Exploring the attentional cycling model of mind wandering through the lens of time perception

By

Liam T. Yeo

A Thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

Master of Arts

Department of Psychology

University of Manitoba

Winnipeg

Copyright © 2024 by Liam T. Yeo

Abstract

Attentional cycling is the adaptive system that allows for individuals to evaluate whether their thoughts, goals, and behaviors are aligned. However, the specific cognitive mechanisms behind controlling and monitoring the shifting of attentional states is largely unknown. The answer might rely on the mechanisms behind another aspect of cognition, time perception. Where the pacemaker-accumulator model of time perception proposes that there are pulses emitted by a pacemaker and that an accumulator counts the pulses and gives us our sense of time perception. These pulses might also serve as a trigger to switch an individual's attentional focus. Therefore, it is important to investigate whether the same mechanisms that control time perception, also control mind wandering and attentional cycling. This was investigated through two experiments, with the first replicating and validating the starfield color tracking task, which was used to manipulate subjective time perception, and we will use the sustained attention to response task to measure mind wandering and see if there is any relationship(n=166). The second is an experimental approach where we adapt the starfield color tracking task to resemble more traditional attentional tasks while still manipulating time perception and measuring mind wandering in the same task (n=103). In experiment 1, we used linear mixed effects models to find that time perception was successfully manipulated through this task and that our sense of time duration was related to mind wandering. In Experiment 2, we used factorial ANOVAS to show that manipulated time perception was able to influence our off-task thoughts. We also find various relationships with trait-level measures, further strengthening the claim that they are connected somehow. Overall, these results imply that the mechanisms underlying time perception also influence our rates of mind wandering and off-task thoughts, but they do not specify which potential model of time perception is the correct one.

Keywords: Attention, Time Perception, Mind Wandering, Perception, Cognition

Table of Contents

Abstract....2

List of Figures....5

List of Tables....6

Introduction....8

- Time Perception....8
- Mind Wandering....12
- Mind Wandering and Time Perception....15
- The Pacemaker-Accumulator Model of Attentional Cycling....18

Experiment 1....19

- Methods....20
- Results....25
- Discussion....32

Experiment 2....34

- Methods....34
- Results....37
- Discussion....41

Exploratory Analyses....42

General Discussion....48

References....53

List of Figures

Figure 1. The starfield color tracking task from Lording et al. (2021) 21

Figure 2. The influence of starfield speed and density on both time duration judgements and passage of time judgments.....29

Figure 3. Predictive graphs showing the relationships between the time perception judgements and the different types of thought content.....32

Figure 4. Proportion of probe responses for each category of response across starfield speed and density.....40

List of Tables

Table 1: Linear mixed effects models for time duration and passage of time from the starfield color tracking task.....27

Table 2: Linear mixed effects models for time duration and passage of time including the thought content from the SART.....30

Table 3: ANOVA table for the proportion of mind wandering.....37

Table 4: ANOVA for the proportion of mind wandering that was categorized as off task with density and speed as independent variables.....38

Table 5: ANOVA table for the proportion of mind wandering that was categorized as task related interference with speed and density as independent variables.....39

Table 6: ANOVA table for the proportion of mind wandering that was categorized as time related thoughts with speed and density as independent variables.....39

Table 7: Means, standard deviations and Cronbach's alpha of all questionnaires.....42

Table 8: Linear regression model for the spontaneous and deliberate mind wandering scales and how they relate to age, sex, slow time span scale, fast time scan scale, and to the other mind wandering scale.....43

Table 9: Linear regression model for the attentional control shifting and distraction scales and how they relate to age, sex, slow time span scale, fast time span scale, and to the other attention control scale.....44

Table 10: Linear regression model of the mindful attention awareness scale and how it relates to age, sex, the slow time span scale, and the fast time span scale.....46

Table 11: Linear regression model for the short boredom proneness scale and how it relates to age, sex, the slow time span scale, and the fast time span scale.....46

Table 12: Linear regression model for the metacognitive questionnaire on time and how it relates to, age, sex, the spontaneous mind wandering scale, the deliberate mind wandering scale, the slow time span scale, and the fast time span scale.....47

Exploring the attentional cycling model of mind wandering through the lens of time perception

Mind wandering is an everyday experience in which our thoughts shift from our goals towards self-generated thoughts. The cognitive processes underlying the initiation and maintenance of mind wandering remain largely unknown. In this project, I investigated the relationship between time perception and mind wandering to determine whether the theoretical mechanisms that enable time perception (e.g., an internal clock) can also explain the initiation of mind wandering. First, I will review theories of time perception, focusing particularly on the most widely accepted one, the pacemaker-accumulator model, and the factors influencing time perception judgements. Then, I will review theoretical perspectives on mind wandering and factors that influence our rates of mind wandering. I will then move onto potential connections between these two phenomena and argue that the pacemaker-accumulator model may hold the key to understanding what causes us to "spontaneously" mind wander. Finally, I will provide an overview of the two experiments aimed at investigating this claim.

Time Perception

Time perception is the subjective experience of time or an individual's overall sense of time. Time perception is most often measured by asking individuals to indicate how quickly it felt like time had passed—a passage of time judgment —or by asking individuals to indicate *how much* time has passed during some interval—a duration of time judgment (Thönes & Stocker, 2019). The passage of time reflects how quickly or slowly people feel time is moving, which can differ from their estimates of how long they believe a certain period lasted for.

Given that time perception is a subjective experience, it can be influenced by internal and external factors. Attention, for instance, is thought to play an important role in both kinds of time

perception: it is needed for accurately discriminating durations and when people pay attention to time, the passage of time typically feels slower (Brown, 1985; Hallez, 2020; for review, see Grondin, 2010).

In contrast, when attention is not directed towards the passage time, people make tend to make systematic errors. Divided attention tasks are often used to measure the effects of inattention on time perception (for review, see Grondin, 2010). In these tasks participants are usually given a primary task and a secondary, concurrent temporal task. When attention is split between these two tasks, or when participants are instructed to focus on the nontemporal task, time perception is contracted and temporal estimation becomes less accurate (for review, see Grondin, 2010). Conversely, when participants are instructed to focus more on the temporal task, time perception is dilated, and temporal discrimination improves. This again showcases the importance of attention and its influence on time perception. Though, it is important to note that these tasks reflect the judgment of very short durations and do not measure time perception over longer periods.

Contextual factors can also influence an individual's subjective experience of time. One study investigating the effect of reward on time perception found that the mere presence of a reward (i.e., caloric primary rewards, secondary rewards, non-caloric primary reward, sweet primary reward) caused overestimation in supra-second timing intervals (Fung et al., 2017). However, this effect did not extend to the reward anticipation. Another study investigating the effects of exercise on time perception judgments found that the higher the effort exerted while exercising, the more contracted subjective time felt (Edwards & McCormick, 2017). This effect was most pronounced at the end of each trial, likely due to the participants' increased attention to physical discomfort, particularly when instructed to exert maximal effort rather than light effort.

Of particular relevance to my study, Jording et al. (2022) demonstrated how low-level stimulus features can influence time perception of 10 to 30 second durations. Their study presented participants with small boxes (red, green, or blue) simulating a moving starfield. While all colors were present, the ratio was such that one color always predominated. The researchers manipulated the starfield speed and density across trials to examine their effects on time duration and passage of time judgements. At the end of each trial, participants had to indicate which color was dominant, how long they the trial lasted, and how quickly the passage of time felt. Across two experiments, they found that faster movement and higher density caused participants to underestimate the passage of time, suggesting that their perception of time moved more quickly. Though, time duration judgements were seemingly unaffected. One limitation is that the second experiment was conducted online which might mean that the participants had access to external distractions and time keeping devices that might influence the results and might provide an unreliable comparison to the first experiments results. The study nevertheless provides evidence that low level stimuli features, and environmental context can influence our time perception.

Theories of human time perception generally fall into one of two categories: theories that require an internal clock and theories that do not (for review, see Grondin, 2010). One non-clock theory proposes that time perception judgments rely on the vividness and strength of one's memory during the interval (Friedman, 1993; Killeen & Grondin, 2022; Taatgen & van Rijn, 2011). The relative strength of these memories is then used to make interval judgements or discriminate from time intervals and gives rise to our subjective experience of the passage of time. Another theory uses a Bayesian framework to explain time perception (Jazayeri & Shadlen, 2010; Shi et al., 2013). Bayesian theories propose that sensory estimates of duration are noisy and unreliable. To increase precision, these estimates are combined with prior statistical

knowledge of typical duration distributions. Thus, when estimating the duration of the passage of time, our initial perception may be unreliable, but by applying our previous knowledge of time passage and duration, we are able to update our judgements and increase our accuracy.

In contrast to these non-clock approaches, one of the more widely accepted theories that does assume an internal clock—and most relevant for my current purposes—is the pacemaker-accumulator model (Gibbon et al., 1984). This model hypothesizes that there is an internal clock or "pacemaker" that sends pulses at regular intervals and an "accumulator" that counts the pulses allowing us to estimate time durations and giving rise to our general sense of the passage of time. Although there is not a clear idea of how the pacemaker works, it is generally assumed that it emits pulses at regular rates (Wearden et al., 2007; Zakay & Block, 1995). Under this view, our perception of how much time has passed is determined by the number of pulses that reach the accumulator. Therefore, when more pulses are counted, we experience a longer subjective experience of time and when fewer pulses are counted, subjective time is shortened, which gives the sense of time flying by. Variations of the pacemaker-accumulator model have had considerable success explaining how people make judgements about time passage (Shi et al., 2013; Taatgen & van Rijn, 2011). Importantly, the rate at which pulses are emitted can be influenced by contextual factors, which can lead to a subjective experience that time is passing faster or slower than the actual duration (Rose & Summers, 1995; Ulrich et al., 2006).

A recent addition to the model has been the attentional gate, where the pacemaker pulses must travel through a gate to reach the accumulator (Zakay & Block, 1995). This gate can close, preventing the pacemaker pulses from reaching the accumulator or slowing the rate of the pacemaker depending on an individual's attentional focus. As noted earlier, directing attention away from the passage of time can lead to the feeling that time is flying by (Brown, 1985;

Hallez, 2020; for review, see Grondin, 2010). Through the accumulator model, this is explained as when an individual's attention is diverted to another task, it closes the gate and restricts the number of pulses that make it to the accumulator and therefore, reducing the number of pulses that are counted, slowing our subjective time.

Mind Wandering

Mind wandering is the shift of attention from a focal task to internal, self-generated thoughts (Smallwood & Schooler, 2006). Most mind wandering studies use what is called a "thought probe" to measure the rate and the depth of mind wandering. Participants typically complete a sustained attention task which pauses periodically for them to self-rate their level of attention to the task or classify the content of their thoughts as on task or off task (i.e. the probe-caught method; Weinstein, 2018). Other studies ask participants to monitor their thoughts and report whenever they notice their thoughts are starting to drift off task, usually with a keypress—this is referred to as 'self-caught' method (Chu et al., 2023). Probe-caught and self-caught mind wandering are not mutually exclusive measures and can be used in conjunction with one another to assess participants meta-awareness by measuring how much probe-caught mind wandering is reported relative to the self-caught (Schooler et al., 2004; Schooler, 2002). If, for example, participants self-catch all their off-task thoughts, then every random thought probe they get should show that the participant is on task and not mind wandering. Though, this is not typically the case as participants still report probe-caught mind wandering, showing that people aren't perfect at monitoring their thoughts and lack meta-awareness of their mind wandering (Schooler et al., 2004).

