning or remembered fictitious scenes that they had *imagined* one week prior. Brain areas recruited across conditions were presumed to underlie scene construction, including the medial temporal lobe

(MTL), long known from lesion studies to be critically involved in episodic memory (Penfield & Milner, 1958; Scoville & Milner, 1957), and more recently recognized as critical for prospection (Andelman et al., 2010; Hassabis, Kumaran, Vann, et al., 2007; Race et al., 2013). Subsequent recruitment from the retrosplenial cortex, parahippocampal cortex, and inferior parietal lobules is consistent with research linking these areas to spatial memory and associative processing (Aminoff, Gronau, & Bar, 2005; Burwell, 2000; Grafton, Hazeltine, & Ivry, 1998; Jacob et al., 2017).

Together, these findings provide support for the idea that scene construction enables the spatial organization of elements during memory and future-oriented imagination (Hassabis & Maguire, 2009; Schacter et al., 2012). Of course, inner speech could be involved in mental time travel as well. For instance, we might use inner speech, or a mixture of inner speech and scene construction, when replaying conversations from social scenarios. However, the majority of research on the link between imagery and mental time travel has tended to focus on scene construction specifically (Hassabis & Maguire, 2009) or construction more generally (Schacter & Addis, 2007).

1.4 Does Mental Imagery Support Spontaneous Thoughts of the Past and Future?

Converging evidence suggests that mental imagery, and specifically scene construction, plays a critical role in mental time travel during spontaneous thought. First, research shows that when thoughts are generated independently from a laboratory task (Stawarczyk, Cassol, & D'Argembeau, 2013; Stawarczyk, Majerus, Maj, et al., 2011) and also when thoughts are 'self-generated' in the context of daily life (Andrews-Hanna et al., 2013), they are frequently focused on the future, and to a slightly lesser (but still comparable) extent on the past. Such evidence has led to the notion that spontaneous thought may serve an adaptive function for memory processing,

identity formation, and future-oriented planning (Andrews-Hanna, 2012; Buckner, Andrews-Hanna, & Schacter, 2008; Buckner & Carroll, 2007; Spreng, Mar, & Kim, 2009), all of which yield clear advantages to our survival and well-being.

Second, there is preliminary evidence to support the link between scene construction and mental time travel at the neural level. Neuroimaging work shows similar patterns of brain activation across tasks where participants remember real life past scenes and imagine novel fictitious scenes (Hassabis, Kumaran, & Maguire, 2007; Hassabis & Maguire, 2007). Importantly, these brain areas recruited during remembering and imagining scenes bear a striking resemblance to a core network that becomes recruited when participants remember the past and imagine the future, regardless of whether given specific instructions to construct scenes (Addis et al., 2007). This has led to the notion that episodic memory and prospection might rely upon the capacity to mentally construct scenes or scenarios of the past and future (Hassabis & Maguire, 2009). However, it is important to note that these research studies all relied upon tasks that required the deliberate construction of remembered and imagined scenes, and that scene construction has yet to be examined during spontaneously unfolding thoughts of the past and future specifically.

Third, results from a quantitative meta-analysis confirm that *both* mental time travel and mind-wandering, the latter being a form of spontaneous thought during wakefulness (Christoff et al., 2016), recruit many of the key brain regions that become engaged during scene construction (Spreng et al., 2009). Furthermore, at the cognitive level, experience sampling research demonstrates that mental imagery is one of the several key characteristics of independently generated thought (Andrews-Hanna et al., 2013). However, the specific structural properties of imagery were not a focus of this research, and so the extent to which spontaneous thought contains

scene construction versus other common forms of imagery (e.g., inner speech or isolated elements) is entirely unknown.

Overall, while there is indirect evidence for theoretical proposals linking scene construction to mental time travel and spontaneous thought (Andrews-Hanna, Reidler, Sepulcre, Poulin, & Buckner, 2010; Hassabis & Maguire, 2009; Spreng et al., 2009), the contribution of scene construction to mental time travel during spontaneous thought has yet to be confirmed and further research is necessary.

1.5 Questions that Remain Unanswered

Despite the converging evidence connecting scene construction to mental time travel during spontaneous thought (Andrews-Hanna, 2012; Hassabis & Maguire, 2009; Spreng et al., 2009), no research has yet directly examined scene construction during spontaneous thought. In fact, not so rudimentary a detail as the rate of spontaneously occurring scene construction is yet known. What's more, no research has examined how rates of scene construction might compare to rates of other forms of imagery during spontaneous thought, such as inner speech (Hurlburt et al., 2013) or contextually isolated elements (Kozhevnikov et al., 2005). Determining the extent to which scene construction versus other forms of imagery might co-occur during spontaneous thought requires a unique approach that is capable of capturing cognitive contents amidst a dynamically unfolding mental landscape.

Similarly, the relationship between scene construction and mental time travel has so far been exclusively examined in situations where participants are explicitly *told* to remember and imagine scenes, and not during spontaneously thought specifically (Hassabis, Kumaran, & Maguire, 2007; Hassabis & Maguire, 2007; Summerfield, Hassabis, & Maguire, 2010). There are obvious strengths to this approach in terms of elucidating the neural connections between scene

construction and mental time travel (Hassabis & Maguire, 2009; Schacter et al., 2012). However, there is also an inherent limitation, namely being that this method artificially coerces the co-occurrence of mental time travel and scene construction *by design*. This invites the question of how often scene construction and mental time travel might co-occur when their relationship is not deliberately forced or constrained by a task, such as during waking rest. Finally, the putative link between scene construction, mental time travel, and spontaneous thought has yet to be investigated from the vantage point of first-person experience.

Mindful of these gaps in the literature, we asked the following questions: *i) What is the relationship between spontaneous thought and scene construction? ii) Is there a trade-off between visual and auditory imagery? iii) What is the relationship between scene construction and mental time travel?*

1.6 The Current Study

The current study aimed to examine the role of scene construction in mental time travel during spontaneous thought. To examine these putative relationships, we pursued three primary research objectives.

First, we examined the relationship between scene construction and spontaneous thought to determine if scene construction and spontaneous thought co-occur, as would be indicated by a positive association. Next, we examined the relationship between scene construction and inner speech to determine if there is an inherent trade-off between visual and auditory imagery, as would be indicated by a negative association. Finally, we examined the relationship between scene construction and mental time travel to determine whether these thought dimensions might co-occur, as would be indicated by a positive association between scene construction and past and

future oriented thoughts, and a negative association between scene construction and present oriented thoughts.

On the basis of the evidence that we reviewed, we hypothesized that: *i) spontaneous thoughts would frequently contain scene construction; ii) individuals who tend to produce more scene construction would also tend to produce less inner speech (indicating a trade-off); and iii) thoughts containing scene construction would be oriented towards the past and future, but not towards the present.* To our knowledge, this study represents the first empirical investigation of the role of mental imagery in spontaneous thoughts of the past and future.

Chapter 2: Methods

2.1 Participants

A total of 87 healthy undergraduate students between the ages of 18 and 34 participated in the study. Seven participants' data were omitted due either to non-compliance (e.g., falling asleep during the task), technical issues (e.g., hardware malfunction) or for not meeting the inclusion criteria (e.g., ADHD diagnosis). This left a total of 80 participants (55 female; 25 male; 1 non-binary; mean age = 19.7±2.2 years). Participants had no history of neurological impairment or current diagnoses of a psychiatric condition and showed no patterns of excessive alcohol or drug use. All participants were recruited through the human subject pool in the psychology department at the University of British Columbia (UBC). The UBC Behavioral Research Ethics Board approved the study protocol. Participants provided informed consent and were debriefed at the end of the study.

2.2 Materials

2.2.1 Thought Probe Cycle

The main unit of analysis in the study is a Thought Probe Cycle. During each thought probe cycle, participants underwent a period of rest that lasted anywhere from 30-60 sec (~45 sec on average) and at an interval unpredictable to the participant, followed by a 2 sec cue to report, and then responded to questions about the thoughts they were having in the moment directly preceding the cue (Figure 2.1). A thought was defined as anything that could be on one's mind, including memories, mental imagery, emotions, sensations, and so on. The thought probe questions are listed in Table 2.1. Participants were allowed 6 sec to respond to each question before the next question appeared. The monitor appeared black during the resting period, white during the cue, and returned

to black with white text when the questions were presented. The intermittent delivery of thought probe questions following brief intervals of waking rest allowed us to capture the emergent characteristics of spontaneous thoughts during the precise moments in which they occurred.

Figure 2.1: Thought probe cycle.

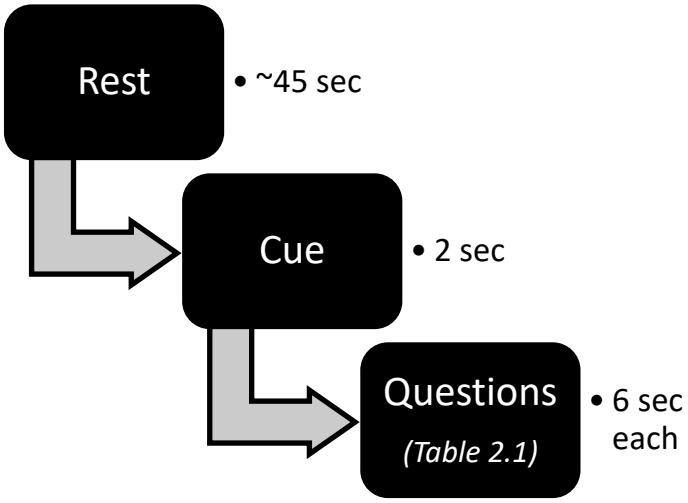


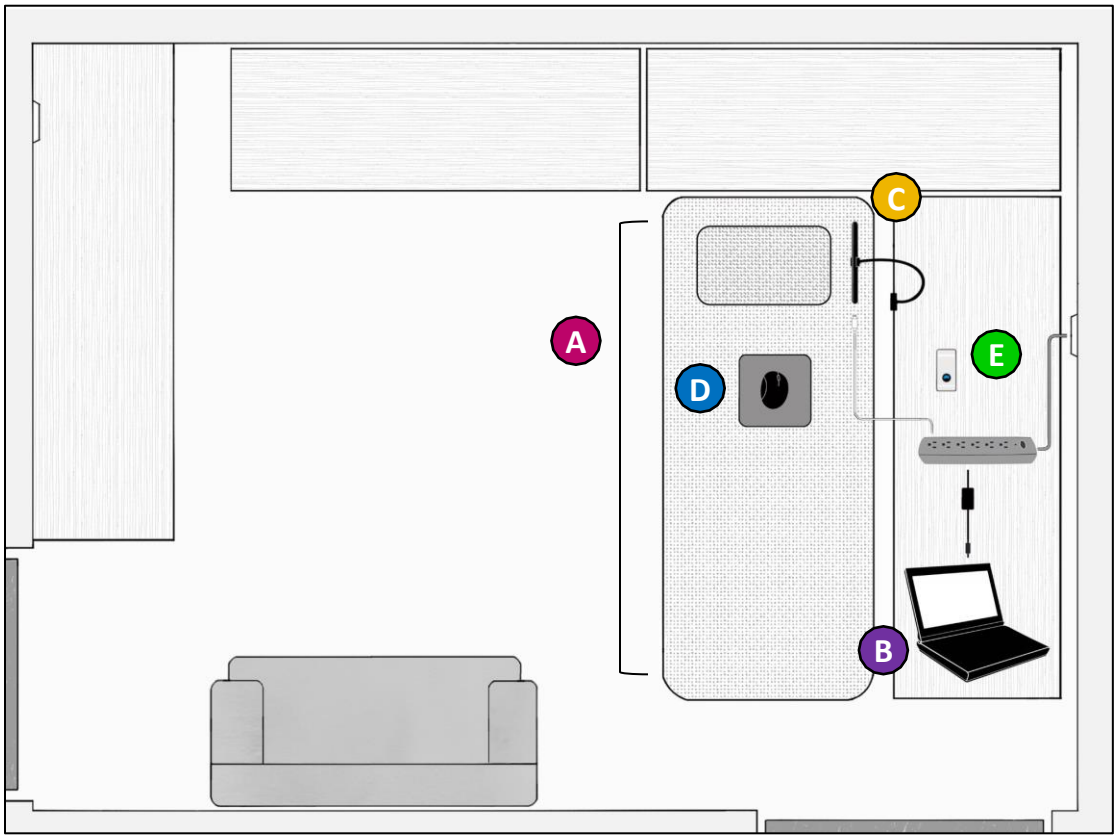
Table 2.1: Thought probe questions.

