COGNITIVE STATES WHILE MIND WANDERING AND ASSOCIATED ALTERATIONS IN TIME PERCEPTION

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Dissertation Prepared for the Degree of

DOCTOR OF PHILOSOPHY

UNIVERSITY OF NORTH TEXAS

August 2022

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Kelly, Megan Erin. *Cognitive States while Mind Wandering and Associated Alterations in Time Perception*. Doctor of Philosophy (Behavioral Science), August 2022, 107 pp., 3 tables, 17 figures, 4 appendices, references, 172 titles.

Time perception is a fundamental aspect of consciousness related to mental health. One cognitive state related to time perception is mind wandering (MW), defined as having thoughts unrelated to the current task. Little research has directly assessed the relationship between these two constructs, despite the overlap in clinical significance and the shared importance of attention for healthy functioning. In the present study, I addressed this by having a sample of 40 adults in the United States complete an online sustained attention to response task remotely while answering thought probes related to thought type and time perception. Multilevel modeling results indicated that cognitive factors were related to the judgements of passage of time (JOPOTs; the feeling that time is passing quickly or slowly) while they had little relation to the estimated duration or the accuracy of those estimations. Specifically, JOPOTs were related to attention to task and emotional valence, and the addition of MW, intentionality, and fixed/dynamic thoughts to the models explained additional variance. Duration estimations and JOPOTs were unrelated to each other, suggesting JOPOTs and duration estimations have different relationships to cognitive factors and should be studied as separate constructs. Additionally, results suggested that the heavy use of dichotomization in the MW literature should be shifted in favor of conceptualizing attention to task as a continuous variable. The difference in effects of MW on estimation durations and JOPOTs specifically is novel finding. This is the first study to evaluate the relationship between MW and both duration estimations and JOPOTs, thus it may advance mechanistic and phenomenological understanding of MW which could in turn inform clinical theories of time perception in disorders including ADHD and depression.

ACKNOWLEDGEMENTS

Graduate school has been a time of high highs, low lows, and remarkable personal growth through discomfort. There are countless people who have supported and guided me tirelessly through constant challenges, without whom I could never have gotten to where I am. As colleagues became friends, friends became family, and family became occasional pilot study research subjects, I felt overwhelmed with love and support. I could not name every person who has helped me, but I will name a few who have left an indelible mark on my spirit through their guidance. Firstly, to my mentor, Dr Ryals, who took me in while I was struggling, encouraged me to use my voice, and always took time to help me. You've changed the way I think about not only science but leadership and mentorship. Thank you. Thank you to my committee members, Drs Slavish, Boals, and Hull, for all your guidance and support on making this almost foolishly ambitious project come to fruition. To my colleagues in the BSci program, who have become like family, and especially Cait, Nathan, Heather, Iván, Justin, and Banan, your endless encouragement and support have never gone unappreciated. Thank you all for being who you are. Thank you to Kayshia, my college friend who has been my cheerleader and supporter through so many twists and turns in life. Thank you to Seth, whose love, support, and encouragement helped make this dissertation happen. Thank you to Axon, the sweetest friend I could have asked for. Thank you to all the members of the Neurocog lab for all your help and support on this project and many others. To all my other friends, colleagues, mentors, and supporters, thank you all so much for being part of my journey. Lastly, to my parents, thank you for believing in my dream of becoming a scientist, for encouraging me to chase that dream across the country, for giving me all the opportunities you could to see me thrive, and for all your love and support. Mom and Dad, I love you and I'm so proud to be your daughter.

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CHAPTER 1

INTRODUCTION

The passage of time is a feeling so inherent to the human condition it is rarely distinguished from the experience of consciousness itself (and indeed consciousness and interval timing have been linked in research, e.g., Yin et al., 2016). Therefore, when the mind wanders and consciousness is averted away from the current moment, our experience of time may be distorted. Understanding the link between cognitive states and the perception of time could answer bigger questions about what it means to be conscious.

Time Perception

Time is experienced as a constant concept, a dimension through which humans continuously and consistently march, and one which guides us from one experience to the next. Records of attempts to understand time date back to ancient philosophers, such as with Plato’s consideration of how time began and Aristotle’s discussions of how time is connected with motion (see Rau, 1953). Up to the present day, however, these topics are still debated, with theories from psychology, neuroscience, physics, philosophy, and other fields vying for a comprehensive explanation of what time is and how we perceive it as humans.

Psychological Research on Time Perception

A classic model of time perception proposed by Church (1984) consists of an internal clock with several working parts. In this model, the pacemaker emits clicks or pulses which are regulated by a switch and counted by an accumulator. The output of the accumulator is then compared with values from working memory or reference memory by a comparator. The nature of the relationship of these separate parts is controlled by variables that may change as a result of an external influence, such as through the pharmacological influence of methamphetamine. This model is the basis for many psychological and neurological theories of time perception, particularly older theories, and is referenced frequently in time perception research; however, the specific calculations associated with the original model are rarely used in modern research.

Another influential model in time perception research is the attentional allocation model. This model states that people have a fixed amount of attentional resources, such that when their attention is drawn away from timekeeping to a particular task, their perception of time is condensed and highly variable. Brown (1997) demonstrated this effect by having participants complete easy or hard non-temporal tasks while simultaneously completing a temporal task (temporal production, explained below). Harder non-temporal tasks resulted in time being perceived as faster and more variable, theoretically because more attention was required for task completion and thus fewer attentional resources were available for mental timekeeping. Indeed, performance on harder math problems was worse while simultaneously timekeeping through temporal production than on trials where participants did not do the temporal production task. This effect, however, did not exist for other non-temporal tasks, suggesting that some tasks, such as mental arithmetic, draw from the same source of attentional resources as those needed for timekeeping, while other tasks, such as visual search tasks, draw from a separate attentional resource (Brown, 1997). In support of this model, Zakay (1998) found that when a participant is distracted by a non-temporal task, timing estimates are shorter.

Alternative models of time include the storage-size model and the contextual-change model. The storage-size model (Ornstein, 1969) relates the volume and complexity of information to the perceived time judgement, such that more complex information presented during an interval leads to a longer temporal judgment. This model, however, has been criticized as “complexity” is difficult to measure empirically and some mixed results have been found

(Block, 1978). The contextual change model proposes that time is measured by the amount of change one experiences in the environment as well as in one's own state, such that more change reflects a greater amount of time (Block, 1978).

Pedri and Hesketh (1993) demonstrated that a gap in time between the to-be-timekept interval and the reporting of time duration impacted behavioral results, as did task difficulty/speed. Participants played a computer game where they were controlling a fast or slow-moving car, which they moved to avoid hitting a dog. When asked to estimate the time duration of the task just after finishing, the fast car (more difficult) condition led to shorter time estimates than the slow car (easier) condition. This matches the attention allocation model because the fast car condition would use more mental resources, thus leaving less available for timekeeping and condensing perceived time. However, when asked to estimate the duration of the task after a five-minute delay, this effect was flipped, with longer time estimates in the fast condition than in the slow car condition. This later estimate better matches the contextual change model because the fast car condition involved a greater number of changes and therefore a longer estimated task duration. As such, none of the models tested appear to perfectly reflect how time is perceived.

Memory and Attention in Time Perception

Psychologists in time perception research have stressed the role of memory in understanding time. That is, if a participant is asked about how much time passed during a task they completed, the participant must rely not only on their time perception but also on their ability to remember their previous perception of time (i.e., they do not just report how much time felt like but what they *remember* about how much time it felt like). As such, informing the participant of whether or not a duration estimation will be required later also impacts cognitive processing. This difference in methodology is called prospective (the participant knows in advance to keep time) versus retrospective (participants must think back to remember the time passed) time perception. This means that prospective judgement relies on attention while retrospective judgment relies on memory (Block & Zakay, 1997). It is possible that retrospective reports of time perception are therefore influenced by the biases of memory, so a model of how time is perceived would not be able to independently determine how time is remembered later. Taken together, results of Pedri and Hesketh (1993) imply support for the attention allocation model and suggest that duration memory reported after a delay is likely distorted due to storage and response biases in memory. This also implies that time perception memory is more similar to semantic memory, which decreases over time after learning (e.g., Ebbinghaus' "forgetting curve"; Ebbinghaus, 1885/1974; replicated by Murre & Dros, 2015) than it is to metacognitive judgements of learning, which get more accurate as time passes (Nelson & Dunlosky, 1991). The present study therefore utilizes prospective time perception to avoid these biases due to memory.

As memory relates to retrospective time perception, attention relates to prospective time perception. Based on the attentional allocation model, it could be expected that diverting a participant's attention during a task would impact their ability to accurately perceive time during that task. This has been demonstrated in Lamotte et al. (2012), who showed that duration estimations were shorter when participants were completing a simultaneous task while timekeeping, and that the magnitude of that time distortion was related to the participant's awareness of the relationship between attention and time as well. Later, Winkler and colleagues (2015) separated out two aspects of time perception – duration of the presentation of the to-be-attended stimulus, and the frequency with which that stimulus was presented. Betsch and colleagues (2010) investigated the relationship of judgements of duration (JODs; a participant's estimation of how much time has passed) and judgments of frequency (JOFs; a participant's estimation of how many trials have passed) in a set of experiments. They found that JODs were biased by JOFs, but the opposite relationship did not occur. That is, JODs varied as a function of the frequency with which the stimulus was presented, but JOFs were unrelated to the perceived duration with which the stimulus was presented. This suggests that participants were using their frequency memory to aid them in making JODs, but were not using their memory of duration to aid their JOFs. In the context of time perception, this means that perception of time may be based not on just how much time has passed but rather by attending to external cues which may be presented at different frequencies. Furthermore, Betsch and colleagues (2010) demonstrated that this bias may be related to the length of participant attention toward the stimuli, indicating that adjustments to participant attention (or perhaps their inattention) could relate to distortions of time perception. As such, in the present study all participants saw the same number of trials per block as other participants so that this bias is controlled for.

Emotions and Time Perception

Psychologists researching time perception have found a number of variables that influence how time duration is perceived by a participant. One such variable shown to influence time perception is emotional state. For example, Danckert and Allman (2005) demonstrated that individuals high in boredom-proneness tend to overestimate the passage of time during a task relative to low boredom-prone individuals, and also that high boredom-prone individuals have less accurate judgements of time durations generally than their low boredom-prone counterparts. Interestingly, boredom-proneness has been linked with depression and affective dysregulation (e.g. Sommers & Vodanovich, 2000). Another emotion thought to be related to time perception is fear. Droit-Volet and colleagues (2011) demonstrated that after watching a scary movie, participants judged durations during a task to be longer than those who had watched a neutral or sad movie before task completion. This study added to a body of work assessing how time is perceived while experiencing an emotional stimulus by having participants judge time intervals after the emotional state had already been induced. Research has shown that there is a relationship between a stimulus that induces fear (e.g., Grommet et al., 2011; Watts and Sharrock, 1984) or anticipation/anxiety (Hare, 1963) and changes in time perception, and that those associations may be related to individual differences between participants (e.g., Tipples, 2008).

Studies such as these brought about the question, is it the valence of the emotion or the degree of physiological arousal that can be implicated in these time distortions? The valence and arousal of an emotion are two aspects of the experience that are co-occurring and related, and can be experimentally manipulated (e.g., Bradley and Lang, 1994). Angrilli and colleagues (1997) tested the relationship of arousal and valence to time perception using International Affective Picture System (IAPS; Lang et al., 2008) and found no main effect for valence or arousal and instead found an interaction. That is, for low-arousal stimuli, negative valence was associated with shorter perceived durations than positive valence stimuli, and for high-arousal stimuli, negative valence was associated with longer perceived durations than positive valence stimuli. This research indicated that both arousal and valence of emotions are important to the experience of time perception and should both be considered in a comprehensive model.

Related Behaviors and Disorders

Oftentimes, researchers frame time perception relative to problematic, or potentially problematic, behaviors. For example, time perception while playing videos games has been shown to be distorted (e.g., Nuyens et al., 2020). Indeed, Wood and colleagues (2007) found that in a sample of 280 gamers, 99% had experienced time loss while playing video games.

Additionally, Tobin and Grondin (2009) found that adolescent verbal estimates of time spent playing video games were shorter than estimates of time spent reading when both activities were actually of the same duration. Similarly, time distortion could explain behaviors such as binge-watching (also known as marathon viewing), whereby people spend excessive amounts of time watching television or videos (see Flayelle et al., 2020; Kelly and Ryals, 2022a [manuscript in preparation]; Merikivi et al., 2020; and Starosta & Izydorczyk, 2020).

Furthermore, changes in time perception can be related to various psychological disorders. For instance, depressed individuals may report that it feels as though time has slowed down, even though they are aware of the actual amount of time that has passed. That is, they know how much time has passed, but that time has felt slower to them than to the rest of the world (see Droit-Volet, 2013). In a classic work, Heideggar (1927) noted that when someone has nothing to hold their attention, they become more aware of the passage of time, so this may be the mechanism by which depression distorts time. That is, depression lessens a person's interest in life experiences, causing them to have nothing to hold their attention and therefore become more aware of the time passing, making that time feel slower. Another possible mechanism is that depressed people may be more consumed with thoughts of death. Indeed, considerations of mortality are related to time perception. For example, Martens and Schmeichel (2011) demonstrated that students assigned to contemplate death perceived time as passing slower than those assigned to a control condition where they thought about social exclusion.

Another disorder related to alterations in the experience of time is schizophrenia. This may include the perception that time is passing very quickly or very slowly, leading to inaccurate estimations of time passage while completing a task (Densen, 1977). This may be due to a number of factors, including alterations in attention and memory related to schizophrenia, or a biological difference in individuals with schizophrenia (Bonnot et al., 2011). Individuals with this disorder may experience moments of abnormal time experience (ATE), which are more common among those with schizophrenia than those with depression, and more common in those with depression than those with no psychiatric diagnosis (Stanghellini et al., 2016). Authors of a 2017 meta-analysis found that patients with schizophrenia had more variable time estimates than those without schizophrenia, and the authors suggested this may be due to cognitive impairments, such as difficulty with control of selective attention, and may result in problems connecting thoughts and actions (Thönes & Oberfeld, 2017).

Additionally, alterations in time experience may be the result of stress or trauma. Holman and Silver (1998) investigated the link between time perception and trauma in adult victims of childhood incest, Vietnam War veterans, and survivors of wildfires in California, and found that past temporal orientation (i.e., having a cognitive focus on past life events) was associated with higher levels of distress across those samples. The authors speculate that this relationship may be reciprocal, such that past temporal orientation causes increased distress, and increased distress causes increased past temporal orientation. As such, Holman and Grisham (2020) speculate that the COVID-19 pandemic may be a collective trauma which could be impacting time perception for those living through it. Indeed, popular press articles have taken an interest in how time perception may be altered during the pandemic (e.g., Pardes, 2020) and research has started coming out on this topic as well. For example, in a study of 604 participants from the UK, Ogden (2020) found that some were experiencing time going slower, and some faster during April of 2020, while they were in lockdown for coronavirus. Additionally, data recently collected from our laboratory suggests that when primed with a visual reminder of the pandemic during lockdown, college students had different recollection of certain time increments compared to individuals presented with a neutral image (Kelly and Ryals, 2022b [manuscript in preparation]). Time perception difficulties have also been linked to other disorders such as ADHD (e.g., Yang et al., 2007), borderline personality disorder (BPD: Berlin & Rolls, 2004), and bipolar disorder, where depressive versus manic states led to different distortions in the perceptions of time (Bschor et al., 2004). The link between distorted time perception and disorder highlights the need for further research in this area.

Terminology of Time Experience

The line of research of Holman and Silver (1998; mentioned above) highlights a distinction some researchers make between time perception and time perspective. Time perception relates to the feeling of time passing and the believed duration of time, whereas time perspective relates to how one views the past, present, and future. Alterations in time perception and time perspective both may be related to disorders such as depersonalization/derealization disorder. Simeon and colleagues (2007) summarize some terms and distinctions in this literature, stating that temporal disintegration, temporal disorganization and time skew are experiences of an alteration in time perspective, whereas time distortion is an alteration of time perception. While not all researchers make this distinction explicitly, most study designs on the psychology of time experience tend to focus on either alterations in time perception or time perspective, but not both. Similarly, there is a difference between a judgement of duration and a judgement of the passage of time (JOPOT), where the former is about quantifying the time (e.g., “that was 30 seconds”) and the latter is about how the time felt (e.g., “time went by fast”). Droit-Volet and Wearden (2016) argue that these constructs are not related and must be considered separately. Additionally, Droit-Volet and Wearden (2015) found that JOPOTs were not different between younger and older people (which differs from the commonly believed notion that time goes by faster as we age), and they were related to emotion and attention. Making the distinction between time perspective, judgements of duration, and JOPOTs clearer in future research may enable researchers to better understand the specific ways in which the experience of time is altered in various disorders or in non-clinical variations in time experience.

Methods in Time Perception Research

Common methods of studying time perception are outlined below:

- *Comparison task* – The participant is presented with two stimuli lasting different durations, which may be indicated through any sensory modality and which may be indicated by the constant presence of some indicator or be marked at the beginning and end. The participant must then indicate which duration was longer or shorter (see Allan, 1979).
- *Peak-interval procedure* – Similar to a reproduction task, the participant is presented with an interval and must respond after a duration of equal length on several trials. In some trials, they are rewarded for accurate responses (fixed-interval reinforcement) but on some trials there is no consequence to responding (probe trials; Matell & Meck, 2004).
- *Production task* – The participant is told a length of time and must perform a behavior, such as pressing a button, for that length of time (see McConchie & Rutschmann, 1971 for an example).
- *Reproduction task* – The participant is presented with a stimulus for some time interval, which may be indicated through any sensory modality, and which may be indicated by the constant presence of some indicator or be marked at the beginning and end. They must then perform some task, such as pressing a button, for the same length of time (see McConchie & Rutschmann, 1971 for an example).

- *Temporal bisection task* – The participant is trained to recognize two different time durations, generally considered short or long. For example, in Kramer et al. (2013), participants learned to recognize durations of 400 and 1600ms. These can be indicated through any sensory modality and may be indicated by the constant presence of some indicator or be marked at the beginning and end. Participants are then presented with other, untrained durations (and possibly trained durations as well) and are asked to determine if the presented duration was more similar to the shorter or longer of the two previously learned durations. (See Kramer et al. 2013 for an example).
- *Verbal estimation task* – The participant is presented with a stimulus for some time interval, which may be indicated through any sensory modality and which may be indicated by the constant presence of some indicator or be marked at the beginning and end. The participant must then make an estimate of how long the time interval lasted (usually in seconds; see McConchie & Rutschmann, 1971 for an example).

Other methods of time perception measurement have been used, however with much less frequency (see Allan, 1979 for review). The verbal estimation procedure is best for durations lasting several minutes, and were used in the present study.

Time Intervals

Another consideration in this area of research is the time length to be considered. Research on humans typically considers durations for under one second, for a number of reasons (see Grondin, 2010). One primary reason is that time perception for durations over one second involves cognitive processing, meaning they may be distorted by cognitive state (Grondin, 2010). Because of that, researchers often only include durations under one second in research. This, however, greatly limits our understanding of how cognitive states impact time perception.

Furthermore, cognition is apparent in as little as 300ms in other lines of research (e.g., the P300 in electrophysiological event-related potential research, see Polich, 2012 for review), suggesting that the assumption that cognition is unimportant to perception of short intervals is flawed. Additionally, this approach to time perception is not generalizable to human experience of time as we are often judging or reflecting on much longer time periods in everyday life. For example, one may be wondering how long it has been since they ordered food at a restaurant or how long it has been since the last commercial break as they watch television. Further research on the relation of cognitive states to time perception for durations over one second is needed, and is considered in the present study.

Neuroscientific Research on Time Perception

While psychological interest in time perception is largely focused on memory and attention as well as disordered time perception, neurobiology has focused more on explaining the mechanism with which timekeeping happens in the body. Two main approaches to the neurobiology of time perception have emerged – those that say that time is perceived via a biological clock which measures time, and those that say that no such clock exists. The neuroscience of time perception does not current provide a clear answer, as several brain regions (and likely a combination of simultaneous network activity among regions) are involved in time perception, which may support either model. As such, one of the brain regions mentioned below may serve as an internal clock that is influenced by other related brain regions, or all regions may work together and the coordination of their communication enables time perception without the need for an internal clock (see Grondin, 2010).

Evidence for a centralized brain-clock comes first from theoretical papers, such as the pacemaker-accumulator model described previously (Church, 1984). Indeed, early work suggested that the pacemaker-accumulator was a single brain structure, however, later work revealed that several areas of the brain are related to temporal processing (see Grondin, 2010). One structure of interest is the cerebellum, which has long been known to control coordination of body movements. It follows, then, that the cerebellum must have some involvement in time perception in order to coordinate the body's movement in time, and indeed this has been backed by research. For example, Ivry and Keele (1989) found that when comparing rhythmic timing performance of individuals with Parkinson's or neuropathy of either the cerebellum, cortex (particularly the frontal lobes), or peripheral nerves with age-matched controls, those with cerebellar neuropathy had increased variability in their tapping. Additionally, the cerebellar neuropathy group also performed poorly on a task requiring temporal discriminations (Ivry and Keele, 1989), which suggests that the cerebellum is involved not only in timing with regards to motor movement but in duration perception and cognition more generally (see also O'Reilly et al., 2008). This line of research has expanded greatly and the hypothesis that the cerebellum is involved in temporal perception has been supported by many research studies. For example, Chang et al. (2021) found that children at risk for developmental coordination disorder (rDCD), a disorder known to affect the development of the cerebellum, showed poorer performance on a rhythm perception task than typically developing controls, even when that task was not dependent on motor coordination. Additionally, Chang et al. (2021) found that during oddball tasks (where participants do not respond to frequent non-target stimuli and do respond to an infrequent target stimulus), rDCD children has delayed MMN latency and delayed P3a latency as compared to typically developing children, supporting the notion that rDCD children have altered temporal perception as compared to typically developing children.

Counter to the cerebellar hypothesis, however, some have found that the cerebellum is only involved with perception of certain time intervals. Which time intervals are perceived by the cerebellum is up for debate as several studies have reported different results (see Grondin, 2010). For example, Lee et al., (2007) used repetitive transcranial magnetic stimulation (rTMS) on the cerebellums of healthy participants while they completed a temporal bisection task and found that rTMS significantly impaired the participant's task performance for durations under one second, but not for durations over one second.

A meta-analysis of fMRI studies on motor and/or perception-based interval duration found cerebellar involvement for motor and perceptual timing for sub-second but not supra-second interval timing (Wiener et al., 2010). Similar results were found implicating the basal ganglia – specifically the caudate, putamen, and globus pallidus, however other studies have reported slightly different results regarding these substructures. For example, in a review, Grondin (2010) concludes that the right caudate, and potentially the putamen, are involved in sub-second timing while either the caudate or putamen or both are involved in supra-second timing. Additionally, several studies demonstrated that the striatum and the substantia nigra pars compacta are integral to duration estimation, such that lesions to these areas results in a rat's inability to perform well on peak-interval and duration bisection tasks (see Matell and Meck, 2004). The striatal beat frequency model suggests that the cortex communicates to the basal ganglia though the striatum, and the striatum communicates to the cortex through the thalamus, and the spiny neurons of the striatum serve as a coincidence-detector, firing only when several presynaptic dopaminergic neurons fire in tandem (i.e., in much closer temporal proximity than is usually required for postsynaptic firing; see Matell and Meck, 2000). This theory is supported by the finding that when rats are trained to detect intervals of either 10 or 40 seconds, striatal neurons will fire in peak-shaped patterns after the trained duration but not at other durations, and these peak-shaped patterns resemble those theorized to occur in the internal clock (Matell et al., 2003). The striatal beat frequency model is one of several coincidence-detection models, otherwise called oscillator models, which have been proposed. These models focus on when duration estimation is dependent on a series of regular signals, which create a rhythm. The rhythm is paired to the stimulus onset over repeated trials to allow for prediction or expectation of temporal stimuli (see Grondin, 2010).

As mentioned above, the cortex is believed to be involved in this process, and several areas have been implicated. Such areas include the supplementary motor area, the dorsolateral prefrontal cortex, and the right posterior parietal cortex (Grondin, 2010). Additionally, the entorhinal cortex is thought to be important for time perception. When mice had their medial entorhinal cortices inactivated, they were no longer able to learn temporal durations, however they were still able to act on durations previously learned, suggesting the medial entorhinal cortex is pivotal to encoding, but not storage or retrieval, of temporal information (Heys et al., 2020). The entorhinal cortex and perirhinal cortex have been implicated in the "binding of item and context" (BIC) model of recognition memory, whereby item and context information are reconnected in the hippocampus after being identified separately (Diana et al., 2007) with some interaction in the entorhinal cortex (Hunsaker et al., 2013). Perhaps the timekeeping function of the entorhinal cortex allows for this binding to be temporally consistent.