Definitions of mind wandering vary considerably across studies (Seli, Kane, et al., 2018; Weinstein, 2018). However, previous research has highlighted several important features that

help characterize typical mind wandering episodes. A lack of awareness, as noted above, is one such feature. Another important distinction is whether a mind wandering episode was initiated deliberately or spontaneously (also referred to as unintentional or intentional; Carriere et al., 2013; Seli et al., 2015). To capture this distinction, researchers ask participants whether they were off-task despite trying to stay on task (spontaneous mind wandering) or off-task without trying to stay on task (deliberate mind wandering).

These problems with defining mind wandering have led to the proposal that mind wandering is not a unitary construct. Instead, some have argued that mind wandering should be considered from a family resemblance perspective which characterizes mind wandering as a natural category with graded membership (Seli et al., 2018a). From this perspective, there is no single definition of mind wandering, but instead prototypical features that exemplify mind wandering experiences. Since mind wandering typically involves unintentional, task-unrelated, and meandering thoughts, these characteristics represent more prototypical cases than intentional or guided off-task thinking—although both types qualify as mind wandering. Seli et al. (2018a) argue that researchers should clearly operationalize the features that are important for their research question. In the context of this proposal, I adopt the traditional definition of mind wandering as task-unrelated thought (Smallwood & Schooler, 2006). However, for the purposes of my study, I will also distinguish between off-task thought and thoughts about time, temporal processes, and task related interference.

While mind wandering has been an important area of study throughout recent years and gained considerable traction (Callard et al., 2013), there is still much we do not understand about mind wandering. Most previous research has focused on the consequence of mind wandering as a form of distraction and demonstrated significant impact on our daily lives (Mooneyham &

Schooler, 2013). For instance, mind wandering has been shown to negatively impact learning, memory, and reading, but can also facilitate thoughts and plans regarding the future and our goals (Smallwood et al., 2008; for review, see Mooneyham & Schooler, 2013; Risko et al., 2012). Mind wandering also has the potential to cause great harm to oneself and others as it has been repeatedly shown that mind wandering while driving increases dangerous driving behaviors that could lead to crashes (Galéra et al., 2012; Yanko & Spalek, 2014). These implications are especially important when 15-50% of our daily lives consists of mind wandering (Smallwood & Schooler, 2006). Since many of these episodes are spontaneous and emerge without warning, understanding what triggers these spontaneous episodes of mind wandering is critically important.

One proposed theory as to when and why spontaneous mind wandering occurs is called "attentional cycling". Attentional cycling refers to an adaptive system that spontaneously cycles through multiple streams of thought to make sure our actions are aligned with our goals (Mooneyham & Schooler, 2013; Schooler et al., 2011). This process mirrors how animals instinctively interrupt their focused activities (such as foraging) with spontaneous checks of their surroundings for potential threats, even in the absence of immediate danger signals. Some have speculated that mind wandering might serve as an evolutionary extension of this process, reflecting a spontaneous shift of attention which enables periodic goal re-evaluation.

Attentional cycling is a closely related to another framework that has been applied to mind wandering referred to as opportunity costs (Kurzban et al., 2013). When engaging in a task, we likely evaluate the value of completing it compared to other potential tasks we could be spending time and effort on. Opportunity costs refer to the situation when the value of completing the current task is lower than an alternate or potential task—in other words, there is

an ’opportunity cost’ to completing the current task. As in the attentional cycling framework, mind wandering reflects goal re-evaluation, triggered by the presence of opportunity costs. For example, when a student is completing a psychology experiment for course credit, they could be missing a subjectively more enticing party at the same time. This would cause the student to become bored with the experiment and not try as hard and potentially rush through it because the value of the course credit does not outweigh the value of the social experience to them. Some have argued that mind wandering tasks are boring and monotonous and usually have no identifiable benefit to them, which should convey opportunity costs and cause participants to mind wander throughout the task (Brosowsky et al., 2020). However, these tasks are also novel to the average participant and would require time to evaluate the benefits or lack thereof in these tasks and which would show less mind wandering initially, but more mind wandering at the end of the task.

Both attentional cycling and the opportunity cost framework view mind wandering as resulting from similar adaptive functions. In the context of the previously discussed implications, it becomes clearer to how phenomena like future thinking can be explained through attentional cycling, where thinking about the future is both adaptive and can allow us time to plan ahead to reduce opportunity costs. Despite often being cited as a potential theory of mind wandering , there is little research characterizing how attentional cycling mechanisms might operate or inform our understanding of mind wandering (Leszczynski et al., 2017; Mooneyham & Schooler, 2013; J. W. Schooler et al., 2011; Ward & Wegner, 2013).

Mind Wandering and Time Perception

Despite having a proposed relationship between attention and time perception, there has been very little research investigating the connection between time perception and mind

wandering. One of the few studies examining this relationship comes from Terhune et al. (2017), who used an oddball task to influence time perception. In this task, participants viewed sequentially presented blue balls but were occasionally presented with green balls. The participants then had to indicate whether these green balls were on screen for a longer or shorter time than the blue balls and whether they were on task or not. The authors used an oddball task that would dilate time perception due to its surprising and infrequent nature and hypothesized that mind wandering would contract, rather than dilate the oddballs. Consistent with this hypothesis, they found that participants who were off-task had a higher probability of saying that the oddball stimulus was shorter and led to worse temporal discrimination. They also replicated this result using the temporal bisection task, a popular task in the time perception literature where participants judge whether intervals are shorter or longer than a baseline interval. As in the first task, participants indicated whether they were on-task-or off-task. The same pattern of results emerged in this replication, albeit with a smaller effect size. These results were explained as being caused by the perceptual decoupling during mind wandering and the lack of resources devoted to processing the visual stimuli.

Seli et al. (2018b) provided further evidence for a potential relationship between time perception and mind wandering. Their study examined the relationship between self-reported mind wandering and participants' ability to monitor time during a separate task. They used two different tasks: the sustained attention to response task (SART) to measure rates of mind wandering, and a time-based prospective memory task to measure temporal monitoring. In the SART, participants were shown a sequence of random numbers from 1-9 and had to respond to every number except a specified number (e.g., 3). To evaluate the frequency of mind wandering, they used periodic thought probes to gauge whether participants’ thoughts were on- or off-task,

and also asked participants to report whenever they noticed their thoughts were had wandered between probes (i.e. the self-caught method). In the time-based prospective memory task, participants were sequentially shown a list of nouns that they had to indicate if the word natural or manmade while also doing a competing task of indicating whenever a minute had passed. Critically, participants could press a button to view a clock to help with the prospective memory task. This clock-checking measure was used to assess how often participants spontaneously thought of the prospective memory task. Interesting, they found a small, but significant positive association between the number of times participants checked the clock and their frequency of self-caught mind wandering. The authors interpreted this result as evidence for a common temporal monitoring system that monitors the contents of consciousness and the progress of ongoing goals.

Although there are few studies directly linking time perception and mind wandering, these two phenomena have both been shown to be closely associated with boredom. For instance, boredom has been shown to be a consistent positive correlate of both self-reported and probe caught mind wandering and mind wandering is even used to check if boredom has been induced in participants (Blondé et al., 2021; Danckert et al., 2018); for review, see Raffaelli et al., 2018). However, the causal direction of this relationship remains unclear. It is uncertain whether boring tasks trigger mind wandering, or if mind wandering leads individuals to perceive tasks as boring.

Similarly, time perception has also been shown to be associated with boredom. In one study, it was shown that high boredom individuals tended to overestimate time more than low boredom individuals, especially at longer intervals. However, neither group differed in the temporal allocation of attention (Danckert & Allman, 2005).

Although the relationship between mind wandering and boredom has been extensively studied, boredom's influence on time perception adds complexity to this relationship. As previously discussed, boredom causes subjective time perception to slow down, but mind wandering apparently causes it to speed up (Danckert & Allman, 2005; Terhune et al., 2017). This raises the question of how and why two similar and closely related constructs cause subjective time perception to move in opposite directions. One limitation of this research is the classification of time-related thoughts as mind wandering or off-task thinking, even when these thoughts are not task-relevant (such as focusing on the task's duration rather than the timing of stimuli). It is possible, that this additional attention to time can make subjective time feel longer, suggesting that the effect on time perception depends on thought content. For example, when in class and you are mind wandering about how long the class is taking or how long until it ends, time would feel slower, whereas if you were mind wandering about a movie you just saw, time would feel faster. Therefore, it may be important partition out thoughts about time from other thoughts not related to the task to get a more accurate result about how time perception influences mind wandering.

The Pacemaker-Accumulator Model of Attentional Cycling

Given the prior research, there may be a direct relationship between time perception and mind wandering. My proposal is that the pacemaker, which is hypothesized to give rise to our sense of time, may also drive the spontaneous shifts in attention that underly attentional cycling. Specifically, I hypothesize that the pacemaker pulses that give rise to sense of time, may each have a probability to spontaneously shift our thoughts. Thus, the pacemaker is the mechanism that causes attentional cycling. Where more pulses that reach the accumulator increasing the chances of shifting our thoughts and fewer pulses would have less chances to shift our thoughts.

For example, someone doing chores might start to mind wander because when doing the chores, they also feel like time is moving slowly. These triggering pulses would not be restricted to shifting our thoughts off task, but could also trigger a shift back to the focal task, explaining both spontaneous mind wandering and spontaneous goal re-evaluation more generally (Seli et al., 2018b)

Experiment 1

In Experiment 1, I examined the relationship between individual differences in time perception and frequency of mind wandering. To do this, I used the starfield color tracking task from Jording et al. (2022) and the sustained attention to response task (SART) that was used in Seli et al. (2018b) to assess individual differences in time perception and spontaneous off-task thought while also further validating the starfield color tracking task for future use. Based on the proposed pacemaker-accumulator account of attentional cycling, I hypothesize that when an individual's time perception is lengthened, we will see a relationship with higher rates of mind wandering and when an individual's time perception is hastened, then we will also see lower rates of mind wandering (i.e. less pacemaker pulses make it to the accumulator, less chances for thoughts to shift). An alternative hypothesis is that slowed time perception will be associated with lower rates of mind wandering rather than hastened time perception. This hypothesis builds on Terhune et al.'s (2017) findings that mind wandering diverts attention away from temporal awareness, leading to an accelerated perception of time.

As exploratory variables, I will also include questionnaires that assess participants' propensity for spontaneous and deliberate mind wandering, their susceptibility to boredom, perception of time's passage, and their awareness of temporal distortions. These measures will help disentangle the precise nature of the relationship between time perception and mind

wandering (e.g. more spontaneous mind wandering may be related to less awareness of temporal distortions and feel that time is moving faster). Additionally, they will allow us to examine whether boredom-related findings replicate previous literature and clarify the interconnections among mind wandering, time perception, and boredom.

Methods

Participants.