Dimension	Question	Response
Freedom of Movement	My mind was moving about freely	Scale (1=not at all; 6=very much)
Visual Imagery	There was visual imagery	Categories (Scene, Isolated Visual Element, No)
Auditory Imagery	There was auditory imagery	Categories (Inner Speech, Isolated Auditory Element, No)
Past Orientation	I was thinking about the past	Binary (Yes, No)
Present Orientation	I was thinking about the present	Binary (Yes, No)
Future Orientation	I was thinking about the future	Binary (Yes, No)

2.2.2 Resting Station

Both the training and experience sampling task were conducted at a resting station in the laboratory (Figure 2.2). The resting station consisted of a portable bed with sheets and pillows so that participants could rest comfortably. A laptop executed the training and experience sampling tasks and was positioned on a table at the foot of the bed. The laptop was positioned facing away from the participant and set at a low brightness to minimize distraction. A small iPad was suspended as a monitor in front of the participant at eye level and set at a low brightness for comfortable viewing. The purpose of the iPad was to guide the participant through the training and task cues to rest and report (see Figure 2.1 Thought Probe Cycle). A mouse and mousepad were placed at a comfortable distance to collect participants' responses to thought probe questions. A buzzer was placed next to the bed so that the participants could call upon the experimenter from the other room in between sessions. The buzzer served two purposes, one being to allow the experimenter to stay outside the resting station area, in case an unfamiliar presence might be intrusive to the participant's thought process, the second being to prevent the participant from falling asleep by facilitating a brief moment of interaction requiring alertness at the end of each session. Throughout the experiment, the room lights were kept dim to prevent excessive sensory distraction.

Figure 2.2: Resting station and environment.



A: Portable bed; B: Task laptop; C: iPad monitor; D: Mouse & mousepad; E: Buzzer

2.2.3 Presentation Software

All training and task stimuli were presented using E-Prime software version 2.0 and projected onto the iPad monitor using TeamViewer software version 12.0.

2.3 Procedures

Phase 1: Introduction

Participants entered the laboratory and filled out two questionnaires: (a) a brief demographics form, and (b) a survey of combined items from the Imaginal Processes Inventory (IPI) daydreaming and night-dreaming scales (Singer & Antrobus, 1970). Questionnaires were presented in the form of an online survey generated using Qualtrics (Qualtrics, Provo, UT). Upon

completing the questionnaires, participants were presented with a set of PowerPoint slides containing detailed instructions on what to expect during the upcoming training and experience sampling task. Throughout, participants were provided with concrete examples of all terms and concepts used to describe the relevant thought dimensions. This initial phase of the experiment lasted ~ 15 minutes.

Phase 2: Training

Following the introductory period, participants underwent a training session which provided an opportunity to become acclimated to the experience sampling task. Prior to the training, participants were reminded of the instructions. The training phase required that participants complete one full session of the experience sampling task (described below), for a total of ~15 minutes of training and 10 Thought Probe Cycles (see Methods 2.2.1). The experimenter remained in an adjacent room during the training except when initiating the training session and until participants buzzed the experimenter to reenter the room at the end of the training session.

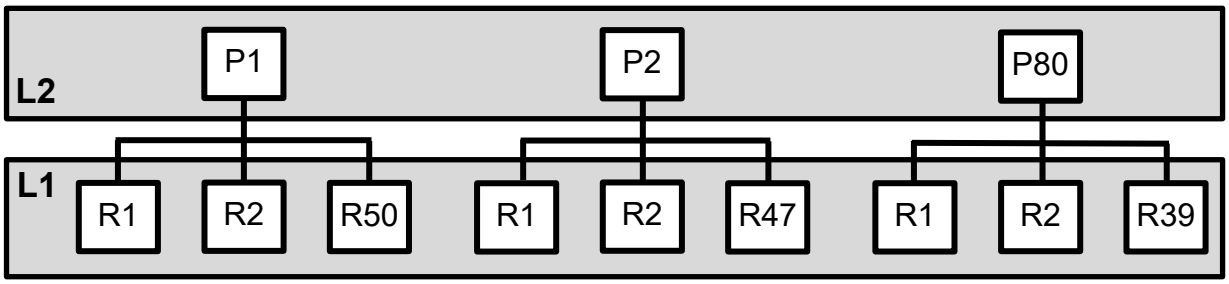
Phase 3: Experience Sampling Task

Upon completion of the training, participants underwent the main experience sampling portion of the experiment. As in the Training, participants completed the experience sampling task while lying down at the resting station (Chapter 2.2 Materials) and the experimenter remained in an adjacent room during the task except when initiating task sessions. At the end of each session (i.e., ~12 minutes and 10 thought probe cycles) participants buzzed the experimenter to reenter the room and start the subsequent session. Participants completed five task sessions for a total of ~60 minutes of experience sampling and 50 thought probe cycles.

2.4 Multi-Level Modeling

We used a multi-level mixed effects modeling approach for data analysis as is recommended for data with a hierarchical structure (Nezlek, 2008). Our dataset has a standard two-level structure (see Figure 2.1 for illustration) with thought reports (Level 1 units) nested within individual participants (Level 2 units). Mixed effects modeling has several advantages, including its ability to preserve between-subject differences in both the baseline ratings for dependent variables (intercept) and in the estimated relationship between independent and dependent variables (slope). Mixed effects modeling also accounts for missing data, which in our case means that the number of self-reports (Level 1 units) can differ across participants (Level 2 units). For all these reasons, we considered multi-level mixed effects modeling to be the best approach. All analyses were conducted in R using the lme4 package (Bates, Mächler, Bolker, & Walker, 2015).

Figure 2.3: Schematic diagram of a dataset with a two-level structure. Level 1 reports are nested within participants at level 2. Note the unequal number of level 1 units, which can vary across level 2 units with multi-level modeling (e.g., participant



P: Participant; R: Report; L1: Level 1; L2: Level 2

Similarities and differences across the analyses discussed in the upcoming Chapters 3.2 through 3.5 are worth noting. For the first analysis (Chapter 3.2), where we addressed the relationship between scene construction and freedom of movement, we used a multi-level linear regression approach. We used this same approach for the fourth analysis (Chapter 3.5), where we

addressed the relationship between temporal orientation and freedom of movement. Linear regression was used in these cases because the dependent variable (i.e., freedom of movement) is of a continuous data type. For the remaining analyses, which addressed the relationship between visual and auditory imagery (Chapter 3.3) and the relationship between scene construction and temporal orientation (Chapter 3.4), we used a multi-level *logistic* regression approach. Logistic regression was used in these cases because the dependent variables (i.e., visual imagery and temporal orientation) are of categorical and binary data types respectively.

Otherwise, all the models were similarly structured to preserve between-participant differences in baseline ratings (random intercept) and estimated relationships (random slope), and to control for individual differences that might have driven effects as opposed to the dimensions of interest. Modeling random intercept and random slope was achieved through standard adjustments to the R lme4 syntax. To account for individual differences, participant means were calculated for the independent variables in each model and were included as additional independent variables within the model. Note that in the chapter that follows, whenever a specific model is introduced, these parameters for random intercept, random slope, and individual differences are implied but not discussed to eliminate redundancy.

Chapter 3: Results

3.1 Descriptive Statistics

In this section, we outline summary statistics for all self-reported cognitive dimensions measured. The dimensions were 1) freedom of movement, 2) mental imagery (including visual categories of scene construction, isolated visual elements, and no visual imagery, and auditory categories of inner speech, isolated auditory elements, and no auditory imagery), and 3) temporal orientation (past, present, and future). Summary statistics are reported in Table 3.1. Note that summary statistics were calculated *after* obtaining the average ratings (or proportions of ratings in the case of the binary variables) for every participant. As such, the Mean in Table 3.1 refers to the *Grand* Mean of all participant means for each thought dimension, the SD refers to the spread of the participant means around this grand mean, while Min, Median and Max represent the lowest, middle-most, and highest participant means for a given thought dimension. Frequency distributions for each thought dimension are graphically depicted in Figures 3.1-3.4.

Table 3.1: Summary statistics for all self-reported cognitive dimensions.

Thought Dimension	Mean	SD	Min	Median	Max	Frequency Distribution
Freedom of Movement	4.1	0.93	2.18	4.8	5.8	Figure 3.1
Scene Construction	35%	0.19	0%	34%	80%	Figure 3.2
Isolated Visual Elements	44%	0.18	2%	46%	76%	Figure 3.2
No Visual Imagery	21%	0.17	0%	17%	92%	Figure 3.2
Inner Speech	44%	0.22	2%	42%	98%	Figure 3.3
Isolated Auditory Elements	33%	0.16	0%	34%	64%	Figure 3.3

No Auditory Imagery	23%	0.17	0%	23%	76%	Figure 3.3
Past	37%	0.18	2%	34	85%	Figure 3.4
Present	39%	0.18	6%	40%	94%	Figure 3.4
Future	44%	0.16	2%	43%	98%	Figure 3.4

Figure 3.1: Frequency distribution of freedom of movement ratings for thought reports.

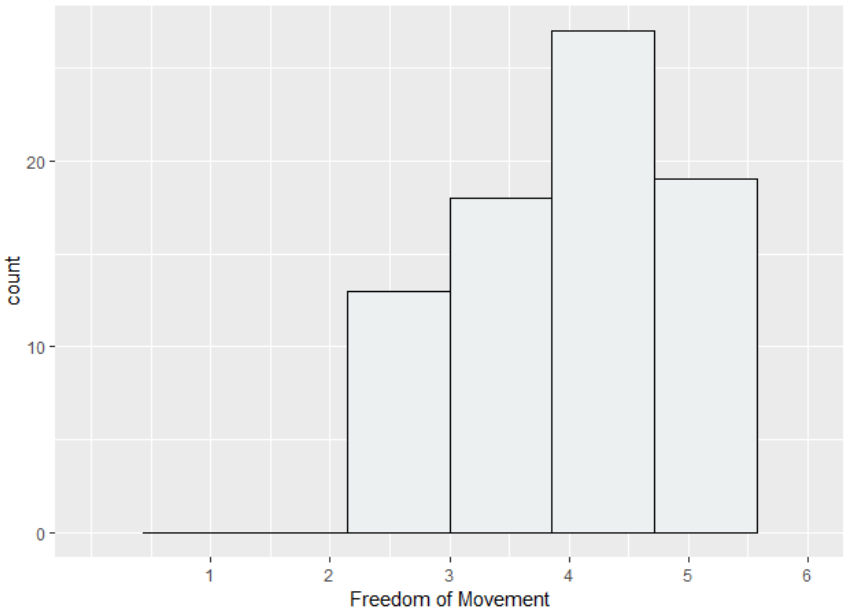


Figure 3.2: Frequency distribution of thoughts containing visual imagery.

