THE EFFECTS OF TEMPORAL CONTRACTION AND TEMPORAL DILATION ON COGNITIVE PERFORMANCE

by

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DEDICATION

I dedicate this work to my children, wife, and parents, who have unconditionally supported me throughout the length of my research. Their support kept me motivated and driven to complete this project. I am thankful for their understanding of missing family events and long days. This project would not have been possible without their support.

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ABSTRACT

THE EFFECTS OF TEMPORAL CONTRACTION AND TEMPORAL DILATION ON COGNITIVE PERFORMANCE

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Temporal dilation and temporal contraction are perceived as duration lasting longer or shorter than the standard time unit, respectively. Social, cognitive, and emotional context influences temporal perception such that socially stressful or cognitively demanding tasks distort the perception of time. In the present study, subjects (N = 123) first experienced a state of mindfulness, reported to cause temporal dilation (Kramer et al., 2013) and then performed a demanding cognitive task, reported to cause temporal contraction (Block et al., 2010). Subjects watched either a guided mindfulness video (experimental) or a relaxing music video (control). Subjects then estimated the duration of the video. They then completed either a 1-back (easy) or a 3-back (hard) working memory task and estimated the time it took for their respective *n*-back condition. Results indicate that after controlling for arousal level and task difficulty, the negative outcome of temporal contraction (i.e. poor performance) was buffered by experiencing temporal dilation (mindfulness), $\beta = -.43$, $t(116) = -3.43$, $p = .001$, $sr^2 = .08$. Our study suggests that experiencing the mindful moment before a cognitively demanding task may restore performance via distorting time perception.

Keywords: time perception, mindful meditation, temporal distortions, working memory.

CHAPTER 1: INTRODUCTION

Everything *in* the universe exists *in* time, with each moment, the world unfolds itself, and our minds interpret this *process* of revealing as a conscious experience of being alive. We open our eyes in the morning after a deep state of slumber, and our visual system is bombarded with lights and colors. In an instant, our brain organizes the optical input into a coherent and stable reality of being in a familiar room. The sound of an alarm triggers the acoustic system while the olfactory system picks up the scent of coffee in the kitchen and mildly prepares the gustatory system. The sensory receptors embedded within the skin detect the change in temperature to generate a perception of being warm. All five senses become activated to different degrees to create a *sense of self*. The observation of change that occurs from moment-to-moment within us and within our environment is defined as being mindful of the present. Brown and Ryan (2003) defined mindfulness as self-awareness of the present experience. Others have defined mindfulness as an ability to focus attention on the present moment, including thoughts or emotions occurring internally without placing judgment on the moment (Carmodey, 2009; Kabat-Zinn, 2003; Kramer, Weger & Sharma, 2013). For this thesis, Mindful Meditation (MM) conceptualized as having a cognitive capacity to observe *self-emergent* thoughts without applying *cognitive appraisal*.

Time perception literature suggests that the subjective experience of time is heavily influenced by the characteristics of a present moment (Chaston & Kingston, 2004; Larson & Eye, 2010; Iwamoto and Hoshiyama, 2011). Cai and Eagleman (2015) claim that depending on the sort of processing our brain is doing, our experience of the moment (subjective time) seem to run slower or quicker than external physical time (real time). In this thesis mindfulness and time perception are assessed through information-processing models.

According to the information processing model proposed by Baars and Gage (2013), human brain receives signals from the environment that are picked up by sensors (sensory input) (Fig.1). These sensory inputs are held in sensory buffers until the central executive exerts top-down voluntary attention and makes the content of the signal conscious. The central executive is one of the components of working memory and has been shown to play an important role in goal-directed behavior (e.g., sustained attention). This model also explains the role of working memory in recalling information stored in long-term memory and "working with" the recalled information (using verbal rehearsal and the visuospatial sketchpad). The final output of this model involves action planning stage (goal-directedness) and response output (behavior) (Baars et al., 2013).