Another important line of neuropsychological research concerns the neurotransmitters implicated in time perception and the effects of neuropharmacological interventions. Dopaminergic activity in the frontal lobes is thought to be related to time perception, such that people who are hypo-dopaminergic in that region experience faster time perception (Mitchell et al., 2018). Administration of catechol-O-methyl-transferase (COMT) inhibitors, which increase presynaptic dopamine release, has previously been shown to impact dopamine systems for the prevention of substance use relapse for those with a particular genetic makeup (Blum et al., 2007). Based on this information, Mitchell et al. (2018) administered tolcapone, a COMT inhibitor, or a placebo for a within-participants fMRI time perception study. They observed that when administered tolcapone, participants gave more accurate duration estimations than in the placebo group, and the strength of the increase in duration estimation was correlated with a decrease in the connection from the right inferior frontal gyrus to the right putamen (Mitchell et al., 2018), confirming the importance of frontal lobe dopamine in time perception. As discussed, time perception may be influenced by cognitive factors, so now we consider one such factor – mind wandering.

Mind Wandering

Smallwood and Schooler (2006) broadly defined mind wandering (MW) as "a shift of attention away from a primary task toward internal information (p. 946)." Mind wandering is thought to account for up to 46.9% of waking thoughts (Killingsworth & Gilbert, 2010) and therefore is sometimes referred to as our mind's default mode. Aside from MW, other terms such as daydreaming, task-unrelated though (TUT), off-task thought, task-unrelated images and thought, stimulus independent thought (SIT), spontaneous thought, self-generated thought, task disengagement, absent-mindedness, zone outs, mind pops, and others have been used in research to describe the same or similar/related phenomena. Some distinctions, however, have been made. For example, self-generated thought can include intentional or unintentional, on-task or off-task thoughts that are cued by the internal rather than the external environment, and may therefore include not only MW but also internal, task-related thoughts (Smallwood & Schooler, 2015).

Psychological Research on Mind Wandering

Researchers often conceptualize MW as when attention turns from external stimuli (often a task that requires cognitive resources including external attention) to internal stimuli (such as thoughts about the future self, for example see Kvavilashvili & Rummel, 2020 for a review of research on MW as prospective planning). Mind wandering is therefore associated with perceptual decoupling, defined as “the capacity for the mind to flexibly disengage/engage attentional processes from sensory input (Smallwood & Schooler, 2015, p. 500).” This term is not usually applied to sensing the passage of time, however this extension may be apt.

Methods in Mind Wandering Research

As with time perception researchers, MW researchers have some common methods used in most studies. Weinstein (2018) categorized this research into four areas, with the objective/indirect methods being reaction time and physiological measures, and the subjective/direct methods being self-caught and probe-caught. Self-caught and probe-caught methods both include asking the participant to introspect and self-report on whether they are MW, usually while completing a concurrent task.

- Self-caught methods require the participant to initiate introspection and report whenever they are MW. Due to fluctuations in meta-awareness, this method is not commonly used (Weinstein, 2018).
- Probe-caught methods, however, are very popular. These methods include participants being “probed” with a question about their internal state while completing some unrelated task.

Results of studies employing the probe-caught method have shown negative correlations between MW and constructs such as memory for lecture content (Risko et al., 2012) working memory (e.g., McVay and Kane, 2009) and task performance (e.g., Krimsky et al., 2017), and the probes themselves do not appear to influence MW (Wiemers & Redick, 2019), making probe-caught methods very helpful for MW research.

By far the most common task used in MW research is the sustained-attention to response task (SART). The SART is a go/no-go type task whereby a participant must respond (usually with a keyboard-button click) to frequent stimuli (which may or may not be identical) but not respond to the specific infrequent "no go" or target stimulus. For example, a participant may be presented sequentially with random digits between one and nine and be told to respond to all digits except for three. This task requires continuous attention making it an ideal way to check for MW. Performance on the task is usually measured by the frequency of button clicks during target trials (i.e., responding to "3"), and poor performance is thought to indicate MW. Performance may also be assessed through other metrics as well, such as reaction time variability (Cheyne et al., 2009). A SART task with thought probes was used in the present study.

Mind Wandering, Mindfulness, and Flow

Mindfulness is usually defined by an attention to the present moment – a description inherently differentiating it from MW. Indeed, they are often conceptualized as opposite ends of a spectrum, where mindfulness is a focus on the current moment while MW is not focused on the current moment (Dust, 2015, but see Agnoli et al., 2018). For example, Mrazek et al. (2012) found that those who scored high on a trait measure of mindfulness self-reported less MW and demonstrated fewer markers of MW (i.e., better SART performance), and concluded that "mindfulness and mind-wandering can reasonably be thought of as opposite sides of the same coin (p. 3)." Additionally, Deng et al. (2014) found that MW and mindfulness are negatively correlated. As mindfulness is often intended to be initiated through mindfulness meditation, many studies have looked at the relationship of mindfulness meditation and outcomes related to

MW. For example, in the same study Mrazek et al. (2012) showed that after a mindful breathing exercise, participants performed better on the SART, implying that increased mindfulness led to decreased MW.

Another concept of interest in this relationship is flow state. A flow state is generally characterized by extreme focus on a task, such that little attention is paid to all other external and internal stimuli. This has also been conceptualized as the antithesis of MW due to the high level of focus on a current task (Weinstein et al., 2018). A reasonable assertion would then surely be that if mindfulness is the opposite of MW and flow state is the opposite of MW then mindfulness and flow states must be the same, however this is not true. Dust (2015) conceptualizes mindfulness as being present in the moment and having wide attentional breadth (that is, one is able to focus on a number of different internal and external stimuli), flow as being present in the moment and having narrow attentional breadth (that is, one is focused on the current task at the exclusion of all other stimuli), and MW as having low present moment attention but having a wide attentional breadth. This conceptualization along two axes rather than one allows for more distinction between states and better understanding of when each is appropriate or detrimental. However, since MW is often thought of as any off-task thought, this would include thoughts of a wide or narrow attentional breadth. Although the term mind "wandering" implies a shifting in thought, instances of rumination (low present moment attention and narrow attention breadth) are often categorized as MW in research as well.

Difficulty and Intentionality

Although MW has generally been treated as one type of experience, mounting evidence suggests it comes in two kinds – intentional/deliberate and unintentional/spontaneous. For example, Seli, Carriere et al. (2015) found that the tendency to MW intentionally versus unintentionally were uniquely and oppositely related to non-reactivity to inner experience, suggesting these two types of MW should be distinguished in research paradigms. Whether one is MW intentionally or unintentionally, however, is believed to be related to task difficulty. To investigate this relationship, Seli, Risko, and Smilek (2016) modified the traditional method used in these types of studies in two ways: 1) they had participants complete either the regular SART (the difficult condition) or an easy version where there is an obvious pattern to correct responding and 2) they included thought probes which asked participants to indicate if they were on task, intentionally MW, or unintentionally MW. They found that while overall MW rates did not vary between conditions, intentional MW was more common in the easy condition and unintentional MW was more common in the difficult condition. Previous research has found more MW overall in easy versus difficult conditions (e.g., Thomson et al., 2013 showed this using a modified Stroop task, but see Kahmann et al., 2021 for opposite directionality) and the bulk of research assumed that all MW was intentional (see Seli, Risko, Smilek & Schacter, 2016). Therefore, it would be assumed that the easy condition would display more unintentional MW than the difficult condition, however Seli, Risko, and Smilek (2016) show the opposite effect.

Relatedly, some have investigated how MW affects task performance. Unsurprisingly, most studies demonstrate that task performance is generally worse while the participant is MW (see Mooneyham & Schooler, 2013 for review). Less intuitive, however, is the directional relationship between task performance and MW. Smallwood et al. (2004) demonstrated that participants display not only task-unrelated thoughts but also thoughts evaluating their own task performance. Based on that information, Cheyne et al. (2009) theorized and demonstrated that task performance and MW have a bidirectional relationship, whereby MW can lead to poor task performance and task performance can lead to reactive MW. To limit this reactive MW in the present study, no feedback on task performance was given to participants.

Models of Mind Wandering

Two prominent models of MW have been proposed. The executive-control failure account posits that MW occurs when there is a failure of cognitive control whereby interfering thoughts overwhelm control systems and lead thoughts away from the task (McVay & Kane, 2010). This model accounts for the fact that MW is often unintentional and therefore may not be controlled by executive resources. Alternatively, the attentional-resources account (Smallwood & Schooler, 2006) posits that MW is goal-directed, however the goal is not to complete the present task. This model states that although MW may be unintentional and outside of one's awareness, it is goal-directed and therefore recruits executive control resources.

These two models, though apparently in opposition with each other with regard to the goal of executive attention systems, may actually be cohesive. Smallwood (2013) notes that a MW episode consists of two important pieces – the onset (or ignition) of MW and subsequent maintenance, an idea called the process-occurrence framework. This theory proposes that a lack of control (e.g., executive-control failure account from McVay & Kane, 2010) could be responsible for the ignition of MW and subsequently executive resources are used to maintain the MW state (e.g., attentional-resources account from Smallwood & Schooler, 2006).

These models are dependent on the understanding that the participant has an interest in completing the task, and the attentional-resources account in particular specifies that the participant has an interest in the content of the MW as well. Therefore, a crucial piece of understanding MW is understanding the participants' motivation. Brosowsky et al., (2020) demonstrated that MW was associated with poorer task performance when motivation was low, however higher motivation mitigated the effects of MW on task performance. It is reasonable to then assume that high motivation may only be lowering intentional MW, and that unintentional MW is not affected. Seli, Cheyne, et al. (2015) demonstrated that participants in a low motivation condition did report more intentional relative to unintentional MW compared with those in the higher motivation condition, however these differences in intentionality did not translate to task performance. That is, whether MW was intentional or unintentional did not relate to task performance. Additionally, Seli, Cheyne, et al. (2015) found that intentional MW was statistically significantly less frequent when motivation was high and although not statistically significant, unintentional MW was also numerically less frequent when motivation was higher. Smith et al. (2021) proposed that this dip in unintentional MW for those high in motivation may be due to a conflation in research between unintentional MW and unconstrained thought.

Here we must discuss the complications of nomenclature in this area. For the sake of simplicity I have been using only the term MW, however the different articles presented use different terms. A common practice in MW research is to conceptualize MW as “task-unrelated thought” (TUT), and measure TUTs as any thought a participant has that is not related to the researcher-assigned task. Christoff et al. (2016) suggested that this is overlooking the dynamic nature of thoughts, focusing too strongly on the content of thoughts rather than on the “wandering” nature of the thoughts. The authors present the example of how both rumination and MW involve task-unrelated thoughts, however MW is a state of changing thoughts while rumination is an inability to leave a particular topic. Due to this confusion, Christoff et al. (2016) conceptualized thoughts in terms of deliberate and automatic constraints on the thought process. Deliberate constraints are those based on cognitive control and automatic constraints are not, such as a sensory experience that impacts thoughts. Therefore, unintentional MW may constitute a case of low deliberate constraints and potentially medium automatic constraints, such as if unintentional mind wandering relates to an experience one is having while completing the task (for example, sitting in an uncomfortable chair). Smith et al. (2021) separated unconstrained thoughts from unintentional TUTs, specifically, and found that unintentional TUTs were no longer lower in groups with different motivation levels. This investigation into different thought types is crucial. Considering factors such as intentionality and the fixed (e.g., rumination) versus dynamic (e.g., true mind "wandering") nature of thoughts is more predictive of behavior than simply categorizing thoughts as on- or off-task, however this approach has never previously been used to understand the relationship between MW and time perception until the present study.

Mind Wandering and Emotions

While research on MW has focused extensively on whether or not the thoughts were on-task or off-task, less focus has been given to other aspects of the thought content. One area where research has been done is on the emotionality of the thought content. Generally, research has shown that MW is associated with poorer task performance (see Mooneyham & Schooler, 2013 for review), however some have posited that emotions play a role in that relationship. Banks et al. (2016) found that negatively valenced thoughts were associated with poorer performance in two of the three studies examined. In particular, they found that SART GO accuracy was significantly lower when the percentage of negative MW thoughts the participant had was higher, but the same was not true for neutral or positive valence thoughts. These results suggest that the valence of MW thoughts may be more predictive of outcomes than analyzing only whether someone is MW or not.

Furthermore, research has been done on how mood is a precursor to, and affected by, MW. In their experience sampling study, Killingsworth and Gilbert (2010) found that people MW frequently (46.9% in their sample), MW happened during almost every daily activity, and people were less happy when MW. Additionally, the authors suggest that MW was causing the negative mood in their sample, while other studies suggested that negative mood is a cause of MW (e.g., Smallwood et al., 2009). Additionally, there is evidence that participants prefer to be doing an activity rather than just MW, even if that activity is unpleasant (Wilson et al., 2014). Poerio et al. (2013) decided to test the two possible directions of this relationship and found that MW is associated with higher levels of prior sadness, but that MW did not predict subsequent sadness 15 minutes later. However, Poerio et al. (2013) also found that negatively-valenced MW was associated with worse mood 15 minutes later, indicating again that the emotional valence of the MW is important for determining outcomes. Important to note, however, is that MW was operationalized in that study as when the participant self-reported thinking about anything other than their current activity, so this reported MW may include instances of rumination. Lastly, Seli et al. (2017) found that MW intentionally was associated with more positively valenced thoughts than MW unintentionally, however this relationship was not statistically significant after Bonferroni correction (*p* = .032).

The Good, The Bad, and The Suggestable

So far we have discussed primarily state-level associations with MW, however the propensity to MW differs not only within individuals, but also between individuals. For example, Marcusson-Clavertz et al. (2012) demonstrated this using ganzfeld, which is a sensory homogenization procedure where participants sat in a sound-attenuated room, had goggles blocking their eyes, and had pink noise playing. The researchers found that those high in hypnotizability and dissociative tendencies tended to MW more frequently during a ganzfeld

SART task than those lower in those attributes. Additionally, those who are medium in hypnotic susceptibility report hypnotic dreams similar to MW thoughts, while those higher in hypnotic suggestibility report hypnotic dreams similar to dreams of those who are asleep, suggesting a continuum of dream-like experiences exists which contains MW (or daydreaming) as well as night dreaming (see Fazekas and Nemth, 2020). Others have pointed to a similarity between MW and a construct called dissociative absorption – a tendency to become so focused on one stimulus, whether internal or external, that one becomes oblivious of all other stimuli – however they have been demonstrated to be separate constructs (Soffer-Dudek, 2019).

MW has been associated with several negative outcomes. People are generally less happy after MW about neutral or negative topics (Killingsworth & Gilbert, 2010), and as mentioned, MW is associated with poorer task performance (see Mooneyham & Schooler, 2013 for review). MW is also associated with disorders. For example, MW is related to attention-deficit/hyperactivity disorder (ADHD), and indeed, one theory of ADHD is the MW hypothesis (Bozhilova et al., 2018). This hypothesis states that MW in healthy populations has similar performance impacts and neurological associations as ADHD does, suggesting ADHD consists of excessive spontaneous/unintentional MW. One study using found that MW and ADHD were not able to be completely distinguished using factor analysis due to the similarity of experiences (Soffer-Dudek, 2019).

MW has also been associated with depressive symptomology (as measured by the Beck Depression Inventory; Deng et al., 2014) and mindfulness (often conceptualized as the opposite of MW) is associated with lower rates of depressive symptoms like rumination (Williams, 2008). Seli, Risko, Purdon et al. (2016) found that intentional, but not unintentional, MW was associated with higher rates of obsessive-compulsive symptoms among a large non-clinical sample. MW has also been associated with schizophrenia, due to how both experiences are characterized by a detachment from reality. Shin et al. (2015) found that participants with schizophrenia reported higher frequencies of MW than control participants, and MW frequency was positively associated with schizophrenia symptom severity. Lastly, people with posttraumatic stress disorder (PTSD) have seen improvements in symptomology after mindfulness-based exposure therapy and that was associated with functional connectivity changes to the default mode network (DMN, described below; King et al., 2016). Fortunately, meditation has been shown to reduce some of the negative impacts of MW (see Sood & Jones, 2013 for a review).

Clearly, there are demonstrated negatives associated with MW, which has led researchers to wonder how this seemingly maladaptive behavior has developed and has come to take up so much of our waking lives. One area where MW is thought to be beneficial is in autobiographical planning – "the anticipation and planning of personally relevant future goals (Baird et al., 2011, p. 1605)," an aspect of autonoetic consciousness (Tulving, 2005). In Baird et al. (2011) it was demonstrated that the largest portion of off-task thoughts were future-focused, while on-task thoughts were generally present-focused, which suggests that MW is central to future planning. Additionally, when engaged in an activity that did not require working memory, participants engaged in more future-related thoughts, and future off-task thoughts were associated with better executive processing. Those with higher working memory capacity did not differ in how much the MW, but they did spend more MW time on future goals than those with lower working memory capacity. Taken together, these results suggest that individuals tend to MW as much as they are able to given the demands of the current task, those thoughts are often of planning for the self in the future, and doing so may be beneficial for the future self. Previous research from episodic memory on autonoetic consciousness is broad and will not be reviewed here, however there is evidence for individual differences in the ability to imagine the self in future situations as an element of episodic memory (e.g., Klein, 2016). For a review of the prospective nature of MW and similar behaviors, see Kvavilashvili and Rummel (2020).

Another area where MW is thought to be beneficial is in creativity (e.g., Godwin et al., 2017). Some believe that MW allows people to consciously or unconsciously make connections between seemingly disparate concepts to form novel ideas (see Williams et al., 2018). It has been demonstrated that self-reported MW frequency is positively associated with creativity, beyond what is explained by fluid intelligence, while metacognition alone is not able to independently predict creativity (Preiss et al., 2016). More specifically, intentional MW is associated with better creativity scores while unintentional MW is associated with worse creativity scores (Agnoli et al., 2018), again pointing to the need to distinguish between these two states. Interestingly, as mindfulness is often believed to be the opposite of MW, mindfulness has a negative relationship with creative performance (Zedelius & Schooler, 2015). Beyond creativity and planning, other benefits of MW have been proposed, such as integrating the sense of self, aiding in memory consolidation (see Gruberger et al., 2011) and a correlation with fluid intelligence (Godwin et al., 2017). Given this research, MW is not a ubiquitously negative construct.

Neuroscientific Research on Mind Wandering

The brain area most commonly associated with MW is the default mode network (DMN). Researchers had noticed that contrary to expectations, when a participant was not actively engaged in a goal-directed task (i.e., their cognition was perhaps focused internally), certain brain areas would consistently become active, and those same areas would be deactivated when goal-oriented tasks were resumed (Shulman et al., 1997). Raichle et al. (2001) investigated this pattern of activation and deactivation using imaging techniques and identified a set of areas representing a default mode of brain function. These areas include the posterior cingulate cortex, the precuneus, the dorsal medial prefrontal cortex, the lateral parietal cortex, (including the angular gyrus), and the entorhinal cortex.(see Raichle et al., 2001; Raichle, 2015).

Further research has verified the importance of DMN areas in MW, however other areas of interest have been highlighted as well, particularly the frontoparietal control network (FPCN). A whole-brain meta-analysis of 24 fMRI/PET MW studies implicated the importance of the following non-DMN regions: the dorsal anterior cingulate cortex, right dorsolateral/rostrolateral prefrontal cortex, left ventrolateral prefrontal cortex, secondary somatosensory cortex, left temporopolar cortex, left mid insula, and left lingual gyrus (Fox et al., 2015). The authors also found activation of all known DMN areas, which they list as the rostromedial prefrontal cortex, medial prefrontal cortex/anterior cingulate cortex, precuneus/posterior cingulate cortex, bilateral inferior parietal lobule, and left medial temporal lobe/parahippocampal cortex (extending somewhat into the cerebellum; Fox et al., 2015). These results suggested that the DMN may work with the FPCN (which includes the anterior cingulate cortex, lateral prefrontal cortex and anterior inferior parietal lobule) during MW, such that the FPCN allows for complex future-oriented thought while the DMN directs attention internally. One may note the lack of involvement of most sensory-processing brain areas during MW, a potential explanation for perceptual decoupling experienced during these states.

To investigate the relationship between the FPCN and the DMN in MW, Godwin et al. (2017) looked at regional connectivity in individuals varying in trait-level MW. They found that FPCN and DMN connectivity did indeed predict MW tendency, and connectivity within the

DMN was correlated with MW tendency as well. More recently, He et al. (2021) conducted a longitudinal study where MW tendency and functional connectivity were analyzed at three time points. Three latent groups were identified with regard to MW: one group of individuals who had high MW scores consistently, one group who had low initial MW scores that increased over time, and one group that had consistently low MW scores. The former two groups had had more functional connectivity in their DMN than members of the latter. Additionally, the study concluded that function connectivity of the DMN could predict future MW tendency, and some FPCN nodes were related to MW as well, but were not predictive of future MW tendency (He et al., 2021).

Further neuroscientific evidence related to MW comes from electroencephalography (EEG) and event-related potentials (ERPs). During a SART task, participants showed decreased amplitude for the P300 ERP component in response to nontargets (i.e., frequent stimuli which participants should respond to) when those nontargets were presented when the participant was MW as compared to when not MW (Smallwood et al., 2008). These lower amplitude ERPs were related to both behavioral (incorrectly responding to targets) and subjective (thought probes) markers of MW. Since oscillatory EEG activity can also be used to distinguish MW from on-task thoughts, Jin et al. (2019) used EEG with thought probes for machine learning, creating an algorithm that could distinguish the two states with 60% accuracy. Jin et al (2019) also noted that activity in the alpha power band was the element of the model that was most predictive of MW.

Mind Wandering and Time Perception

Research on the relationship between mind wandering and time perception is severely lacking. A small body of recent evidence supports the notion that MW leads to a distorted perception of time (e.g., Terhune et al., 2017). One mode through which this may happen is by perceptual decoupling. As mentioned previously, perceptual decoupling is the ability to disengage attention from sensory perception and it is a key component of MW. Therefore, it stands to reason that perception of time may be impacted by the perceptual decoupling which comes with MW.

Another reason a relationship between MW and time perception is likely is because they are both related to attention. As review above, the attentional allocation model of time perception states that when there are few attention resources available for timekeeping, time estimates become distorted and shortened (Brown, 1997). As such, MW may in itself be a demand on attentional resources that impacts time perception in the same way. This would be in line with the attention-resources account of MW, which states that MW is a goal-directed behavior that pulls attention resources away from other tasks. Together, these two theories can explain how MW may impact time perception. Indeed, this view is supported by a study that demonstrated that when participants MW, their estimations of temporal intervals were shorter and more variable (Terhune et al., 2017). Clearly, this demonstrated MW had the same impact on time perception as cognitively-demanding non-temporal tasks did in Brown (1997), as would be expected if both the attentional allocation model of time perception and the attention-resources account of MW are accurately describing these experiences.

Mindfulness is often described as the opposite of MW because of the focus on the current moment (e.g., Deng et al., 2014; Dust, 2015; and Mrazek et al., 2012). Based on the combinations of models presented above, one would then expect that mindfulness meditation would result in longer perceived time durations and more accurate duration estimates than when MW. Kramer et al. (2013) had participants complete a mindfulness meditation or a control task (not specifically MW) and found that those who completed the mindfulness meditation produced longer duration estimates than those in the control task. The authors did not report if there were differences in accuracy of duration estimations between groups. Thönes and Wittmann (2016) also had participants complete a mindfulness meditation or control activity and did find that duration judgements were more accurate in the meditation group. They also found that the meditation group produced shorter duration estimations, however, this effect could be explained by the fact that the faster passage of time was positively correlated with experienced relaxation, and experienced relaxation was higher in the meditation versus the control group. This implies that the emotional quality of the activity was influencing time perception and not just the attention to the moment, explaining why the meditation group may have reported a shorter duration (Thönes and Wittmann, 2016). For more information about how attention is related to the relationship of mindfulness meditation and time perception, see Wittmann and Schmidt (2014).

Another cognitive state thought to be in opposition to MW is flow state, where all attention is directed to a task. This would theoretically leave no available attentional resources for timekeeping, so in keeping with the combination of theories presented, one would expect flow state to be associated with distortions in time perception and shorter estimated time durations, just like those seen in mindfulness meditation. Im and Varma (2018) tested this and found when in the condition with the highest rates of flow state reported, participants experienced time going by faster (i.e., shorter durations). Similar results have also been found in video game play, where flow states involving underestimation of time intervals are common (see Nuyens et al., 2020 for review). One meta-analysis of the relationship of flow and time perception was attempted (Hancock et al., 2019) and no relationship was found between the two, however the authors note that this is likely due to the very small number of studies in this area which met their qualifications.

As stated previously, MW is associated with disorders, such as ADHD, which some have proposed is a case of excessive MW (e.g., Bozhilova et al., 2018; Soffer-Dudek, 2019). Interestingly, ADHD is also associated with distortions in time perception, such that it has even been proposed as a symptom of ADHD, and those treated for ADHD see improvements in their time perception accuracy (see Ptacek et al., 2019). Taken together, this indicates that excessive MW and distortion in time perception go hand-in-hand, and yet the reason for that relationship is not well understood. Additionally, depression is related to MW (e.g., Deng et al., 2014, Seli et al., 2019) and distortions in the experience of time (Thönes and Oberfeld, 2015), and schizophrenia is also related to both MW (e.g., Iglesias-Parro et al., 2020; Shin et al., 2015) and time perception (Densen. 1977). To summarize, MW and time distortions are often co-occurring in clinical populations, and therefore understanding the connection between these two constructs is both theoretically and clinically important.