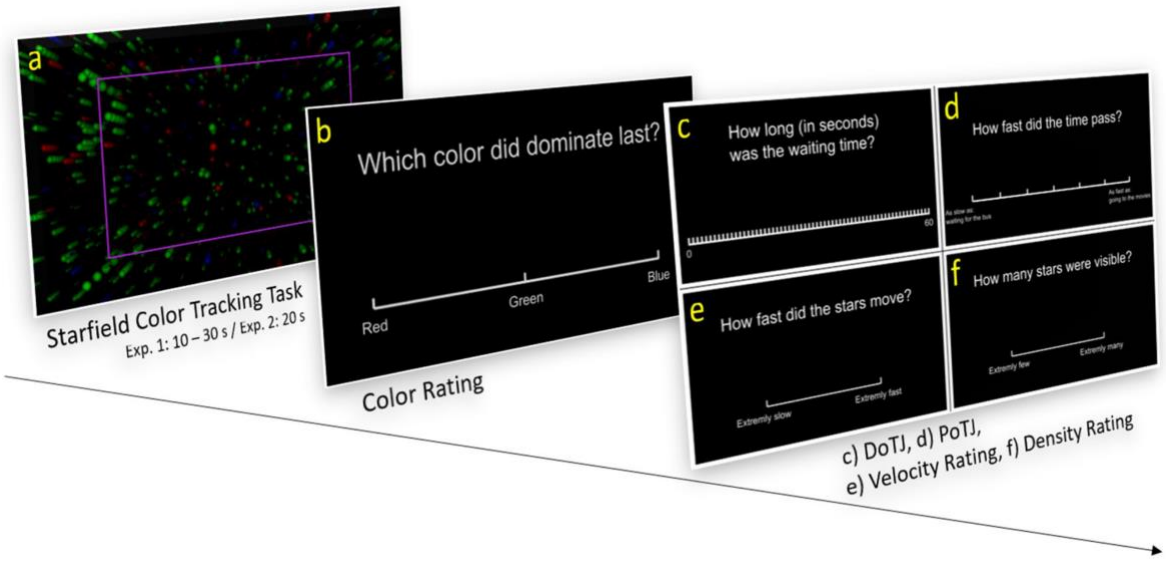
To detect a correlation of between 0.2-0.3 with a power of 80%, we required between 84 -193 participants. Using the University of Manitoba's SONA system, we recruited 194 undergraduate students that were taking a first-year psychology course and were compensated with course credit.

Tasks.

Starfield Color Tracking Task. This experiment contains two tasks, the starfield color tracking task and the sustained attention to response task (SART), the order of which will be counterbalanced across participants. In the starfield color tracking task, participants will see colored pixels simulating stars that are flying towards the screen and unpredictably changing color. They can be one of three different colors (red, green, and blue) and all colors will be present on the screen, but the ratio of colors is changes to allow one color to dominate the screen. The starfield will last between 10-30 seconds with 2 second intervals (10s, 12s, 14s, etc.) and will have different speeds and densities (slow/fast and sparse/dense). Participants will see all combinations of speeds and densities for each duration over the course of the experiment for a total of 44 trials. At the end of each starfield trial participants will be what color last dominated the screen, how fast the stars seemed to travel, how dense the starfield was, how fast time seemed to go during the trial, and how long they thought the trial lasted.

Figure 1

The starfield color tracking task from Jording et al. (2022)



Sustained Attention to Response Task. The second task will be the SART, where participants will have to press the spacebar for every number between 1-9, except the number "3" where they are explicitly told they will have to withhold their response whenever it appears. Numbers are randomly presented without replacement so the participants can't predict the sequence of numbers and must maintain their attention throughout the task. Numbers are presented for 2 seconds and then an encircled "x" mask appears for an additional second, making each trial a total of 3 seconds. Each number is also given a random font size of 36px to 108px in 12px increments (36, 48, 60, etc.). The main difference between this task and the original is that participants will see what was described as a "content probe" from Kane et al., 2021. This probe is used to assess not only if the participant was on or off task, but also what they were thinking about. These probes will randomly appear, and participants must indicate what they were thinking about with the options being: the task, task experience/performance, everyday things,

current state of being, personal worries, external environment, the passage or duration of time, or other.

Questionnaires.

Boredom Proneness Scale. To measure boredom and see how it relates to time perception, mind wandering, and task related influence, we plan on using the short boredom proneness scale (Struk et al., 2017). This scale is used to measure the propensity to experience boredom and has a Cronbach's alpha of .88. Higher scores indicate a higher propensity to become bored and consists of 8 questions that are answered on a 7-point Likert scale ranging from "Strongly agree" to "Strongly disagree".

Deliberate and Spontaneous Mind Wandering Scales. We also plan on using the mind wandering spontaneous and deliberate scale to gauge the propensity of engage in different types of mind wandering in the participants (Carriere et al., 2013). It consists of two scales, the spontaneous mind wandering scale (MW-S), and the deliberate mind wandering scale (MW-D). They are both 4 item scales (8 items total) that are answered through a 7-point Likert scale where the range is different for certain questions (e.g. "rarely" to "a lot", almost never" to "almost always", etc.). Higher scores on the MW-S indicate a higher propensity to spontaneously mind wander and a higher score on the MW-D indicates a higher propensity to deliberately mind wander. Both scales have a Cronbach's alpha above .80 according to multiple sources (Carriere et al., 2013; Marcusson-Clavertz & Kjell, 2019).

Individual Time Span Scales. We will use the individual time span scales as another measure to investigate participants time perception (Nowack, 2023). It is used to measure individual differences in time as duration and consists of 10 items that are answered using a 7-point Likert scale from "disagree" to "agree". It consists of two different scales that load onto

two different factors, fast time span scales and slow time span scales, where the higher the score for the fast scale indicate feeling that time flows faster, and a higher score for the slow time span scale indicates a feeling of time moving slowly. While this may seem contradictory to each other, these experiences are not mutually exclusive and can both occur at different times. In fact, Nowack (2023) found a negative correlation between the two scales, indicating that the more time a person spends with a sped up or slowed down perception, the less time they spend on the other. The fast time span scale has a Cronbach's alpha of .80, while the slow time span scale has an alpha of .75.

Metacognitive Questionnaire on Time. We used the 12 questions in the "self" scale that load on both the emotion and attention factors of the metacognitive questionnaire on time (Lamotte et al., 2014). These questions pertain to self-awareness of temporal distortions that are answered using a 5-point Likert scale ranging from "totally agree" to "totally disagree", with higher scores less awareness to temporal distortions. The attention factor on the "self" scale has a Cronbach's alpha of .80 while the emotion factor has a Cronbach's alpha of .71.

Attentional Control: Distraction and Shifting Scales. These scales are each 4 items long that reflect self-reported susceptibility to individual distractions and trouble shifting between tasks (Carriere et al., 2013). It uses a 5-point Likert scale that ranges from "almost never" to "always". Higher scores indicate trouble with distraction and trouble with shifting attention to or between different tasks. The distraction scale has a Cronbach's alpha of .80 and the shifting scales have a Cronbach's alpha of .82.

Adult Self-Report ADHD Scale. This scale is used to determine if there is a high probability of the participant having ADHD (Kessler et al., 2005). It is a 6-item set that uses a 0 to 4 Likert scale that goes from "low occurrence" to "high occurrence", where if the final score is

a 4 or above, indicating a high probability of the participant having ADHD. The full version has a Cronbach's alpha of .88.

Mindful Attention Awareness Scale. The mindful attention awareness scale is used to measure trait levels of mindfulness (i.e. the sensitive awareness of what is taking place in the immediate surroundings) (K. W. Brown & Ryan, 2003). It is measured using a 6-point Likert scale ranging from "infrequently" to "frequently", with higher scores reflecting more mindfulness. It has a Cronbach's alpha of around .85 between a student sample an adult sample.

Personal Concerns Scale. This scale is modified from the personal concerns inventory and lists various aspects of life that participants rate how concerned they are about these aspects on a scale from 1 (not at all concerned) to 7 (very concerned) (Cox & Klinger, 2003). The complete list is home and household matters, employment, finances, partner, family, friends, love, intimacy and sexual matters, self-changes, education and training, physical health, cognitive health, mental health, substance use, spiritual/religious matters, and hobbies, pastimes, and recreation.

Environmental Distraction Questionnaire. This 3-item questionnaire is used to gauge how distracting was the environment they were in when doing the experiment. Specifically, it asks the participants when they were doing the questionnaires, how often was there music or a video playing in the background, listening to background conversations, or other distractions. The items are rated on a 7-point Likert scale based on how often these distractions occurred (from "never" to "all of the time").

Demographic Questionnaire. These were 6 total questions to get the participant's age, biological sex, gender, ethnicity, first language, and country of residence.

Procedure

The experiment would be present on the screen and when the participants were ready, they would press a button where it would go into full screen. They would read the consent form, acknowledge they understand what will happen in the experiment, how long it will approximately take, and to turn off their phones. Once they have done so, they begin one of the two experiments which will be counterbalanced across participants. Once participants have finished one of the tasks, they will start the next task. After they finished the second task, they filled out the questionnaires, the order of which will be counterbalanced across participants, and then finish by reading the debriefing form. Any clock in the room will be covered up to avoid having in-person participants looking at it.

Data Cleaning and Exclusion Criteria

There was multiple exclusion criteria based on both SART and starfield metrics that we used to identify bad participants. For the SART, we used the standard cutoff criteria of excluding participants from analysis if their go trial accuracy was lower than 80% or their no-go trial accuracy was lower than 20%. Since Jording et al. (2022) did not exclude participants, we decided that if participant color tracking accuracy was not at chance level of 33%, we would exclude their data. Overall, this excluded 35 participants from the final analyses (33 from the SART, 2 from the starfield), giving us a final total of 164 participants (58 men, 108 women, 2 non-binary).

Results

Starfield Replication

First, to determine whether the starfield color tracking manipulations were successful, I employed a linear mixed effects model to assess how changes in star speed and the changes in density influenced an individual’s subjective time duration and their passage of time. Using time

duration and time perception as response variables and video length, the speed of the stars, the density of the stars, the interaction between video length and speed, video length and density, speed and the density, and a three-way interaction between video length, density, and speed as fixed effects. With random slopes for each participant based on the influence of video length, speed, and density, the two-way interactions between video length and speed, video length and density, density and speed, and the three-way interaction. The model converged with the bobyqa (bound optimization by quadratic approximation) optimizer in R. One change from Jording et al. (2021) is that instead of looking at time duration in terms of how accurate the participants were in estimating it (i.e. $\log\left(\frac{Dutation_{estimate}}{Duration_{real}}\right)$), we looked at how long the duration felt on average. We decided that this change better suited our research question (more psychological vs. more physical properties) and because Jording et al. transform the durations this way to control for the different video durations and to allow them to directly compare the different estimates, which we already control for by mean-centering our estimates (subtracting the participants score by the mean and dividing it by the standard deviation).

The time duration model only had significant main effect of video length ($\hat{\beta} = 0.35$, 95% CI [0.31,0.39], $t(178.09) = 18.25$, $p < .001$). Starfield density was not statistically significant ($\hat{\beta} = -0.03$, 95% CI [−0.07,0.01], $t(288.19) = -1.58$, $p = .114$) and starfield speed was also not statistically significant ($\hat{\beta} = -0.04$, 95% CI [−0.09,0.01], $t(170.11) = -1.47$, $p = .145$). As expected, the duration of the video was an influence on participant's perceived duration showed a positive slope in the model, indicating that duration judgements would increase with video length. No two-way or three-way interaction was significant.