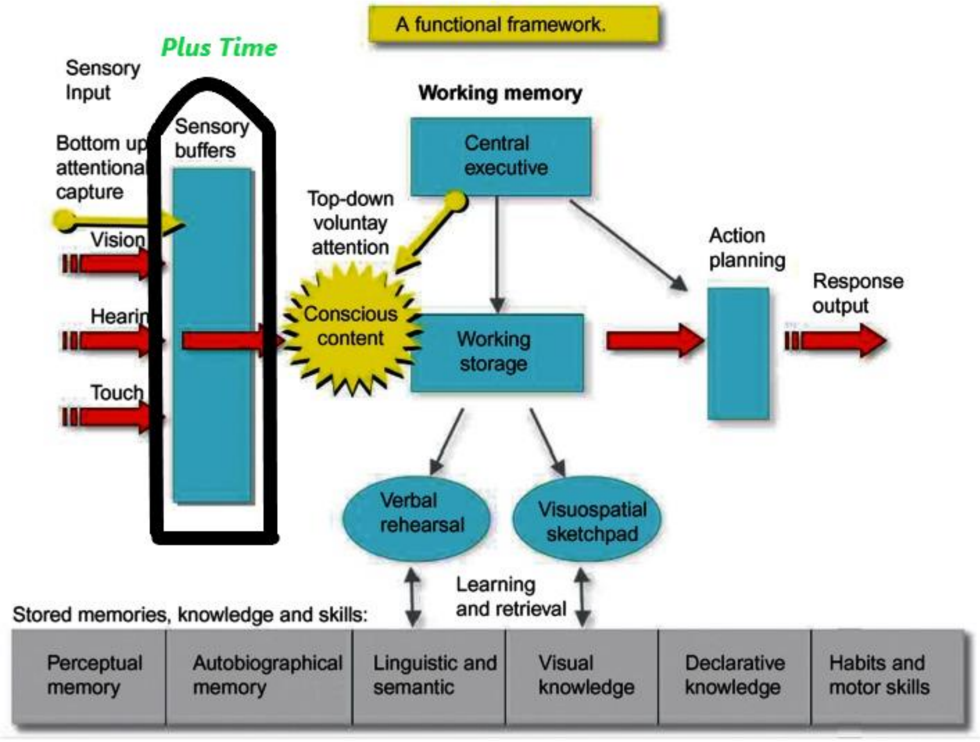

Figure 1. A theoretical framework for cognitive functions modified to include internal-clock at the sensory buffer stage. Modified from Baars and Gage (2013).

The section of the model that is most relevant for this thesis is the “sensory buffer” stage. It is at this stage where all sensory information is held until it is sequenced in the most *appropriate* order (executive control function). One of the plausible neural substrates for this buffering phase is thought to involve the thalamus. Thalamus is the main sensory input hub before the information is distributed to the rest of the cortex (Baars et al., 2013). Perhaps it is at this “buffering phase” that *time* plays an important role. A visual input integrated over time results in motion perception in the medial temporal lobe. Audio signals combined over time is perceived as speech or music in Wernicke’s and Broca’s areas.

Time perception models

The information-processing model of interval timing is a cognitive model with neural correlates. The model is conceptualized as a three-order system (Figure 2). The first order is a clock stage that has three significant sub-components: pacemaker, mode switch and an accumulator. The second order of the model involves memory, more precisely the role of working memory and reference memory interactions. The third order, decision stage consists of a comparator, an evaluative processor that produces a yes/no response to duration judgment (Church, 1984; Zakay et al., 1997). The focus of this section is to describe the mechanisms involved in interval timing and duration judgments.