The Present Study

The present study has been designed to answer a number of questions raised by a consideration of previous research. Using a SART task with thought probes asking about thought type, time estimation, and judgements of passage of time, I separate out the differential effects of variables known to influence time perception (such as emotion) from the cognitive states with unknown effects. I attempt to understand how different thought types relate to different forms of distortions in time perception. Below is a list of primary research questions, followed by some considerations for each and corresponding hypotheses.

1. Are duration estimations shorter or longer on trials where participants are MW than

on trials where they are not MW? This is a theoretical replication of findings from Terhune et al. (2017).

H_1: I hypothesize that duration estimations will be shorter when participants are MW.

2. Are duration estimates more or less accurate while MW?

H_2: I hypothesize that duration estimation accuracy will be worse on MW trials.

3. Does time feel like it is going by faster or slower when MW? JOPOTs are affected by emotion, with higher reports of negative affect related to slower JOPOTs and high arousal related to faster JOPOTs across age groups (Droit-Volet & Wearden, 2015). However, it is unknown whether MW in general will impact JOPOTs, or in what direction.

H_3: This is an exploratory analysis with no directional hypothesis.

4. Is duration estimation more or less variable while MW than while not MW? This research question serves as a theoretical replication of findings from Terhune et al. (2017) and according to the attentional allocation model, duration estimations are likely to be more variable while MW.

H_4: I hypothesize that durations estimations will be statistically significantly more variable on trials where MW is reported than on trials where no MW is reported.

5. Is accuracy of estimations more or less variable while MW? Higher variability may be expected due to the expected variation in estimations generally (as per attentional allocation model).

H_5: I hypothesize that estimation accuracy will be more variable in MW trials.

6. Are the judgements of passage of time (JOPOTs) more variable while MW? Most research has investigated duration estimations, and those estimations are not the same as a JOPOT, so the effect may be different than it was for duration estimations. JOPOTs are more highly related to emotion than duration estimations are (Droit-Volet & Wearden, 2016), and

therefore would be expected to vary more when MW because emotional state may change with the changing thoughts while emotions will be more consistent during on-task thoughts.

> H_6: I hypothesize that JOPOTs will be more variable when MW than when not MW.

7. Do fixed or dynamic thought processes while MW relate to shorter or longer duration estimations? The contextual-change model posits that more change leads to a longer estimation of time. A dynamic thought process, where one is bouncing from one thought to the next, would be expected to be related to longer duration estimations than a fixed thought process where one is consistently thinking the same thing. Therefore, proponents of the contextual-change model would expect dynamic thoughts to be related to longer duration estimations than fixed thoughts. However, the attentional allocation model posits that it is not the amount of change but rather the attentional engagement that will lead to different duration estimations. As such, proponents of the attentional allocation model would expect no difference between fixed and dynamic thoughts while MW in their relation to estimation duration.

> H_7: Due to the high volume of studies in support of the attentional allocation model, I hypothesize that there will not be a statistically significant difference between fixed and dynamic thoughts on the duration estimation.

8. Are fixed or dynamic thoughts while MW related to more accurate duration estimations? Proponents of the contextual-change model would expect that duration estimations would vary by thought type and therefore one would be more accurate than the other. Proponents of the attentional allocation model would not expect to see those differences in duration estimations.

> H_8: I hypothesize that there will be no difference in duration estimations between trials with fixed versus dynamic thoughts reported.

9. Are fixed or dynamic thoughts while MW related to faster JOPOTs? As JOPOTs are related to emotion (valence and arousal), and emotion as related to fixed versus dynamic

thoughts during a SART task has not been investigated, it is unclear how these thought types relate to JOPOTs.

> H_9: This an exploratory analysis with no directional hypothesis.

10. Does the intentionality of MW relate to the subsequent impact on duration estimation? MW intentionality is related to difficulty such that more difficult tasks have more unintentional MW and vice versa. This may be because easier tasks do not require all attentional resources and therefore superfluous attentional resources may be devoted to intentional MW, while difficult tasks require more attention and therefore no attentional resources are intentionally diverted elsewhere. If this is the case, it would be expected that if one is able to MW intentionally, they may have the additional attentional resources necessary to keep time which are unavailable to those MW unintentionally.

> H_{10}: I hypothesize that when participants MW intentionally they report longer duration estimations than when MW unintentionally.

11. Does the intentionality of MW relate to the accuracy of duration estimations? Similar to above, I expect that when MW intentionally one may have enough attentional resources available to keep time more accuracy than when MW unintentionally.

> H_{11}: I hypothesize that MW intentionally will be related to more accurate duration estimations than MW unintentionally.

12. Is MW intentionality related to JOPOTs? MW intentionally may be expected to contain more positively valenced thoughts which is not surprising since the participant can choose the thought. Because positive thoughts are related to faster JOPOTs and MW intentionally may have more positive thoughts, faster JOPOTs may be expected.

> H_{12}: I hypothesize that MW intentionally will relate to faster JOPOTs than MW unintentionally.

13. Is self-reported attention to task related to duration estimation? Higher attention to

task could signify better attentional control overall, meaning more attention to timekeeping as well (leading to longer duration estimations), or it could mean that valuable attentional resources are being devoted to the task by being pulled away from timekeeping (meaning shorter duration estimations). Due to how MW is believed to be associated with shorter duration estimations, and MW is itself a lack of attention to task, it would be expected that attention would be related to longer duration estimations.

> H_{13}: I hypothesize that self-reported attention to task will be positively related to duration estimation.

14. Is self-reported attention to task related to duration estimation accuracy? As above, low attention to task could mean more MW, which would be related to lower duration estimation accuracy.

> H_{14}: I hypothesize that self-reported attention to task will be positively related to duration estimation accuracy.

15. Is self-reported attention to task related to the JOPOT? In Droit-Volet and Wearden (2015), self-reported attention to task was related to slower JOPOTs.

> H_{15}: I hypothesize that attention to task will be related to slower JOPOTs.

16. What are the relative influences of attention to task, emotion (valence and arousal), intentionality and fixed versus dynamic thoughts on duration estimation?

> H_{16}: This research question is to understand the influence of each relative to each other and as this has not been done before, it is an exploratory analysis with no directional hypothesis.

17. What are the relative influences of attention to task, emotion (valence and arousal), intentionality and fixed versus dynamic thoughts on duration estimation accuracy?

> H_{17}: This research question is to understand the influence of each relative to each other and as this has not been done before, it is an exploratory analysis with no directional hypothesis.

18. What are the relative influences of attention to task, emotion (valence and arousal), intentionality and fixed versus dynamic thoughts on the JOPOT?

> H_{18}: This research question is to understand the influence of each relative to each other and as this has not been done before, it is an exploratory analysis with no directional hypothesis.

19. Is duration estimation related to the JOPOT? Droit-Volet and Wearden (2016) found that JOPOTs and duration estimations were not related, and I will be attempting a theoretical replication of this finding.

> H_{19}: I hypothesize that duration estimation and JOPOT will not be statistically significantly related to each other.

CHAPTER 2

METHODS

Participants

One sample of 45 adults in the US was recruited via Amazon Mechanical Turk, a crowdsourcing marketplace for paid research participation. Participation involved using E-Prime Go, a program that is only compatible with Windows 7, 8, 10, and 11 operating systems. Therefore, only people with access to a compatible machine were recruited for participation. All procedures were approved by the institutional review board of the University of North Texas (see informed consent in Appendix B) and participants were compensated with $7.25.

Sample Size and Experimental Power Considerations

A sample of 45 participants was collected, and five were excluded (see below) for a final sample size of 40. Each participant answered a total of 8 thought probes (explained below), leading to a total sample size of 320 cases. Previous research on intentional versus unintentional MW had large effect sizes (e.g., Seli et al., 2018), however the impact of intentional versus unintentional MW on time perception has not been measured previously and therefore a medium effect size was expected. Scherbaum and Ferreter (2009) showed that for a medium effect size and a level-1 sample size of 8, between 35 and 40 level-2 clusters were necessary to achieve 80% power in multilevel modeling (MLM). Additionally, McNeish and Stapleton (2016) demonstrated that when assessing level-1 fixed effects on a continuous outcome, only 5 clusters were needed to have an unbiased estimate, and only 10 clusters were needed for an unbiased estimate of level-1 variance. Furthermore, it is known that when assessing only level-1 effects, the level-1 sample size is more important than the level-2 sample size (Mathieu et al., 2012). The current sample consists of 40 individuals with 8 time points per individual for a total level-1 sample size of 320, which is higher than what is needed for ordinary least squares (OLS) regression (estimated sample size is 159 for a *t* test with 80% power, medium effect size, and alpha = .05 according to G*Power, Faul et al., 2007). Other studies of first level effects have used similar sample sizes in the past as well (e.g., Nezlek et al., 2012). Additionally, the sample size of 40 is in a similar range to studies with similar methods and different analytic techniques (e.g., Smallwood et al., 2004; Martel et al., 2019; Deng et al., 2014).

Participant Exclusion

Participants' data was excluded from analysis in a few circumstances. One is if they indicated dishonesty (by selecting "No, I was not truthful") when asked "Were you truthful in your responses throughout participating in this study?". It should be noted that participants were also told that indicating they were not truthful would not affect their compensation, and they were encouraged to be honest. Additionally, participants were excluded if their pattern of responding indicated a lack of understanding of the instructions, such as through a lack of variability in responses (e.g., choosing the same answer to every question) or choosing duration estimations in a linear pattern (suggesting they misunderstood the instructions to be asking for a cumulative estimate of time passed in the study rather than as the time passed during just the current block). In total, one participant was excluded for indicating dishonesty, one for choosing durations in a linear fashion, and 3 for a lack of variability. The total final sample size was 40 participants. Blocks with missing data were excluded listwise from analyses – no data were imputed.

Participant Demographics

Of the 40 participants, 36 filled out the demographics questionnaire (see Appendix C). The average age of participants was 39 (*SD* = 11.16, range from 19 to 66). For biological sex, 17 identified as female, 19 identified as male, and no one identified as any other biological sex. For gender, 18 selected man, 18 selected woman, and no one selected non-binary or any other gender. One participant identified as transgender. For race/ethnicity, 27 identified as White, four as Latinx/Latino American/Hispanic, four as African American/Black, three as Native American/Alaskan Native, and none as Asian. Note that they were able to choose multiple races/ethnicities and two participants identified as multiple races/ethnicities. Six participants reported that they had been diagnosed with a mental health disorder, and reported disorders included depression, anxiety, and insomnia. All participants were fluent in English and lived in the United States across 19 different states.

Materials

Amazon Mechanical Turk

Amazon Mechanical Turk (MTurk) is a tool for research participants to find active research studies and be paid for participation. All participation is voluntary and money for compensation was distributed through the MTurk platform.

REDCap

REDCap is an Electronic Data Capture (EDC) system (Harris et al., 2009; Harris et al., 2019). Once participants saw the available study on MTurk, they were directed to REDCap where they completed the informed consent form (see Appendix B) and had the opportunity to contact the researcher with any questions before beginning. REDCap was also used to collect demographic information. Data were stored securely, and only de-identified data were used for analyses.

E-Prime Go

Behavioral data were collected through E-Prime Go. E-Prime Go (PST Inc) is a stimulus presentation and response measurement tool that can accessed remotely via a website. Participants were directed from REDCap to E-Prime Go where they were able to download the application. Participants using machines running Windows 7, 8, 10, or 11 only were included, as is recommended by E-Prime Go due to problems in measurement on other operating systems. Data were then automatically sent to the researcher after the participant completed the study on their own computer.

Procedure

Participation took approximately 1 hour and participants were compensated with $7.25. Participants found the study via MTurk and were then directed to REDCap where they had the opportunity to read about the study, contact the researcher if they wished, and agree to the informed consent. After completing the informed consent, they downloaded E-Prime Go, and were asked to cover/block all clocks from their view before beginning the SART/time perception task. They were given task instructions and completed two practice trials before beginning the task.

Sustained Attention to Response Task

In the SART task, stimuli were presented sequentially in the center of the screen. Stimuli consisted of digits 1-9, presented in random order. Each was presented for 250ms. Between stimuli there was a 2065ms gap, meaning the inter-stimulus interval (ISI) was 2315ms, because these time lengths have been demonstrated to maximize MW (Martel et al., 2019). The participants were instructed to respond with a button press to digits 1, 2, and 4-9 but to withhold responding to the digit 3. They were able to respond at any time during the trial. All participants had the same number of trials per block and the same block lengths. They did not receive feedback on their responses so that negative feedback did not influence thoughts. Blocks were ranged in length from approximately 30s to 120s and were presented in random order. Exact block lengths were as follows: 32.41s (14 trials), 48.61s (21 trials), 57.87s (25 trials), 69.45s (30 trials), 78.71s (34 trials), 85.65s (37 trials), 101.860s (44 trials), and 118.06s (51 trials). Those times were chosen pseudorandomly so that the task length in total did not exceed 10 minutes (total time = 9 minutes, 52.64s) to avoid fatigue, and so that there was not a fixed difference between blocks that could aid participants in duration estimations.

Thought Probes

While completing the SART task, at the end of each block participants were prompted with the following: "STOP AND THINK – WHAT WERE YOU JUST THINKING ABOUT, AND HOW LONG HAS IT BEEN SINCE (YOU STARTED/YOU LAST ANSWERED SURVEY QUESTIONS?)". Following this, they were asked to give an estimate of the block length in minutes and seconds. They were instructed not to round answers or give numbers that end with 0 or 5, as a tendency to provide "round" estimates can bias duration estimation procedures (Loehlin, 1959) and this method has been used previously (Pedri and Hasketh, 1993). Next, participants were asked to give a judgement of passage of time (JOPOT) on a scale from 1-100, where 1 indicated that time was going by very slowly and 100 indicated that time was going by very quickly.

After that, participants were asked to categorize their thought processes. Accordingly, they indicated if they were having an on-task thought, an intentionally off-task thought, or an unintentionally off-task thought. Next, they indicated if their thoughts were fixed (thinking about one thing consistently) or dynamic (thoughts shifting between multiple topics). They were asked about the emotional valence of their thoughts, which they reported on a scale from 1 to 100, with low numbers indicating negative thoughts and high numbers indicating positive thoughts. They then reported their emotional arousal on a scale from 1 to 100, with low numbers indicating low arousal and high numbers indicated high arousal. Lastly, they were asked to indicate how much they were paying attention to the task at the time, on a scale from 1-100 with higher numbers indicating more attention to task. See the Appendix A for verbiage of all thought probe questions. The participants were then prompted that the next block was about to begin and were reminded of the task instructions. Finally, after completing the full SART task, participants completed a demographics form on REDCap.

Statistical Analyses

All research questions were addressed using a series of multilevel models (MLMs). MLM is a technique for modeling data which is nested within structures, such as multiple observations nested within a particular individual. Because data collected from one individual is more likely to be similar to other data from the same individual than to data from another individual, data with this structure would violate the assumption of independence of observations in single level general linear model analyses, and therefore a MLM is warranted.

For each analysis, individual blocks were on the first level, and participants were on the second level, because there were multiple blocks per individual. All predictors were entered at the first level, and all outcome variables were first level variables. All models included actual block length as a covariate because estimates of time are likely to vary based on actual time passed in that interval. For each analysis, a model was created without the predictor of interest included, followed by another model including the predictor of interest. Next, the percent of variance in the outcome variable explained by adding that predictor into the model was calculated using the following formula:

$$(\sigma_{\text{ModelWithoutPredictor}}{}^{2} - \sigma_{\text{ModelWithPredictor}}{}^{2}) / \sigma_{\text{ModelWithoutPredictor}}{}^{2}$$

where σ^2 is the first level residual variance. Fixed effects of each model were also analyzed. For example, when the fixed effect of slope is statistically significant ($p < .05$), it means that the fixed effect term in the equation is statistically significantly different from 0. Analysis of intentionality was dummy-coded with MW intentionally as the reference group, and that model was compared to the model with MW/not MW entered as a dichotomous variable to see if parsing apart intentional versus unintentional MW explained more variance than just MW versus not MW predicted alone. Hypotheses regarding variability were addressed by calculating a mean outcome for each individual on each of the three time perception measures (i.e., duration estimation, duration estimation inaccuracy, and JOPOT), then subtracting from that each individual outcome score and the absolute value was taken to get a difference score. Difference scores were then entered as the outcome variable for those analyses, so that the variability of outcomes under different circumstances could be analyzed. Inaccuracy was calculated by taking the absolute value of the actual amount of time passed minus the estimated duration.

All MLM analyses were run using IBM SPSS Statistics 26. Data processing and management was conducted through IBM SPSS Statistics 26 and Microsoft Excel. Data was cleaned by checking for participants for inclusion/exclusion (described above). Because answers during the task were selected from options provided, there was no need to screen for unusual answers or check for typos. No data was imputed in order to preserve the integrity of the original pattern of data, and because there was a small amount of data missing.

CHAPTER 3

RESULTS

Out of a total of 320 observations across 40 people, there were 76 instances (23.75%) where participants were MW, 45 of which were intentional and 31 which were unintentional, 6 unreported, and 269 (84.06%) where participants were not MW. Participants reported they were having fixed thoughts on 251 (78.44%) thought probes and dynamic thoughts on 63 (19.69%) thought probes with 6 missing. The average emotional valence reported was 59.89 (*SD* = 23.79) on a scale from 0-100 where higher numbers represent more positive feelings. The average emotional arousal reported was 55.66 (*SD* = 31.10) on a scale form 0-100 where higher numbers indicate a more intense feeling. When asked how much they were paying attention to the task, the average response was 80.75 (*SD* = 24.39) on a scale from 0-100 where 0 means paying no attention and 100 means paying full attention. Duration estimations ranged from 5 seconds to 9 minutes 52 seconds. On average people's estimates were off by 75.66 seconds. JOPOTs were reported across the entire 0-100 scale (where 0 means time felt like it was passing very slowly and 100 means time felt like it was passing very quickly), and the average was 55.21 (*SD* = 26.27). There were little missing data, with at least 314 cases included in each analysis. Model equations are given in Appendix D.

Research Question 1

This analysis investigated whether duration estimations were shorter or longer on trials where participants were MW than on trials where they were not MW. First, a null model (Null.DurEst) was run with only the actual duration of each block (ActDur) as a level-1 predictor and the outcome variable of duration estimation (DurEst). The fixed effect of ActDur was statistically significantly different from 0 (Estimate = 1.06, $p < .001$), indicating that participant's estimates of time passed were related to the actual amount of time passed, which is unsurprising. The level 1 residual variance was 2553.70. Next, whether or not the participant was MW on that trial was added to the model as a dichotomous variable, where 0 means not MW and 1 means MW. In this new model (MW.DurEst), the fixed effect of ActDur was still statistically significantly different from 0 (Estimate = 1.04, $p = .004$) and the fixed effect of MW was not statistically significantly different from 0 (Estimate = 17.22, $p = .131$). The model equation was as follows: DurEst = 49.82 + 1.04(ActDur) + 17.22(MW). See Figure 1 for graphical representation of the fixed effects. The residual level-1 variance of MW.DurEst was 2505.08. The percent of variance explained by adding MW to the model was 1.90%. See Table 1 for summary data.

Research Question 2

This analysis investigated whether duration estimations were more or less accurate on trials where participants were MW than on trials where they were not MW. First, a null model (Null.Inaccuracy) was run with only the actual duration of each block (ActDur) as a level-1 predictor and the outcome variable of inaccuracy. Inaccuracy was calculated by taking the absolute value of the actual duration minus the estimated duration. In the null model, fixed effect of ActDur was statistically significantly different from 0 (Estimate = 0.39, $p = .010$), indicating that participant's level of inaccuracy varied by the actual amount of time passed, with estimates being more inaccurate in longer blocks than shorter blocks. The level 1 residual variance was 1905.64. Next, whether or not the participant was MW on that trial was added to the model as a dichotomous variable, where 0 means not MW and 1 means MW. In this new model (MW.Inaccur), the fixed effect of ActDur was no longer statistically significantly different from 0 (Estimate = .38, $p = .883$) and the fixed effect of MW was not statistically significantly different from 0 either (Estimate = 11.88, *p* = .204). The model equation was as follows: Accuracy = 44.16 + 0.38(ActDur) + 11.88(MW). See Figure 2 for graphical representation. The residual level-1 variance of MW.Inaccuracy was 2021.59. The percent of variance explained by adding MW to the model was negative, indicating that the null model was better than the model including MW. See Table 2 for summary data.

Research Question 3

This analysis investigated whether time felt faster or slower (JOPOT) on trials where participants were MW than on trials where they were not MW. JOPOT was measured on a scale from 0-100 with 0 meaning time felt like it was passing very slowly and with 100 meaning time felt like it was passing very quickly. First, a null model (Null.JOPOT) was run with only the actual duration of each block (ActDur) as a level-1 predictor and the outcome variable of JOPOT. The fixed effect of ActDur was statistically significantly different from 0 (Estimate = -0.20, *p* < .001), indicating that the more time that passed, the slower the time felt. The level 1 residual variance was 414.40. Next, whether or not the participant was MW on that trial was added to the model as a dichotomous variable, where 0 means not MW and 1 means MW. In this new model (MW.JOPOT), the fixed effect of ActDur was no longer statistically significantly different than 0 (Estimate = -0.21, *p* = .881) and the fixed effect of MW was not statistically significantly different than 0 either (Estimate = -1.84, *p* = .631). The model equation was as follows: JOPOT = 71.18 - 0.21(ActDur) – 1.84(MW). See Figure 3 for graphical representation. The residual level-1 variance of MW.JOPOT was 361.94. The percent of variance explained by adding MW to the model was 12.66%. See Table 3 for summary data.

Research Question 4

This analysis investigated whether duration estimations were more or less variable on trials where participants were MW than on trials where they were not MW. Difference scores were calculated by first taking the mean duration estimation for each individual, then for each block subtracting the duration estimation of that block from that participant's average, and taking the absolute value to determine how many seconds away from their own average they were on each block (i.e., creating a difference score). A null model (Null.DiffDurEst) was run with only the actual duration of each block (ActDur) as a level-1 predictor and the outcome variable of difference scores of duration estimation (DiffDurEst). The fixed effect of ActDur was not statistically significantly different from 0 (Estimate = 0.10, $p = .248$), indicating that variability of participant's estimates of time passed did not differ as a function of the amount of time passed in the block. The level 1 residual variance was 1468.99. Next, whether or not the participant was MW on that trial was added to the model as a dichotomous variable, where 0 means not MW and 1 means MW. In this new model (MW.DiffDurEst), the fixed effect of ActDur was still not statistically significantly different from 0 (Estimate = 0.08 $p = .972$) and the fixed effect of MW was not statistically significantly different from 0 either (Estimate = 6.01, $p = .421$). The model equation was as follows: DiffDurEst = 30.85 + 0.08(ActDur) + 6.01(MW). See Figure 4 for graphical representation of the fixed effects. The residual level-1 variance of MW.DiffDurEst was 1236.09. The percent of variance explained by adding MW to the model was 15.85%.

Research Question 5

This analysis investigated whether the inaccuracy of duration estimations was more or less variable on trials where participants were MW than on trials where they were not MW. Difference scores for inaccuracy were calculated in the same way that they were calculated for DurEst in Research Question 4. A null model (Null.DiffInaccur) was run with only the actual duration of each block (ActDur) as a level-1 predictor and with the outcome variable being the difference scores of the inaccuracy of duration estimation (DiffInaccur). The fixed effect of ActDur was not statistically significantly different from 0 (Estimate = 0.05, *p* = .500), indicating that variability of the inaccuracy of participant's estimates of time passed did not differ as a function of the amount of time passed in the block. The level 1 residual variance was 986.91. Next, whether or not the participant was MW on that trial was added to the model as a dichotomous variable, where 0 means not MW and 1 means MW. In this new model (MW.DiffInaccur), the fixed effect of ActDur was still not statistically significantly different from 0 (Estimate = 0.04, *p* = .977) and the fixed effect of MW was also not statistically significantly different from 0 (Estimate = 4.77, *p* = .415). The model equation was as follows: DiffInaccur = 24.48 + 0.04(ActDur) + 4.77(MW). See Figure 5 for graphical representation of the fixed effects. The residual level-1 variance of MW.DiffAccur was 924.12. The percent of variance explained by adding MW to the model was 6.36%.

Research Question 6

This analysis investigated whether JOPOTs were more or less variable on trials where participants were MW than on trials where they were not MW. Difference scores for JOPOTs were calculated in the same way that they were calculated for DurEst in Research Question 4. A null model (Null.DiffJOPOT) was run with only the actual duration each block (ActDur) as a level-1 predictor and the outcome variable of difference scores of JOPOT (DiffJOPOT). The fixed effect of ActDur was not statistically significantly different from 0 (Estimate = 0.00, *p* = .977), indicating that variability of JOPOTs did not differ as a function of the amount of time passed in the block. The level 1 residual variance was 148.71. Next, whether or not the participant was MW on that trial was added to the model as a dichotomous variable, where 0 means not MW and 1 means MW. In this new model (MW.DiffJOPOT), the fixed effect of

ActDur was still not statistically significantly different from 0 (Estimate = 0.00, *p* = .995) and the fixed effect of MW was also not statistically significantly different from 0 (Estimate = -1.09, *p* = .633). The model equation was as follows: DiffJOPOT = 14.62 + 0.00(ActDur) – 1.09(MW). See Figure 6 for graphical representation of the fixed effects. The residual level-1 variance of MW.DiffJOPOT was 147.20. The percent of variance explained by adding MW to the model was 1.02%.