The passage of time model had significant main effects of video length ($\hat{\beta} = 0.29$, 95% CI [0.24,0.33], $t(163.96) = 12.71$, $p < .001$), starfield density ($\hat{\beta} = 0.28$, 95% CI [0.23,0.34],

$t(312.08) = 10.36$, $p < .001$), starfield speed ($\hat{\beta} = 0.56$, 95% CI [0.47,0.65], $t(163.55) = 12.10$, $p < .001$), the two-way interaction between the video length and density ($\hat{\beta} = -0.07$, 95% CI $[-0.12, -0.02]$, $t(171.36) = -2.67$, $p = .008$), and the two way interaction between starfield speed and density ($\hat{\beta} = -0.08$, 95% CI $[-0.16,0.00]$, $t(202.98) = -2.08$, $p = .039$). Video length had a statistically significant and positive slope to indicate that longer videos were associated with slower percieved passage of time. Density also had a statistically significant positive slope, where lower density starfields were associated with slower passage of time. Starfield speed had a larger association with passage of time, with slower star speeds being related to slower percieved passage of time. The two-way interactions had negative slopes, indicating the different effects of density at different video lengths and the different effects of speed at different densities.

Table 1

Linear mixed effects models for time duration and passage of time from the starfield color tracking task

	Time Duration			Passage of Time		
Predictors	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*
(Intercept)	0.03	-0.09 – 0.16	0.570	-0.40	-0.49 – -0.31	**<0.001**
Video Length	0.35	0.31 – 0.39	**<0.001**	0.29	0.24 – 0.33	**<0.001**
Star Density [Low]	-0.03	0.07 – 0.01	0.113	0.28	0.23 – 0.34	**<0.001**
Star Speed [Low]	-0.04	-0.09 – 0.01	0.143	0.56	0.47 – 0.65	**<0.001**
Video Length x Density [Low]	0.02	-0.02 – 0.05	0.377	-0.07	-0.12 – -0.02	**0.008**
Video Length x Speed [Low]	-0.00	-0.04 – 0.03	0.832	-0.05	-0.10 – 0.00	0.056

Density [Low] x Speed [Low]	-0.00	-0.05 – 0.05	0.857	-0.08	-0.16 – -0.00	**0.037**
Video Length x Density [Low] x Speed [Low]	0.00	-0.05 – 0.05	0.970	0.07	-0.01 – 0.14	0.069

Random Effects

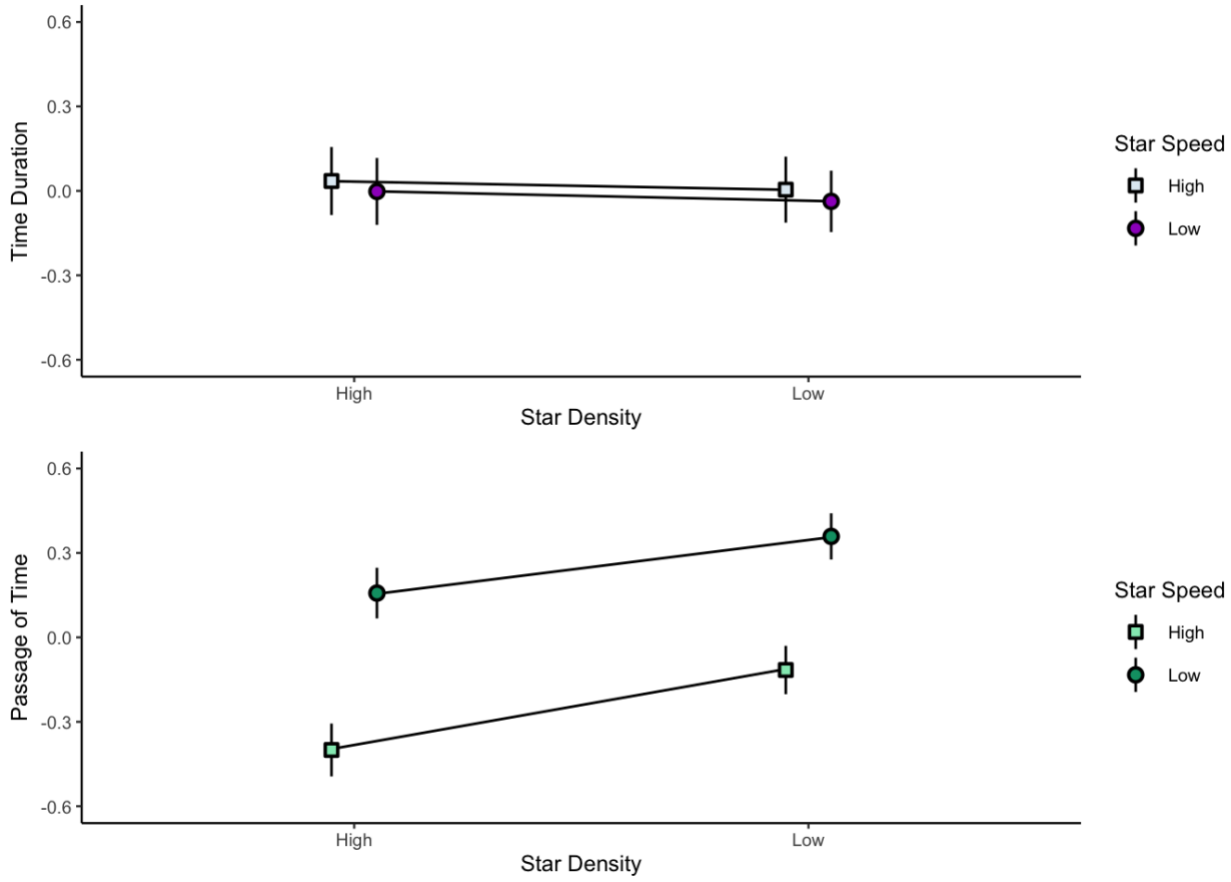
σ^2	0.28	0.54
τ_{00}	0.60 $_{sub_id}$	0.33 $_{sub_id}$
τ_{11}	0.04 $_{sub_id.Seconds}$	0.03 $_{sub_id.Seconds}$
	0.01 $_{sub_id.StarsLow}$	0.03 $_{sub_id.StarsLow}$
	0.05 $_{sub_id.SpeedLow}$	0.25 $_{sub_id.SpeedLow}$
	0.01 $_{sub_id.Seconds:StarsLow}$	0.02 $_{sub_id.Seconds:StarsLow}$
	0.00 $_{sub_id.Seconds:SpeedLow}$	0.02 $_{sub_id.Seconds:SpeedLow}$
	0.01 $_{sub_id.StarsLow:SpeedLow}$	0.06 $_{sub_id.StarsLow:SpeedLow}$
	0.00 $_{sub_id.Seconds:StarsLow:SpeedLow}$	0.04 $_{sub_id.Seconds:StarsLow:SpeedLow}$
ρ_{01}	0.36	0.05
	-0.30	-0.48
	-0.21	-0.49
	0.43	-0.00
	0.57	-0.05
	-0.62	-0.03
	0.52	-0.05
N	164 $_{sub_id}$	164 $_{sub_id}$
Observations	7216	7216
Marginal R^2 / Conditional R^2	0.316 / NA	0.208 / NA

A closer examination of the duration and passage of time graphs in Figure 1 reveals key patterns. Duration judgements show a weak effect of density, while passage of time demonstrates a strong effect of speed and a smaller effect of density, replicating Jording et al. (2021). We also observed a small interaction between speed and density where denser and faster starfield show a more hastened passage of time than a low density and slow starfield. It is also important to note that, density and speed did not influence perceived passage of time to the same extent. Where a

slower, denser starfield is perceived as having a slower passage of time than a faster, sparse starfield.

Figure 2

The influence of starfield speed and density on both time duration judgements (top graph) and passage of time judgments (bottom graph)



Mind Wandering Relationship

Next, I examined the relationship between time perception and mind wandering using two linear mixed-effects models with both time duration and passage of time as the response variables and off-task thoughts, task-related interference, thoughts about time, video length, starfield speed and density, and the interaction between the two as fixed effects. The random

effects were the influences of video length, starfield density, starfield speed and the two- and three-way interactions between speed, density, and video length on individual participants. The models both converged with the bobyqa optimizer.

There was a small, but significant, association between time perception and mind wandering. For time duration, we see that there is a significant positive relationship with task unrelated thoughts ($\hat{\beta} = 0.11$, 95% CI [0.01,0.20], $t(164.53) = 2.09$, $p = .038$), but no relationship with task related interference, or thoughts about time. This indicates that time duration estimates were positively associated with rates of off-task thought. On the other hand, passage of time has no association with any type of thought content, but there was a marginal effect of time related thoughts ($\hat{\beta} = 0.07$, 95% CI [0.00,0.15], $t(160.65) = 1.94$, $p = .054$).

Table 2

Linear mixed effects models for time duration and passage of time including the thought content from the SART

	SF: Time Duration			SF: Passage of Time		
Predictors	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*
(Intercept)	0.03	-0.09 – 0.16	0.569	-0.40	-0.49 – -0.31	**<0.001**
SART: TUT	0.11	0.01 – 0.20	**0.037**	-0.03	-0.11 – 0.05	0.491
SART: TRI	-0.03	-0.13 – 0.07	0.512	-0.08	-0.15 – 0.00	0.064
SART: Time-Related	0.08	-0.02 – 0.17	0.110	0.07	-0.00 – 0.15	0.052
SF: Video Length	0.35	0.31 – 0.39	**<0.001**	0.29	0.24 – 0.33	**<0.001**
SF: Star Density [Low]	-0.03	-0.07 – 0.01	0.113	0.28	0.23 – 0.34	**<0.001**
SF: Star Speed [Low]	-0.04	-0.09 – 0.01	0.143	0.56	0.47 – 0.65	**<0.001**