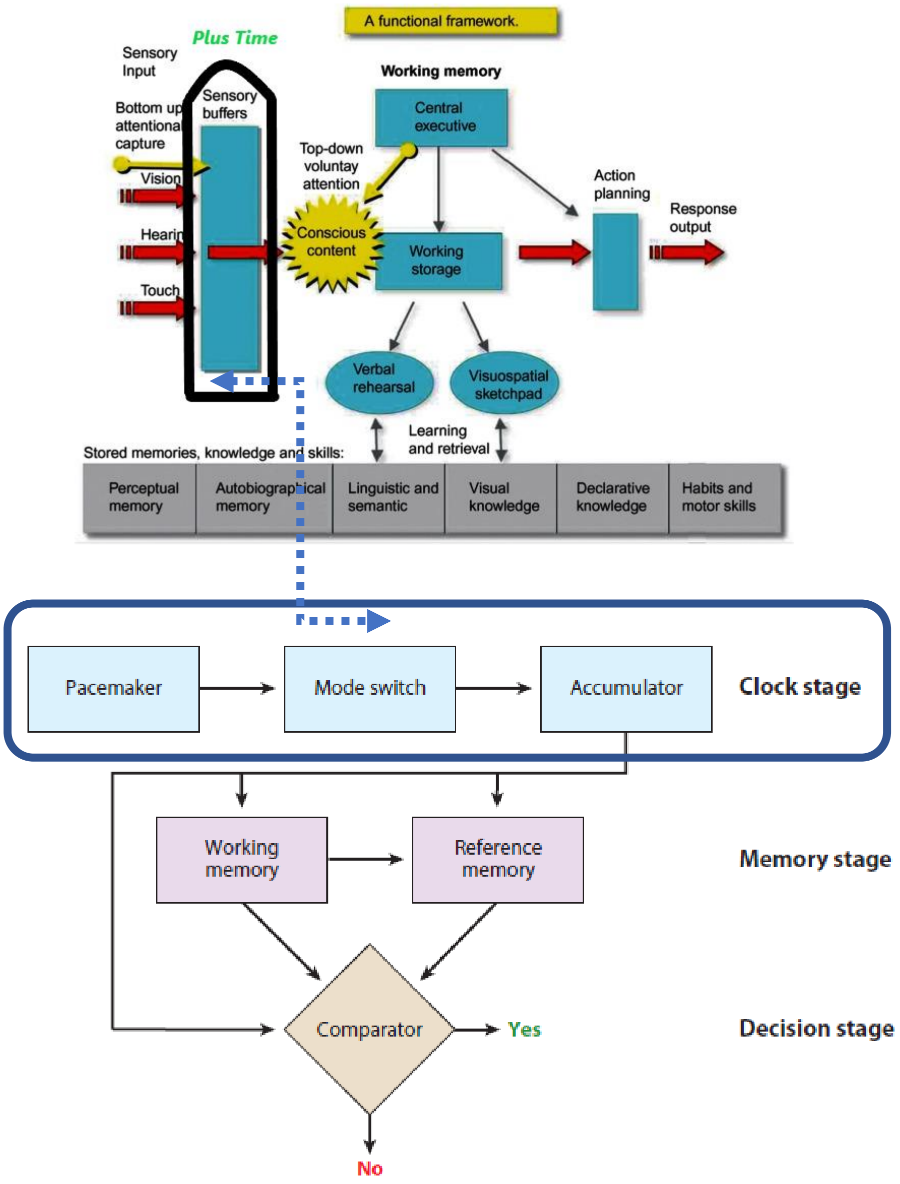

Figure 2. A theoretical framework for cognitive functions modified by adding an internal time clock at the sensory buffer stage. Modified from Baars and Gage (2013). Three-stages of the information-processing model of interval timing. Adapted from Church (1984), Gibbon et al. (1984), Meck (1984), and Treisman (1963, 1984).

Clock stage

Corticostriatal and cortico-cerebellar circuits are involved in the generation of oscillations that are rhythmic in nature (Baars, 2013). These pulses may be functioning as a pacemaker for the rest of the cortex (Baars, 2013). Which and how many circuits are responsible for the pacing function of the pacemaker is currently an area of extensive research (see Finnerty, Shadlen, Nobre, and Buonomano, 2015; Smythies, Edelstein, and Ramachandran, 2014; Teki & Griffiths, 2016).