Research Question 7

This analysis investigated whether duration estimations were shorter or longer on trials where participants were having fixed versus dynamic thoughts. The null model (Null.DurEst) has already been run (see Research Question 1). Whether the participant was having fixed or dynamic thoughts was added to the model (Fixed.DurEst), where fixed thoughts is coded as 0 and dynamic thoughts are coded as 1. The fixed effect of ActDur on DurEst is no longer statistically significantly different from 0 (Estimate = 1.04, *p* = .822) and the fixed effect of Fixed/Dynamic thoughts on DurEst was also not statistically significantly different from 0 (Estimate = 2.62, *p* = .830). The model equation was as follows: DurEst = 53.17 + 1.04(ActDur) + 2.62(Fixed/Dynamic). See Figure 7 for graphical representation of the fixed effects. The residual level-1 variance of Fixed.DurEst was 2983.19. The percent of variance explained by adding MW to the model was negative, indicating that the null model was a better fit to the data than the model including thought type. See Table 1 for summary data.

Research Question 8

This analysis investigated whether duration estimations were more or less accurate on trials where participants were having fixed versus dynamic thoughts. The null model (Null.Inaccuracy) has already been run (see Research Question 2). Whether the participant was having fixed or dynamic thoughts was added to the model (Fixed.Inaccuracy), where fixed thoughts is coded as 0 and dynamic thoughts are coded as 1. The fixed effect of ActDur on inaccuracy is no longer statistically significantly different from 0 (Estimate = 0.38, *p* = .909) and the fixed effect of Fixed/Dynamic thoughts on inaccuracy was also not statistically significantly different from 0 (Estimate = -1.87, *p* = .897). The model equation was as follows: inaccuracy = 46.84 + 0.38(ActDur) – 1.87(Fixed/Dynamic). See Figure 8 for graphical representation of the fixed effects. The residual level-1 variance of Fixed.Inaccuracy was 2125.79. The percent of variance explained by adding fixed/dynamic to the model was negative, again indicating that the null model was a better model than that with the thought type included. See Table 2 for summary

Research Question 9

This analysis investigated whether JOPOTs were faster or slower on trials where participants were having fixed versus dynamic thoughts. The null model (Null.JOPOT) has already been run (see Research Question 3). Whether the participant was having fixed or dynamic thoughts was added to the model (Fixed.JOPOT), where fixed thoughts is coded as 0 and dynamic thoughts are coded as 1. The fixed effect of ActDur on JOPOT is no longer statistically significantly different from 0 (Estimate = -0.19, *p* = .895) and the fixed effect of Fixed/Dynamic thoughts on JOPOT was also not statistically significantly different from 0 (Estimate = -0.77, *p* = .852). The model equation was as follows: JOPOT = 69.88 – 0.19(ActDur) – 0.77(Fixed/Dynamic). See Figure 9 for graphical representation of the fixed effects. The residual level-1 variance of Fixed.JOPOT was 379.10. The percent of variance explained by adding fixed/dynamic to the model was 8.52%. See Table 3 for summary data.

Research Question 10

This analysis investigated whether estimations of duration were shorter or longer when participants were MW intentionally versus unintentionally. The null model (Null.DurEst) has already been run and the model with MW predicting duration estimation (MW.DurEst) has also already been run (see Research Question 1). Intentionality was dummy coded so that not MW, MW intentionally, and MW unintentionally could be modeled with 2 dichotomous variables. Note that the first dummy coded variable, intA is the same as the MW variable used in previous analyses, except here 0 = MW and 1 = Not MW. The variable intB has MW unintentionally coded as 1 and not MW and MW intentionally as 0, so that MW intentionally is the reference group. Both dummy coded variables were entered into the analysis at the same time to create the model (Int.DurEst). In this model, the fixed effect of ActDur on DurEst is no longer statistically significantly different from 0 (Estimate = 1.05, $p = .812$) as it had been in both the null model and the model with MW (see Research Question 1 for full results). The fixed effects of intA (Estimate = -21.88, $p = .243$) and intB (Estimate = -11.31, $p = .565$) were also not statistically significantly different from 0. The model equation was as follows: DurEst = 71.29 + 1.05(ActDur) – 21.88(intA) – 11.31(intB). From this, 3 equations were generated:

- When participant is not MW: DurEst = 49.42 + 1.05(ActDur)
- When participant is MW intentionally: DurEst = 71.29 + 1.05(ActDur)
- When participant is MW unintentionally: DurEst = 59.98 + 1.05(ActDur)

These equations are shown in Figure 10. The residual level-1 variance of was 2836.45. Adding intentionality to the model did not improve it relative to the null model or the model with only MW entered. See Table 1 for summary data.

Research Question 11

This analysis investigated whether estimations of duration were more or less accurate when participants were MW intentionally versus unintentionally. The null model

(Null.Inaccuracy) has already been run and the model with MW predicting inaccuracy (MW.inaccuracy) has also already been run (see Research Question 2). Intentionality was dummy coded in the same way as in Research Question 10 above. Both dummy coded variables were entered into the analysis at the same time to create the model (Int.Inaccur). In this model, the fixed effect of ActDur on DurEst is no longer statistically significantly different from 0 (Estimate = 0.38, p = .933). The fixed effect of intA (Estimate = -4.45, p = .766) and intB (Estimate = 0.34, p = .986) were also not statistically significantly different from 0. The model equation was as follows: Inaccuracy = 49.44 + 0.38(ActDur) – 4.45(intA) + 0.34(intB). From this, three equations were generated:

- When participant is not MW: Inaccuracy = 44.99 + 0.38(ActDur)
- When participant is MW intentionally: Inaccuracy = 49.44 + 0.38(ActDur)
- When participant is MW unintentionally: Inaccuracy = 49.77 + 0.38(ActDur)

These equations are shown in Figure 11. The residual level-1 variance of was 2251.49. Adding intentionality to the model did not improve it relative to the null model or the model with only MW entered. See Table 2 for summary data.

Research Question 12

This analysis investigated whether JOPOTs were faster or slower when participants were MW intentionally versus unintentionally. The null model (Null.JOPOT) has already been run and the model with MW predicting JOPOT (MW.JOPOT) has also already been run (see Research Question 3). Intentionality was dummy coded in the same way as in Research Question 10 above. Both dummy coded variables were entered into the analysis at the same time to create the model Int.JOPOT. In this model, the fixed effect of ActDur on JOPOT was not statistically significantly different from 0 (Estimate = -0.21, p = .903). The fixed effect of intA (Estimate =

3.78, *p* = .503) and intB (Estimate = 4.15, *p* = .505) were also not statistically significantly different from 0. The model equation was as follows: JOPOT = 67.05 – 0.21(ActDur) + 3.78(intA) + 4.15(intB). From this, three equations were generated:

- When participant is not MW: JOPOT = 70.83 - 0.21(ActDur)
- When participant is MW intentionally: JOPOT = 67.05 - 0.21(ActDur)
- When participant is MW unintentionally: JOPOT = 71.21 - 0.21(ActDur)

These equations are shown in Figure 12. The residual level-1 variance of was 352.11. Adding intentionality to the model improved it relative to the null model (15.03% of variance explained) and relative to the model with MW entered (2.72% of variance explained). See Table 3 for summary data.

Research Question 13

This analysis investigated whether duration estimations were shorter or longer as a function of how much participants were paying attention to the task. The null model (Null.DurEst) was already run (See Research Question 1). Attention to task (Atten) was added as a continuous level-1 variable to create the model (Atten.DurEst). In this model, ActDur was still statistically significantly different from 0 (Estimate = 1.03, $p < .001$) but Atten was not (Estimate = -0.20, *p* = .312). The model equation was as follows: DurEst = 69.54 + 1.03(ActDur) – 0.20(Atten). See Figure 13 for graphical representation of the fixed effects. The residual level-1 variance was 2563.24. The percent of variance explained by including attention in the model was negative, indicating that the null model, without attention included, was a better model. See Table 1 for summary data.

Research Question 14

This analysis investigated whether duration estimations were more or less accurate as a function of how much participants were paying attention to the task. The null model (Null.Inaccuracy) was already run (See Research Question 2). Attention to task (Atten) was added as a continuous level-1 variable to create the model (Atten.Inaccur). In this model, ActDur was still statistically significantly different from 0 (Estimate = 0.37, *p* = .033) but Atten was not (Estimate = -0.14, *p* = .417). The model equation was as follows: Inaccuracy = 57.55 + 0.37(ActDur) – 0.14(Atten). See Figure 14 for graphical representation of the fixed effects. The residual level-1 variance was 1926.53. The percent of variance explained by including attention in the model was negative, indicating that the model without attention (the null model) was a better model. See Table 2 for summary data.

Research Question 15

This analysis investigated whether JOPOTs were faster or slower as a function of how much participants were paying attention to the task. The null model (Null.JOPOT) was already run (See Research Question 3). Attention to task (Atten) was added as a continuous level-1 variable to create the model (Atten.JOPOT). In this model, ActDur was still statistically significantly different from 0 (Estimate = -0.19, *p* = .001) and Atten was also statistically significantly different from 0 (Estimate = 0.26, *p* = .038), meaning that the more the participant was paying attention to the task, the faster time felt like it was passing. The model equation was as follows: JOPOT = 46.10 – 0.19(ActDur) + 0.26(Atten). See Figure 15 for graphical representation of the fixed effects. The residual level-1 variance was 363.53. The percent of variance explained by including attention in the model was 12.28%. See Table 3 for summary data.

Research Question 16

This analysis was run to investigate the relative influences of several factors on duration estimation. Results from previous analyses were compared and two additional models were run. First, a model was run with thought valence (0-100 with higher numbers indicating more positive thoughts) added to the model as compared to the Null.DurEst model. In this model, the fixed effect of ActDur was statistically significantly different from 0 (Estimate = 1.02, $p < .001$) but the fixed effect of valence was not (Estimate = -0.26, $p = .297$). The level-1 variance of the model was 2686.24, meaning that including valence in the model made the model worse. A similar model was run with arousal (0-100 with higher numbers indicating higher self-reported arousal) as the predictor. Again, the fixed effect of ActDur was statistically significantly different from 0 (Estimate = 1.05, $p < .001$) but the fixed effect of arousal was not (Estimate = -0.10, $p = .499$). The level-1 variance was 2536.43 meaning that 0.68% of variance was explained by adding arousal to the model.

Table 1 lists the percent of variance explained by each predictor of interest as compared to the null model with only the actual duration as a predictor. Overall, these predictors explained very little variance in duration estimation, but of them, MW was the best predictor.

Research Question 17

This analysis investigated the relative influences of several factors on the inaccuracy of duration estimations. Results from previous analyses were compared and two additional models were run. First, a model was run with thought valence (0-100 with higher numbers indicating more positive thoughts) added to the model (Val.inaccur) as compared to the Null.Inaccuracy model. In this model, the fixed effect of ActDur was statistically significantly different from 0 (Estimate = 0.38, $p = .012$) but the fixed effect of valence was not (Estimate = -0.28, $p = .138$). The level-1 variance of the model was 1912.71, meaning that the null model did a better job than the model including valance. A similar model was run with arousal (0-100 with higher numbers indicating higher self-reported arousal) as the predictor. Again, the fixed effect of ActDur was statistically significantly different from 0 (Estimate = 0.39, $p = .014$) but the fixed effect of arousal was not (Estimate = 0.06, $p = .624$). The level-1 variance was 1919.15 meaning that the null model was better than the model with arousal.

Table 2 summarizes the results of all predictors tested on the accuracy of estimation durations. None of the variables of interest were able to improve the null model of inaccuracy. Inaccuracy was higher on trials of longer durations but no cognitive factors investigated gave additional information about predicting inaccuracy.

Research Question 18

This analysis investigated the relative influences of several factors on JOPOTs. Results from previous analyses were compared and two additional models were run. First, a model was run with thought valence (0-100 with higher numbers indicating more positive thoughts) added to the model (Val.JOPOT) as compared to the Null.JOPOT model. In this model, the fixed effect of ActDur was statistically significantly different from 0 (Estimate = -0.17, $p = .002$) and the fixed effect of valence was also statistically significantly different from 0 (Estimate = 0.43, $p < .001$). The model equation was as follows: JOPOT = 41.03 – 0.17(ActDur) + 0.43(valence). See Figure 16 for graphical representation. The level-1 variance of the model was 407.43, meaning that 1.68% of variance was explained by adding valence to the model. A similar model was run with arousal (0-100 with higher numbers indicating higher self-reported arousal) as the predictor. The fixed effect of ActDur was statistically significantly different from 0 (Estimate = -0.20, $p = .001$) but the fixed effect of arousal was not (Estimate = -0.03, $p = .681$). The level-1 variance was 424.07 meaning that the model without arousal did a better job than the model with arousal included. Table 3 lists the percent of variance explained by each predictor of interest as compared to the null model with only the actual duration as a predictor. Overall, several variables contribute to understanding JOPOT. Intentionality explained the most variance, however this analysis included whether or not they were MW and if it was intentional, and the addition of intentionality only explained an additional 2.72% of variance above what is explained by whether or not they were MW. As a single predictor, MW explained the most variance in JOPOT.

Research Question 19

This analysis investigated whether the feeling of time passing (JOPOT) predicted behavioral estimates of time passed. The null model (Null.DurEst) was already run (see Research Question 1). JOPOT was entered as a predictor into the model. In this model, the fixed effect of ActDur was still statistically significantly different from 0 (Estimate = 1.04, $p < .001$) but the fixed effect of JOPOT was not statistically significantly different from 0 (Estimate = 0.01, $p = .966$). The model equation was as follows: DurEst = 52.54 + 1.04(ActDur) + 0.01(JOPOT). See Figure 17 for a graphical representation of fixed effects. The residual level-1 variance was 2457.76, meaning the percent variance explained by adding JOPOT to the model was 3.76%.

Table 1

The Fixed Effects of Predictors of Interest on Duration Estimation and Variance Explained

Predictor	Fixed Effect of Predictor *p* Value	Variance Explained by Adding Predictor to the Model
MW	.131	1.90%
Intentionality (versus null model)	.243 and .565	None
Intentionality (versus model with MW)	-	None
Fixed/Dynamic Thoughts	.830	None
Attention to Task	.312	None
Valence	.297	None
Arousal	.499	0.68%

Table 2

The Fixed Effects of Predictors of Interest on Estimation Accuracy and Variance Explained

Predictor	Fixed Effect of Predictor *p* Value	Variance Explained by Adding Predictor to the Model
MW	.204	None
Intentionality (versus null model)	.766 and .933	None
Intentionality (versus model with MW)	-	None
Fixed/Dynamic Thoughts	.897	None
Attention to Task	.417	None
Valence	.138	None
Arousal	.624	None

Table 3

The Fixed Effects of Predictors of Interest on JOPOTs and Variance Explained

Predictor	Fixed Effect of Predictor *p* Value	Variance Explained by Adding Predictor to the Model
MW	.613	12.66%
Intentionality (versus null model)	.503 and .505	15.03%
Intentionality (versus model with MW)	-	2.72%
Fixed/Dynamic Thoughts	.582	8.52%
Attention to Task	.038	12.28%
Valence	<.001	1.68%
Arousal	.681	None

Figure 1

The Effect of MW on Duration Estimation as a Function of Actual Time Passed

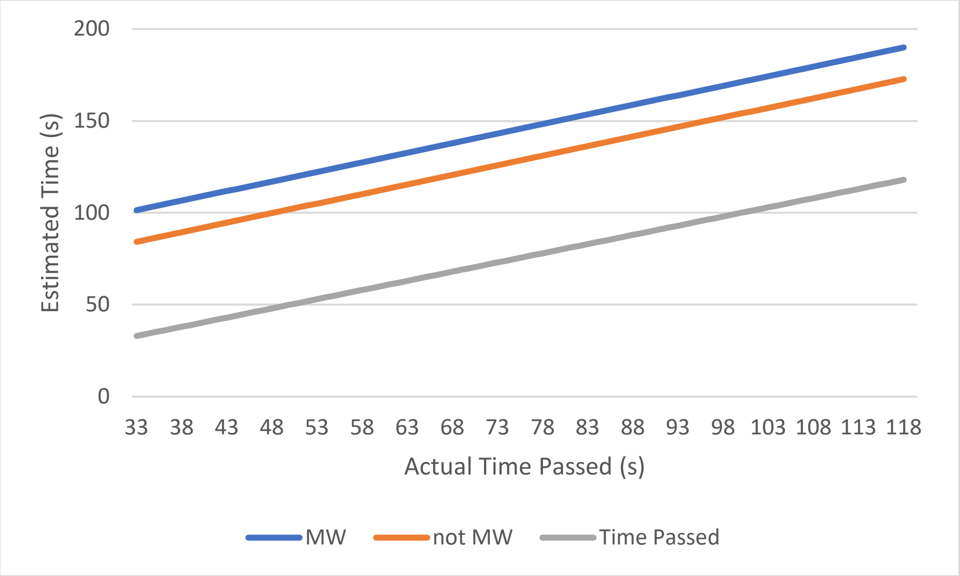


Figure 2

The Effect of MW on the Inaccuracy of Duration Estimations as a Function of Actual Time Passed

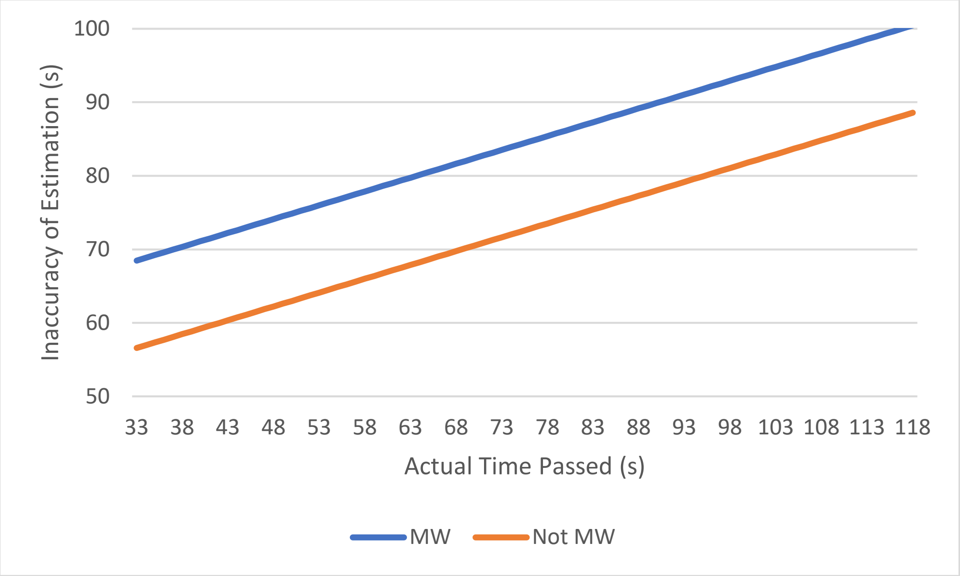


Figure 3

The Effect of MW on JOPOT as a Function of Actual Time Passed

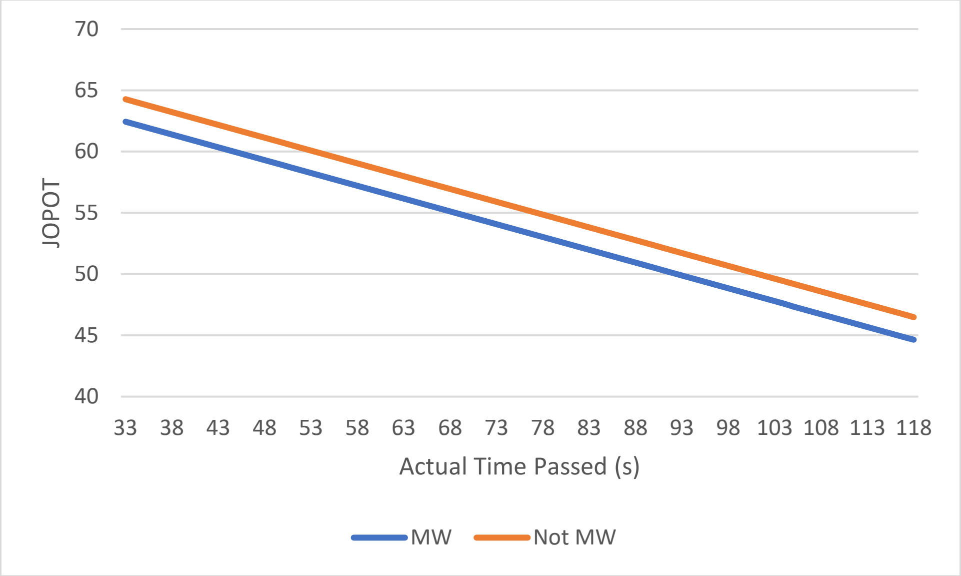


Figure 4

The Effect of MW on the Variability of Duration Estimations as a Function of the Amount of Time Passed

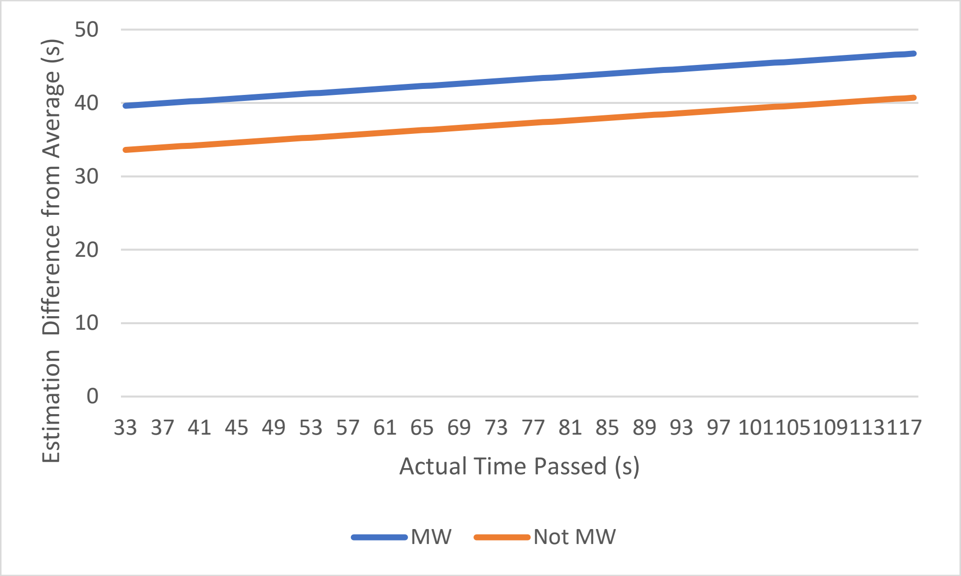


Figure 5

The Effect of MW on the Variability of the Inaccuracy of Estimations as a Function of Actual Time Passed

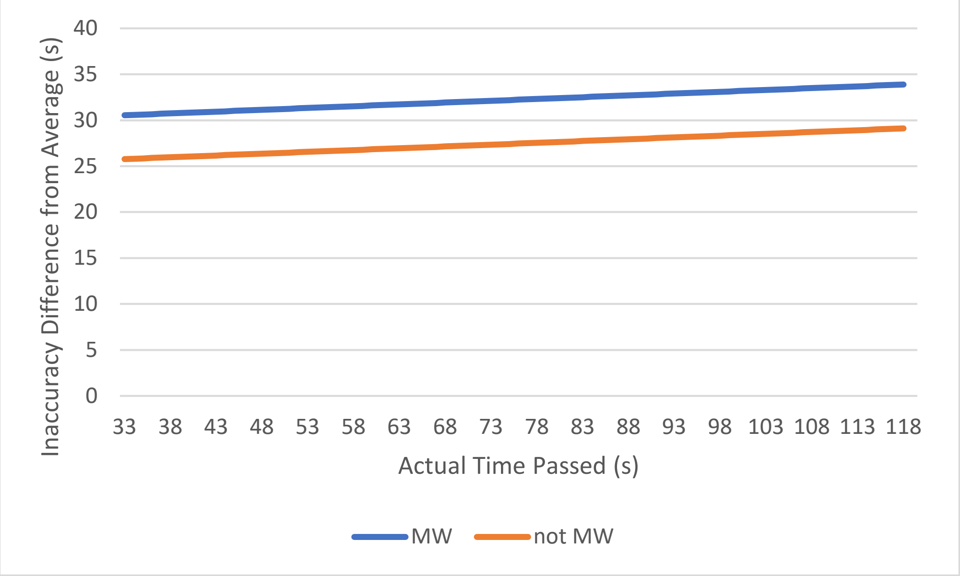


Figure 6

The Effect of MW on the Variability of JOPOT as a Function of the Actual Amount of Time Passed

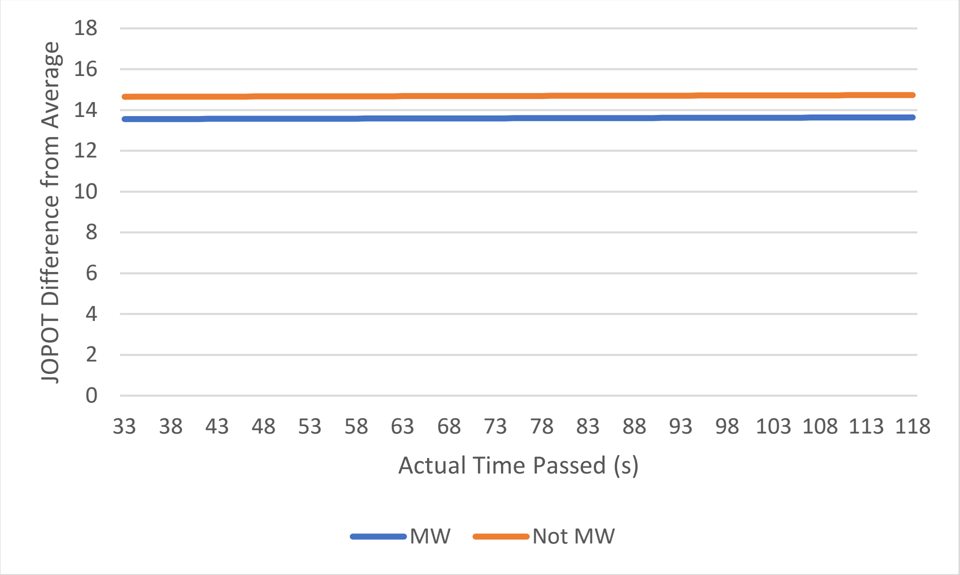
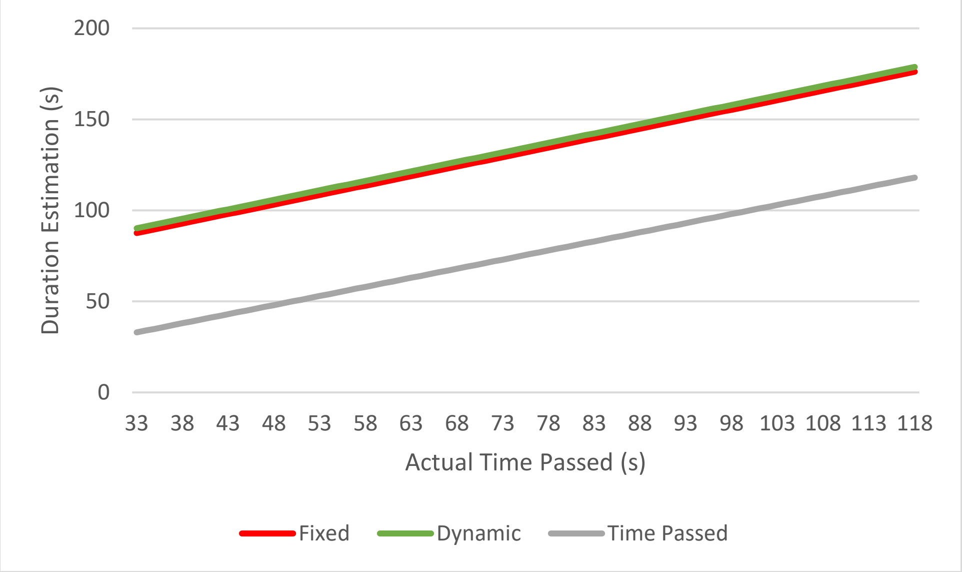


Figure 7

The Effect of Fixed and Dynamic Thoughts of Durations Estimations as a Function of Actual Time Passed



Note. Actual time passed is included as a line for reference.