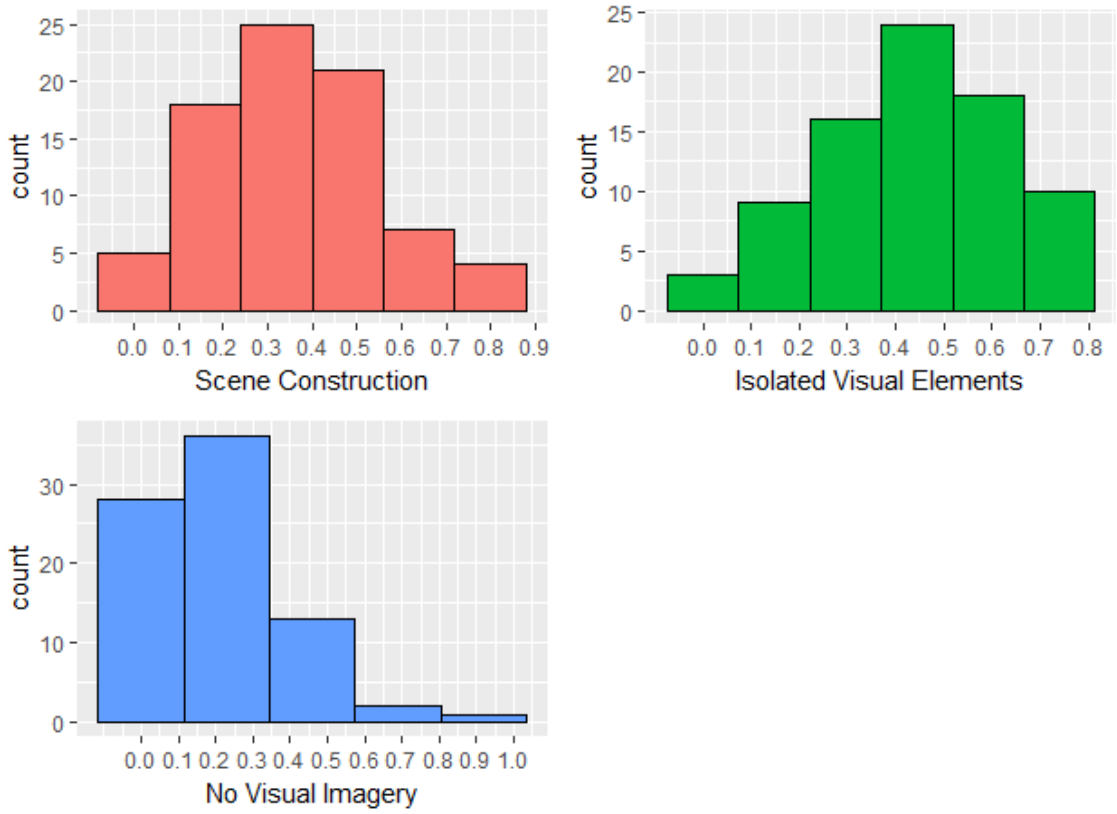


Figure 3.3: Frequency distribution of thoughts containing auditory imagery.

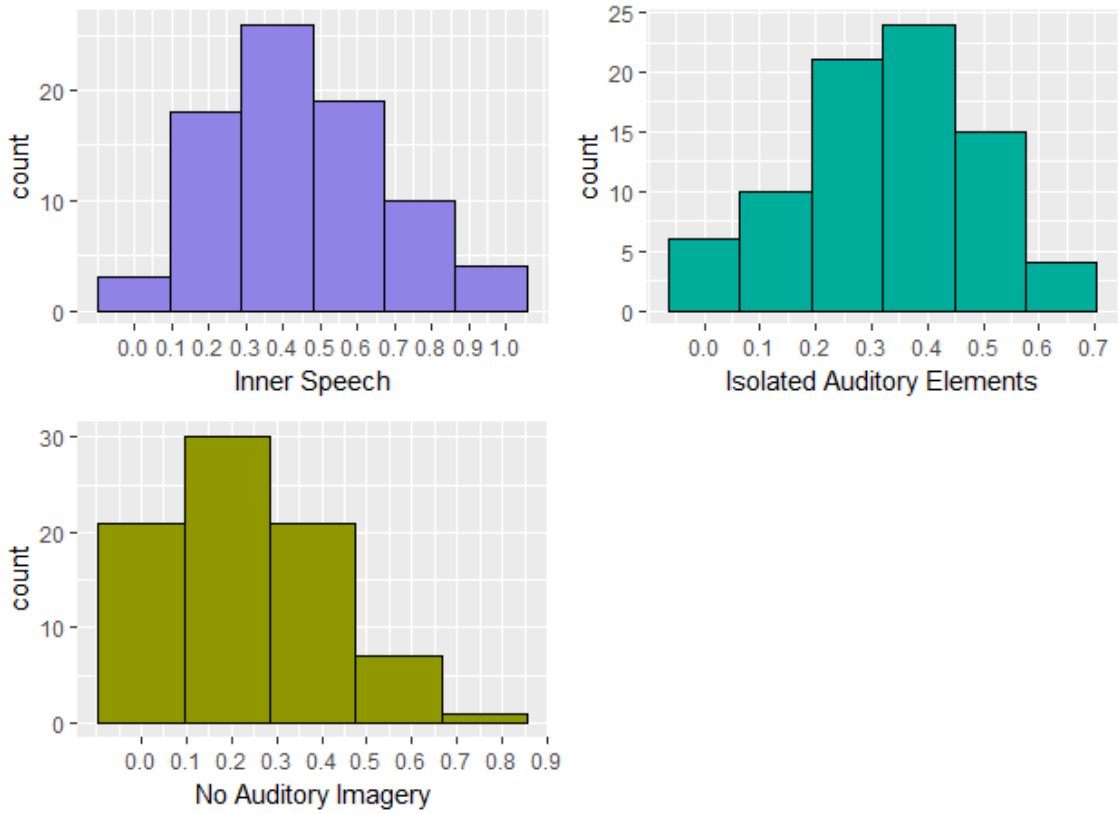
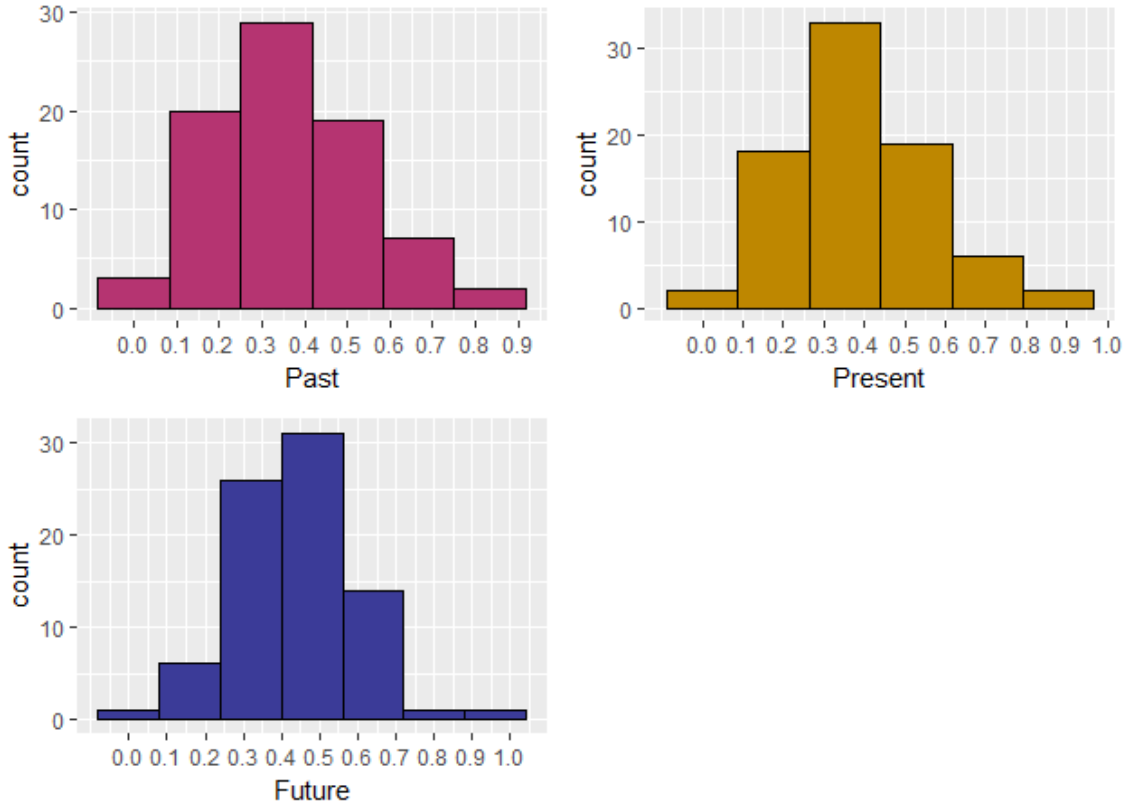


Figure 3.4: Frequency distribution of temporally oriented thoughts.



3.2 The Relationship Between Mental Imagery and Freedom of Movement

To test whether scene construction is associated with spontaneous thought, we evaluated the relationship between freedom of movement and visual imagery, using a multilevel mixed-effects linear regression approach. If scene construction co-occurs with spontaneous thoughts, we would expect scene construction and freedom of movement to show a positive relationship (indicated by a positive coefficient). Similarly, if other forms of imagery beyond scene construction (i.e., isolated visual elements, inner speech, and isolated auditory elements) co-occur with spontaneous thoughts, we would expect them to relate positively with freedom of movement.

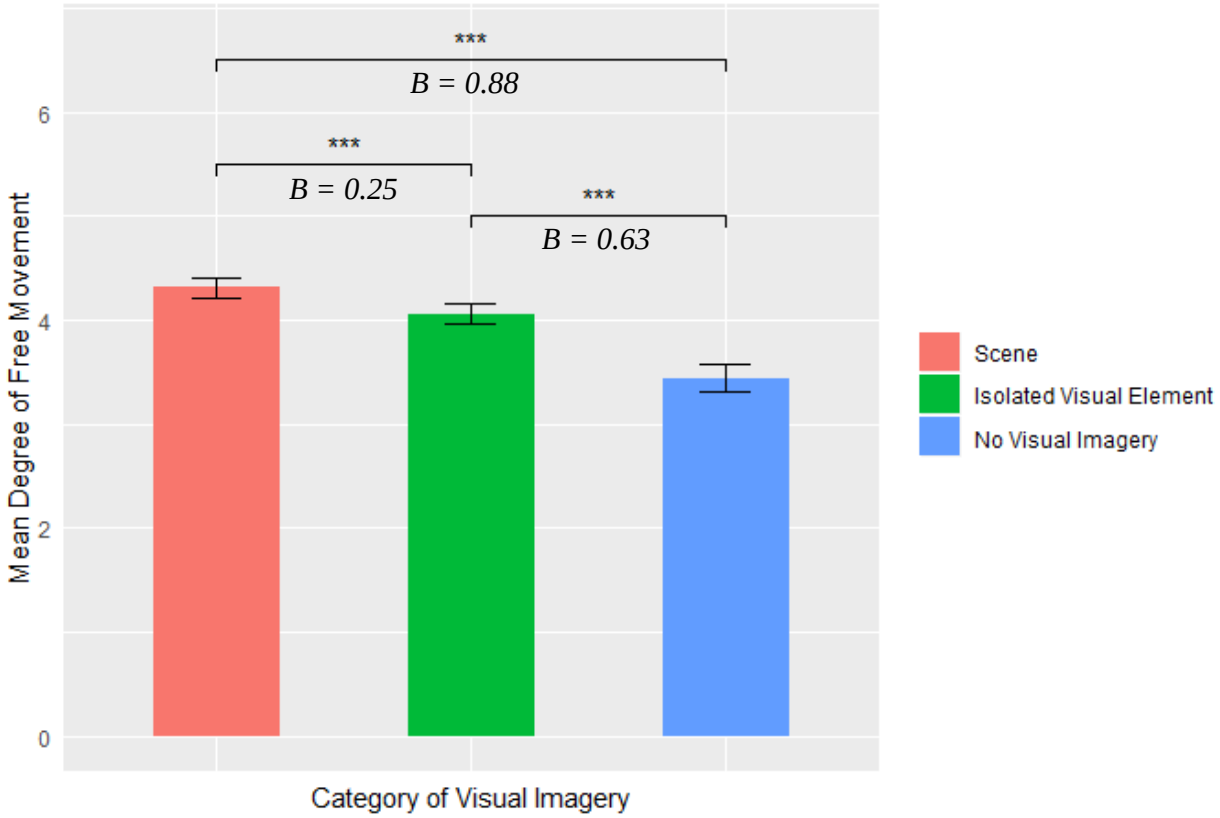
3.2.1 Visual Imagery and Freedom of Movement

We ran a model with freedom of movement as the dependent variable and auditory imagery as the independent variable. Freedom of movement is a continuous variable (a scale from 1 to 6). Visual imagery was coded as a factor with three levels: 1) scene construction, 2) isolated visual elements, 3) no visual imagery), using no visual imagery as the control. Scene construction (B =.88, t = 9.87, p < .001) and isolated visual elements (B = .63, t = 9.05, p < .001) both showed greater freedom of movement ratings compared to no visual imagery.