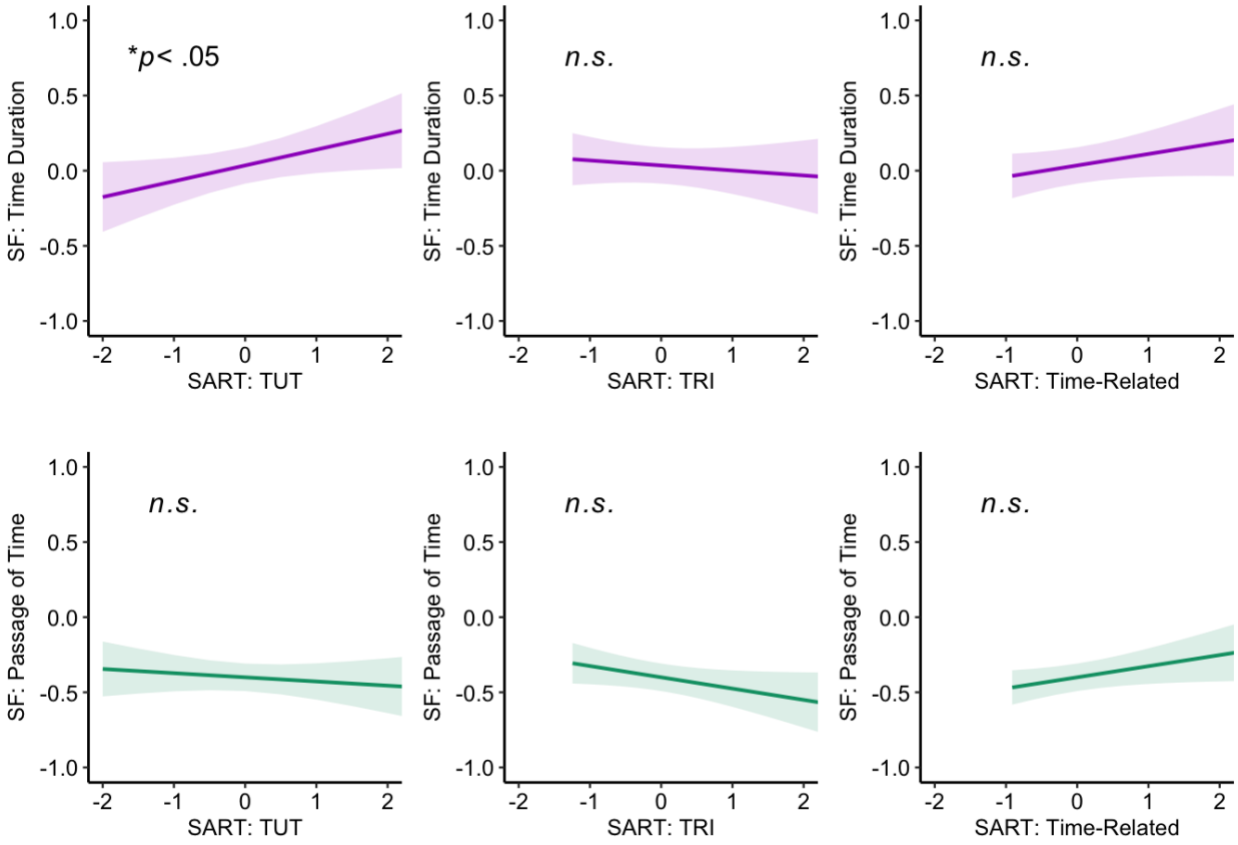
Video Length x Density [Low]	0.02	-0.02 – 0.05	0.378	-0.07	-0.12 – -0.02	**0.008**
Video Length x Speed [Low]	-0.00	-0.04 – 0.03	0.832	-0.05	-0.10 – 0.00	0.056
Density [Low] x Speed [Low]	-0.00	-0.05 – 0.05	0.857	-0.08	-0.16 – -0.00	**0.037**
Video Length x Density [Low] x Speed [Low]	0.00	-0.05 – 0.05	0.970	0.07	-0.01 – 0.14	0.069

Random Effects

σ^2	0.28	0.54
τ_{00}	0.59 $_{sub_id}$	0.31 $_{sub_id}$
τ_{11}	0.04 $_{sub_id.Seconds}$	0.03 $_{sub_id.Seconds}$
	0.01 $_{sub_id.StarsLow}$	0.03 $_{sub_id.StarsLow}$
	0.05 $_{sub_id.SpeedLow}$	0.25 $_{sub_id.SpeedLow}$
	0.01 $_{sub_id.Seconds:StarsLow}$	0.02 $_{sub_id.Seconds:StarsLow}$
	0.00 $_{sub_id.Seconds:SpeedLow}$	0.02 $_{sub_id.Seconds:SpeedLow}$
	0.01 $_{sub_id.StarsLow:SpeedLow}$	0.06 $_{sub_id.StarsLow:SpeedLow}$
	0.00 $_{sub_id.Seconds:StarsLow:SpeedLow}$	0.04 $_{sub_id.Seconds:StarsLow:SpeedLow}$
ρ_{01}	0.36	0.03
	-0.28	-0.49
	-0.24	-0.48
	0.47	0.00
	0.47	0.02
	-0.60	0.01
	0.53	-0.10
N	164 $_{sub_id}$	164 $_{sub_id}$
Observations	7216	7216
Marginal R^2 / Conditional R^2	0.347 / NA	0.223 / NA

Figure 3

Predictive graphs showing the relationships between the time perception judgements and the different types of thought content



Discussion

The starfield task, following Jording et al. (2021), demonstrated that low-level visual features significantly influenced subjective time perception. Specifically, both increased speed and density of the starfield stimuli were associated with participants perceiving a hastened passage of time. We also replicated their findings of limited influence on perceived time duration, with only an influence of video length on our sense of duration. Jording et al. explain the lack of effects for duration judgements in their second experiment due to being underpowered and participants being affected by being asked both duration judgements and

passage of time judgements. With the current study being adequately powered and asking both duration and passage judgements, time duration appears to not be influenced by the starfield or low-level stimulus features. When looking at the two-way interactions, we can see that the passage of time judgements has a smaller difference between speeds at lower densities and a smaller difference between different video lengths at lower densities. The effects of speed, however, were not influenced by video lengths. The lack of an effect on time duration seems to support the conclusion that rather than influencing time perception, it is probably best described as a task that primarily influences only perceived passage of time.

Our analysis of mind wandering and time perception using linear mixed effects models revealed unexpected results. Where we anticipated finding associations with time-related thoughts, none emerged. Passage of time showed only a marginal, but not statistically significant effect and there was clearly no association with time duration. This is surprising considering the previous and anecdotal evidence showing connections between subjective time perception and time-related thoughts and how focusing on time seems to slow it. This lack of a findings may be attributed to the shorter videos and brief time durations (e.g. ~10 seconds) being insufficient to make time feel like it is moving slower.

We did find an association between task-unrelated thoughts measured in the SART, and time duration judgements measured in the starfield color tracking task. Participants who frequently overestimated the duration of time judgements in the starfield task were also more likely to engage in task-unrelated thoughts during the SART. This association aligns with previous research demonstrating increased with time on task (Risko et al., 2012; for review, see Zanesco et al., 2024) and is consistent with our hypothesis that lengthened time perception would result in increased mind wandering due to the shared underlying mechanism. However, due to

our experimental design, causal relationships between time perception and mind wandering cannot be established without direct manipulation of time perception.

Experiment 2

While Experiment 1 examined individual differences in time perception and mind wandering through separate tasks, Experiment 2 directly manipulated time perception and measured resulting changes in participants' mind wandering rates within a single task. This integration allows us to establish causal relationships and determine directionality. Using a variation of the starfield color tracking task, participants continuously reported whenever the dominant color changed (Jording et al., 2022). Mind wandering was measured through thought probes at the end of each trial, enabling us to observe how variations in speed and density affect mind wandering rates.

My hypotheses parallel those of Experiment 1. When time perception is hastened, I predict that rates of mind wandering will decrease, and when time perception is slowed, I expect higher rates of mind wandering. This is due to more pulses reaching the accumulator and allowing for more chances for thoughts to shift inward while also slowing down our sense of time perception at the same time as opposed to time perception directly causing a change in our rates of mind wandering. Alternatively, if fewer pulses reach the accumulator (faster time perception) and mind wandering increases, this might suggest that mind wandering episodes occur to account for accelerated time perception, reflecting the known association between mind wandering and faster time perception.

Method

Participants.

Again, students enrolled in a first-year psychology course were recruited through the University of Manitoba's "SONA" system. They completed the study to receive course credit. Based on a power analysis, to detect an effect size (d) around 0.3, we needed at least 90 participants for a matched samples t-test with 80% power. We managed to get 119 participants.

Tasks.

Continuous Response Starfield Color Tracking Task. Adapted from the starfield color tracking task in experiment 1, participants did an adapted starfield color tracking task where colored "stars" will fly towards the screen and the ratio of colors changed unpredictably and participants must indicate via a keypress when they thought a color had dominated the screen. They either pressed "R" for red, "G" for green, or "B" for blue. Trial durations lasted between 30-60 seconds in 4 second intervals (32s, 36s, 40s, etc.) with the starfield having different combinations of being slow or fast, and sparse or dense. Participants saw all combinations of starfield at each duration. At the end of each trial, participants answered the Kane et al. thought probe to see if the participant was on-task, off task or having task related interference in terms of either the task experience or difficulty or in regards to thoughts about time. This thought probe asked participants if they were thinking about the task, the task experience/difficulty, everyday things, current state of being, personal worries, daydreams, external environment, the passage or duration of time (e.g. thinking about how much time has passed or how much time is left in the experiment), and an option for an unlisted topic. The creators of the starfield color tracking task have stated that the task instructions to focus on the color should help the participants avoid thoughts related to time, the inclusion of a time related TRI question helps validate this claim and allow for exploratory analyses regarding TRI and how it might be potentially being confused as mind wandering. The changes to the starfield from experiment 1 were done to make the task

more equivalent with a sustained attention task and to try and keep participant attention directed towards the task throughout the entirety of the starfield trial.

Questionnaires.

The questionnaires are the same as Experiment 1: the boredom proneness scale, the deliberate and spontaneous mind wandering scale, the individual time span scales, and the "self" scale of the metacognitive questionnaire on time, the distraction and shifting scales for attentional control, the adult self-report ADHD scale, the mindful attention awareness scale, the personal concerns scale, environmental distraction questionnaire, and our demographic questionnaire.

Procedure

Our procedure had participants come in, press a button to make the experiment full screen, read our consent form, acknowledge that they understand what will be happening in the experiment and then begin the experiment. They will complete the experiment in a room with other students where they will be instructed to keep the experiment in full screen, so the computers digital clock is covered up and for their phones to be turned off to avoid distraction or any ability to track time (e.g., alarms). When participants are finished with the experiment, they will then complete the questionnaires, the order of which will be counterbalanced across participants, read a debriefing form and then leave.

Data Cleaning and Exclusion Criteria

Since we set the experiment to record 100 keyboard responses, we wanted to make sure we weren't using trials that exceeded these 100 responses or participants that frequently exceeded this limit. Another problem is participant's not responding which we also wanted to remove trials or participants with limited responses. Since the starfield would change between 5-

11 times depending on the video length, we wanted to set the exclusion criteria to be around 20 responses. We therefore removed any trial with an excess of 20 responses, and all participant data was removed if they had more than 4 trials with an excess of 20 responses or no responses recorded, that participant was removed from the data. We removed a total of 16 participants with 102 participants data available for analysis (24 men, 73 women, 1 non-binary, 4 self-described).

Results

We used a repeated measures factorial ANOVA to analyze if rates of mind wandering change with subjective time perception. The response variable is the proportion of mind wandering with a 2 (starfield speed: fast or slow) by 2 (starfield density: dense or sparse) by 3 (thought content: TUT, task related interference, or time related thoughts).

Critically, the results indicated a significant three-way interaction ($F(1.70,171.84) = 5.57, p = .007$). Additionally, there was a significant two-way interaction between the starfield speed and the type of mind wandering ($F(1.75,176.66) = 17.83, p < .001$) and a main effect of speed ($F(1,101) = 20.96, p < .001$). There was no difference in starfield density and the two-way interactions between starfield speed and density and between starfield density and type of mind wandering were not significant. Corrections for sphericity were done using the Greenhouse-Geisser correction.

Table 3

ANOVA table for the proportion of mind wandering

Effect	df	MSE	F	η_g^2	p-value
Density	1, 101	0.01	1.62	<.001	.206
Speed	1, 101	0.01	20.96 ***	.004	**<.001**
Probe Response Category	1.55, 156.07	0.14	208.91 ***	.525	**<.001**
Density:Speed	1, 101	0.01	0.00	<.001	.964
Density:Probe Response Category	1.73, 174.39	0.03	0.32	<.001	.692
Speed:Probe Response Category	1.75, 176.66	0.03	17.83 ***	.019	**<.001**
Density:Speed:Probe Response Category	1.70, 171.84	0.02	5.57 **	.005	**.007**

Three-way Interaction Investigation

To further understand the three-way interaction and the effects the starfield had on mind wandering, we analyzed each of the thought probe responses separately using a two-way ANOVA with starfield speed and density as the factors.