Figure 8

The Effect of Fixed and Dynamic Thoughts on the Inaccuracy of Estimated Durations as a Function of Actual Time Passed

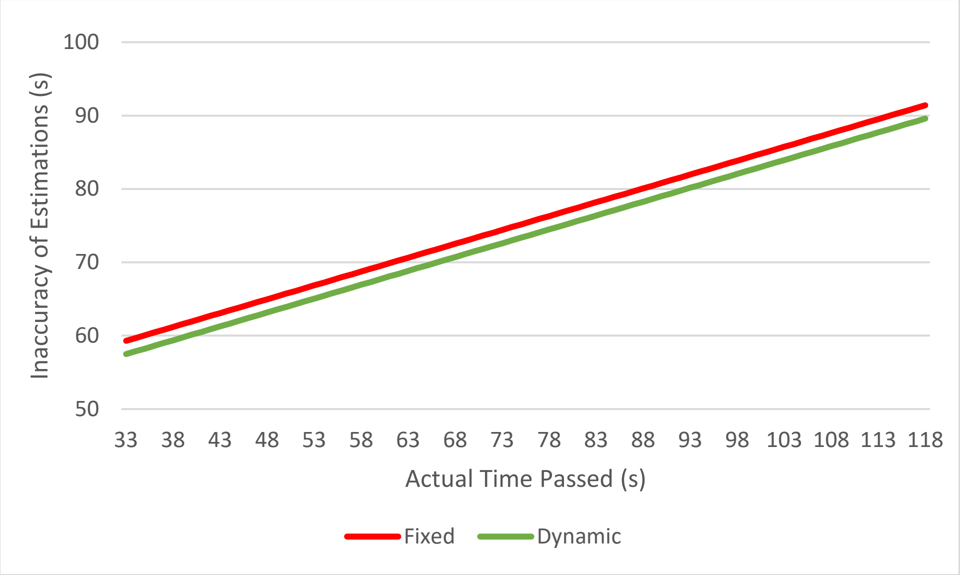


Figure 9

The Effect of Fixed and Dynamic Thoughts on JOPOT as a Function of Actual Time Passed

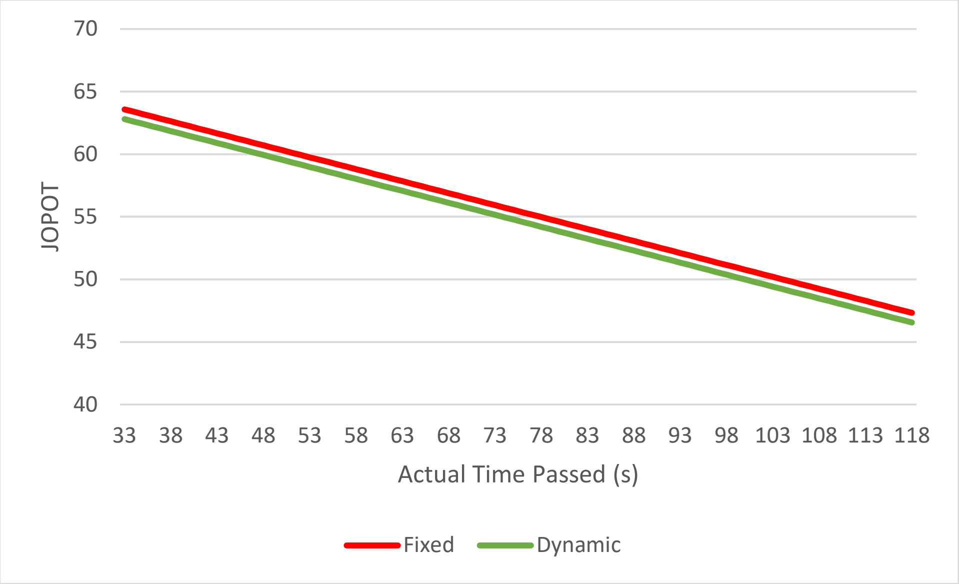
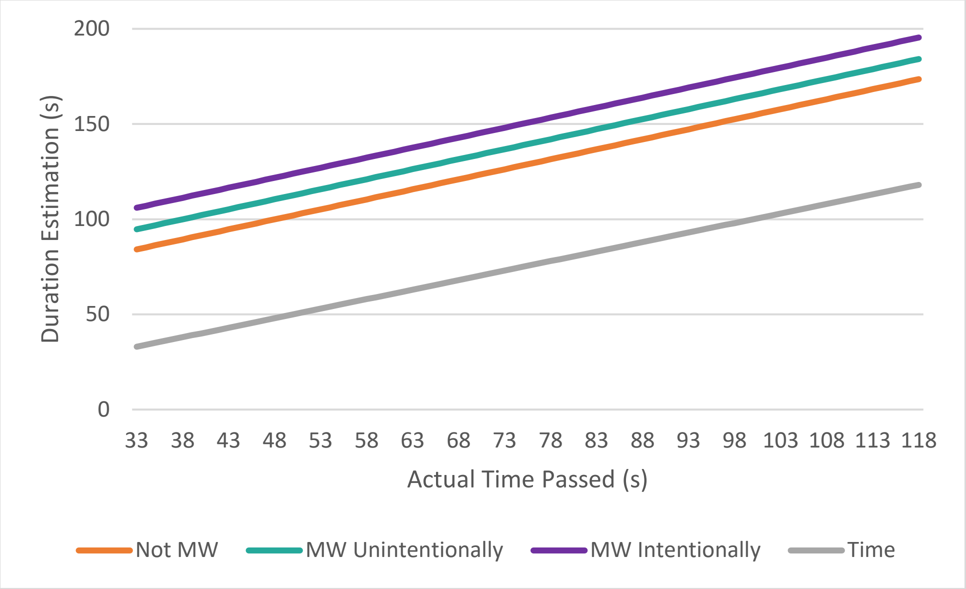


Figure 10

The Effect of Intentionality of MW on Duration Estimation as a Function of Actual Time Passed



Note. Actual time is included as well as a reference.

Figure 11

The Effect of Intentionality of MW on the inaccuracy of Estimations as a Function of Actual Time Passed

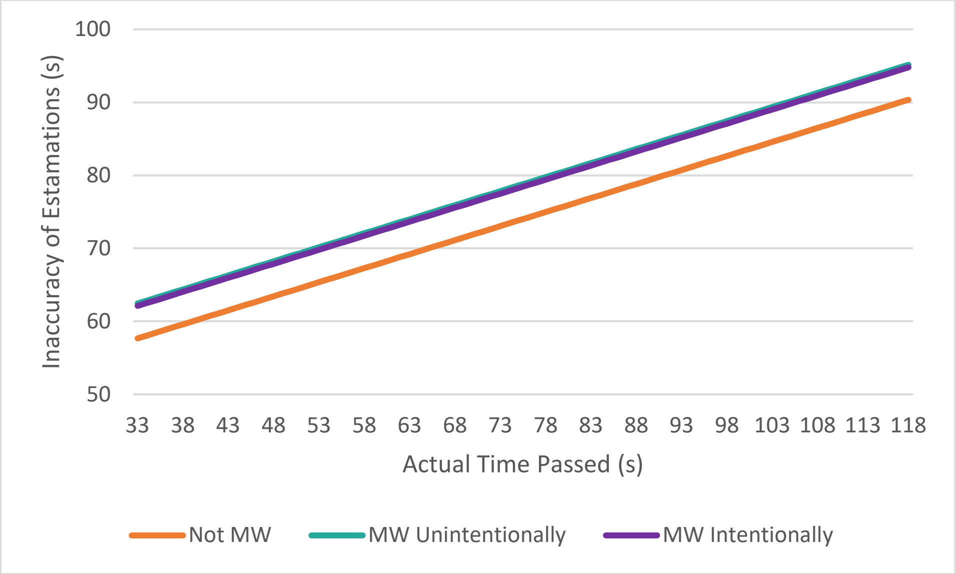


Figure 12

The Effect of Intentionality on JOPOT as a Function of Actual Time Passed

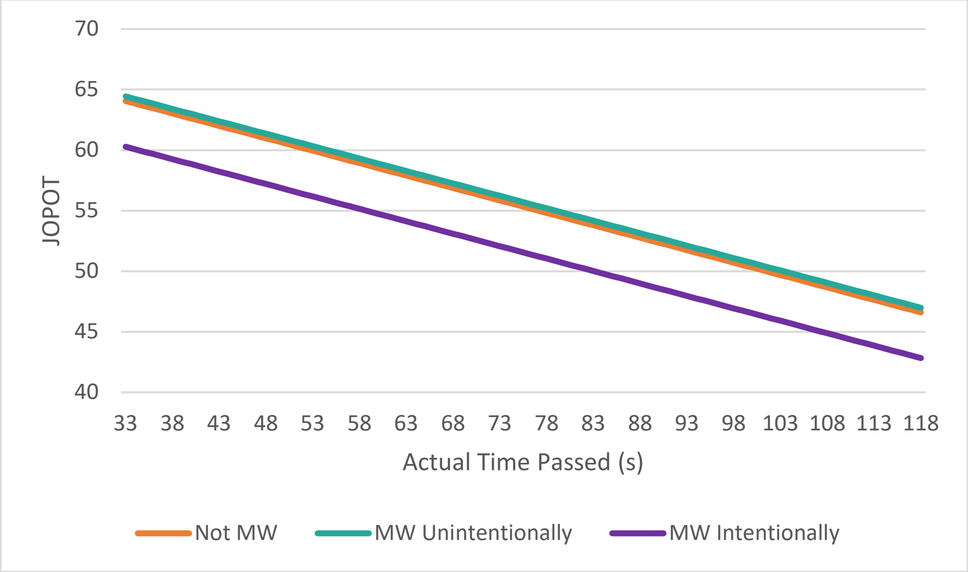


Figure 13

The Effect of Attention on Duration Estimation as a Function of Actual Time Passed

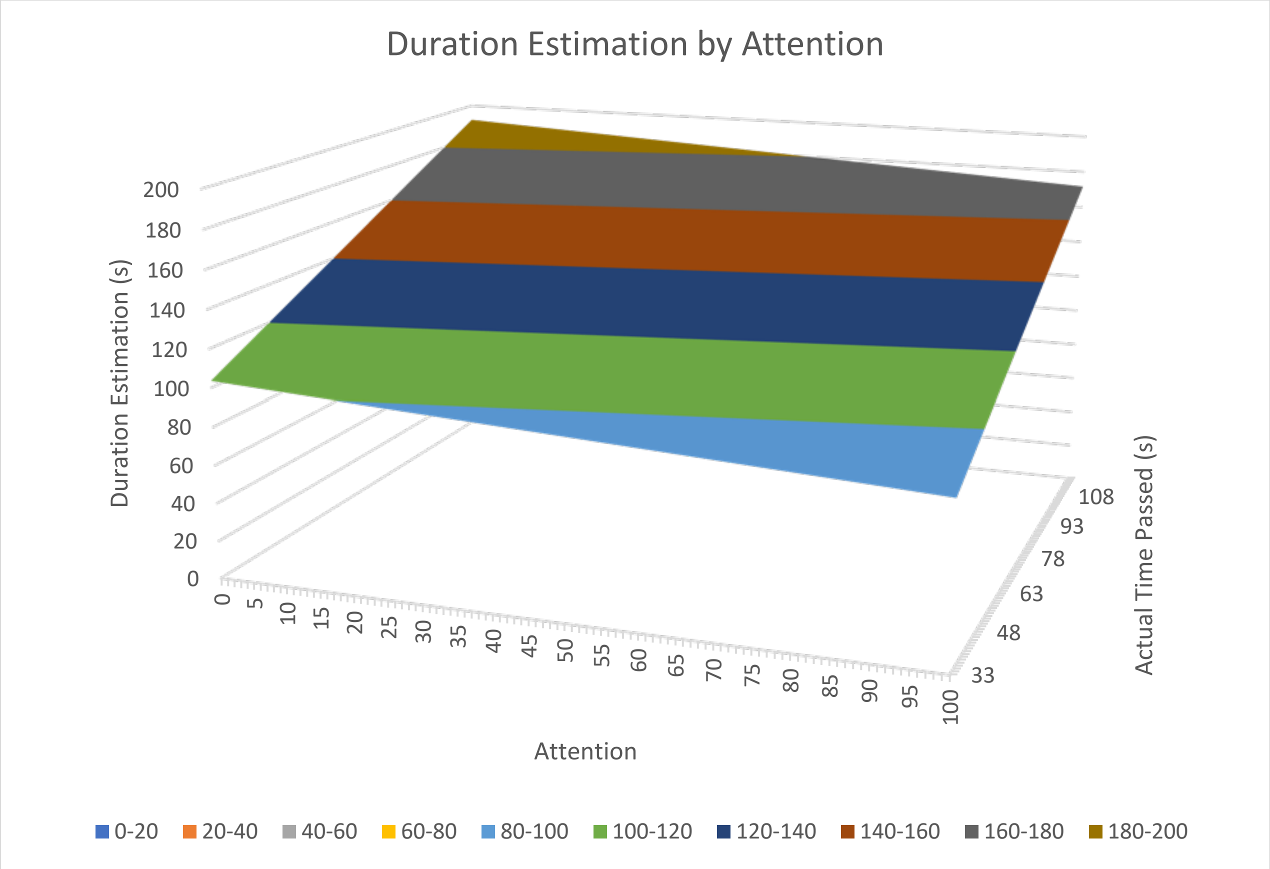


Figure 14

The Effect of Attention to Task on the Inaccuracy of Duration Estimations as a Function of Actual Time Passed