We ran a second model that was nearly identical except for using isolated visual elements as the control. This allowed us to evaluate the difference in freedom of movement ratings for scene construction compared with isolated visual elements. Scene construction showed greater freedom of movement ratings (B = .25, t = 4.31, p < .001) compared to isolated visual elements. The observed effects were not due to individual differences (B = 1.12, t = 1.58, p = .118; B = 1.08, t = 1.65, p = .103; B = .45, t = 0.72, p < .473).

To correct for multiple comparisons, we controlled for the false discovery rate (FDR) of each family of analyses using the Benjamini-Hochberg (BH) procedure (Benjamini & Hochberg, 1995). All reported significant p-values in the current analysis survived the correction for multiple comparisons using an FDR threshold of 0.05. Together, these results demonstrate that as predicted, thoughts containing scene construction are also often freely moving.

Figure 3.5: The impact of visual imagery on freedom of movement.

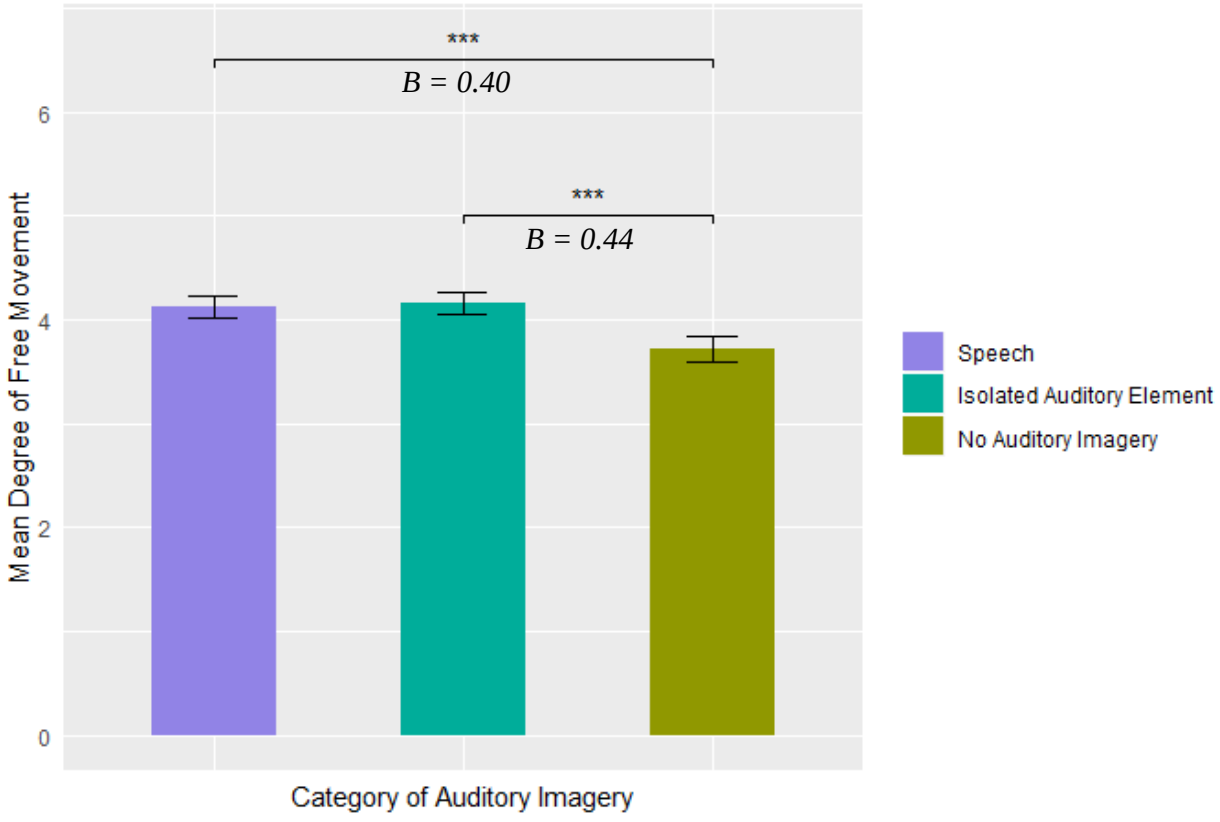


3.2.2 Auditory Imagery and Freedom of Movement

Next, we examined whether inner speech is associated with spontaneous thoughts. We evaluated the relationship between freedom of movement and inner speech, again using a multilevel mixed-effects linear regression approach. Freedom of movement was the dependent variable and auditory imagery was the independent variable. Similar to the preceding analysis (section 3.2.1), freedom of movement is a continuous variable (a scale from 1 to 6) and auditory imagery was coded as a factor with three levels: 1) inner speech, 2) isolated auditory elements, 3) no auditory imagery), using no auditory imagery as the control. Inner speech (B = .40, t = 5.33, p < .001) and isolated auditory elements (B = .44, t = 5.89, p < .001) both showed greater freedom of movement ratings compared to no auditory imagery. We ran a second model that was identical

to the preceding, using isolated visual elements as the control. This allowed us to evaluate the difference in freedom of movement ratings for inner speech compared with isolated auditory elements. Freedom of movement ratings did not significantly differ between inner speech and isolated auditory elements (B = - 0.05, t = - 0.901, p = .371). These results were not due to individual differences (B = 1.43, t = 1.64, p = .106; B = 0.49, t = 0.81, p = .422; B = 0.98, t = 1.43 p = .156). All reported significant p-values in the current analysis survived the correction for multiple comparisons using an FDR threshold of 0.05. Thus, the data suggest that, as with scene construction, thoughts containing inner speech are also often freely moving.

Figure 3.6: The impact of auditory imagery on freedom of movement.



3.3 The Relationship Between Auditory and Visual Imagery

To test whether there is a trade-off between auditory and visual imagery, we evaluated the relationship between auditory imagery and visual imagery using a multilevel mixed-effects logistic regression approach. If there was a trade-off between inner speech and scene construction, we would expect these variables to show a negative relationship. If, however, inner speech and scene construction are not incompatible, we would expect these variables to show a positive relationship.

3.3.1 Auditory Imagery and Scene Construction

We ran a model with scene construction as the dependent variable and auditory imagery as the independent variable. Scene construction is a binary variable (1 = yes, 0 = no). Auditory imagery is coded as a factor with three levels: 1) inner speech, 2) isolated auditory elements, 3) no auditory imagery, using no auditory imagery as the control. Scene construction showed a strong, positive relationship with inner speech ($B = .84$, $z = 5.00$, $p < .001$) and isolated auditory elements ($B = .65$, $z = 3.78$, $p < .001$). Scene construction did not significantly differ between inner speech and isolated auditory elements ($B = 0.19$, $z = 1.11$, $p = .269$). These effects were not due to individual differences ($B = 0.28$, $z = 0.25$, $p = .805$; $B = 0.27$, $z = 0.36$, $p = .722$; $B = 0.28$, $z = 0.248$, $p = .804$) and all reported significant p-values in the current analysis survived the correction for multiple comparisons using an FDR threshold of 0.05. Just like in a linear regression, a coefficient in logistic regression is the slope of the regression line. Unlike linear regression, the dependent variable is replaced by the log odds that the dependent variable takes on the value of 1. Table 3.2 displays formulas for converting between the log odds, odds, and probability. Using these conversions, the regression coefficient can be meaningfully interpreted in terms of odds and probability.

Table 3.2: Formulas for converting between log odds, odds, and probability. Log-odds or 'logit' is the raw coefficient computed in R software for logistic regression by default. It is computed as log(p/(1-p)) where log is the natural log (ln) and p is the probability.

Conversion	Frequency Distribution
Log Odds to Odds	exp (log odds)
Odds to Probability	odds / (1 + odds)

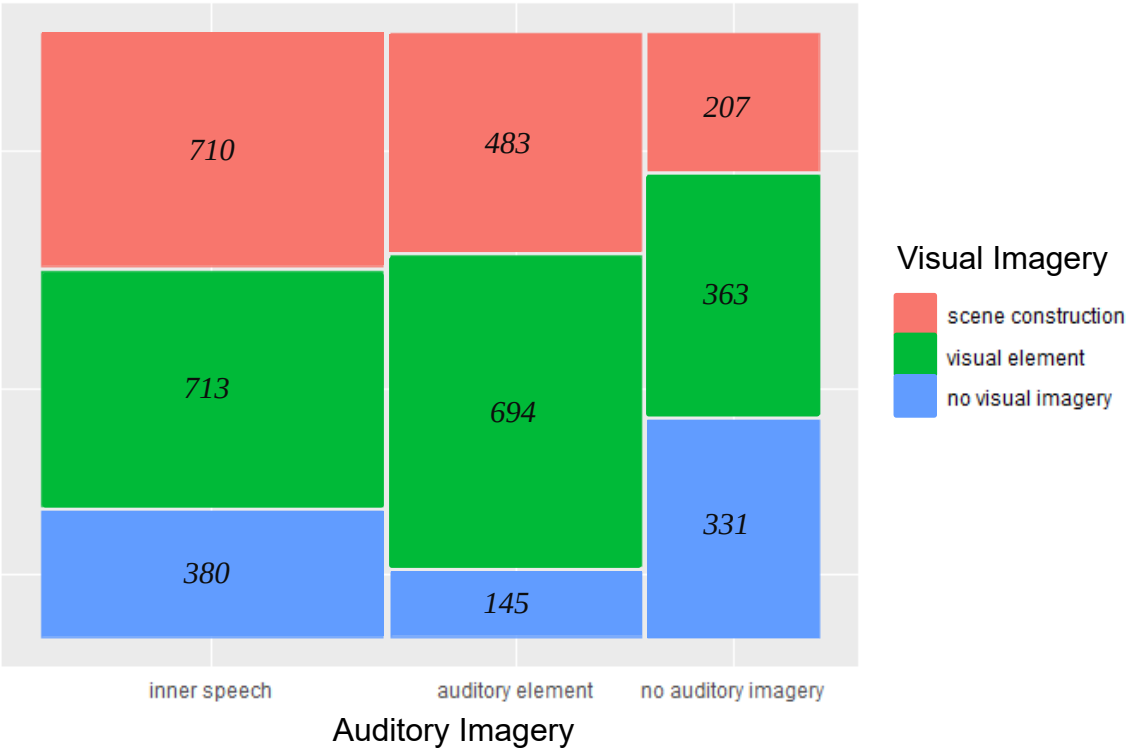
The odds of reports containing scene construction when inner speech is present (inner speech = 1), divided by the odds that inner speech is absent (no inner speech = 0), is 2.32, when holding isolated auditory elements constant. In terms of probability, this implies that if a thought contains inner speech, it will also contain scene construction 70% of the time (Figure 3.7). The odds of reports containing scene construction when isolated auditory elements are present (isolated auditory elements = 1), divided by the odds that that isolated auditory elements are absent (no isolated auditory elements = 0), is 1.92, holding inner speech constant. This means that if a thought contains isolated auditory elements it will also contain scene construction 66% of the time (Figure 3.7).