Off Task

Table 4

ANOVA for the proportion of mind wandering that was categorized as off task with density and speed as independent variables

Effect	df	MSE	F	η_g^2	p-value
Density	1, 101	0.03	0.01	<.001	.940
Speed	1, 101	0.03	17.30 ***	.021	**<.001**
Density:Speed	1, 101	0.02	4.69 *	.004	**.033**

For the off-task 2 x 2 ANOVA, we see there is a main effect of speed ($F(1,101) = 17.30$, $p < .001$) and an interaction between speed and density ($F(1,101) = 4.69$, $p = .033$), but no main effect of density. Due to this interaction, we took an even closer look to determine what the specific direction of the interaction through two t-tests. Through these t-tests, we can see that there is a bigger difference in off-task thoughts between high and low speeds at higher densities ($\Delta M = -0.10$, 95% CI $[-0.17, -0.04]$, $t(201.96) = -3.04$, $p = .003$) than at lower densities ($\Delta M = -0.04$, 95% CI $[-0.11, 0.03]$, $t(199.30) = -1.16$, $p = .247$.

Task Related Interference

Table 5

ANOVA table for the proportion of mind wandering that was categorized as task related interference with speed and density as independent variables

Effect	df	MSE	F	η_g^2	p-value
Density	1, 101	0.02	0.00	<.001	>.999
Speed	1, 101	0.01	21.46 ***	.021	**<.001**
Density:Speed	1, 101	0.01	9.45 **	.010	**.003**

For the task related interference ANOVA, we also find a main effect of starfield speed ($F(1,101) = 9.45$, $p = .003$)and an interaction between stars and speed ($F(1,101) = 21.46$, $p < .001$) and no main effect of density. We again see that there is a larger difference of task related interference between high and low speeds at higher densities ($\Delta M = 0.08$, 95% CI $[0.03, 0.13]$, $t(199.18) = 3.41$, $p < .001$) than at lower densities ($\Delta M = 0.02$, 95% CI $[-0.03, 0.06]$, $t(201.83) = 0.70$, $p = .487$)

Time-Related

Table 6

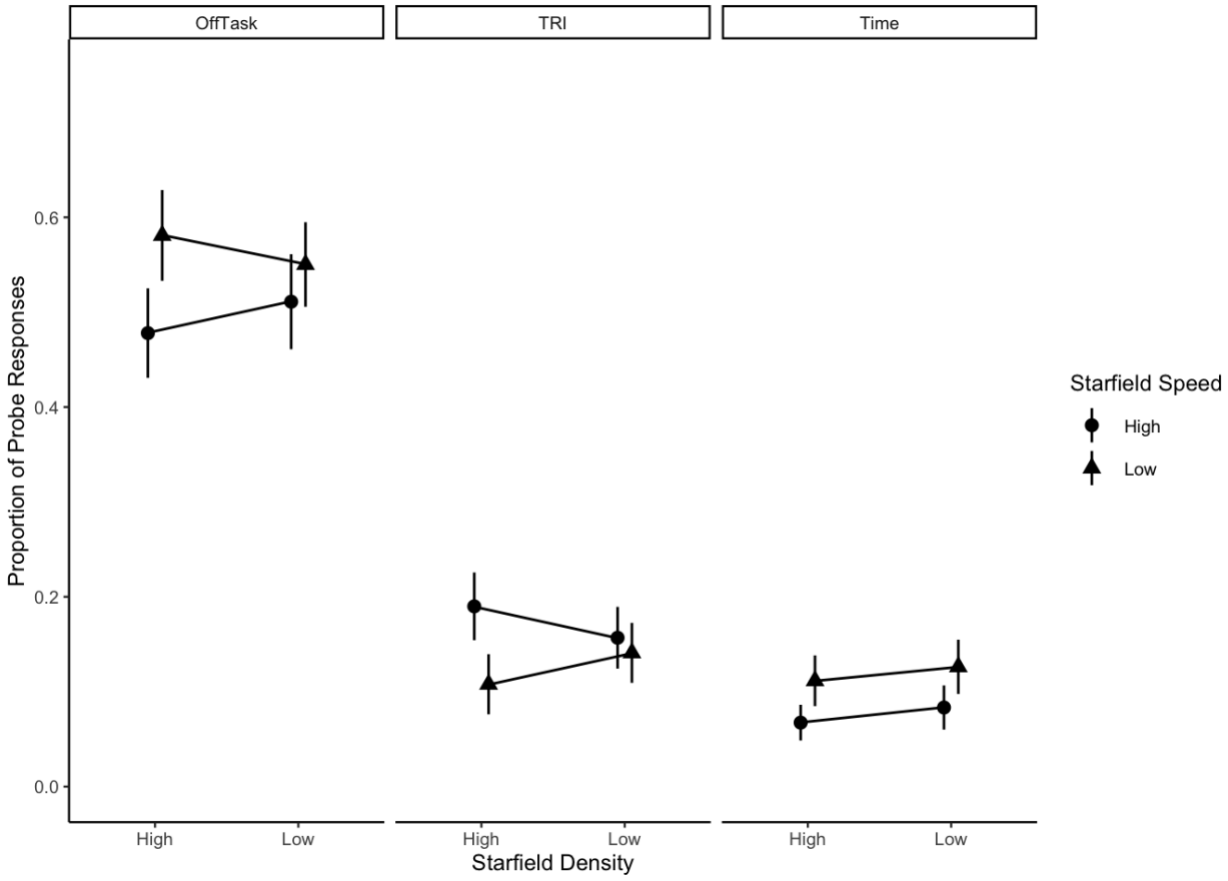
ANOVA table for the proportion of mind wandering that was categorized as time related thoughts with speed and density as independent variables

Effect	df	MSE	F	η_g^2	p-value
Density	1, 101	0.01	2.66	.004	.106
Speed	1, 101	0.01	17.48 ***	.029	**<.001**
Density:Speed	1, 101	0.01	0.00	<.001	.953

For time-related thoughts, we only see an effect of speed ($F(1,101) = 17.48, p < .001$) and no main effect of density, nor an interaction between the two. Therefore, we did not do any further investigation into time-related thoughts.

Figure 4

Proportion of probe responses for each category of response across starfield speed and density



Based on Experiment 1's findings that perceived time duration increased with video length, and given previous research showing mind wandering increases with time on task, we conducted a separate ANOVA to examine potential differences in both the frequency and type of mind wandering across different video durations. We found no difference in mind wandering between the different lengths of the video ($F(6.54,660.55) = 1.99, p = .059$) but this effect was marginal. We also find that video length did not interact with the type of mind wandering ($F(10.61,1071.44) = 1.21, p = .274$).

Discussion

The relationship between mind wandering and time perception is complex. In this experiment, I manipulated the starfield and while measuring off-task thoughts, time-related thoughts and task-related interference throughout the task. I found that rates of off-task thought were more frequent in the low- versus high-speed conditions, but only at high densities. Since both mind wandering and time perception judgements (from Experiment 1) were influenced by starfield speed, this suggests they share an underlying mechanism – as hypothesized.

Task-related interference showed an opposite pattern, with the highest levels occurring during faster and denser starfields. The difference between speeds was more pronounced at higher densities as well. This may have been due to faster and denser starfields being more distracting and requiring more attention than slower and sparser starfields. Finally, time-related thoughts were influenced solely by speed, increasing during slower starfields regardless of density.

Different types of mind wandering occurred at varying frequencies. Task unrelated thoughts occurred the most often, around 50-60% of the time on average. This is above the previously described rates of mind wandering which posit that these thoughts occur at around 30-

50% of our daily lives (Smallwood & Schooler, 2006). Although, there have also been differences in the proportion of off-task thoughts found in the lab and those found in more naturalistic environments, which might explain the increase here (Varao-Sousa et al., 2018). I also observed similar rates of task related interference, time related thoughts, and on-task thoughts, each comprising 10-25% of responses. The separation of these thought categories likely resulted in lower proportions of mind wandering and on-task thoughts compared to if they had been combined.

Exploratory Analyses

Table 7

Means, standard deviations and Cronbach's alpha of all questionnaires

Questionnaires	Mean	Standard Deviation	Cronbach's Alpha
Adult Short Report ADHD Scale	3.38	0.67	0.72
Mindful Attention Awareness Scale	3.56	0.82	0.85
Spontaneous Mind Wandering Scale	4.99	1.29	0.88
Deliberate Mind Wandering Scale	4.85	1.34	0.89
Attentional Control: Distraction Scale	3.55	0.80	0.81
Attentional Control: Shifting Scale	3.15	0.81	0.85
Short Boredom Proneness Scale	3.89	1.22	0.89

Questionnaires	Mean	Standard Deviation	Cronbach's Alpha
Individual Time Span Scale	4.43	0.63	NA
Individual Time Span Scale: Fast	5.18	0.94	0.80
Individual Time Span Scale: Slow	3.69	0.83	0.58
Metacognitive Questionnaire on Time	2.44	0.26	NA
Metacognitive Questionnaire on Time: Attention	2.50	0.38	0.32
Metacognitive Questionnaire on Time: Emotion	2.34	0.47	0.41
Personal Concerns Inventory	4.32	1.13	0.88

To gain a complete picture of how mind wandering and time perception are related, I compared the relationships between time perception and attention as measured by the various questionnaires. I combined participants from experiment 1 and 2 because they all completed the same questionnaire data, and the increased participant count helps to improve power and validity of these results.

Table 8

Linear regression model for the spontaneous and deliberate mind wandering scales and how they relate to age, sex, slow time span scale, fast time scan scale, and to the other mind wandering scale

	Mind Wandering - Spontaneous			Mind Wandering - Deliberate		
Predictors	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*
(Intercept)	0.08	-0.37 – 0.52	0.737	0.25	-0.21 – 0.71	0.287
age	0.00	-0.02 – 0.02	0.848	-0.02	-0.04 – 0.01	0.156
sex [Male]	-0.36	-0.56 – -0.16	**0.001**	0.24	0.02 – 0.45	**0.029**
ITSS: Slow	0.14	0.05 – 0.24	**0.003**	0.10	-0.00 – 0.20	0.057
ITSS: Fast	0.17	0.07 – 0.26	**0.001**	0.10	-0.00 – 0.20	0.060
MW-D	0.41	0.32 – 0.51	**<0.001**			
MW-S				0.45	0.34 – 0.56	**<0.001**
Observations	313			313		
R^2 / R^2 adjusted	0.307 / 0.296			0.265 / 0.253		

Mind wandering and ITSS. First, using a linear regression model, I examined the relationship between self-reported deliberate and spontaneous mind wandering and the ITSS which measure the propensity to star mind wandering randomly (i.e. spontaneously) or purposefully (i.e. deliberate). The individual time span scales measure individual differences in time and contains two scales that measure how fast (i.e. fast time span scale) or slow (i.e. slow time span scale) moves. Here, I found that both fast ($b = 0.17$, 95% CI [0.07,0.26], $t(307) = 3.42$, $p < .001$) and slow ($b = 0.14$, 95% CI [0.05,0.24], $t(307) = 2.96$, $p = .003$) time perception as measured by the individual time span scales, were only related to spontaneous mind wandering and both showed positive estimates implying that increases in spontaneous mind wandering are associated with increases in both faster and slower perceptions of time.