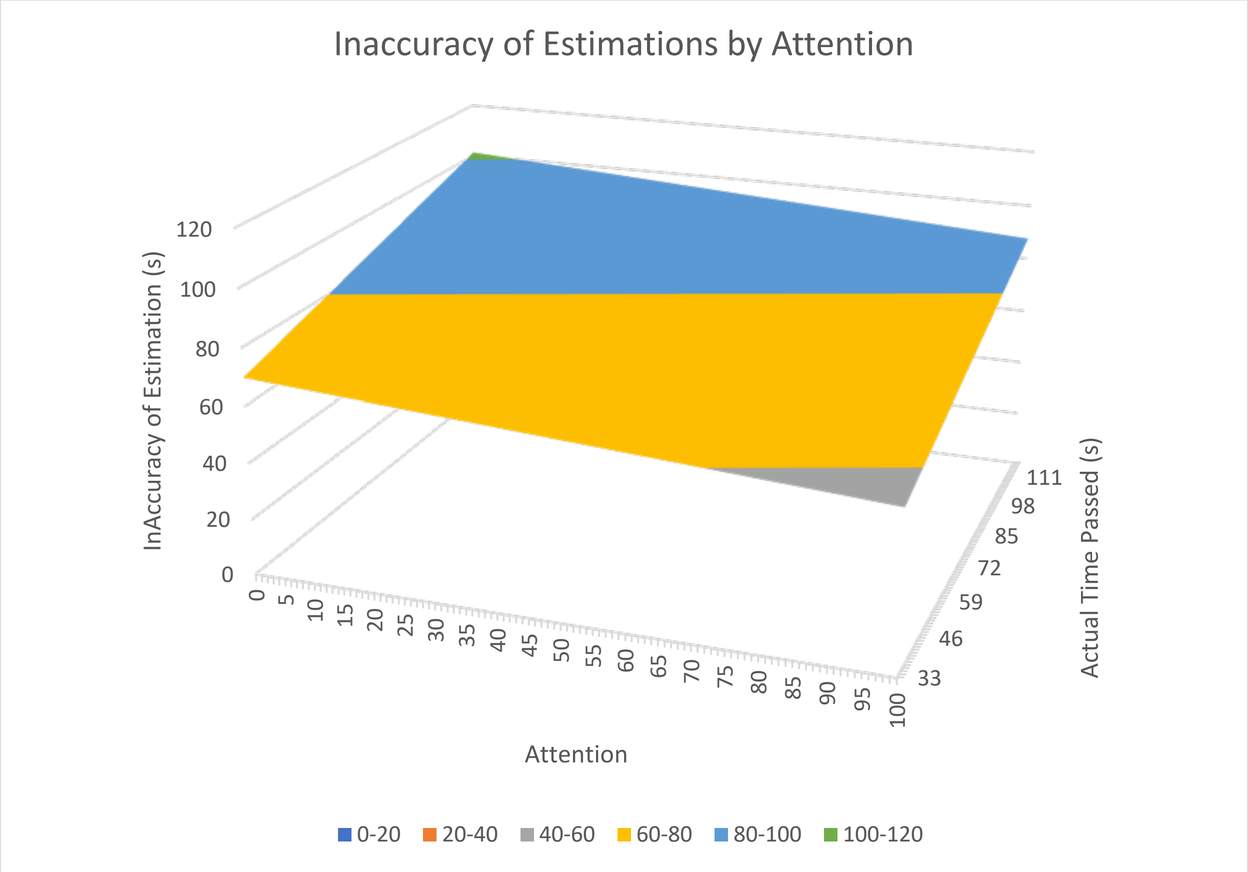


Figure 15

The Effect of Attention of JOPOT as a Function of Actual Time Passed

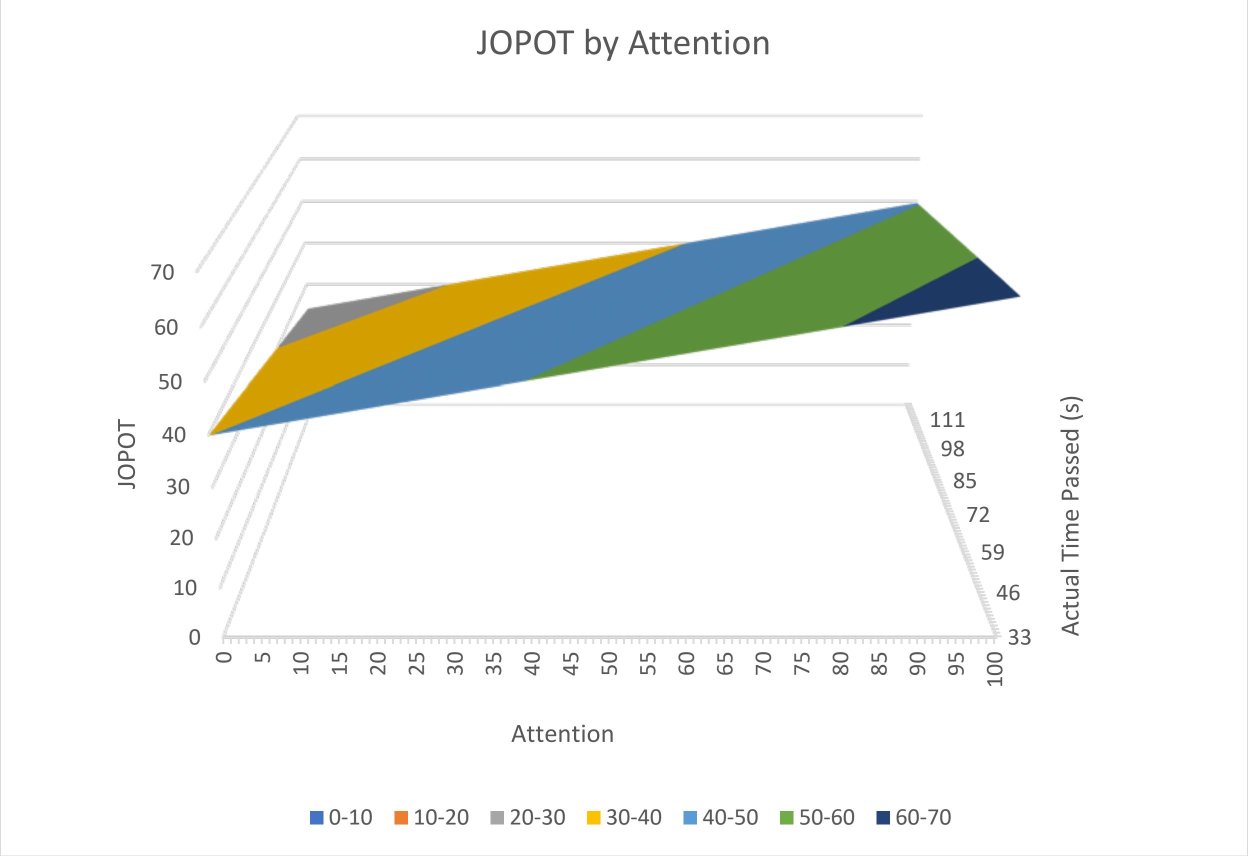


Figure 16

The Effect of Valence on JOPOT as a Function of Actual Time Passed

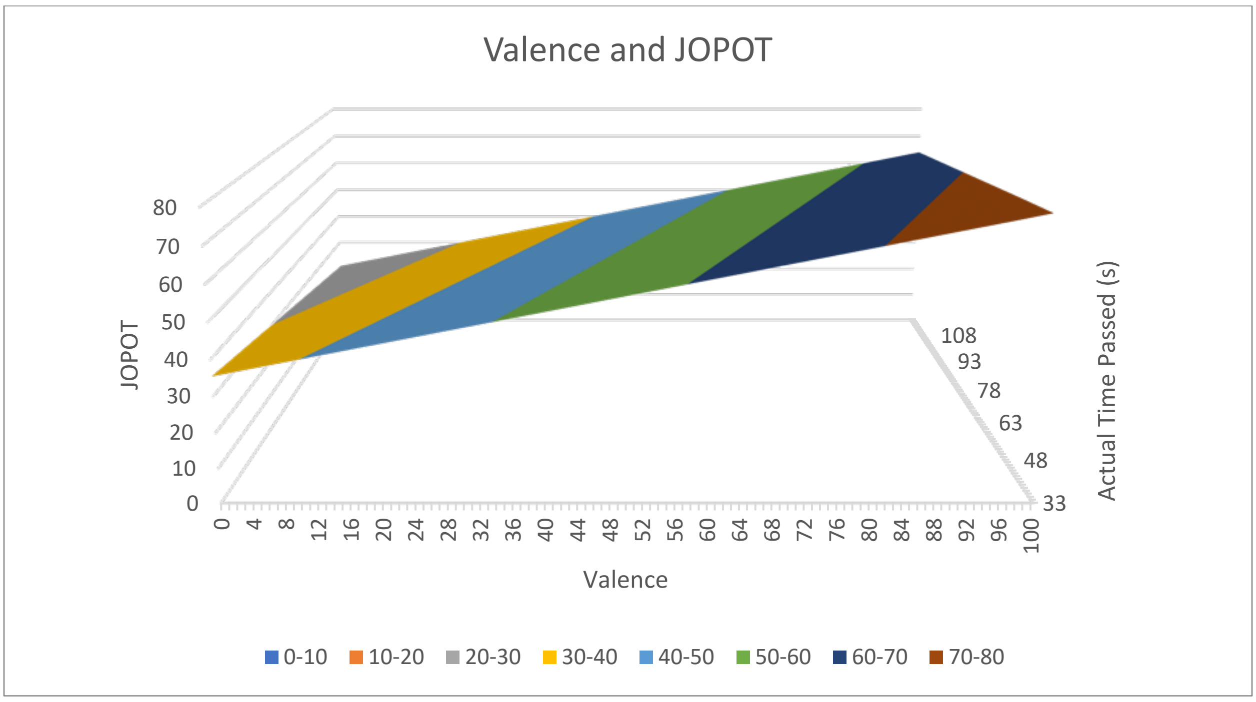
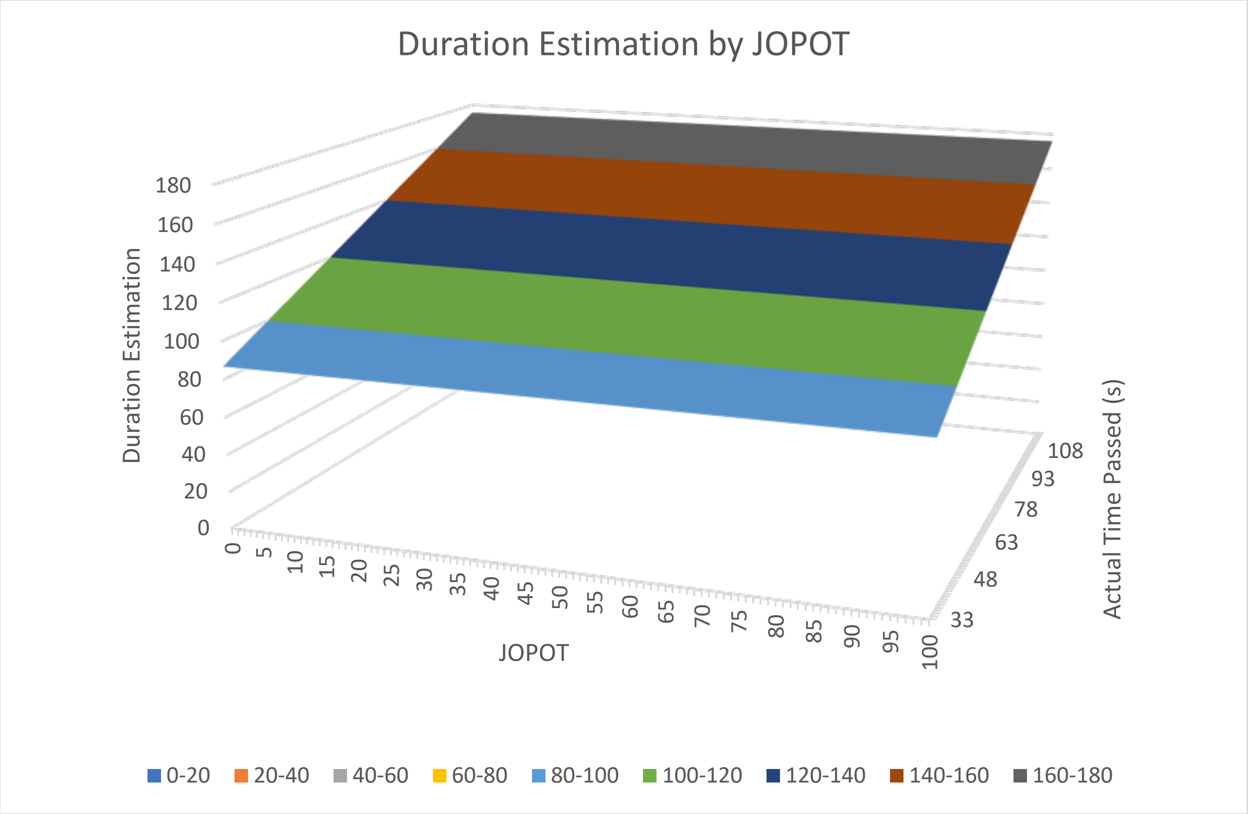


Figure 17

JOPOTs Predicting Duration Estimation as a Function of Actual Time Passed



CHAPTER 4

DISCUSSION

In the present study I evaluated the relationship between MW and related cognitive factors with distortions in time perception. The most significant take-away from the present results was that estimation durations – participants' objective sense of how much actual time has passed during a given window – were not closely related to the cognitive factors investigated (i.e., MW, intentionality of MW, fixed/dynamic thoughts, attention to task, emotional valence, and arousal), nor were the accuracy of such estimations. What were, in fact, closely related to cognitive factors were the JOPOTs – the subjective feelings of time slugging on, flying by, or somewhere in between. In particular, attention to task (indexed as MW or not or as a continuous variable of self-reported attention), the intentionality of MW, and valence of emotions were able to explain the most variance in JOPOTs, with categorizing of thoughts as either fixed or dynamic also making a small contribution.

Admittedly, JOPOTs are not the time distortion metric usually used in studies, so many of these findings relating to JOPOTs are novel. For example, this is the first study to investigate whether time felt faster or slower while someone was MW versus when they are having an on-task thought. The difference in the JOPOT between MW and not MW was small, however adding it to the model explained a substantial degree of variance, indicating that this small difference may have some meaning worth investigating further. When attention to task was framed as a continuous variable rather than as a binary, (as it had been previously in the MW literature, e.g., Smallwood & Schooler, 2006) it was statistically significantly related to JOPOT, where the more someone was paying attention to the task, the faster time felt like it was passing. It is possible that this continuous variable for attention was statistically significant while the dichotomous variable was not because dichotomizing a variable takes away from the variance and makes the researcher less likely to find a statistically significant difference. This brings about an important implication for the MW field – use of a continuous variable may allow for more variance to be captured, and therefore have more explanatory power, than dichotomizing MW versus not MW. In the present study, the two analyses revealed a pattern in the same direction (i.e., not MW lead to faster perceptions of time, as did paying more attention to task as a continuous measure), indicating these two variables may have been measuring the same thing, and the continuous variable allows for a better understanding of mental state. This result also offers an important replication of a pattern observed in Droit-Volet and Wearden (2016), where JOPOTs were related to attention and emotion, but duration estimations were not.

One hypothesis I had was that MW intentionally would relate to faster feelings of time than MW unintentionally, however the data indicate the opposite. MW unintentionally and not MW were very similar, while MW intentionally was associated with slower feelings of time passing. This result is surprising because I expected intentional MW to relate to more positively valenced thoughts and therefore faster JOPOTs. Instead, these results raise an important question of directionality – are people experiencing time more slowly because they are MW intentionally, or do people MW intentionally because time feels slow? If the latter is true, theoretically an individual could voluntarily choose a positive thought leading to a faster feeling of time to make up for this difference (if they want the time to feel faster). A simultaneous analysis of valence and intentionality on JOPOTs could help elucidate this relationship further. Understanding this relationship further could have important implications for theories of attention. For example, perhaps people are experiencing negative emotions and a slow passage of time, so they choose not to pay attention to the current moment. This could explain some cognitive deficits seen in disorders like depression (e.g., Rock et al., 2014), or the negative emotionality seen in individuals with ADHD (Kearns & Ruebel, 2011). This result also indicates that an intentional disengagement from reality is distinct from an accidental one, providing further evidence that intentional and unintentional MW should be considered separately (e.g., Seli, Carriere et al., 2015).

Interestingly, even though valence was statistically significantly related to JOPOT, it explained little of the variance in JOPOT, while the opposite was true for cognitive factors like MW and intentionality. This may be because of the relationship each predictor has with the covariate for all analyses – actual time passed. If the actual time passed was related to the cognitive factors, variance could be shared between those two predictors, making the individual fixed effects no longer statistically significantly different from zero, even though much of the variance is explained. For example, the actual duration was statistically significantly related to the JOPOT in the null model (which had actual duration as the only predictor), however when MW was added to the model, neither predictor was statistically significantly different from zero and 12.66% of variance was explained. If MW covaried with the actual duration, the shared variance was explained in the null model, so adding MW split that variance between two predictors, making each no longer statistically significantly different from zero, even though MW explains more than just duration alone. The opposite may be true for valence: if valence was not related to the duration of time passed, then all variance explained by valence would be attributed to it uniquely in the fixed effect estimate, making it easier to find it statistically significantly different from zero even if it explains relatively little variance. A future study could investigate this further by focusing on understanding the relationship between actual time passed and cognitive factors used as predictors in the current study. The implication of this pattern is that how much time passed likely matters. Many studies use only one duration to look at time perception, but the effects of predictors are likely to vary across time points, so many time points should be considered. The use of multiple time points is a strength of the current study. Furthermore, this relates to human attentional capacity over time. It does not take long for the mind to begin to wander – it happened in under 34 seconds in the present study – and this can impact other aspects of cognition, such as the feeling of time passing. Another potential reason for the model to be improved even when the fixed effect of the predictor is not statistically significant is if the random components impacted the model fit. For example, if the relationship between MW and JOPOT varied as a function of who was doing the MW, the random effect of the model could be statistically significantly different from zero, improving model fit. Potential second-level predictors should be considered in future studies.

One unexpected finding in the present study is the lack of relationship between cognitive factors and duration estimations. This is particularly surprising given that previous research has shown a relationship (Terhune et al., 2017). One potential reason for this is that Terhune et al. (2017) used much shorter durations (325 – 675ms) while the present study used longer durations (approximately 33-118s). The relationship between cognitive factors and time perception therefore appears to be duration-dependent. Longer durations may allow for more fluctuations in attention (i.e., participants may be MW for only part of the window rather than for the whole duration) and for more complex thought patterns (i.e., they may have time to have multiple thoughts with varying emotional or cognitive components, leading to less similarity between MW episodes). This relates to MW as well as to the other cognitive factors investigated. Because there was no apparent relationship between MW and duration estimation, it was unsurprising then that the other cognitive factors investigated (which are likely related to MW) also did not show a relationship to duration estimation. It is also possible that the results of Terhune et al. (2017) were different from those of the current study because of heterogeneity in methods. For instance, Terhune et al. (2017) studied individuals in-person while the present study was remote, the age ranges of participants were different across studies, the data were collected in different parts of the world, and the precise research methods used were different as well.

Another interesting discovery in the present study was the lack of relationship between duration estimation inaccuracy and the cognitive factors investigated. None of the factors investigated were able to explain any variance in the inaccuracy of people's estimations. This is unexpected because I hypothesized that when someone was MW, they would be paying less attention to the task and therefore would have had a more "random" guess of time passed than someone who was focused, thus leading to a less accurate estimate. The current data do not support this prediction. On average, when people were MW they were 11.88 seconds less accurate in their estimations. One reason this may not have been statistically significantly different from zero could be because of the unequal group sizes between MW and not MW blocks, leading to less power to detect differences. That, however, would not explain the lack of relationship between attention as a continuous variable and inaccuracy. The relationship was trending in the expected direction; however, it was not enough of a difference to reach the threshold of statistical significance. One potential reason for this relationship may be that people were already having difficulty guessing durations, even if they were not MW. On average, people's estimations were off by *75* seconds, which is a very large window relative to the durations presented in the study. It is possible that people had globally poor time increment estimation abilities, such that it may not have mattered if they were MW or not – they already had to "randomly" guess (i.e., this is similar to a floor effect). If that is the case, a study using shorter durations may be better equipped to answer questions regarding inaccuracy of verbal duration estimations because shorter estimations are likely to be easier to make correctly. It is also possible that the lack of relationship shown in this study shows a true lack of relationship between cognitive factors and the accuracy of duration estimations. This would contradict Terhune et al. (2017), who found that temporal precision was decreased when participants were MW. Follow-up studies using different time increments, or allowing participants to choose the time from a preselected list rather than choosing any increment may increase the accuracy and allow for differences between groups to be seen.

In addition to replicating one pattern seen in Droit-Volet and Wearden's (2016) findings (that JOPOTs were related to emotion and attention, while duration estimations were not) the present study also replicated another finding from Droit-Volet and Wearden (2016), in that JOPOTs and duration estimations were unrelated to each other. This provides further evidence that JOPOTs and duration estimations should be considered as separate constructs. Interestingly, the majority of time perception research has utilized duration estimation approaches (e.g.,Angrilli et al., 1997; Betsch et al., 2010; Chang et al., 2021; Danckert and Allman, 2005; Grondin, 2010; Heys et al., 2020; Lamotte et al., 2012; Lee et al., 2007; Matell et al., 2003; Mitchell et al., 2018; Wiener et al., 2010) but fewer studies have assessed JOPOTs or related concepts of time (e.g., Droit-Volet & Wearden, 2016; Friedman & Janssen, 2010; see Droit-Volet, 2013 for review). The present study provides evidence that JOPOTs should be measured and studied in addition to duration estimations to understand time perception. Additionally, this study provides evidence that information gathered using duration estimation procedures cannot be applied to JOPOTs (i.e., an underestimation of a duration does not equate to time feeling fast). Given the clinical significance of distortions in time perception, a better understanding of (and more research on) JOPOTs is needed.

To summarize results, in the present study I supported hypotheses 7, 8, and 19. Hypotheses 4 and 5 contributed some explanation to variance but the fixed effects did not reach statistically significance. Hypotheses 10 and 14 suggested a numerical pattern in the predicted direction but did not result in variance explained or reach statistical significance. Hypotheses 1, 2, 6, 11, 12, 13 and 15 were not supported. Finally, hypotheses 3, 9, 16, 17 and 18 were exploratory, meaning there was no prediction made *a priori*, but they did produce meaningful results, such as that there was variance explained in JOPOT by adding MW to the model, that the fixed effect of emotional valence on JOPOTs was statistically significant, and the comparison of different cognitive factors on time perception showed the varied impact of each.

While the present study was novel in many ways, it is important to consider limitations that arose. One limitation was that because participants completed the task from home, it was impossible to assess if they were honest and accurate in all their self-reporting. Additionally, the nature of each remote study environment may have influenced results. Participants were instructed to be in a distraction-free environment, but without having the level of control in a laboratory environment, levels of distraction may not have been consistent between individuals. That is a trade-off, however, because with the loss of environmental control, this study gained more external validity. For example, these participants may have completed the study in the same environment they used to work from home, meaning that the results of the present study may be more generalizable to their everyday lives than one conducted in a laboratory. Another limitation is that because the time intervals used were between 30 seconds and 2 minutes, participants may have had multiple different thought processes within that time frame, and the thought probe itself may not be an accurate reflection of their state of mind through the entire block. A future study could use physiological measures rather than self-report to determine participant's cognitive state, which would allow for a better understanding of participants thoughts throughout the entire block, rather than just at the end as in the present study. For instance, it is theoretically plausible to identify an electrophysiological marker predicting MW states based on neural activity alone using machine learning and artificial neural network approaches (e.g., Kawashima et al., 2022). Lastly, a larger sample size may have been better for finding the effects of interest, particularly given the number of analyses that were run on the data.

In future research, physiological measures could also be used to help train participants to notice MW on their own. For example, if researchers can learn to identify MW in real-time using EEG, electrodermal activity, eye-tracking and/or other physiological methods, they could train the participant to notice their own MW and correct it. This could lead to a potential therapeutic intervention for disorders related to MW and altered JOPOTs, such as ADHD. Another potential future direction based on the current study is to investigate the trait-level variables that may be impacting results. For example, perhaps MW is associated with overestimations of durations for some people, but underestimation for others, leading to a net neutral effect across participants, thus explaining the null results in the present study. Comparing time perception to monitoring processes in metacognition (i.e., awareness of one's own cognitive states) which allow an individual to self-identify MW, may be an important and theoretically interesting avenue for determining that directionality or magnitude (e.g., Oyarzo et al., 2022). Another key suggestion for future research area is to adopt the use of JOPOTs in time perception research generally. Future experimental work could help to understand the directionality of the relationship between valence and JOPOTs. For example, one could exposure participants to negative or positively-valenced images or videos and then measure JOPOTs to determine if mood directionality impacts JOPOTs (similarly to how Droit-Volet et al., 2011, used duration estimations). Finally, some researchers have suggested that time perception is altered (i.e., accelerated) in additional clinical conditions such as in positive symptoms of schizophrenia and in bipolar mania (e.g., Northoff et al., 2018; Ueda at al., 2018). Future work could investigate whether these time-distortions manifest through objective or subjective estimates of time perception, and if such distortions are indicative of a form of spatiotemporal psychopathology generally (e.g., Arantes-Goncalves et al, 2021).

In the present study I present several key findings, including that the feeling of time passing is unrelated to the actual estimation of time that has passed, and that the feeling of time is more related to cognitive factors than the actual estimation is. Additionally, I found that attention to task is associated with a faster feeling of time, as are positive emotions, and MW seems to be related to the feeling of time passing, however conceptualizing attention to task as a continuous variable may be better at capturing variance than the dichotomous variable. Lastly, MW intentionally versus unintentionally may have different impacts on the feeling of time passing. These results show that research must consider the differences between duration estimations and judgements of passage of time, as using judgements of passage of time may better predict behavior that covaries with attention, such as in pathological conditions involving time distortion.

APPENDIX A

PROMPTS SHOWN TO PARTICIPANTS

First, participants are greeted:

"Welcome to the study!

This study will involve guessing amounts of time. For that reason, it is important that you cannot view any clock while completing the study.

Please cover all clocks from your view. For example, take off any watches, remove or block wall clocks, put phone out of view, etc.

When you have all timekeeping devices out of view, press enter to go to the next screen.

Next, they see the first phase of instructions:

You will be complete a task that requires you to pay attention and answer quickly.

Please complete this in a distraction-free environment.

You will be presented with numbers on the screen one at a time. Your task is to press the spacebar every time a number comes up UNLESS it is the number 3. Do not press any button if the number 3 comes up.

Press enter to go to the next page.

And then a second phase of instructions:

As you are completing the task, you will be interrupted with questions about your mental state and sense of time. When answering the questions, consider what you were thinking about just before you were interrupted. When answering the questions, use your mouse to select your answer.

You will not be penalized for your answers to the questions, so please answer honestly.

When you understand these instructions, press enter to begin a practice round.

Next they have 2 practice blocks (which have the same wording as real trials, below). After practice blocks they are notified that the real (i.e., experimental) blocks are beginning:

That concludes the practice round.

Now you are ready to begin your first block.

Remember to answer the questions as honestly as possible.

When you are ready to begin the actual test, press the spacebar.

In the task, digits 1-9 are presented in the center of the screen in white font, size 140, Arial, on a black background. They were interrupted in the task with thought probes. The first screen was as follows:

STOP AND THINK – WHAT WERE YOU JUST THINKING ABOUT, AND HOW LONG HAS IT BEEN SINCE YOU LAST ANSWERED SURVEY QUESTIONS?

Press enter to continue.

Next, they are prompted to give their duration estimation. The instructions were:

How much time do you believe has passed since beginning the past block?

In other words, how long has it been since you last answered survey questions and began the task again?

Please answer in minutes and seconds.

*Note – please do not round your answers. Correct answers never end with a 0 or 5. For example, instead of guessing 20 seconds, guess 22 seconds.

Below these instructions, there are two scales. The first is minutes (0-10 min) and the second is seconds (0-60 sec). They can click along those axes with the mouse, then press enter to continue (as written at the bottom of the screen).

On the next screen they report their JOPOT. The instructions at the top of the screen are:

While completing the task just now, did it feel like time was passing faster or slower than usual?

Use the scale to indicate how it felt like time was passing.

1 means time was going by very slowly

100 means time was going by very quickly

You may choose any number between 1 and 100.

Below the instructions is a 0-100 scale where they may use the mouse to select their answer. On the bottom of the screen it says "Press enter to continue".

Next they see the following prompt:

Please answer the following questions regarding what you were thinking about JUST BEFORE

you were interrupted in the task.

Press enter to continue.

Next participants answered the MW question:

Were you thinking about the task or something else? If you were thinking about something else,

were you doing so on purpose or by accident?

There were 3 options presented, and participants could use their mouse to select one of these responses:

-I was thinking about the task

-I was thinking about something else on purpose

-I was thinking about something else by accident

Where the first answer indicates they were not MW, the second indicates they were MW intentionally, and the third indicates they were MW unintentionally. They then pressed enter to continue.

On the next screen they were asked if they were having fixed or dynamic thoughts and given two answer options:

Were you thinking about one thing consistently, or were your thoughts shifting between multiple topics?

-I was thinking about one thing consistently

-My thoughts were shifting between multiple topics

Where the first answer indicated fixed thoughts and the second indicated dynamic thoughts. The pressed enter to continue.

Next they indicated the valence of their emotion:

How would you describe the emotion of the thought you were having when you were told to stop the task?

Please choose a value between 1 and 100, where 1 means it was a very negative thought (such as despair or rage), 50 is neutral, and 100 is very positive (such as joy or pleasure).

Remember you may pick any value between 1 and 100.

Below the prompt was a scale from 0 to 100 along which they could mouse-click their response, then press enter to continue.

Next they indicated the arousal level of their emotion:

How would you describe the intensity of the emotion you felt just before you stopped the task?

Please choose a value between 1 and 100, where 1 means it was not an intense feeling at all and 100 means it was an extremely intense feeling.

Remember you may pick any value between 1 and 100.

Below that prompt was a scale from 0 to 100 along which they could mouse-click their response, then they pressed enter to continue.

Next they were asked about their attention:

Just before you stopped doing the task, how much were you paying attention to the task?

Please answer with a number between 1 and 100 where 1 means you were not paying any attention to the task and 100 means you were completely paying attention to the task.

Remember you can choose any value between 1 and 100.

Below this prompt was a scale from 0 to 100 along which participants could mouse-click their response, then press enter to continue.

Next participants were told the next block would begin:

YOU WILL NOW BEGIN THE NEXT BLOCK. THE INSTRUCTIONS ARE THE SAME.

REMEMBER, PRESS A BUTTON ONE TIME WHEN YOU SEE ANY NUMBER EXCEPT FOR 3. DO NOT PRESS ANYTHING WHEN YOU SEE THE NUMBER 3.

Press the spacebar to begin the next block.

These probe questions were repeated with every probe (2 practice probes and 8 real data probes). After completing all blocks, they were given the following instructions for accessing the demographics survey and concluding participation.

That concludes this portion of the study.

Next you will go back to the survey website and enter the code 543COMPLETE.

(NOTE – that is NOT the code for MTurk)

You must enter that code to get credit for your study participation.

You will also be asked more questions.

If you do not have access to the survey anymore, DO NOT SIGN UP AGAIN! Email MeganKelly3@my.unt.edu to receive a link to continue.

Press enter to exit this program.

APPENDIX B

INFORMED CONSENT

Informed Consent for Studies with Adults

TITLE OF STUDY: Understanding the Cognitive Mechanisms of Memory, Emotion, and Awareness (Online)

RESEARCH TEAM: Primary investigator: Anthony Ryals Ph.D., UNT Department of Psychology (email: anthony.ryals@unt.edu department phone: 940- 565-2671)

You are being asked to participate in a research study. Taking part in this study is voluntary. The investigators will explain the study to you and will any answer any questions you might have. It is your choice whether or not you take part in this study. If you agree to participate and then choose to withdraw from the study, that is your right, and your decision will not be held against you.

Your participation in this online study first involves completing online questionnaires including demographic information. You will also complete a combination of questionnaires that may ask about psychological factors including personality characteristics, depression/anxiety, history of traumatic life events and symptoms, perception of time, and awareness of memory. Finally, this study may also involve you completing specialized computerized tests of memory to be run on your computer.

You might want to participate in this study if you are between the ages of 18 and 55, and if you are interested in human cognition, emotion, memory, and awareness processes. However, you may not want to participate in this study if you do not have adequate time to complete all measures or if you have a history of memory problems.

The reasonably foreseeable risks or discomforts to you if you choose to take part are mild mental and emotional fatigue. There are no direct personal benefits to participating beyond advancement of scientific knowledge as detailed below. You will receive compensation in the form of two (2) SONA credits if you are enrolled in a course allowing SONA participation. Please see your instructor for alternatives to participating in research for SONA credit. If you are recruited through MTURK or Prolific websites, you will be compensated with $ 7.20 for participation.