3.3.2 Auditory Imagery and Isolated Visual Imagery

We next ran a model with isolated visual elements as the dependent variable and auditory imagery as the independent variable. Isolated visual imagery is a binary variable (1 = yes, 0 = no). As in the previous analysis, auditory imagery was coded as a factor with three levels: 1) inner speech, 2) isolated auditory elements, 3) no auditory imagery, using no auditory imagery as the control. Isolated visual elements showed a positive relationship with isolated auditory elements (B = .50, z = 2.82, p < .01) and no significant relationship with inner speech (B = - .01, z = - .052, p = .958), and these effects were not due to individual differences (B = - 0.10, z = - 0.18, p = .06; B = 1.43 z = 1.86, p = .06). The likelihood of isolated visual imagery being present was lower for

inner speech than for isolated auditory elements (B = - 0.51, t = - 3.78, p < .001) and this effect was partially due to individual differences (B = 1.46, z = 2.46, p < .05). All reported significant p-values in the current analysis survived the correction for multiple comparisons using an FDR threshold of 0.05.

Figure 3.7: The co-occurrence of visual imagery and auditory imagery. The mosaic plot shows the rates of co-occurrence for all combinations of visual imagery and auditory imagery. Similar to a stacked bar plot, a mosaic plot spatially represents a contingency table (3 X 3 in this case). However, unlike a stacked bar plot, values on both the x and y axes are represented spatially (hence why the widths of the x-axis columns vary). Counts represent the number of reports that were found to contain each categorical combination.



When interpreted as odds, we can say that the odds of reports containing isolated visual elements when inner speech is present (inner speech = 1), divided by the odds that inner speech is absent (no inner speech = 0), is 1.65, holding isolated auditory elements constant. In terms of probability, this means that if a thought contains inner speech, it will also contain isolated auditory elements 50% of the time (Figure 3.7). The odds of reports containing isolated visual elements

when isolated auditory elements are present (isolated auditory elements = 1), divided by the odds that isolated auditory elements are absent (no isolated auditory elements = 0), is 1.01, holding inner speech constant. In other words, if a thought report contains isolated visual elements it will also contain isolated auditory elements 62% of the time (Figure 3.7).

Taken together, the results from Chapters 3.2.1 and 3.3.2 do not suggest a trade-off between visual and auditory imagery, even when taking individual differences into account. To the contrary, the results suggest that visual and auditory imagery are not incompatible, and in fact, frequently co-occur.

3.4 The Relationship Between Mental Imagery and Mental Time Travel

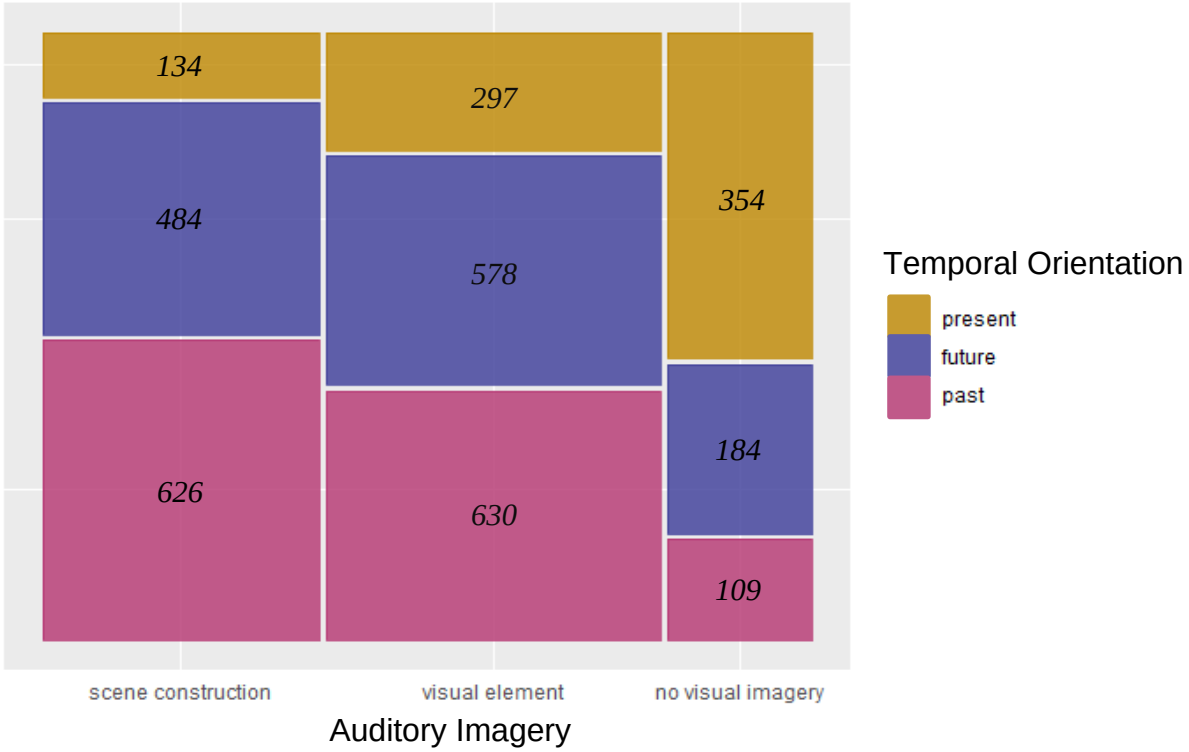
To determine if scene construction is associated with mental time travel, we evaluated the relationship between visual imagery and temporal orientation using multilevel mixed-effects logistic regression. If scene construction is associated with mental time travel, we would expect scene construction to have a positive relationship with past and future oriented thoughts, and a negative relationship with present oriented thoughts. To determine if inner speech is associated with temporal orientation, we evaluated the relationship between temporal orientation and auditory imagery. If inner speech is associated with mental time travel, we would expect inner speech to have a positive relationship with both past and future oriented thoughts, and a negative relationship with present oriented thoughts.

3.4.1 Visual Imagery and Temporal Orientation

We ran three separate models, with the categories of temporal orientation (past, present, and future) serving as the separate dependent variables. Visual imagery was the independent variable for all three models and was coded as a factor with three levels: 1) scene construction, 2) isolated visual imagery, 3) no visual imagery), using no visual imagery as the control. Scene

construction and isolated visual elements both showed a positive relationship with past (B = 1.71, z = 10.12, p < .001; B = 1.33, z = 8.20, p < .001) and future orientation (B = 1.36, z = 9.07, p < .001; B = 1.22, z = 9.06, p < .001) and a negative relationship with present orientation (B = - 1.74, z = - 10.10, p < .001; B = - 1.11, z = - 7.24, p < .001).

Figure 3.8: The co-occurrence of visual imagery and temporal orientation. The 3X3 mosaic plot shows the rates of co-occurrence for all combined categories of visual imagery and temporal orientation. Counts represent the number of reports that were found to contain each categorical combination.



When interpreted as odds, the odds of reports being past oriented when scene construction is present (scene construction = 1), divided by the odds that scene construction is absent (scene construction = 0), is 5.53, when holding isolated visual elements constant. In terms of probability, this implies that if a thought contains scene construction, it will be past oriented 85% of the time (Figure 3.8). The odds of reports being past oriented when isolated visual elements are present (isolated visual elements = 1), divided by the odds that that isolated visual elements are absent (no

isolated visual elements = 0), is 3.78, holding scene construction constant. This means that if a thought contains isolated visual elements it will also be past oriented 79% of the time (Figure 3.8). The odds of reports being future oriented when scene construction is present (scene construction = 1), divided by the odds that scene construction is absent (scene construction = 0), is 3.90, when holding isolated visual elements constant. In terms of probability, this implies that if a thought contains scene construction, it will be future oriented 80% of the time (Figure 3.8). The odds of reports being future oriented when isolated visual elements are present (isolated visual elements = 1), divided by the odds that that isolated visual elements are absent (no isolated visual elements = 0), is 3.39, holding scene construction constant. This means that if a thought contains isolated visual elements it will also be future oriented 77% of the time (Figure 3.8).

The odds of reports being present oriented when scene construction is present (scene construction = 1), divided by the odds that scene construction is absent (scene construction = 0), is 0.18, when holding isolated visual elements constant. In terms of probability, this implies that if a thought contains scene construction, it will be present oriented 15% of the time (Figure 3.8). The odds of reports being present oriented when isolated visual elements are present (isolated visual elements = 1), divided by the odds that that isolated visual elements are absent (no isolated visual elements = 0), is 0.33, holding scene construction constant. This means that if a thought contains isolated visual elements it will also be present oriented 25% of the time (Figure 3.8).

We ran three models that were identical to the previous, except using isolated visual elements as the control. This allowed us to differentiate between scene construction and isolated visual elements in terms of their separate impact on temporal orientation. We found that scene construction was more likely to co-occur with past orientation ($B = 0.43$, $z = 4.14$, $p < .001$) and less likely to co-occur with present orientation ($B = -0.66$, $z = 5.13$, $p < .001$) than isolated visual

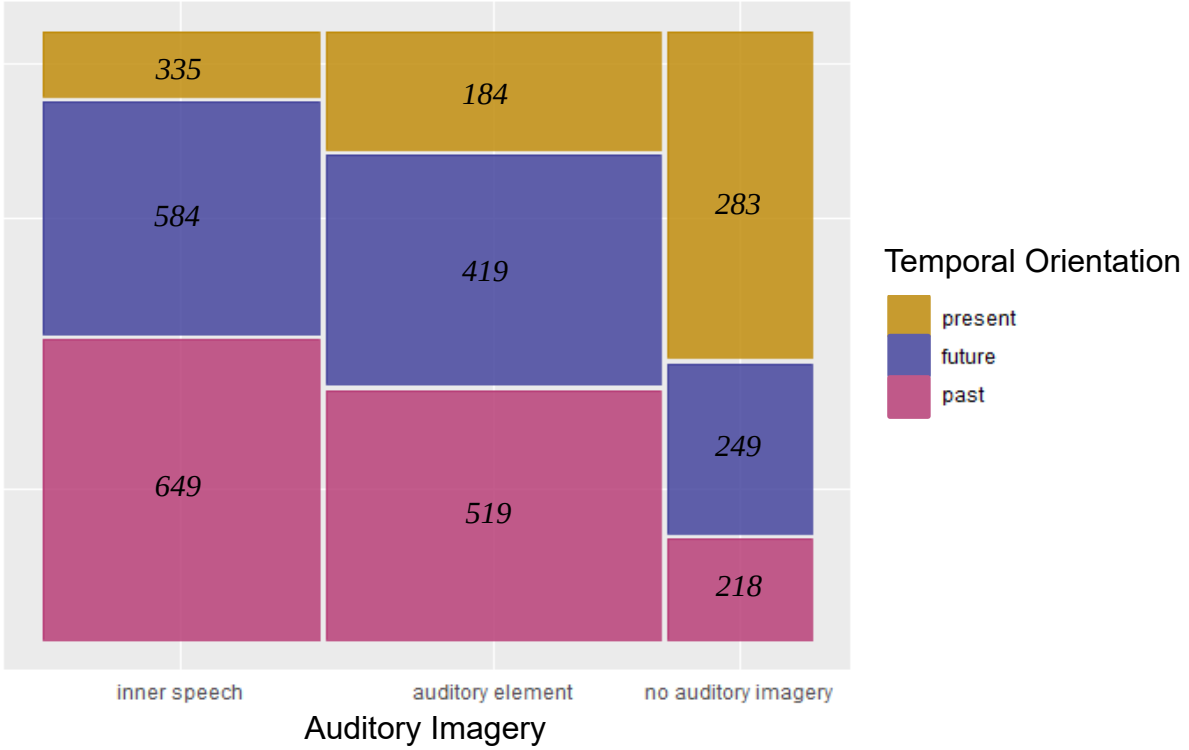
elements. There was no significant difference between scene construction and isolated visual elements for future orientation (B = 0.11, z = 1.20, p = .230). These observed effects were not due to individual differences for past (B = 1.14, z = 1.67, p = .094; B = .89, z = 1.44, p = .151; B = 0.30, z = 0.54, p = .591), future (B = 0.36, z = .65, p = .52; B = .17, z = .32, p = .746; B = 0.02, z = 0.03, p = .974), or present orientation (B = 1.28, z = 1.92, p = .055; B = 1.00, z = 1.57, p = .117; B = 0.01, z = - .223, p = .982). All reported significant p-values in the current analysis survived the correction for multiple comparisons using an FDR threshold of 0.05.