Table 9

Linear regression model for the attentional control shifting and distraction scales and how they relate to age, sex, slow time span scale, fast time span scale, and to the other attention control scale

	AC: Shifting			AC: Distraction		
Predictors	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*
(Intercept)	-0.34	-0.78 – 0.10	0.133	0.35	-0.10 – 0.79	0.125
Age	0.02	-0.00 – 0.04	0.114	-0.02	-0.04 – -0.00	**0.045**
Sex [Male]	-0.03	-0.24 – 0.18	0.789	0.34	0.13 – 0.54	**0.001**
ITSS: Slow	-0.20	-0.29 – -0.11	**<0.001**	-0.01	-0.11 – 0.09	0.850
ITSS: Fast	0.05	-0.04 – 0.15	0.274	-0.13	-0.22 – -0.03	**0.008**
AC: Distraction	0.49	0.40 – 0.59	**<0.001**			
AC: Shifting				0.51	0.41 – 0.60	**<0.001**
Observations	313			313		
R^2 / R^2 adjusted	0.317 / 0.306			0.313 / 0.302		

Attentional Control: Shifting and Distraction Scales. Looking at the shifting and distraction scales, which measure troubles in attentional control when switching between tasks or with mitigating distractions, I found a similar effect. The results show that having trouble with shifting between tasks are negatively associated with the slow time span scale ($b = -0.20$, 95% CI $[-0.29, -0.11]$, $t(307) = -4.21$, $p < .001$), which means that the when an individual has a difficulties in switching between tasks, the more likely they are to also have a slower time perception with time standing still or lasting longer. The shifting scales are not associated with a faster time perception though ($b = 0.05$, 95% CI $[-0.04, 0.15]$, $t(307) = 1.10$, $p = .274$). However, the opposite occurs for the shifting scales, where there is a negative association between the faster time span scale and trouble with distractions ($b = -0.13$, 95% CI

$[-0.22, -0.03]$, $t(307) = -2.68$, $p = .008$). There is not any association with the slow time span scale ($b = -0.01$, 95% CI $[-0.11, 0.09]$, $t(307) = -0.19$, $p = .850$) and shows how time perception differentially loads onto attentional control.

Table 10

Linear regression model of the mindful attention awareness scale and how it relates to age, sex, the slow time span scale, and the fast time span scale

	Mindful Attention Awareness Scale		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	-0.06	-0.55 – 0.42	0.794
age	0.00	-0.02 – 0.02	0.990
sex [Male]	0.18	-0.04 – 0.41	0.110
ITSS: Slow	-0.32	-0.42 – -0.21	**<0.001**
ITSS: Fast	-0.14	-0.24 – -0.03	**0.009**
Observations	313		
R^2 / R^2 adjusted	0.136 / 0.124		

Mindful Attention Awareness Scale. The mindful attention awareness scale measures trait levels of mindfulness and is also related to time perception. Where mindfulness is negatively associated with both the fast ($b = -0.14$, 95% CI $[-0.24, -0.03]$, $t(308) = -2.62$, $p = .009$) and slow time span scales ($b = -0.32$, 95% CI $[-0.42, -0.21]$, $t(308) = -6.05$, $p < .001$). While they are in the same direction, slower time perception is more strongly related than a faster time perception.

Table 11

Linear regression model for the short boredom proneness scale and how it relates to age, sex, the slow time span scale, and the fast time span scale

	Short Boredom Proneness Scale		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	4.28	3.70 – 4.87	**<0.001**
age	-0.02	-0.05 – 0.01	0.200
sex [Male]	-0.08	-0.35 – 0.19	0.563
ITSS: Slow	0.45	0.33 – 0.58	**<0.001**
ITSS: Fast	0.15	0.03 – 0.27	**0.018**
Observations	313		
R^2 / R^2 adjusted	0.172 / 0.161		

Short Boredom Proneness Scale. This scale measures boredom proneness and has an interesting relationship with time perception. While both fast ($b = 0.15$, 95% CI [0.03,0.27], $t(308) = 2.37$, $p = .018$) and slow ($b = 0.45$, 95% CI [0.33,0.58], $t(308) = 7.25$, $p < .001$) time spans are related to boredom proneness, the slow time perception is more strongly related to boredom proneness. Showing how boredom and slower time perception are obviously related, but that boredom can also lead to a hastened sense of time.

Table 12

Linear regression model for the metacognitive questionnaire on time and how it relates to, age, sex, the spontaneous mind wandering scale, the deliberate mind wandering scale, the slow time span scale, and the fast time span scale

	Metacognitive Questionnaire on Time		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	2.42	2.28 – 2.56	**<0.001**
age	0.00	-0.01 – 0.01	0.792
sex [Male]	0.02	-0.04 – 0.09	0.490

MW-S	0.02	-0.02 – 0.05	0.270
MW-D	-0.01	-0.05 – 0.02	0.492
ITSS: Slow	0.01	-0.02 – 0.04	0.701
ITSS: Fast	-0.01	-0.04 – 0.02	0.377
Observations	313		
R^2 / R^2 adjusted	0.008 / -0.012		

Metacognitive Questionnaire on Time. Finally, when looking at the metacognitive questionnaire on time which measures individual awareness of temporal distortions, there was no relationship between either types of mind wandering (spontaneous: $b = 0.02$, 95% CI $[-0.02,0.05]$, $t(306) = 1.11$, $p = .270$, deliberate: $b = -0.01$, 95% CI $[-0.05,0.02]$, $t(306) = -0.69$, $p = .492$) or either time span scales (fast: $b = -0.01$, 95% CI $[-0.04,0.02]$, $t(306) = -0.88$, $p = .377$, slow: $b = 0.01$, 95% CI $[-0.02,0.04]$, $t(306) = 0.38$, $p = .701$). Showing how our awareness to changes in our subjective time perception does not depend on or is even associated with the specific change in time perception or type of mind wandering.

General Discussion

The relationship between time perception and mind wandering, while evident in both behavioral and trait level measurements, proved more complex than hypothesized. In Experiment 1, I examined the relationship between time perception and mind wandering using time duration and passage of time judgments from the starfield color tracking task and the rates of different types of mind wandering as measured by the SART. I replicated Jording et al. (2022) using the starfield task to manipulate individual time perception, however this only influenced the passage of time judgments. Regarding the thought content, I did not find the expected relationship

between either aspect of time perception and time related thoughts, but I did find a positive relationship between mind wandering and overestimating time duration judgments. Thus, participants who reported more frequent mind wandering in one task, also tended to overestimate time duration judgments in the other task.

In Experiment 2, I experimentally manipulated rates of mind wandering through changes in speed and density during the starfield color tracking task. I found a three-way interaction between starfield density, speed, and the specific type of thought content. Where off- task responses increased when the starfield was slower rather than higher and that this difference between speeds was larger for high density starfields as opposed to low density starfields. Task-related interference had the greatest proportion in higher speed starfields with the biggest difference between speeds also being at higher densities. Finally, time related thoughts only increased for higher speed lower speed starfields with no difference in proportion at either density. Overall, I observed a relationship between mind wandering and time perception through my starfield manipulations. The differential effects of speed on task-unrelated thoughts and task-related interference may have been influenced by video length, as Experiment 1 found that density effects varied with video duration, and this effect might similarly influence density at these longer durations.

Finally, across the exploratory analyses, I observed associations with mind wandering and time perception and with related variables. Interestingly, I found a direct connection between trait level measures of spontaneous mind wandering and fast and slow senses of time perception in the same direction, but there were no associations with deliberate mind wandering. Similar findings emerged with mindfulness awareness and boredom proneness in the same direction. A differentiation was found with the different types of attentional control where slower time

perception was related to trouble with switching between multiple tasks and faster time perception was associated with trouble dealing with distractions. There appears to be no relationship between susceptibility to temporal illusions and either sense of time perception or either type of trait-level mind wandering.

Taken together the results demonstrate a clear relationship between time perception and mind wandering with evidence in both self-report and behavioral measures – making this the first study to show this relationship with robust evidence. This relationship is evidence in three ways: the correlation between overestimating time duration and the frequency of off-task thoughts in Experiment 1, the increase in off-task thoughts resulting from time perception in Experiment 2, and the associations between both levels of time perception and spontaneous mind wandering. However, the data does not provide a straightforward interpretation, especially in the context of the pace-maker accumulator model of time perception.

These results do not support either hypothesis – that increased pulses would slow time perception and increase mind wandering, or that hastened time perception would trigger mind wandering episodes. Instead, the highest rates of mind wandering occurred with starfields that produced neither faster nor a slower sense of time perception, but rather a more medium pace. Within the pacemaker-accumulator framework, receiving pulses at a medium rate led to the most attentional changes. While this does put the idea that each pulse has a chance to change our thoughts, there is the potential that the pulses must meet a certain threshold before our thoughts could change and that certain conditions could either lower the threshold or allow the pulses to more easily reach the threshold.

These results align with the attentional cycling theory. Both slower and faster time perceptions might correspond to situations demanding immense concentration or instinctual

reactions (e.g. monitoring the hunting ground for prey, fighting for your life against a predator). In contrast, more mundane and "normal" situations permit mind wandering – suggesting that off-task might be a "privilege" available primarily in circumstances that enable medium time perception.

While these results can be explained from the pacemaker-accumulator model of time perception, this study was not designed to definitively prove that it is the superior model, and our results do fit with other time perception theories. For example, in memory models of time perception we could explain our results as the memory traces from previously measured intervals could be influenced by mind wandering during the interval. Overall, this study does not support one model over another, it just provides evidence that the same mechanisms that give us our sense of time perception are the same, or at the very least, overlap with, the mechanisms that control the frequency of our shifts in attention.

Alternative Explanations, Limitations and Future Research.

No study is without limitations, and this is no exception and while we tried to cover all of them, there were a few that remained that could cause issues with our analysis and explanations. Firstly, while the experiment was fullscreen, the starfield did not take up the entire screen with black space filling up the remaining area between the edge of the starfield and the edge of the monitor. This does not seem to have influenced our findings, but it does raise the question as to whether we might find something different or a bigger effect if the starfield filled up more of the participants field of vision. To combat this, future research should not only try to have the starfield match the size of the display but perhaps also try and use equipment like virtual reality headsets to completely fill the participants vision and lead to potentially less susceptibility to distractions in the external environment.

As we previously alluded to, each experiment had different lengths of videos and while it did show that the starfield does influence time perception at shorter durations, the effects on mind wandering raise some questions. Perhaps time perception only influences mind wandering rates over longer intervals and that we would not find anything at these shorter durations. Therefore, future research could run experiment 1 again but using longer duration intervals or experiment 2 at shorter intervals. Future research should also investigate sub-10 second intervals and see how time perception would influence mind wandering as if there is a bidirectional relationship at these lengths.

Finally, future research should investigate how different types of mind wandering influence time perception. Previously, Mathews et al., (2024) found that remembered mind wandering and feelings of inattention both loaded onto the spontaneous mind wandering scale rather than the deliberate mind wandering scale. This might help explain why a medium time perception is the most conducive for mind wandering as certain time perceptions might differentially influence different types of mind wandering and why both why we see both time span scales being related to the spontaneous mind wandering scale. In the current experiment, our findings are more representative of an overall view of the influence of time perception on mind wandering and could be missing more of the nuanced details of this relationship and how it relates to our executive functioning and attentional resources. This difference in mind wandering is also very important as participants may not remember their thought content and be able to reliably and accurately answer the probe if they can't remember what they were thinking about.