DETAILED INFORMATION ABOUT THIS RESEARCH STUDY

PURPOSE OF THE STUDY: You are being asked to participate in a research study exploring how differences in certain psychological factors play a role in how we remember emotional information, how we are aware of information we remember, and how certain life events play a role in memory and memory awareness.

TIME COMMITMENT: The duration of the total participation time should be approximately 60 minutes (one hour).

STUDY PROCEDURES: There are two parts to this study.

If you are recruited through SONA, you will respond to the announcement posted on the UNT SONA website to initiate the consent process and proceed with the study. Detailed instructions will walk you through each step of the study.

If you are recruited through MTURK or Prolific, you will respond to the announcement posted on either website to initiate the consent process and proceed with the study. Detailed instructions will walk you through each step of the study.

At the end of the study you will be given a debrief form with more information and some helpful resources for further information.

Below is a description of the two different procedures used in this study

METHOD 1: QUESTIONNAIRES
The first phase of this study will involve an online questionnaire to learn a little bit about your background, including educational history, age, race/ethnicity, language preference, and non-specific history of psychiatric or memory issues. Each form of the study will contain some form of either electronic questionnaires used to learn a little bit more about you and your background. Topics that these questionnaires cover may include: how well you judge your own memory abilities, the strength of memories for particular events in your life, how you cope with difficult situations in life, and how often you experience certain emotions. Some of these questions may ask about whether you have experienced traumatic events in your past. Examples of these traumatic events could include sexual assault, natural disasters, combat exposure in the military, and violent victimization. Some questionnaires will also ask you about personality characteristics such as introversion and extroversion, and others will ask about your perception of time during daily life.

METHOD 2: COMPUTERIZED BEHAVIORAL TESTING
The second phase of this study will have you complete brief computerized tests of learning and memory. These test will involve looking at pictures of words, objects, or scenes on a computer screen. Sometimes we will ask you to look at particular objects instead of other objects, and sometimes we will ask you to remember certain objects for a later memory test. Finally, we will ask you to respond to a series of questions by pushing keyboard buttons or a mouse..

POSSIBLE BENEFITS: You are not likely to have any direct benefit from being in this research study. However, taking part in this study may help scientists to better understand the relationship between cognitive functioning, learning, memory, emotion, and psychological factors leading to differences in these processes.

POSSIBLE RISKS/DISCOMFORTS: Participation in this online study involves risks to confidentiality similar to a person’s everyday use of the internet, and there is always a risk of breach of confidentiality. Study data will be physically and electronically secured by the research team. As with any use of electronic means to store data, there is a risk of breach of data security. Participation 2 may also lead to mild cognitive fatigue or emotional fatigue, however this risk is equivalent to that which you would experience in everyday life.

If you experience excessive discomfort when completing this research activity, you may choose to stop participating at any time without penalty. The researchers will try to prevent any problem that could happen, but the study may involve risks to the participant, which are currently unforeseeable.

It is possible that some of the questions asking about specific emotional or traumatic events in your life and/or graphic images will cause you to become uncomfortable or upset. If this is the case, there are several options available to you. First, if possible, you are encouraged to speak to the primary investigator of the study (Dr. Ryals) who may be able to help you or refer you to a mental health professional. If you need to discuss your discomfort further, please contact a mental health provider, or you may contact the researcher who will refer you to appropriate services. If your need is urgent, helpful resources include the UNT Counseling and Testing Center located in Chestnut Hall at (940) 565-2741, and outside resources include but are not limited to: Denton County MHMR crisis hotline at 1-800-762-0157; UNT Mental Health Emergency line at (940)-565-2741. Please be aware that UNT does not provide medical services, or financial assistance for emotional distress or injuries that might happen from participating in this research.

COMPENSATION FOR PARTICIPANTS: Participation in this study will involve no cost to you. If you are recruited through SONA, you will be granted two (2) course credits through SONA designated to a course of your choice based on your ability to participate through your instructor.. If you are participating through SONA for a course, your instructor will have an alternative non-research activity with equivalent time and effort. Please speak to your instructor for details regarding these alternatives.

If you are recruited through Amazon's Mechanical Turk (MTurk) or Prolific websites, you will be compensated $ 7.25 for your time.

CONFIDENTIALITY: This research may use third party software called Mturk and Prolific and if so, are subject to the privacy policies of this software note here: https://www.mturk.com/privacy-notice & https://www.prolific.co/assets/docs/Prolific_privacy-policy.pdf

This research examines The Cognitive Mechanisms of Memory, Emotion, and Awareness. You will be asked a series of questions about issues related to these topics. The study should take approximately 60 minutes to complete. If you complete the study using MTurk or Prolific, after completing the survey, you will be paid $ 7.25 for your participation. We do not ask for your name or any other information that might identify you. You may withdraw at any time any you may choose not to answer any question but you must proceed to the final screen of the study in order to receive your completion code, which you must submit in order to be paid. In accordance with Mechanical Turk policies, we may reject your work if the HIT was not completed correctly or the instructions were not followed. If you have any questions about the research please contact Anthony.ryals@unt.edu if you have questions about your rights as a research subject, contact UNT's Institutional Review Board at untirb@unt.edu or 940-565-4643.

Efforts will be made by the research team to keep your personal information private, and disclosure will be limited to people who have a need to review this information. All paper and electronic data collected from this study will be stored in a secure location on the UNT campus and/or a secure UNT server for at least three (3) years past the end of this research. Specifically, these data will be stored in the UNT Neurocognitive Laboratory in Terrill Hall room 287 in a locked file cabinet or on an encrypted and password protected computer. Research records will be labeled with a numerical code and the master key linking participant names with codes will be maintained in a separate and secure location. The results of this study may be published and/or presented without naming you as a participant.

While absolute confidentiality cannot be guaranteed, the research team will make every effort to protect the confidentiality of your records, as described here and to the extent permitted by law. In addition to the research team, the following entities may have access to your records, but only on a need-to-know basis: the U.S. Department of Health and Human Services, the FDA (federal regulating agencies), the reviewing IRB, and sponsors of the study. Part one of this study uses third-part software called RedCap and is subject to the privacy policies of the software noted here: https://projectredcap.org/software/mobile-app/privacypolicy/

CONTACT INFORMATION FOR QUESTIONS ABOUT THE STUDY: If you have any questions about the study you may contact Anthony Ryals (anthony.ryals@unt.edu) with questions you have regarding your rights as a research subject, or complaints about the research may be directed to the Office of Research Integrity and Compliance at 940-565-4643, or by email at untirb@unt.edu.

CONSENT:

- Your signature below indicates that you have read, or have had read to you all of the above.
- You confirm that you have been told the possible benefits, risks, and/or discomforts of the study.
- You understand that you do not have to take part in this study and your refusal to participate or your decision to withdraw will involve no penalty or loss of rights or benefits.
- You understand your rights as a research participant and you voluntarily consent to participate in this study; you also understand that the study personnel may choose to stop your participation at any time.
- By signing, you are not waiving any of your legal rights.

Please check the box below if you are at least 18 years old and voluntarily agree to participate in this study.

☐ I agree to participate in this research study
☐ I do not agree to participate in this research study

*If you agree to participate through SONA, your research team will provide you with an opportunity to keep a copy for your records.

APPENDIX C

DEMOGRAPHIC QUESTIONS

How old are you? ___________________________________

What is your biological sex?
Male
Female
Other (please specify)
(if “Other”) What is your biological sex? ___________________________________

What is your gender identity?
Man
Woman
Nonbinary
Other (Please Specify)
(if “Other”)What is your gender identity? ___________________________________

Would you consider yourself:
Cisgender (i.e. my gender is the same as what I was assigned at birth)
Transgender (i.e. my gender is different from what I was assigned at birth)
Prefer not to say

How would you classify your sexual identity?
Heterosexual
Gay
Lesbian
Bisexual or Pansexual
Asexual
Other (Please Specify)
(if “Other”)How would you classify your sexual identity?

What would you consider your race/ethnicity (please select all that apply):
Asian American
Latinx/Latino American/ Hispanic
African American (Black)
Native American/Alaskan Native
European/White/Caucasian
Other (Please Specify)
(if “Other”)What would you consider your race/ethnicity?
Country of birth: ___________________________________

What is you families' current household income in U.S. (if unsure, please give best estimate)?
Less than $25,000 dollars
$25,000 to $49,999
$50,000 to $74,999
$75,000 or more

Are you fluent in English?

- Yes
- No

What state do you live in?

- Alabama (AL)
- Alaska (AK)
- American Samoa (AS)
- Arizona (AZ)
- Arkansas (AR)
- California (CA)
- Colorado (CO)
- Connecticut (CT)
- Delaware (DE)
- District of Columbia (DC)
- Florida (FL)
- Georgia (GA)
- Guam (GU)
- Hawaii (HI)
- Idaho (ID)
- Illinois (IL)
- Indiana (IN)
- Iowa (IA)
- Kansas (KS)
- Kentucky (KY)
- Louisiana (LA)
- Maine (ME)
- Maryland (MD)
- Massachusetts (MA)
- Michigan (MI)
- Minnesota (MN)
- Mississippi (MS)
- Missouri (MO)
- Montana (MT)
- Nebraska (NE)
- Nevada (NV)
- New Hampshire (NH)
- New Jersey (NJ)
- New Mexico (NM)
- New York (NY)
- North Carolina (NC)
- North Dakota (ND)
- Northern Mariana Islands (MP)
- Ohio (OH)
- Oklahoma (OK)
- Oregon (OR)

Pennsylvania (PA)
Puerto Rico (PR)
Rhode Island (RI)
South Carolina (SC)
South Dakota (SD)
Tennessee (TN)
Texas (TX)
Utah (UT)
Vermont (VT)
Virgin Islands (VI)
Virginia (VA)
Washington (WA)
West Virginia (WV)
Wisconsin (WI)
Wyoming (WY)

Have you ever been hospitalized for a psychiatric, psychological, or emotional issue?
Yes
No

Have you ever been prescribed psychiatric medication like antidepressants or anxiety medication?
Yes
No

Have you been diagnosed with ADD or ADHD?
Yes and I am currently on medication
Yes, but I am not currently on medication
No

Have you ever been diagnosed with a major mental health disorder? (Examples: Major Depression, Anxiety, Bipolar Disorder) Please specify what disorder
Yes
No ___________________________________

Do you have a history of problems with your memory?
Yes
No

Were you truthful in your responses throughout participating in this study? *Note - indicating that you were untruthful will not affect your compensation so please be honest.
Yes I was truthful
No I was not truthful

APPENDIX D

MODEL EQUATIONS

Model equations for the null MLM analysis were as follows:

Level 1: $\text{Outcome}_{ij} = \beta_{0j} + \beta_{1j}\text{ActDur}_{ij} + e_{ij}$

Level 2: $\beta_{0j} = \gamma_{00} + U_{oj}$

$\beta_{1j} = \gamma_{10} + U_{1j}$

Model equations for models used in all research questions except questions 10, 11, and 12:

Level 1: $\text{Outcome}_{ij} = \beta_{0j} + \beta_{1j}\text{ActDur}_{ij} + \beta_{2j}\text{Predictor}_{ij} + e_{ij}$

Level 2: $\beta_{0j} = \gamma_{00} + U_{oj}$

$\beta_{1j} = \gamma_{10} + U_{1j}$

$\beta_{2j} = \gamma_{20} + U_{2j}$

Model equations for models used in research questions 10, 11, and 12:

Level 1: $\text{Outcome}_{ij} = \beta_{0j} + \beta_{1j}\text{ActDur}_{ij} + \beta_{2j}\text{InA}_{ij} + \beta_{3j}\text{InB}_{ij} + e_{ij}$

Level 2: $\beta_{0j} = \gamma_{00} + U_{oj}$

$\beta_{1j} = \gamma_{10} + U_{1j}$

$\beta_{2j} = \gamma_{20} + U_{2j}$

$\beta_{3j} = \gamma_{30} + U_{3j}$

REFERENCES

Agnoli, S., Vanucci, M., Pelagatti, C., & Corazza, G. E. (2018). Exploring the link between mind wandering, mindfulness, and creativity: A multidimensional approach. *Creativity Research Journal, 30*(1), 41-53. https://doi.org/10.1080/10400419.2018.1411423

Allan, L. G. (1979). The perception of time. *Perception & Psychophysics, 26*(5), 340-354. https://doi.org/10.3758/BF03204158

Angrilli, A., Cherubini, P., Pavese, A., and Manfredini, S. (1997). The influence of affective factors on time perception. *Percept. Psychophys. 59*, 972–982. https://doi.org/10.3758/BF03205512

Arantes-Gonçalves, F., Wolman, A., Bastos-Leite, A. J., & Northoff, G. (2021). Scale for space and time experience in psychosis: Converging phenomenological and psychopathological perspectives. *Psychopathology*, 1-11. https://doi.org/10.1159/000519500

Baird, B., Smallwood, J., & Schooler, J. W. (2011). Back to the future: Autobiographical planning and the functionality of mind-wandering. *Consciousness and Cognition, 20*(4), 1604-1611. https://doi.org/10.1016/j.concog.2011.08.007

Banks, J. B., Welhaf, M. S., Hood, A. V., Boals, A., & Tartar, J. L. (2016). Examining the role of emotional valence of mind wandering: All mind wandering is not equal. *Consciousness and Cognition, 43*, 167-176. https://doi.org/10.1016/j.concog.2016.06.003

Berlin, H. A., & Rolls, E. T. (2004). Time perception, impulsivity, emotionality, and personality in self-harming borderline personality disorder patients. *Journal of Personality Disorders, 18*(4), 358-378. https://doi.org/10.1521/pedi.2004.18.4.358

Betsch, T., Glauer, M., Renkewitz, F., Winkler, I., & Sedlmeier, P. (2010). Encoding, storage and judgment of experienced frequency and duration. *Judgment and Decision Making, 5*(5), 347.

Block, R., A. (1978). Remembered duration: Effects of event and sequence complexity. *Memory & Cognition, 6*(3), 320-326. https://doi.org/10.3758/BF03197462

Block, R. A., & Zakay, D. (1997). Prospective and retrospective duration judgments: A meta-analytic review. *Psychonomic Bulletin & Review*, *4*(2), 184-197. https://doi.org/10.3758/BF03209393

Blum, K., Chen, T. J., Meshkin, B., Waite, R. L., Downs, B. W., Blum, S. H., Mengucci, J. F., Arcuri, V., Braverman, E. R., & Palomo, T. (2007). Manipulation of catechol-O-methyl-transferase (COMT) activity to influence the attenuation of substance seeking behavior, a subtype of Reward Deficiency Syndrome (RDS), is dependent upon gene polymorphisms: A hypothesis. *Medical Hypotheses, 69*(5), 1054-1060. https://doi.org/10.1016/j.mehy.2006.12.062

Bonnot, O., de Montalembert, M., Kermarrec, S., Botbol, M., Walter, M., & Coulon, N. (2011). Are impairments of time perception in schizophrenia a neglected phenomenon?. *Journal of Physiology-Paris*, *105*(4-6), 164-169. https://doi.org/10.1016/j.jphysparis.2011.07.006

Bozhilova, N. S., Michelini, G., Kuntsi, J., & Asherson, P. (2018). Mind wandering perspective on attention-deficit/hyperactivity disorder. *Neuroscience & Biobehavioral Reviews, 92*, 464-476. https://doi.org/10.1016/j.neubiorev.2018.07.010

Bradley, M. M., & Lang, P. J. (1994). Measuring emotion: The self-assessment manikin and the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry*, *25*(1), 49-59. https://doi.org/10.1016/0005-7916(94)90063-9

Brosowsky, N. P., DeGutis, J., Esterman, M., Smilek, D., & Seli, P. (2020). Mind wandering, motivation, and task performance over time: Evidence that motivation insulates people from the negative effects of mind wandering. *Psychology of Consciousness: Theory, Research, and Practice*. Advanced online publication. https://doi.org/10.1037/cns0000263

Brown, S. W. (1997) Attentional resources in timing: Interference effects in concurrent temporal and nontemporal working memory tasks. *Perception & Psychophysics*, *59*(7), 1118-1140. https://doi.org/10.3758/BF03205526

Bschor, T., Ising, M., Bauer, M., Lewitzka, U., Skerstupeit, M., Müller-Oerlinghausen, B., & Baethge, C. (2004). Time experience and time judgment in major depression, mania and healthy subjects. A controlled study of 93 subjects. *Acta Psychiatrica Scandinavica*, *109*(3), 222-229. https://doi.org/10.1046/j.0001-690X.2003.00244.x

Chang, A., Li, Y. C., Chan, J. F., Dotov, D. G., Cairney, J., & Trainor, L. J. (2021). Inferior auditory time perception in children with motor difficulties. *Child Development*. https://doi.org/10.1111/cdev.13537

Cheyne, J. A., Solman, G. J., Carriere, J. S., & Smilek, D. (2009). Anatomy of an error: A bidirectional state model of task engagement/disengagement and attention-related errors. *Cognition, 111*(1), 98-113. https://doi.org/10.1016/j.cognition.2008.12.009

Christoff, K., Irving, Z. C., Fox, K. C., Spreng, R. N., & Andrews-Hanna, J. R. (2016). Mind-wandering as spontaneous thought: A dynamic framework. *Nature Reviews Neuroscience, 17*(11), 718-731. https://doi.org/10.1038/nrn.2016.113

Church, R. M. (1984). Properties of the internal clock. *Annals of the New York Academy of Sciences*, *423,* 566–582. https://doi.org/10.1111/j.1749-6632.1984.tb23459.x

Danckert, J. A., & Allman, A. A. A. (2005). Time flies when you're having fun: Temporal estimation and the experience of boredom. *Brain and Cognition*, *59*(3), 236-245. https://doi.org/10.1016/j.bandc.2005.07.002

Deng, Y. Q., Li, S., & Tang, Y. Y. (2014). The relationship between wandering mind, depression and mindfulness. *Mindfulness, 5*(2), 124-128. https://doi.org/10.1007/s12671-012-0157-7

Densen, M. E. (1977). Time perception and schizophrenia. *Perceptual and Motor Skills*, *44*(2), 436-438. https://doi.org/10.2466/pms.1977.44.2.436

Diana, R. A., Yonelinas, A. P., & Ranganath, C. (2007). Imaging recollection and familiarity in the medial temporal lobe: A three-component model. *Trends in Cognitive Sciences, 11*(9), 379-386. https://doi.org/10.1016/j.tics.2007.08.001

Droit-Volet, S. (2013). Time perception, emotions and mood disorders. *Journal of Physiology-Paris, 107*(4), 255-264. https://doi.org/10.1016/j.jphysparis.2013.03.005

Droit-Volet, S., Fayolle, S. L., & Gil, S. (2011). Emotion and time perception: Effects of film-induced mood. *Frontiers in Integrative Neuroscience*, *5*, 33. https://doi.org/10.3389/fnint.2011.00033

Droit-Volet, S., & Wearden, J. H. (2015). Experience sampling methodology reveals similarities in the experience of passage of time in young and elderly adults. *Acta Psychologica, 156*, 77-82. https://doi.org/10.1016/j.actpsy.2015.01.006

Droit-Volet, S., & Wearden, J. (2016). Passage of time judgments are not duration judgments: Evidence from a study using experience sampling methodology. *Frontiers in Psychology, 7*, 176. https://doi.org/10.3389/fpsyg.2016.00176

Dust, S. B. (2015). Mindfulness, flow, and mind wandering: The role of trait-based mindfulness in state-task alignment. *Industrial and Organizational Psychology*, *8*(4), 609. https://doi.org/10.1017/iop.2015.87

Ebbinghaus, H. (1885/1974). *Memory: A contribution to experimental psychology.* Dover.

Faul, F., Erdfelder, E., Lang, A.G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*, 175-191. https://doi.org/10.3758/BF03193146

Fazekas, P., & Nemeth, G. (2020). Dreaming, mind-wandering, and hypnotic dreams. *Frontiers in Neurology*, 11, 565673. https://doi.org/10.3389/fneur.2020.565673

Flayelle, M., Maurage, P., Di Lorenzo, K. R., Vögele, C., Gainsbury, S. M., & Billieux, J. (2020). Binge-watching: What do we know so far? A first systematic review of the evidence. *Current Addiction Reports*, *7*(1), 44-60. https://doi.org/10.1007/s40429-020-00299-8

Fox, K. C., Spreng, R. N., Ellamil, M., Andrews-Hanna, J. R., & Christoff, K. (2015). The wandering brain: Meta-analysis of functional neuroimaging studies of mind-wandering and related spontaneous thought processes. *Neuroimage*, *111*, 611-621. https://doi.org/10.1016/j.neuroimage.2015.02.039

Friedman, W. J., & Janssen, S. M. (2010). Aging and the speed of time. *Acta Psychologica, 134*(2), 130-141. https://doi.org/10.1016/j.actpsy.2010.01.004

Godwin, C. A., Hunter, M. A., Bezdek, M. A., Lieberman, G., Elkin-Frankston, S., Romero, V. L., Witkiewitz, K., Clark, V. P., & Schumacher, E. H. (2017). Functional connectivity within and between intrinsic brain networks correlates with trait mind wandering. *Neuropsychologia, 103*, 140-153. https://doi.org/10.1016/j.neuropsychologia.2017.07.006

Grommet, E. K., Droit-Volet, S., Gil, S., Hemmes, N. S., Baker, A. H., and Brown, B. (2011). Effects of a fear cue on time estimation in human observers. *Behavioural Processes 86*(1), 88–93. https://doi.org/10.1016/j.beproc.2010.10.003

Grondin, S. (2010). Timing and time perception: a review of recent behavioral and neuroscience findings and theoretical directions. *Attention, Perception, & Psychophysics, 72*(3), 561-582. https://doi.org/10.3758/APP.72.3.561

Gruberger, M., Simon, E. B., Levkovitz, Y., Zangen, A., & Hendler, T. (2011). Towards a neuroscience of mind-wandering. *Frontiers in Human Neuroscience, 5*(56), 1-11. https://doi.org/10.3389/fnhum.2011.00056

Hancock, P. A., Kaplan, A. D., Cruit, J. K., Hancock, G. M., MacArthur, K. R., & Szalma, J. L. (2019). A meta-analysis of flow effects and the perception of time. *Acta Psychologica, 198*, 102836. https://doi.org/10.1016/j.actpsy.2019.04.007

Hare, R. D. (1963). The estimation of short temporal intervals terminated by shock. *Journal of Clinical Psychology, 19*(3), 378-380. https://doi.org/10.1002/1097-4679(196307)19:3<378::AID-JCLP2270190340>3.0.CO;2-F

Harris, P. A., Taylor, R., Minor, B. L., Elliott, V., Fernandez, M., O'Neal, L., McLeod, L., Delacqua, G, Delacqua, F., Kirby, J., Suda, S. N., & REDCap Consortium. (2019). The REDCap consortium: Building an international community of software platform partners. *Journal of Biomedical Informatics, 95*, 103208. https://doi.org/10.1016/j.jbi.2019.103208

Harris, P. A., Taylor, R., Thielke, R., Payne, J., Gonzalez, N., & Conde, J. G. (2009). Research electronic data capture (REDCap)—a metadata-driven methodology and workflow process for providing translational research informatics support. *Journal of Biomedical Informatics, 42*(2), 377-381. https://doi.org/10.1016/j.jbi.2008.08.010

He, H., Li, Y., Chen, Q., Wei, D., Shi, L., Wu, X., & Qiu, J. (2021). Tracking resting-state functional connectivity changes and mind wandering: A longitudinal neuroimaging study. *Neuropsychologia, 150*, 107674. https://doi.org/10.1016/j.neuropsychologia.2020.107674

Heidegger, M. (1927). Sein und Zeit [Being and Time] (E. Martineau, I. Lechaux and E. Ledru, Trans. 1985 ed.).