As predicted, the data support the hypothesis that past and future oriented thoughts frequently co-occur with scene construction. In addition to scene construction, the data suggest that mental time travel frequently co-occurs with isolated visual elements as well.

3.4.2 Auditory Imagery and Temporal Orientation

We ran three separate models, once again, using the categories of temporal orientation (past, present, and future) as separate dependent variables. Auditory imagery was the independent variable for all three models and was coded as a factor with three levels: 1) inner speech, 2) isolated auditory imagery, 3) no auditory imagery), and no auditory imagery was the control. Following the patterns for visual imagery (section 3.4.1), inner speech and isolated auditory elements showed a positive relationship with past (B = .84, z = 5.73, p < .001; B = .77, z = 6.03, p < .001) and future orientation (B = .55, z = 4.35, p < .001; B = .44, z = 3.49, p < .001) and a negative relationship with present orientation (B = - .38, z = - 2.64, p < .01; B = - .66, z = - 5.26, p < .001).

Figure 3.9: The co-occurrence of auditory imagery and temporal orientation. The 3X3 mosaic plot shows the rates of co-occurrence for all combined categories of auditory imagery and temporal orientation. Counts represent the number of reports that were found to contain each categorical combination.



When interpreted as odds, the odds of reports being past oriented when inner speech is present (inner speech = 1), divided by the odds that inner speech is absent (inner speech = 0), is 2.32, when holding isolated visual elements constant. In terms of probability, this implies that if a thought contains inner speech, it will be past oriented 70% of the time (Figure 3.9). The odds of reports being past oriented when isolated auditory elements are present (isolated auditory elements = 1), divided by the odds that that isolated auditory elements are absent (no isolated auditory elements = 0), is 2.16, holding inner speech constant. This means that if a thought contains isolated auditory elements it will also be past oriented 68% of the time (Figure 3.9).

The odds of reports being future oriented when inner speech is present (inner speech = 1), divided by the odds that inner speech is absent (inner speech = 0), is 1.73, when holding isolated

auditory elements constant. In terms of probability, this implies that if a thought contains inner speech, it will be future oriented 68% of the time (Figure 3.9). The odds of reports being future oriented when isolated auditory elements are present (isolated auditory elements = 1), divided by the odds that that isolated auditory elements are absent (no isolated auditory elements = 0), is 1.55, holding inner speech constant. This means that if a thought contains isolated auditory elements it will also be future oriented 61% of the time (Figure 3.9).

The odds of reports being present oriented when inner speech is present (inner speech = 1), divided by the odds that inner speech is absent (inner speech = 0), is 0.68, when holding isolated auditory elements constant. In terms of probability, this implies that if a thought contains inner speech, it will be present oriented 40% of the time (Figure 3.9). The odds of reports being present oriented when isolated auditory elements are present (isolated auditory elements = 1), divided by the odds that that isolated auditory elements are absent (no isolated auditory elements = 0), is 0.52, holding inner speech constant. This means that if a thought contains isolated auditory elements it will also be present oriented 34% of the time (Figure 3.9).

We ran three models that were identical to the previous, except using isolated auditory elements as the control. This allowed us to differentiate between inner speech and isolated auditory elements in terms of their impacts on temporal orientation. We found that inner speech was more likely to co-occur with present orientation than isolated auditory elements (B = 0.28, z = 2.26, p < .05). There were no significant differences between scene construction and isolated visual elements for either past (B = 0.03, z = .25, p = .803) or future orientation (B = 0.08, z = .75, p = .453). The observed effects were not due to individual differences for past (B = 0.52, z = .61, p = .544; B = - .87, z = - 1.39, p = .165; B = 1.15, z = 1.78, p = .075), future (B = - 0.09, z = - .12, p = .908; B = .34, z = .62, p = .539; B = - 0.52, z = - 0.91, p = .363), or present orientation (B = - 0.99,

z = - 1.21, p = .227; B = - .14, z = - .231, p = .818; B = - 1.04, z = - 1.62, p = .095). All reported significant p-values in the current analysis survived the correction for multiple comparisons using an FDR threshold of 0.05.

Taken together, these results suggest that in addition to scene construction and isolated visual elements, both inner speech and isolated auditory elements frequently co-occur with mentally traveling away from the present to focus on the past and future.

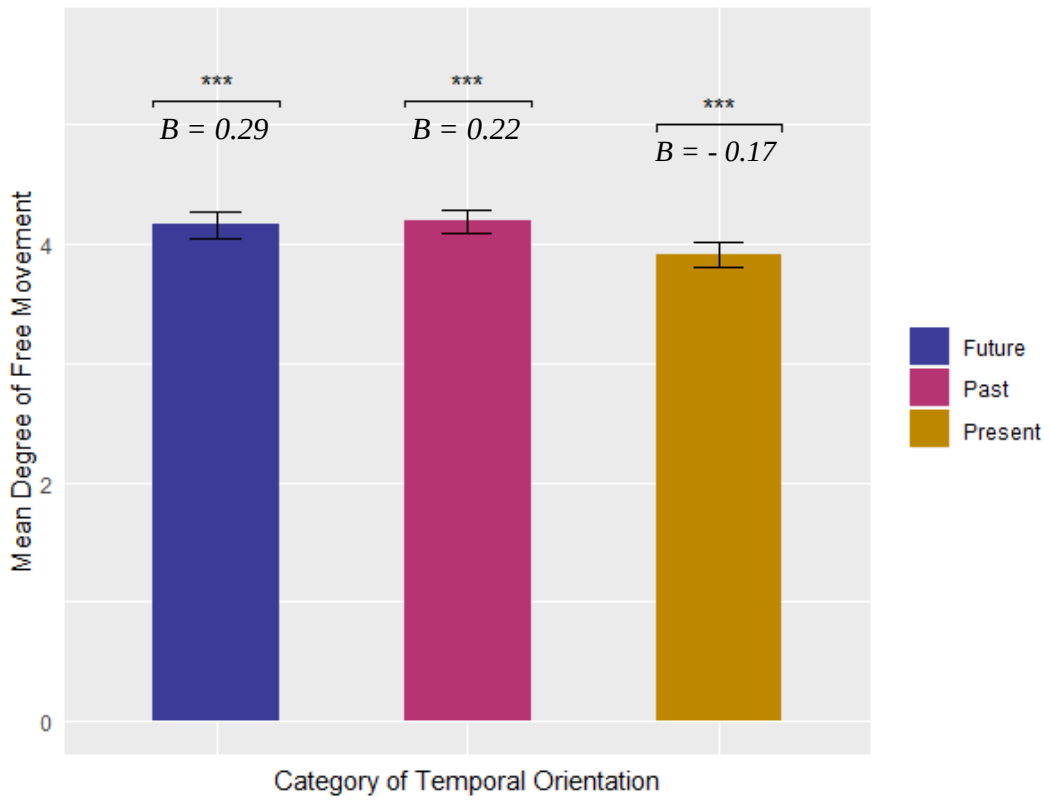
3.5 The Relationship Between Mental Time Travel and Spontaneous Thought

To better understand the results from the previous analyses (Sections 3.3 and 3.5), we conducted an additional analysis examining the relationship between mental time travel and spontaneous thought on an exploratory basis. Analysis 3.2 tells us that mental imagery and spontaneous thought co-occur, but it cannot tell us why. Analysis 3.4 further informs us that mental imagery co-occurs with mental time travel, but it does not confirm that such co-occurrence is during spontaneous thought. If in the current analysis, mental time travel (which co-occurs with mental imagery; Section 3.2) turns out to co-occur with spontaneous thought (which co-occurs with mental imagery; Section 3.4), then this would strengthen the argument that mental imagery plays a role in mental time travel during spontaneous thought. In addition, the results from section 3.2 showing co-occurrence between mental imagery and spontaneous thought could be explained as owing to the mind's quick readiness to become spontaneously preoccupied with the personal past and future as if by *default* (Andrews-Hanna, 2012).

We ran a model with freedom of movement as the dependent variable and past orientation as the independent variable. Freedom of movement is a continuous variable (a scale from 1 to 6). Past orientation is a binary variable with two levels (1 = the presence of past orientation, 0 = the absence of past orientation). The absence of past orientation served as the control. The presence

of past orientation (B = .22, t = 4.34, p < .001) showed greater freedom of movement ratings compared to the absence of past orientation. The observed effects were not due to individual differences (B = .17, t = 0.29, p = .772). These results show that thoughts oriented towards the past are also often freely moving.

Figure 3.10: The impact of temporal orientation on freedom of movement. Coefficients are derived from the separate contrasts between the presence and absence of each category of temporal orientation.



Next, we ran a model with freedom of movement as the dependent variable and future orientation as the independent variable. Freedom of movement is a continuous variable (a scale from 1 to 6). Future orientation is a binary variable with two levels (1 = the presence of future orientation, 0 = the absence of future orientation). The absence of future orientation served as the control. The presence of future orientation (B = .29, t = 6.22, p < .001) showed greater freedom of movement ratings compared to the absence of future orientation. The observed effects were not

due to individual differences (B = - .15, t = - 0.22, p = .825). These results show that thoughts oriented towards the future are also often freely moving.

Finally, we ran a model with freedom of movement as the dependent variable and present orientation as the independent variable. Freedom of movement is a continuous variable (a scale from 1 to 6). Present orientation is a binary variable with two levels (1 = the presence of present orientation, 0 = the absence of present orientation). The absence of present orientation served as the control. The presence of present orientation (B = - .17, t = - 3.49, p < .001) showed lower freedom of movement ratings compared to the absence of present orientation. The observed effects were not due to individual differences (B = .59, t = 0.98, p = .328). All reported significant p-values in the current analysis survived the correction for multiple comparisons using an FDR threshold of 0.05. These results demonstrate that thoughts oriented towards the present are less freely moving (i.e., more deliberately constrained).