References

Blondé, P., Sperduti, M., Makowski, D., & Piolino, P. (2021). Bored, distracted, and forgetful: The impact of mind wandering and boredom on memory encoding. *Quarterly Journal of Experimental Psychology (2006)*, 174702182110263. https://doi.org/10.1177/17470218211026301

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*. https://doi.org/10.1037/cns0000263

Brown, K. W., & Ryan, R. M. (2003). The benefits of being present: Mindfulness and its role in psychological well-being. *Journal of Personality and Social Psychology*, *84*(4), 822–848. https://doi.org/10.1037/0022-3514.84.4.822

Brown, S. W. (1985). Time perception and attention: The effects of prospective versus retrospective paradigms and task demands on perceived duration. *Perception & Psychophysics*, *38*, 115–124.

Carriere, J. S. A., Seli, P., & Smilek, D. (2013). Wandering in both mind and body: Individual differences in mind wandering and inattention predict fidgeting. *Canadian Journal of Experimental Psychology / Revue Canadienne de Psychologie Experimentale*, *67*(1), 19–31. https://doi.org/10.1037/a0031438

Chu, M. T., Marks, E., Smith, C. L., & Chadwick, P. (2023). Self-caught methodologies for measuring mind wandering with meta-awareness: A systematic review. *Consciousness and Cognition*, *108*, 103463. https://doi.org/10.1016/j.concog.2022.103463

Cox, W. M., & Klinger, E. (Eds.). (2003). *Handbook of Motivational Counseling: Concepts, Approaches, and Assessment* (1st ed.). Wiley. https://doi.org/10.1002/9780470713129

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

Danckert, J., Hammerschmidt, T., Marty-Dugas, J., & Smilek, D. (2018). Boredom: Under-aroused and restless. *Consciousness and Cognition*, *61*, 24–37. https://doi.org/10.1016/j.concog.2018.03.014

Edwards, A. M., & McCormick, A. (2017). Time perception, pacing and exercise intensity: Maximal exercise distorts the perception of time. *Physiology & Behavior*, *180*, 98–102. https://doi.org/10.1016/j.physbeh.2017.08.009

Friedman, W. J. (1993). Memory for the time of past events. *Psychological Bulletin*, *113*(1), 44–66. https://doi.org/10.1037/0033-2909.113.1.44

Fung, B. J., Murawski, C., & Bode, S. (2017). Caloric primary rewards systematically alter time perception. *Journal of Experimental Psychology: Human Perception and Performance*, *43*(11), 1925–1936. https://doi.org/10.1037/xhp0000418

Galéra, C., Orriols, L., M'Bailara, K., Laborey, M., Contrand, B., Ribéreau-Gayon, R., Masson, F., Bakiri, S., Gabaude, C., & Fort, A. (2012). Mind wandering and driving: Responsibility case-control study. *Bmj*, *345*. https://www.bmj.com/content/345/bmj.e8105.abstract

Gibbon, J., Church, R. M., & Meck, W. H. (1984). Scalar timing in memory. *Annals of the New York Academy of Sciences*, *423*, 52–77. https://doi.org/10.1111/j.1749-6632.1984.tb23417.x

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

Hallez, Q. (2020). Time contraction caused by a distractor in children and adults: The influence of inhibition capacities. *Acta Psychologica*. https://doi.org/10.1016/j.actpsy.2020.103186

Jazayeri, M., & Shadlen, M. N. (2010). Temporal context calibrates interval timing. *Nature Neuroscience*, *13*(8), 1020–1026. https://doi.org/10.1038/nn.2590

Jording, M., Vogel, D. H. V., Viswanathan, S., & Vogeley, K. (2022). Dissociating passage and duration of time experiences through the intensity of ongoing visual change. *Scientific Reports*, *12*(1), Article 1. https://doi.org/10.1038/s41598-022-12063-1

Kane, M. J., Smeekens, B. A., Meier, M. E., Welhaf, M. S., & Phillips, N. E. (2021). Testing the construct validity of competing measurement approaches to probed mind-wandering reports. *Behavior Research Methods*, *53*(6), 2372–2411. https://doi.org/10.3758/s13428-021-01557-x

Kessler, R. C., Adler, L., Ames, M., Demler, O., Faraone, S., Hiripi, E., Howes, M. J., Jin, R., Secnik, K., Spencer, T., Ustun, T. B., & Walters, E. E. (2005). The World Health Organization adult ADHD self-report scale (ASRS): A short screening scale for use in the general population. *Psychological Medicine*, *35*(2), 245–256. https://doi.org/10.1017/S0033291704002892

Killeen, P. R., & Grondin, S. (2022). A trace theory of time perception. *Psychological Review*, *129*(4), 603–639. https://doi.org/10.1037/rev0000308

Kurzban, R., Duckworth, A., Kable, J. W., & Myers, J. (2013). An opportunity cost model of subjective effort and task performance. *The Behavioral and Brain Sciences*, *36*(6), 10.1017/S0140525X12003196. https://doi.org/10.1017/S0140525X12003196

Lamotte, M., Chakroun, N., Droit-Volet, S., & Izaute, M. (2014). Metacognitive Questionnaire on Time: Feeling of the Passage of Time. *Timing & Time Perception*, *2*(3), 339–359. https://doi.org/10.1163/22134468-00002031

Leszczynski, M., Chaieb, L., Reber, T. P., Derner, M., Axmacher, N., & Fell, J. (2017). Mind wandering simultaneously prolongs reactions and promotes creative incubation. *Scientific Reports*, *7*(1), 1–9.

Marcusson-Clavertz, D., & Kjell, O. N. E. (2019). Psychometric Properties of the Spontaneous and Deliberate Mind Wandering Scales. *European Journal of Psychological Assessment*, *35*(6), 878–890. https://doi.org/10.1027/1015-5759/a000470

Mathews, N. K., Bin Faiz, U., & Brosowsky, N. P. (2024). How do you know if you were mind wandering? Dissociating explicit memories of off task thought from subjective feelings of inattention. *Open Mind*, *8*, 666–687.

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), 11–18. https://doi.org/10.1037/a0031569

Nowack, K. (2023). The Individual Time Span Scales (ITSS): Introducing a self-report questionnaire to measure individual differences in the perception of time as duration.

Personality and Individual Differences, *206*, 112116. https://doi.org/10.1016/j.paid.2023.112116

Raffaelli, Q., Mills, C., & Christoff, K. (2018). The knowns and unknowns of boredom: A review of the literature. *Experimental Brain Research*, *236*(9), 2451–2462. https://doi.org/10.1007/s00221-017-4922-7

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

Rose, D., & Summers, J. (1995). Duration Illusions in a Train of Visual Stimuli. *Perception*, *24*(10), 1177–1187. https://doi.org/10.1068/p241177

Schooler, J., Reichle, E. D., & Halpern, D. V. (2004). Zoning-out during reading: Evidence for dissociations between experience and meta-consciousness. *Thinking and Seeing: Visual Metacognition in Adults and Children*, 204–226.

Schooler, J. W. (2002). Re-representing consciousness: Dissociations between experience and meta-consciousness. *Trends in Cognitive Sciences*, *6*(8), 339–344. https://doi.org/10.1016/S1364-6613(02)01949-6

Schooler, J. W., Smallwood, J., Christoff, K., Handy, T. C., Reichle, E. D., & Sayette, M. A. (2011). Meta-awareness, perceptual decoupling and the wandering mind. *Trends in Cognitive Sciences*, *15*(7), 319–326.

Seli, P., Carriere, J. S. A., & 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., Kane, M. J., Smallwood, J., Schacter, D. L., Maillet, D., Schooler, J. W., & Smilek, D. (2018). Mind-wandering as a natural kind: A family-resemblances view. *Trends in Cognitive Sciences*, *22*(6), 479–490. https://doi.org/10.1016/j.tics.2018.03.010

Seli, P., Smilek, D., Ralph, B. C. W., & Schacter, D. L. (2018). The Awakening of the Attention: Evidence for a Link between the Monitoring of Mind Wandering and Prospective Goals. *Journal of Experimental Psychology. General*, *147*(3), 431–443. https://doi.org/10.1037/xge0000385

Shi, Z., Church, R. M., & Meck, W. H. (2013). Bayesian optimization of time perception. *Trends in Cognitive Sciences*, *17*(11), 556–564. https://doi.org/10.1016/j.tics.2013.09.009

Smallwood, J., McSpadden, M., & Schooler, J. W. (2008). When attention matters: The curious incident of the wandering mind. *Memory & Cognition*, *36*(6), 1144–1150. https://doi.org/10.3758/MC.36.6.1144

Smallwood, J., & Schooler, J. W. (2006). The restless mind. *Psychological Bulletin*, *132*(6), 946–958. https://doi.org/10.1037/0033-2909.132.6.946

Struk, A. A., Carriere, J. S. A., Cheyne, J. A., & Danckert, J. (2017). A Short Boredom Proneness Scale: Development and Psychometric Properties. *Assessment*, *24*(3), 346–359. https://doi.org/10.1177/1073191115609996

Taatgen, N., & van Rijn, H. (2011). Traces of times past: Representations of temporal intervals in memory. *Memory & Cognition*, *39*(8), 1546–1560. https://doi.org/10.3758/s13421-011-0113-0

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

Experimental Psychology: Human Perception and Performance, *43*(11), 1864–1871. https://doi.org/10.1037/xhp0000461

Thönes, S., & Stocker, K. (2019). A standard conceptual framework for the study of subjective time. *Consciousness and Cognition*, *71*, 114–122. https://doi.org/10.1016/j.concog.2019.04.004

Ulrich, R., Nitschke, J., & Rammsayer, T. (2006). Perceived duration of expected and unexpected stimuli. *Psychological Research*, *70*(2), 77–87. https://doi.org/10.1007/s00426-004-0195-4

Varao-Sousa, T. L., Smilek, D., & Kingstone, A. (2018). In the lab and in the wild: How distraction and mind wandering affect attention and memory. *Cognitive Research: Principles and Implications*, *3*, 42. https://doi.org/10.1186/s41235-018-0137-0

Ward, A., & Wegner, D. (2013). Mind-blanking: When the mind goes away. *Frontiers in Psychology*, *4*. https://www.frontiersin.org/articles/10.3389/fpsyg.2013.00650

Wearden, J. H., Norton, R., Martin, S., & Montford-Bebb, O. (2007). Internal clock processes and the filled-duration illusion. *Journal of Experimental Psychology: Human Perception and Performance*, *33*, 716–729. https://doi.org/10.1037/0096-1523.33.3.716

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

Yanko, M. R., & Spalek, T. M. (2014). Driving With the Wandering Mind: The Effect That Mind-Wandering Has on Driving Performance. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *56*(2), 260–269. https://doi.org/10.1177/0018720813495280

Zakay, D., & Block, R. A. (1995). An attentional-gate model of prospective time estimation. *Time and the Dynamic Control of Behavior, 5*, 167–178.

Zanesco, A. P., Denkova, E., & Jha, A. P. (2024). Mind-wandering increases in frequency over time during task performance: An individual-participant meta-analytic review. *Psychological Bulletin*. https://psycnet.apa.org/record/2024-58385-001