Heys, J. G., Wu, Z., Mascaro, A. L. A., & Dombeck, D. A. (2020). Inactivation of the medial entorhinal cortex selectively disrupts learning of interval timing. *Cell Reports, 32*(12), 108163. https://doi.org/10.1016/j.celrep.2020.108163

Holman, E. A., & Grisham, E. L. (2020). When time falls apart: The public health implications of distorted time perception in the age of COVID-19. *Psychological Trauma: Theory, Research, Practice, and Policy, 12*(S1), S63-S65. https://doi.org/10.1037/tra0000756

Holman, E. A., & Silver, R. C. (1998). Getting" stuck" in the past: temporal orientation and coping with trauma. *Journal of Personality and Social Psychology*, *74*(5), 1146. https://doi.org/10.1037/0022-3514.74.5.1146

Hunsaker, M. R., Chen, V., Tran, G. T., & Kesner, R. P. (2013). The medial and lateral entorhinal cortex both contribute to contextual and item recognition memory: A test of the binding of items and context model. *Hippocampus*, *23*(5), 380-391. https://doi.org/10.1002/hipo.22097

Iglesias-Parro, S., Soriano, M. F., Prieto, M., Rodríguez, I., Aznarte, J. I., & Ibáñez-Molina, A. J. (2020). Introspective and neurophysiological measures of mind wandering in schizophrenia. *Scientific Reports, 10*:4833. https://doi.org/10.1038/s41598-020-61843-0

Im, S. H., & Varma, S. (2018). Distorted time perception during flow as revealed by an attention-demanding cognitive task. *Creativity Research Journal*, *30*(3), 295-304. https://doi.org/10.1080/10400419.2018.1488346

Ivry, R. B., & Keele, S. W. (1989). Timing functions of the cerebellum. *Journal of Cognitive Neuroscience, 1*(2), 136-152. https://doi.org/10.1162/jocn.1989.1.2.136

Jin, C. Y., Borst, J. P., & van Vugt, M. K. (2019). Predicting task-general mind-wandering with EEG. *Cognitive, Affective, & Behavioral Neuroscience, 19*(4), 1059-1073. https://doi.org/10.3758/s13415-019-00707-1

Kahmann, R., Ozuer, Y., Zedelius, C. M., & Bijleveld, E. (2021). Mind wandering increases linearly with text difficulty. *Psychological Research*, 1-10. https://doi.org/10.1007/s00426-021-01483-9

Kawashima, I., Takahashi, T., Kikai, T., Sugiyama, F., & Kumano, H. (2022). A method of measuring the ability of disengagement from mind-wandering using electroencephalogram and its relationship to mindfulness and depressive symptoms. *Psychology & Neuroscience*, *15*(1), 14-27. https://doi.org/10.1037/pne0000285

Kearns, T. B., & Ruebel, J. B. (2011). Relationship between negative emotion and ADHD among college males and females. *Journal of Postsecondary Education and Disability, 24*(1), 31-42.

Kelly, M. E. & Ryals, A. J. (2022a). A data-driven approach to observing and differentiating extreme television and video viewing behavior. Manuscript in preparation.

Kelly, M. E. & Ryals, A. J. (2022b). COVID-19 reminder image primed differential recollection of time increments during lockdown. Manuscript in preparation.

Killingsworth, M. A., & Gilbert, D. T. (2010). A wandering mind is an unhappy mind. *Science, 330*(6006), 932-932. https://doi.org/10.1126/science.1192439

King, A. P., Block, S. R., Sripada, R. K., Rauch, S., Giardino, N., Favorite, T., Angstadt, M., Kessler, D., Welsh, R., & Liberzon, I. (2016). Altered default mode network (DMN) resting state functional connectivity following a mindfulness-based exposure therapy for posttraumatic stress disorder (PTSD) in combat veterans of Afghanistan and Iraq. *Depression and Anxiety, 33*(4), 289-299. https://doi.org/10.1002/da.22481

Klein, S. B. (2016). Autonoetic consciousness: Reconsidering the role of episodic memory in future-oriented self-projection. *Quarterly Journal of Experimental Psychology, 69*(2), 381-401. https://doi.org/10.1080/17470218.2015.1007150

Kramer, R. S., Weger, U. W., & Sharma, D. (2013). The effect of mindfulness meditation on time perception. *Consciousness and Cognition, 22*(3), 846-852. https://doi.org/10.1016/j.concog.2013.05.008

Krimsky, M., Forster, D. E., Llabre, M. M., & Jha, A. P. (2017). The influence of time on task on mind wandering and visual working memory. *Cognition, 169*, 84-90. https://doi.org/10.1016/j.cognition.2017.08.006

Kvavilashvili, L., & Rummel, J. (2020). On the nature of everyday prospection: A review and theoretical integration of research on mind-wandering, future thinking, and prospective memory. *Review of General Psychology, 24*(3), 210-237. https://doi.org/10.1177/1089268020918843

Lamotte, M., Izaute, M., & Droit-Volet, S. (2012). Awareness of time distortions and its relation with time judgment: A metacognitive approach. *Consciousness and Cognition, 21*(2), 835-842. https://doi.org/10.1016/j.concog.2012.02.012

Lang, P. J., Bradley, M. M., and Cuthbert, B. N. (2008). *International affective picture system (IAPS): Affective ratings of pictures and instruction manual*. Technical Report A-8. University of Florida, Gainesville, FL.

Lee, K. H., Egleston, P. N., Brown, W. H., Gregory, A. N., Barker, A. T., & Woodruff, P. W. (2007). The role of the cerebellum in subsecond time perception: Evidence from repetitive transcranial magnetic stimulation. *Journal of Cognitive Neuroscience, 19*(1), 147-157. https://doi.org/10.1162/jocn.2007.19.1.147

Loehlin, J. C. (1959). The influence of different activities on the apparent length of time. *Psychological Monographs: General and Applied*, *73*(4), 1. https://doi.org/10.1037/h0093741

Marcusson-Clavertz, D., Terhune, D. B., & Cardeña, E. (2012). Individual differences and state effects on mind-wandering: Hypnotizability, dissociation, and sensory homogenization. *Consciousness and Cognition, 21*(3), 1097-1108. https://doi.org/10.1016/j.concog.2012.04.002

Martel, A., Arvaneh, M., Robertson, I., Smallwood, J., & Dockree, P. (2019). Distinct neural markers for intentional and unintentional task unrelated thought. *bioRxiv*, 705061. https://doi.org/10.1101/705061

Martens, A., & Schmeichel, B. J. (2011). Evidence that thinking about death relates to time-estimation behavior. *Death Studies*, *35*(6), 504-524. https://doi.org/10.1080/07481187.2011.573174

Matell, M. S., & Meck, W. H. (2000). Neuropsychological mechanisms of interval timing behavior. *Bioessays, 22*(1), 94-103. https://doi.org/10.1002/(SICI)1521-1878(200001)22:1<94::AID-BIES14>3.0.CO;2-E

Matell, M. S., & Meck, W. H. (2004). Cortico-striatal circuits and interval timing: Coincidence detection of oscillatory processes. *Cognitive Brain Research, 21*(2), 139-170. https://doi.org/10.1016/j.cogbrainres.2004.06.012

Matell, M. S., Meck, W. H., & Nicolelis, M. A. (2003). Interval timing and the encoding of signal duration by ensembles of cortical and striatal neurons. *Behavioral Neuroscience, 117*(4), 760. https://doi.org/10.1037/0735-7044.117.4.760

Mathieu, J. E., Aguinis, H., Culpepper, S. A., & Chen, G. (2012). Understanding and estimating the power to detect cross-level interaction effects in multilevel modeling. *Journal of Applied Psychology, 97*(5), 951. https://doi.org/10.1037/a0028380

McConchie, R. D. M., & Rutschmann, J. (1971). Human time estimation: On differences between methods. *Perceptual and Motor Skills, 32*(1), 319-336. https://doi.org/10.2466/pms.1971.32.1.319

McNeish, D. M., & Stapleton, L. M. (2016). The effect of small sample size on two-level model estimates: A review and illustration. *Educational Psychology Review, 28*(2), 295-314. https://doi.org/10.1007/s10648-014-9287-x

McVay, J. C., & Kane, M. J. (2009). Conducting the train of thought: working memory capacity, goal neglect, and mind wandering in an executive-control task. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35*(1), 196. https://doi.org/10.1037/a0014104

McVay, J. C., & Kane, M. J. (2010). Does mind wandering reflect executive function or executive failure? Comment on Smallwood and Schooler (2006) and Watkins (2008). *Psychol Bull, 136*(2), 188-207. https://doi.org/10.1037/a0018298

Merikivi, J., Bragge, J., Scornavacca, E., & Verhagen, T. (2020). Binge-watching serialized video content: A transdisciplinary review. *Television & New Media, 21*(7), 697-711. https://doi.org/10.1177/1527476419848578

Mitchell, J. M., Weinstein, D., Vega, T., & Kayser, A. S. (2018). Dopamine, time perception, and future time perspective. *Psychopharmacology, 235*(10), 2783-2793. https://doi.org/10.1007/s00213-018-4971-z

Mooneyham, B. W., & Schooler, J. W. (2013). The costs and benefits of mind-wandering: A review. *Canadian Journal of Experimental Psychology/Revue canadienne de psychologie expérimentale, 67*(1), 11. https://doi.org/10.1037/a0031569

Mrazek, M. D., Smallwood, J., & Schooler, J. W. (2012). Mindfulness and mind-wandering: Finding convergence through opposing constructs. *Emotion, 12*(3), 442. https://doi.org/10.1037/a0026678

Murre, J. M., & Dros, J. (2015). Replication and analysis of Ebbinghaus' forgetting curve. *PloS one, 10*(7), e0120644. https://doi.org/10.1371/journal.pone.0120644

Nelson, T. O., & Dunlosky, J. (1991). When people's judgments of learning (JOLs) are extremely accurate at predicting subsequent recall: The "delayed-JOL effect". *Psychological Science, 2*(4), 267-271. https://doi.org/10.1111/j.1467-9280.1991.tb00147.x

Nezlek, J. B., Wesselmann, E. D., Wheeler, L., & Williams, K. D. (2012). Ostracism in everyday life. *Group Dynamics: Theory, Research, and Practice, 16*(2), 91. https://doi.org/10.1037/a0028029

Northoff, G., Magioncalda, P., Martino, M., Lee, H. C., Tseng, Y. C., & Lane, T. (2018). Too fast or too slow? Time and neuronal variability in bipolar disorder—a combined theoretical and empirical investigation. *Schizophrenia Bulletin, 44*(1), 54-64. https://doi.org/10.1093/schbul/sbx050

Nuyens, F. M., Kuss, D. J., Lopez-Fernandez, O., & Griffiths, M. D. (2020). The potential interaction between time perception and gaming: A narrative review. *International Journal of Mental Health and Addiction*, *18*, 1226-1246. https://doi.org/10.1007/s11469-019-00121-1

O'Reilly, J. X., Mesulam, M. M., & Nobre, A. C. (2008). The cerebellum predicts the timing of perceptual events. *Journal of Neuroscience*, *28*(9), 2252-2260. https://doi.org/10.1523/JNEUROSCI.2742-07.2008

Ogden, R. S. (2020). The passage of time during the UK Covid-19 lockdown. *PLOS One*, *15*(7), e0235871. https://doi.org/10.1371/journal.pone.0235871

Ornstein, R. E. (1969). *On the experience of time*. Penguin Books.

Oyarzo, P., Preiss, D. D., & Cosmelli, D. (2022). Attentional and meta-cognitive processes underlying mind wandering episodes during continuous naturalistic reading are associated with specific changes in eye behavior. *Psychophysiology*, e13994. https://doi.org/10.1111/psyp.13994

Pardes, A. (2020, May 8). There are no hours or days in coronatime. *Wired*. https://www.wired.com/story/coronavirus-time-warp-what-day-is-it/

Pedri, S., & Hesketh, B. (1993). Time perception: Effects of task speed and delay. *Perceptual and Motor Skills, 76*(2), 599-608. https://doi.org/10.2466/pms.1993.76.2.599

Poerio, G. L., Totterdell, P., & Miles, E. (2013). Mind-wandering and negative mood: Does one thing really lead to another?. *Consciousness and Cognition, 22*(4), 1412-1421. https://doi.org/10.1016/j.concog.2013.09.012

Polich, J. (2012). Neuropsychology of P300. In S. J. Luck & E. S. Kappenman (Eds.), *The Oxford handbook of event-related potential components* (pp. 159–188). Oxford University Press.

Preiss, D. D., Cosmelli, D., Grau, V., & Ortiz, D. (2016). Examining the influence of mind wandering and metacognition on creativity in university and vocational students. *Learning and Individual Differences*, *51*, 417-426. https://doi.org/10.1016/j.lindif.2016.07.010

Ptacek, R., Weissenberger, S., Braaten, E., Klicperova-Baker, M., Goetz, M., Raboch, J., Vnukova, M., & Stefano, G. B. (2019). Clinical implications of the perception of time in attention deficit hyperactivity disorder (ADHD): A review. *Medical Science Monitor: International Medical Journal of Experimental and Clinical Research, 25,* 3918-3924. https://doi.org/10.12659/MSM.914225

Raichle, M. E. (2015). The brain's default mode network. *Annual Review of Neuroscience, 38,* 433-447. https://doi.org/10.1146/annurev-neuro-071013-014030

Raichle, M. E., MacLeod, A. M., Snyder, A. Z., Powers, W. J., Gusnard, D. A., & Shulman, G. L. (2001). A default mode of brain function. *Proceedings of the National Academy of Sciences, 98*(2), 676-682. https://doi.org/10.1073/pnas.98.2.676

Rau, C. (1953). Theories of time in ancient philosophy. *The Philosophical Review*, *62*(4), 514-525. https://doi.org/10.2307/2182458

Risko, E. F., Anderson, N., Sarwal, A., Engelhardt, M., & Kingstone, A. (2012). Everyday attention: Variation in mind wandering and memory in a lecture. *Applied Cognitive Psychology, 26*(2), 234-242. https://doi.org/10.1002/acp.1814

Rock, P. L., Roiser, J. P., Riedel, W. J., & Blackwell, A. (2014). Cognitive impairment in depression: A systematic review and meta-analysis. *Psychological Medicine, 44*(10), 2029-2040. https://doi.org/10.1017/S0033291713002535

Scherbaum, C. A., & Ferreter, J. M. (2009). Estimating statistical power and required sample sizes for organizational research using multilevel modeling. *Organizational Research Methods, 12*(2), 347-367. https://doi.org/10.1177/1094428107308906

Seli, P., Beaty, R. E., Marty-Dugas, J., & Smilek, D. (2019). Depression, anxiety, and stress and the distinction between intentional and unintentional mind wandering. *Psychology of Consciousness: Theory, Research, and Practice, 6*(2), 163-170. https://doi.org/10.1037/cns0000182

Seli, P., Carriere, J. S., & Smilek, D. (2015). Not all mind wandering is created equal: Dissociating deliberate from spontaneous mind wandering. *Psychological Research, 79*(5), 750-758. https://doi.org/10.1007/s00426-014-0617-x

Seli, P., Cheyne, J. A., Xu, M., Purdon, C., & Smilek, D. (2015). Motivation, intentionality, and mind wandering: Implications for assessments of task-unrelated thought. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 41*(5), 1417. https://doi.org/10.1037/xlm0000116

Seli, P., Konishi, M., Risko, E. F., & Smilek, D. (2018). The role of task difficulty in theoretical accounts of mind wandering. *Consciousness and Cognition, 65*, 255-262. https://doi.org/10.1016/j.concog.2018.08.005

Seli, P., Ralph, B. C., Konishi, M., Smilek, D., & Schacter, D. L. (2017). What did you have in mind? Examining the content of intentional and unintentional types of mind wandering. *Consciousness and Cognition, 51*, 149-156. https://doi.org/10.1016/j.concog.2017.03.007

Seli, P., Risko, E. F., Purdon, C., & Smilek, D. (2016). Intrusive thoughts: Linking spontaneous mind wandering and OCD symptomatology. *Psychological Research, 81*(2), 392-398. https://doi.org/10.1007/s00426-016-0756-3

Seli, P., Risko, E. F., & Smilek, D. (2016). On the necessity of distinguishing between unintentional and intentional mind wandering. *Psychological Science, 27*(5), 685-691. https://doi.org/10.1177/0956797616634068

Seli, P., Risko, E. F., Smilek, D., & Schacter, D. L. (2016). Mind-wandering with and without intention. *Trends in Cognitive Sciences, 20*(8), 605-617. https://doi.org/10.1016/j.tics.2016.05.010

Shin, D. J., Lee, T. Y., Jung, W. H., Kim, S. N., Jang, J. H., & Kwon, J. S. (2015). Away from home: the brain of the wandering mind as a model for schizophrenia. *Schizophrenia Research, 165*(1), 83-89. https://doi.org/10.1016/j.schres.2015.03.021

Shulman, G. L., Fiez, J. A., Corbetta, M., Buckner, R. L., Miezin, F. M., Raichle, M. E., & Petersen, S. E. (1997). Common blood flow changes across visual tasks: II. Decreases in cerebreal cortex. *J Cogn Neurosci, 9*(5), 648-663. https://doi.org/10.1162/jocn.1997.9.5.648

Simeon, D., Hwu, R., & Knutelska, M. (2007). Temporal disintegration in depersonalization disorder. *Journal of Trauma & Dissociation, 8*(1), 11-24. https://doi.org/10.1300/J229v08n01_02

Smallwood, J. (2013). Distinguishing how from why the mind wanders: A process–occurrence framework for self-generated mental activity. *Psychological Bulletin, 139*(3), 519. https://doi.org/10.1037/a0030010

Smallwood, J., Beach, E., Schooler, J. W., & Handy, T. C. (2008). Going AWOL in the brain: Mind wandering reduces cortical analysis of external events. *Journal of Cognitive Neuroscience, 20*(3), 458-469. https://doi.org/10.1162/jocn.2008.20037

Smallwood, J., Davies, J. B., Heim, D., Finnigan, F., Sudberry, M., O'Connor, R., & Obonsawin, M. (2004). Subjective experience and the attentional lapse: Task engagement and disengagement during sustained attention. *Consciousness and Cognition, 13*(4), 657-690. https://doi.org/10.1016/j.concog.2004.06.003

Smallwood, J., Fitzgerald, A., Miles, L. K., & Phillips, L. H. (2009). Shifting moods, wandering minds: Negative moods lead the mind to wander. *Emotion, 9*(2), 271. https://doi.org/10.1037/a0014855

Smallwood, J., & Schooler, J. W. (2006). The restless mind. *Psychological Bulletin, 132*(6), 946. https://doi.org/10.1037/0033-2909.132.6.946

Smallwood, J., & Schooler, J. W. (2015). The science of mind wandering: Empirically navigating the stream of consciousness. *Annual Review of Psychology, 66*, 487-518. https://doi.org/10.1146/annurev-psych-010814-015331

Smith, A. C., Brosowsky, N. P., Ralph, B. C., Smilek, D., & Seli, P. (2021). Re-examining the effect of motivation on intentional and unintentional task-unrelated thought: Accounting for thought constraint produces novel results. *Psychological Research, 1*-11. https://doi.org/10.1007/s00426-021-01487-5

Sommers, J., & Vodanovich, S. J. (2000). Boredom proneness: Its relationship to psychological- and physical-health symptoms. *Journal of Clinical Psychology*, *56*(1), 149-155. https://doi.org/10.1002/(SICI)1097-4679(200001)56:1<149::AID-JCLP14>3.0.CO;2-Y

Sood, A., & Jones, D. T. (2013). On mind wandering, attention, brain networks, and meditation. *Explore, 9*(3), 136-141. https://doi.org/10.1016/j.explore.2013.02.005

Soffer-Dudek, N. (2019). Dissociative absorption, mind-wandering, and attention-deficit symptoms: Associations with obsessive-compulsive symptoms. *British Journal of Clinical Psychology, 58*(1), 51-69. https://doi.org/10.1111/bjc.12186

Stanghellini, G., Ballerini, M., Presenza, S., Mancini, M., Raballo, A., Blasi, S., & Cutting, J. (2016). Psychopathology of lived time: Abnormal time experience in persons with schizophrenia. *Schizophrenia Bulletin*, *42*(1), 45-55. https://doi.org/10.1093/schbul/sbv052

Starosta, J. A., & Izydorczyk, B. (2020). Understanding the phenomenon of binge-watching—A systematic review. *International Journal of Environmental Research and Public Health, 17*(12), 4469. https://doi.org/10.3390/ijerph17124469

Terhune, D. B., Croucher, M., Marcusson-Clavertz, D., & Macdonald, J. S. (2017). Time contracts and temporal precision declines when the mind wanders. *Journal of*

Experimental Psychology: Human Perception and Performance, 43(11), 1864. https://doi.org/10.1037/xhp0000461

Thomson, D. R., Besner, D., & Smilek, D. (2013). In pursuit of off-task thought: Mind wandering-performance trade-offs while reading aloud and color naming. *Frontiers in Psychology, 4,* 360. https://doi.org/10.3389/fpsyg.2013.00360

Thönes, S., & Oberfeld, D. (2015). Time perception in depression: A meta-analysis. *Journal of Affective Disorders, 175*, 359-372. https://doi.org/10.1016/j.jad.2014.12.057

Thönes, S., & Oberfeld, D. (2017). Meta-analysis of time perception and temporal processing in schizophrenia: Differential effects on precision and accuracy. *Clinical Psychology Review, 54*, 44-64. https://doi.org/10.1016/j.cpr.2017.03.007

Thönes, S., & Wittmann, M. (2016). Time perception in yogic mindfulness meditation—Effects on retrospective duration judgments and time passage. *Psychology of Consciousness: Theory, Research, and Practice, 3*(4), 316. https://doi.org/10.1037/cns0000088

Tipples, J. (2008). Negative emotionality influences the effects of emotion on time perception. *Emotion, 8*(1), 127. https://doi.org/10.1037/1528-3542.8.1.127

Tobin, S., & Grondin, S. (2009). Video games and the perception of very long durations by adolescents. *Computers in Human Behavior, 25*(2), 554-559. https://doi.org/10.1016/j.chb.2008.12.002

Tulving, E. (2005). Episodic memory and autonoesis: Uniquely human? In H. S. Terrace & J. Metcalfe (Eds.), *The missing link in cognition: Origins of self-reflective consciousness* (pp. 3–56). Oxford University Press.

https://doi.org/10.1093/acprof:oso/9780195161564.003.0001

Ueda, N., Maruo, K., & Sumiyoshi, T. (2018). Positive symptoms and time perception in schizophrenia: A meta-analysis. *Schizophrenia Research: Cognition, 13*, 3-6. https://doi.org/10.1016/j.scog.2018.07.002

Watts, F. N., & Sharrock, R. (1984). Fear and time estimation. *Perceptual and Motor Skills, 59*(2), 597-598. https://doi.org/10.2466/pms.1984.59.2.597

Weinstein, Y. (2018). Mind-wandering, how do I measure thee with probes? Let me count the ways. *Behavior Research Methods, 50*(2), 642-661. https://doi.org/10.3758/s13428-017-0891-9

Weinstein, Y., De Lima, H. J., & Van Der Zee, T. (2018). Are you mind-wandering, or is your mind on task? The effect of probe framing on mind-wandering reports. *Psychonomic Bulletin & Review, 25*(2), 754-760. https://doi.org/10.3758/s13423-017-1322-8

Wiemers, E. A., & Redick, T. S. (2019). The influence of thought probes on performance: Does the mind wander more if you ask it?. *Psychonomic Bulletin & Review, 26*(1), 367-373. https://doi.org/10.3758/s13423-018-1529-3

Wiener, M., Turkeltaub, P., & Coslett, H. B. (2010). The image of time: A voxel-wise meta-analysis. *Neuroimage*, *49*(2), 1728-1740. https://doi.org/10.1016/j.neuroimage.2009.09.064

Williams, J. M. G. (2008). Mindfulness, depression and modes of mind. *Cognitive Therapy and Research, 32*(6), 721-733. https://doi.org/10.1007/s10608-008-9204-z

Williams, K. J., Lee, K. E., Hartig, T., Sargent, L. D., Williams, N. S., & Johnson, K. A. (2018). Conceptualising creativity benefits of nature experience: Attention restoration and mind wandering as complementary processes. *Journal of Environmental Psychology*, *59*, 36-45. https://doi.org/10.1016/j.jenvp.2018.08.005

Wilson, T. D., Reinhard, D. A., Westgate, E. C., Gilbert, D. T., Ellerbeck, N., Hahn, C., Brown, C. L., & Shaked, A. (2014). Just think: The challenges of the disengaged mind. *Science*, *345*(6192), 75-77. https://doi.org/10.1126/science.1250830

Winkler, I., Glauer, M., Betsch, T., & Sedlmeier, P. (2015). The impact of attention on judgments of frequency and duration. *PloS one*, *10*(5), e0126974. https://doi.org/10.1371/journal.pone.0126974

Wittmann, M., & Schmidt, S. (2014). Mindfulness meditation and the experience of time. In S. Schmidt & H. Walach (eds.), *Meditation–neuroscientific approaches and philosophical implications* (pp. 199-209). Springer. https://doi.org/10.1007/978-3-319-01634-4_11

Wood, R. T., Griffiths, M. D., & Parke, A. (2007). Experiences of time loss among videogame players: An empirical study. Cyberpsychology & Behavior, 10(1), 38-44. https://doi.org/10.1089/cpb.2006.9994

Yang, B., Chan, R. C., Zou, X., Jing, J., Mai, J., & Li, J. (2007). Time perception deficit in children with ADHD. *Brain Research*, *1170*, 90-96. https://doi.org/10.1016/j.brainres.2007.07.021

Yin, B., Terhune, D. B., Smythies, J., & Meck, W. H. (2016). Claustrum, consciousness, and time perception. *Current Opinion in Behavioral Sciences*, *8*, 258-267. https://doi.org/10.1016/j.cobeha.2016.02.032

Zakay, D. (1998). Attention allocation policy influences prospective timing. *Psychonomic Bulletin & Review, 5(*1), 114-118. https://doi.org/10.3758/BF03209465

Zedelius, C. M., & Schooler, J. W. (2015). Mind wandering "Ahas" versus mindful reasoning: Alternative routes to creative solutions. *Frontiers in Psychology, 6*, 834. https://doi.org/10.3389/fpsyg.2015.00834