Chapter 4: Discussion

4.1 The Contents and Dynamics of Thought During Waking Rest

The majority of thoughts obtained from waking rest were spontaneous, as is indicated by the high freedom of movement ratings (mean of 4.1 on a six-point scale). These thoughts were also highly visuo-spatial and auditory in nature, and included imagery of scenes (35%), simulated speech (44%), and isolated visual and auditory elements (44% and 33%). Furthermore, thoughts generated during waking rest were typically future oriented (44%) followed by present (39%) and past oriented (37%). Our results expand upon a growing body of knowledge on thought dynamics (Mills et al., 2018; Smith et al., 2018) and thought contents (Andrews-Hanna et al., 2013; Perogamvros et al., 2017) and replicate the results of previous research showing that thoughts arising in the absence of a task are most frequently focused on the future and to a slightly lesser but still comparable extent on the past (Andrews-Hanna et al., 2013; Stawarczyk, Cassol, & D'Argembeau, 2013).

4.2 The Relationship Between Thought Contents and Thought Dynamics

4.2.1 Scene Construction Co-occurs with Spontaneous Thought

A key finding was that scene construction is strongly associated with greater freedom of movement (i.e., spontaneous thought). As there is no dearth of easily imaginable instances in which mental imagery would be generated deliberately, this result may at first glance seem surprising. For instance, we might engage in deliberate scene construction when struggling to remember where the car is parked or engage in deliberate inner speech when planning out a difficult conversation. Moreover, documented examples of lucid dreaming illustrate how individuals can exert deliberate control over their inner narratives during sleep, even so far as influencing the outcome of oneiric events as they spontaneously unfold (Dresler et al., 2012;

Kahan & LaBerge, 1994; La Berge, Nagel, Dement, & Zarcone, 1981; Schredl & Erlacher, 2004; Snyder & Gackenbach, 1988; Stumbrys, Erlacher, Schädlich, & Schredl, 2012; Zadra, Donderi, & Pihl, 1992). Finally, several neuroimaging studies have relied upon participants' ability to deliberately imagine scenes on cue (Hassabis, Kumaran, & Maguire, 2007; Hassabis, Kumaran, Vann, et al., 2007; Hassabis & Maguire, 2007). All these examples serve to illustrate that mental imagery and deliberate thought are by no means incompatible.

Yet when external demands are low, such as in the absence of a task, the mind defaults to an inward narrative filled with past reflections and future prospections (Andrews-Hanna et al., 2013; Klinger, 1971; Singer, 1970; Stawarczyk, Cassol, & D'Argembeau, 2013; Stawarczyk et al., 2011). And in fact, even when engaged in a task, the mind does so great persistence (Stawarczyk, Majerus, Maj, et al., 2011). Not to mention there is a growing body of evidence to suggest that waking rest critically facilitates the *automatic* processing of memories and associations (Binder et al., 1999; Brokaw et al., 2016; Graveline & Wamsley, 2017; Schlichting & Preston, 2014; Tambini & Davachi, 2013; Tambini, Ketz, & Davachi, 2010). Considering the ease with which the mind defaults to preoccupation with the past and future, and considering the role that mental imagery plays in memory and future simulations, it should come as no surprise that in the current study, thoughts containing scene construction were predominantly freely moving (i.e., spontaneous). However, scenes are not the only type of imagery that form the fabric of the inner narrative.

4.2.2 Inner Speech Co-occurs with Spontaneous Thought

Beyond scene construction, we found that inner speech was positively associated spontaneous thoughts. This finding suggests that spontaneous imagery is more richly representative of multi-modal experience than is captured by visual imagery alone. Inner speech constitutes a complex form of auditory imagery involving inner monologues and dialogues. The

finding of an association between inner speech and freely moving thought is novel, although the presence of inner speech in everyday thoughts has long been known, and is in this sense, unsurprising. Thus, these findings are in line with previous research demonstrating the occurrence of inner speech in daily thoughts, and also shed novel light on the types of contents that spontaneous thoughts can produce.

4.2.3 Isolated Elements Co-occur with Spontaneous Thought

A more novel finding still was that beyond scene construction and inner speech, spontaneous thoughts co-occurred considerably with contextually isolated elements. While a distinction between visual and auditory imagery has long been recognized, a lesser recognized distinction is sometimes made between spatial and object imagery (Kozhevnikov et al., 2005). Kozhevnikov and colleagues (2005) have argued that individuals can be classified as spatial versus object visualizers, with spatial visualizers reliably performing better on holistic spatial tasks, and object visualizers performing better on tests requiring attention to object details. The current study did not yield an effect of individual differences in the production of spatial scenes versus isolated elements. However, we observed comparable rates of scene construction (35%) and isolated visual elements (44%), and in addition, scene construction was more predictive of spontaneous thought than visual elements. Our findings do seem to support, at the very least, the validity of the previously drawn distinction between visuo-spatial and object imagery (Hassabis, Kumaran, & Maguire, 2007; Kozhevnikov et al., 2005; Sugiura et al., 2005).

A similar distinction can be made between inner speech and isolated auditory elements. While the production of smaller elements of inner speech (e.g., a word or phrase) is acknowledged in the literature, there has been little exploration of auditory elements beyond the current study. Comparable rates of inner speech (44%) and isolated auditory elements (33%) were reported in

support of a distinction between complex and simple auditory imagery. Furthermore, we observed a significant positive association between spontaneous thoughts and isolated auditory elements which further reveals the heterogeneity of mental representations that are possible during spontaneous thoughts.

4.3 The Relationship Between Scene Construction and Inner Speech

Despite clear individual differences in the rates of producing different categories of imagery (Figures 3.2-3.4) we found no inherent trade-off between visual and auditory imagery for either the between-subject or within-subject analyses. Instead, greater rates of visual imagery were associated with a greater likelihood of auditory imagery for both within and between participant analyses, which suggests that visual and auditory imagery are not incompatible. This finding is congruent with what is known about the multi-modal nature of imagery (Fernandino et al., 2016; Nanay, 2018; Sepulcre, Sabuncu, Yeo, Liu, & Johnson, 2012) and stands in direct contrast to the idea that there are visualizers and verbalizers, at least, in the most radical sense of the argument (Bartlett, 1932; James, 1890). Instead, differences found in rates of imagery production from past research (Paivio, 1971; Richardson, 1977), as well as in the current study, may be better explained by individual differences in the production of mental imagery *in general*, rather than due to trait-specific reliance on a single mode of processing over another. In other words, some people may simply tend to produce more frequent or more vivid mental imagery overall, regardless of modality.

4.4 The Relationship Between Mental Imagery and Mental Time Travel

4.4.1 Scene Construction and Mental Time Travel

Of primary importance, we found that scene construction was positively associated with mental time travel. This connection was supported on two levels, including by 1) a positive

relationship with past and future orientation, and a 2) negative relationship with present orientation. By definition, mental time travel involves a cognitive shift in perspective away from the present to focus on the past and future (Suddendorf & Corballis, 1997; Suddendorf, Addis, & Corballis, 2009; Tulving, 2002), and it has long been known that during in moments of waking rest, our thoughts become preoccupied with reflections on the past and prospections on the future. This general notion is supported by a growing number of studies showing that naturally occurring thoughts tend to be focused on the past and especially the future (Andrews-Hanna et al., 2013; Beaty et al., 2018; Stawarczyk, Majerus, Radomska, Van der Linden, & D'Argembeau, 2011).

It has also been speculated that memory and prospection rely upon scene construction, a form of visual-spatial imagery that mentally organizes elements, including people, objects, and events, into a setting or environment (Hassabis & Maguire, 2009). While there are a number of reasons to believe that mental time travel involves scene construction, this putative connection had yet to be examined during spontaneous thought specifically. Instead, the relationship between scene construction and mental time travel has been examined in situations where participants are explicitly *told* to remember and imagine scenes (Hassabis, Kumaran, & Maguire, 2007; Hassabis, Kumaran, Vann, et al., 2007; Hassabis & Maguire, 2007; Summerfield et al., 2010). Such methods have artificially coerced the connection between scene construction and mental time travel, leaving little room for capturing the relationship between scene construction and mental time travel as it occurs naturally within the mental landscape. The current study contributes to the extant literature by providing the first direct evidence in support of the widely hypothesized role of scene construction in spontaneous thoughts of the past and future.

4.4.2 Inner Speech and Mental Time Travel

Beyond scene construction, we found that inner speech had a positive relationship with mental time travel. This suggests that mental time travel involves auditory imagery to a greater extent than previous frameworks have tended to emphasize (Addis et al., 2007; Hassabis & Maguire, 2009; Schacter et al., 2012; Tulving, 1985, 2002). Yet, despite this lack of emphasis on auditory imagery, our experience of the world is multi-modal (Moulton & Kosslyn, 2009), involving visual as well as auditory stimuli, and these same frameworks have nevertheless suggested that mental time travel reconstructs the details of lived experience (Addis et al., 2007; Hassabis & Maguire, 2009; Schacter et al., 2012; Tulving, 1985, 2002). In this sense, the finding that both visual and auditory imagery were present in memories and future-oriented simulations during spontaneous thought is overall compatible with existing frameworks.

4.4.3 Isolated Elements and Mental Time Travel

A more difficult to explain, but nevertheless intriguing finding, is that mental time travel was positively associated with contextually isolated elements. This was the case for elements of both visual and auditory modalities. At first glance, this finding seems at odds with standard conceptions of mental time travel.

In addition to focusing on visual attributes, theories of mental time travel and episodic simulation have tended to emphasize the contextual attributes of remembering and prospecting, including namely the spatial and temporal context of mentally simulated events. The episodic simulation hypothesis has, for instance, rested upon the idea that imagining the future relies upon the same constructive mechanisms that underpin episodic memory, with episodic memory conceptualized as the veridical resurrection of the elements and spatiotemporal context of a previously experienced event. This invites the question of why, in the current study, elements

appearing in the absence of a surrounding spatial context (or linguistic context in the case of auditory elements) would have predicted mental time travel as well as contextualized forms of imagery -- i.e., scene construction and inner speech.

There are at least three possible ways to interpret these results. First, should the definition of mental time travel rest invariably upon the assumption that mental time travel requires an immersive spatiotemporal context, then one could reasonably argue that, by definition, remembering or prospecting isolated elements does not in fact constitute mental time travel. Assuming this position bears only the responsibilities of (i) conceding that not all forms of remembering and prospecting require a spatial context, and (ii) deciding on what to call such decontextualized forms of remembering and prospecting, if not mental time travel.

Another way of interpreting these findings is to expand definitions of mental time travel to include decontextualized elements. Addis et al (2018) have recently updated their episodic simulation hypothesis to argue that the mental simulation or construction of events (renamed 'constructive simulation') relies upon semantic memory as well as episodic memory. One might similarly choose to reconceptualize mental time travel and the related construct of constructive simulation to include all types of imagery, including simpler elements that are not immersed in a surrounding spatial context.

A third interpretation rests upon considering an important detail from our results (see Chapter 3.3). Figure 3.7 shows the rates of co-occurrence for all possible combinations of visual and auditory imagery in thought reports. Note that two of the highest rates of co-occurrence are between different imagery modalities (i.e., visual and auditory). That is, isolated visual elements often co-occurred with inner speech, and isolated auditory elements often co-occurred with scene construction. As elements from one modality usually co-occurred with the complex form of

imagery from the alternate modality, this could mean that, in these instances, the greater likelihood of mental time travel was not associated with the presence of isolated elements per se, but rather, was associated with the complex form of imagery from the opposite modality. Alternately, complexity stemming from the multi-modal nature of visual and auditory imagery *in combination* could also have predicted the greater likelihood of mental time travel.

The extent to which the isolated elements versus potential sources of complexity from co-occurring scene construction and inner speech might drive the greater likelihood of mental time travel is unclear and further research is necessary. Nevertheless, our results show that beyond complex scene construction and inner speech, contextually isolated visual and auditory elements can also co-occur with remembering the past and imagining the future. Future research might aim to parse out possible effects from simplicity (e.g., isolated visual elements) versus both unimodal complexity (e.g., scene construction or inner speech) and multi-modal complexity (e.g., scene construction combined with isolated auditory elements, or inner speech combined with isolated visual elements) on the likelihood of mental time travel during spontaneous thought.

4.4.4 The Absence of Mental Imagery and Present Orientation

The negative association between the absence of mental imagery and mental time travel (or inversely, the positive relationship between no mental imagery and present orientation) is entirely consistent with the previous finding of a positive association between mental imagery and mental time travel. It would make sense that thoughts focused on the present moment would not contain mental imagery, as awareness of the present time and place does not require imagery; rather, it requires perception. One exception to this might be when we are thinking about what is happening somewhere else (i.e., another scene or situation) in the present moment, or when we are having internal monologue about the current situation (e.g., self-talk about one's ongoing

movements, thoughts, and activities). And in fact, this might explain why a smaller but nonetheless substantial proportion of thoughts generated during waking rest contained imagery while also being focused on the present moment (as is indicated by the probabilities of 15% for scene construction, 40% for inner speech, 25% for visual elements, and 30% for auditory elements in terms of co-occurrence with present orientation). Also, the fact that inner speech was the most likely of all forms of imagery to be focused on the present moment (40%) is an intuitive finding that could potentially be related to the distinction between self-talk (directed towards the self generally and without specific temporal orientation) and simulated conversation (either previously experienced or novel/hypothetical). The relationship between temporal orientation and different types of inner speech (i.e., self-talk vs. simulated conversation) during spontaneously generated thoughts might be an interesting avenue for future research.

4.5 The Relationship Between Mental Time Travel and Spontaneous Thought

Finally, we found that mental time travel predicted spontaneous thought, and that spontaneous thought was most strongly associated with a focus on the future, followed by a focus on the past. In contrast, spontaneous thought was negatively associated with a focus on the present (which thus implies that deliberate thought was associated with a focus on the present). As stated in Chapter 3.5, the analyses in Chapter 3.2 and 3.5 respectively inform us that spontaneous thoughts are positively associated with mental imagery (including scene construction, inner speech, and isolated elements), and that mental imagery is positively associated with mental time travel. However, the direct connection between spontaneous thought and mental time travel is unclear from these results alone. The final set of analyses (Chapter 3.5) allowed us to confirm that spontaneous thoughts are indeed positively associated with mental time travel, in addition to allowing us to compare the degree to which spontaneous thought tends to be past versus future

focused. This yielded a similar pattern of results to previous studies, with spontaneous thought being frequently oriented towards the future, and to only a slightly lesser (but still comparable) extent the past.

4.6 The Adaptive Role of Spontaneous Thought

It has long been suggested that in the absence of a task, such as during waking rest, spontaneous imagery of the past and future unfolds within the mental landscape. Spontaneous thought is widely believed to serve an adaptive function in processing past experiences and preparing for the future. Support for this idea comes from studies showing that in the absence of a task, and even during task engagement, the mind frequently defaults to an internal narrative filled with previous life events and hypothetical future-oriented scenarios.

Moreover, it has been argued that mental imagery plays a central role in memory and prospection by allowing us to create and hold within the mind a life-like simulation of past and future scenarios. While emphasis has typically been placed on event and scene construction (Hassabis & Maguire, 2009; Schacter & Addis, 2007; Schacter et al., 2012), mental imagery resembles the multi-modal and multi-level organization of the external world it emulates (Gottfried, Smith, Rugg, & Dolan, 2004; Moulton & Kosslyn, 2009; Wheeler, Petersen, & Buckner, 2000), and as such, may involve simulated speech and simple elements. This implies that mental time travel could involve mentally hearing conversations with friends (i.e., inner speech) just as well as it could involve picturing oneself in a room with them (i.e., scene construction), and it also implies that mental simulations are constructed from the "building blocks" of real-life experience (i.e., simple elements).

The current study provides direct evidence that thoughts generated during waking rest are largely spontaneous and that such spontaneous thought incorporates mental imagery involving

scene construction, inner speech, and both visual and auditory elements. Subsequently, this spontaneous imagery is typically oriented towards the past and especially the future. In contrast, deliberate thoughts generated during waking rest are usually lacking in mental imagery and focused on the present.

Taken together, these data strongly suggest that mental imagery plays a central role in mental time travel during spontaneous thought. In addition to providing direct empirical support for the idea that spontaneous thoughts of the past and future draw upon scene construction (as well as inner speech and isolated elements), our results add to a growing body of evidence that in the absence of a task, the mind relaxes into a default state of processing whereby simulations of alternative times and places emerge spontaneously within the mind's eye (Andreasen et al., 1995; Andrews-Hanna, 2012; Buckner et al., 2008; Buckner & Carroll, 2007; Christoff et al., 2016; Spreng et al., 2009; Wamsley, 2013). Considering the extent to which spontaneous thought processes memories and future-oriented simulations, it would appear that spontaneous thought is not merely a sign of mindless distraction or unproductivity, as the more negative portrayals of mind-wandering would seem to suggest (Killingsworth & Gilbert, 2010; McVay & Kane, 2010; Mooneyham & Schooler, 2013; Mrazek, Franklin, Phillips, Baird, & Schooler, 2013; Reichle, Reineberg, & Schooler, 2010; Smallwood & O'Connor, 2011; Teasdale et al., 1995). On the contrary, spontaneous thought is a vehicle for several adaptive and pragmatic forms of cognition which yield clear advantages for human survival (Andrews-Hanna, 2012; Buckner & Carroll, 2007; Schacter et al., 2012; Spreng et al., 2009) and well-being (McMillan, Kaufman, & Singer, 2013; Schooler et al., 2011; Singer, 1966).

4.7 Limitations

The study has several limitations that should be acknowledged. An inevitable consequence of using a laboratory-based experience sampling task is that despite our collecting thought reports during periods of "unconstrained" waking rest, a task was still necessarily required for guiding participants through the thought probe cycles (Figure 2.2.1). As such, participants were partially constrained by the anticipation of cues to rest and report. While this might appear to detract from our claim to have examined unconstrained waking rest, we instead acknowledge this limitation as a necessary step towards investigating more naturalistic thought processes in the laboratory setting. As mentioned earlier, previous paradigms have relied upon coercing specific types of thought contents through the use of explicit cues (Hassabis, Kumaran, & Maguire, 2007; Hassabis, Kumaran, Vann, et al., 2007; Hassabis & Maguire, 2007; Summerfield et al., 2010). As the present paradigm avoids such explicit content cueing, we believe it to be an improvement for accessing more naturalistic thought processes broadly, and spontaneous thought specifically. The use of daily life or smartphone experience sampling to examine the relationship between spontaneous thought, mental time travel, and mental imagery in the natural environment could resolve this limitation even further, if not completely.

Another limitation stems from our use of experience sampling, a necessarily introspective method, for obtaining reports of inner experience. The unique challenges of introspective reporting have long been acknowledged, with some authors going so far as to claim that we have "little to no introspective access to higher-order cognitive processes" (Nisbett & Wilson, 1977). To some extent, concerns about the reliability of introspective reports seem warranted. After all, there is no avoiding the fact that inner experience can only be accessed by the observer. Subsequently, experience with introspection (e.g., mindfulness meditation) is known to enhance introspective

accuracy (Fox et al., 2012), and since the current study did not control for individual differences in introspective experience, it remains possible that participants were not all equally capable of providing accurate subjective reports.

At the same time, the longstanding mistrust of subjective reporting as a valid empirical tool has become largely recognized as unwarranted (Lutz & Thompson, 2003; Solomonova, Fox, & Nielsen, 2014; Varela & Shear, 1999; Windt, 2013) as decades of research on perceptual errors such as inattentional blindness (Mack & Rock, 1998) and change blindness (Pashler, 1988; Simons & Rensink, 2005) demonstrate that accurate reporting on the external environment is not without its challenges -- and yet, reporting on perceptual experience receives not nearly the same criticism. Furthermore, a central issue raised about retrospective bias in introspection can be resolved by adjusting experience sampling methods such that participants report only on the mental state that took place immediately preceding the cues to report (Hurlburt & Akhter, 2006; Hurlburt & Heavey, 2015). Above all, experience sampling possesses a distinct advantage over traditional "stimulus-and-response" paradigms, being that the most direct way to access inner experience is, and will likely always be, to simply *ask* participants what is on their minds (Hurlburt & Akhter, 2006; Solomonova et al., 2014; Wamsley, 2013; Windt, 2013). For all these reasons, we remain optimistic about the use of experience sampling as the most effective tool for probing the depths of inner experience. (Lutz & Thompson, 2003)

Finally, we wish to highlight an issue that arises when multiple analyses are performed within a given research study. In recent years, increasing attention has been paid to the problem of multiple comparisons, referring to the increase in the rate of false positives (Type I error) that can occur as the number of statistical tests increases within a given study (Miller, 1977). Considering the current study ran multiple models per hypothesis, a correction for multiple comparisons

seemed justified. To correct for multiple comparisons, we used the Benjamini-Hochberg (BH) procedure (Benjamini & Hochberg, 1995), which, as stated (see Chapter 3.1.2), controls for the false discovery rate (FDR) of each family of analyses. Using what is commonly considered to be a conservative FDR threshold of 0.05, all reported significant p-values were robust to the correction for multiple comparisons.

The Benjamini-Hochberg procedure is recommended over the Bonferroni correction (Bland & Altman, 1995) for datasets with large numbers of multiple comparisons, given the increased rate of false negatives (Type II error) that can result from the Bonferroni method. However, as with the Bonferroni correction for multiple comparisons, the BH procedure has its own set of limitations. Take for instance the fact that had we increased our FDR above the recommended range, several *non*-significant p-values including those pertaining to the analyses of individual differences would have become significant. Although we used a conservative threshold for commonly reported FDRs (FDR = 0.05 based on the recommended range from .05 to .01), the fact that our results and interpretation would have differed in a meaningful way with a more relaxed threshold illustrates the imperfect science behind correcting for multiple comparisons. As such, we encourage readers to interpret our findings with these caveats in mind.

4.8 Conclusions

In sum, we found that thoughts generated during waking rest were largely spontaneous, and that spontaneous thoughts frequently contained mental imagery of scenes, inner speech, and contextually isolated elements. Furthermore, we found that such spontaneous imagery was typically oriented towards the future, and to a slightly lesser but still comparable extent, the past. In contrast, deliberate thoughts generated during waking rest tended to lack mental imagery and were focused on the present moment.

It has been speculated that during spontaneous thoughts, mental simulations depicting scenes of the past and future arise within the mind's eye. Up until the current study, no prior research had examined the relationship between scene construction and mental time travel during mind-wandering. Our findings are consistent with several prominent theoretical frameworks drawing a connection between mental simulation, mental time travel, and spontaneous thought, and extend these frameworks to suggest that beyond scene construction, spontaneous thoughts of the past and future also involve inner speech and isolated elements. Future research examining the relationship between mental imagery, mental time travel, and spontaneous thought in relation to the brain's default network will be useful next step, especially with the aim of understanding how the default network subsystems contribute to these overlapping processes.

These data provide direct evidence in support of the idea that mental imagery plays a role in spontaneous thoughts of the past and future. In addition to informing a basic science understanding of healthy and adaptive mental states, including remembering the past and planning for the future, this work has the potential to inform clinical research aimed at better understanding the characteristics of maladaptive mental states, such as what occurs in depressive rumination and anxiety. Overall, this research highlights the remarkable human capacity for imagining times and places beyond the immediate environment, and sheds light on the variety of contents that can occupy the mind when it is freely moving.

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