The first component of the internal clock is the pacemaker unit. It generates pulses that are selected by attention to be collected in the accumulator (attentional gate model of Block and Zakay, 2010). The emitted pulses correspond to the changes in the environment (number of changes over some time). The brain must adapt to a continually changing environment, and the measurement of these changes occurring can be measured by an external clock (i.e., real-time). The function of an internal clock is to translate the real-time into a subjective experience of time (i.e., felt time) (Church 1984; Triesman 1963; Block and Zakay, 1995; Meck, 1983). Factors such as arousal level, mood, and emotions can alter the rate of the emitted pulses by the pacemaker (Triesman, 1963; Gibbon et al., 1984; Zakay et al. 1995; Droit-Volet, 2007; Allman, 2013). The rate of pulses emitted by the pacemaker can be modulated by administering indirect dopamine agonists such as cocaine and methamphetamine, which speed up the clock (Cheng et al., 2006, 2007; Matell et al. 2004, 2006; Meck 1983, 2007). In contrast, a dopamine receptor antagonist (Haldol) leads to a decrease in emitted pulses. Frontal cortex and corticostriatal neurons seem to play a role in the control of pacemaker speed (Meck 1996, 2006a; Meck et al. 1986).

The pulses generated by the pacemaker then pass through an attentional gate as proposed by Zakay and Block (1997). According to the modified version of the original internal-clock model, attention to temporal processing plays a vital role in interval timing behavior (i.e., duration judgment). Only the pulses that attention selects make it into the accumulator, and other pulses are *lost* and thus lead to interval-timing errors (Zakay et al., 1997). This version of the model cannot explain the effects of "lost" pulses as they are no longer addressed further in their version of the model. According to some researchers, "lost" pulses do not naturally decay; rather they may play a role in calculating sub-second durations via deeper neural networks — non-conscious temporal processing (Karmarkar & Buonomano 2007, Laje & Buonomano 2013). The timing of supra-second durations (order of seconds to minutes) however does seem to be accounted for by the attention gated model.

The accumulator collects the incoming pulses and transfers (encodes) them into short-term memory. The scalar theory model of internal clock assumes that the accumulator has a scalar property, that is, it obeys Weber's law (Gibbon 1977). In other words, as real-time duration increases, the time felt increases proportionally. The implication of this hypothesis is such that human brains are good at differentiating between 1 second and 2 seconds but not so much when differentiating between 23 seconds and 24 seconds (time invariance). The function of an accumulator is to "package" pulses into patterns that are representative of perceptual inputs. Factors that influence the encoding process include the speed at which encoding takes place (memory storage constant) and the rhythmic patterns of pulses (duration-based timing and beat-based timing). These "packaged pulses" are consequently encoded in short-term memory where they are harmonized with *similar* "packaged pulses" warehoused in the long-term memory (reference memory).

Memory Stage:

Pulse accumulation is dependent on working memory capacity. Working memory is defined as, *temporarily* holding information available for processing (Miyake & Shah, 1999). Miller (1956) suggested that the content capacity for working memory is seven +/-2 chunks of information. Research advocates a content limit yet research addressing the duration limit — i.e., how long is working memory *temporarily* active *for*— is limited. Current research suggests the content capacity of information that can be worked on at a time is 4 +/- 2 chunks and the information is available for manipulation between 10 seconds to 30 seconds (Baars, 2013).

A memory storage constant (*k**) is hypothesized by the scalar timing theory (Gibbon et al. 1984; Gibbon & Church 1984, 1990, 1992; Church 2003, Meck 1983). If the memory storage constant is larger than 1.0, then an individual would expect the end of an event to occur later than real time (time felt > real time). If the memory storage constant is smaller than 1.0, then an individual would expect the end of an event to occur earlier than real time (time felt < real time) (Allman et al., 2013). The remembered interval of an event is dependent on the amount of time required to transfer the set of pulses from working memory into reference memory. The mental representation of time in long-term memory exists on various temporal scales, ranging from milliseconds to hours (Simchy-Gross & Margulis, 2017). Short-term representations in the range of milliseconds to seconds are highly unstable and prone to errors resulting in temporal memory errors.

Decision Stage

Decision stage involves a processor called a comparator in the internal-clock models. The function of the comparator is to compare the pulse pattern in the working memory with similar pulse patterns in the reference memory. A judgment of event interval (duration estimation) is made by "looking up" the value stored in the reference memory (past) *for* current pulse pattern (present) (Block & Zakay, 1992, 1995; Bar-Haim & Zakay, 2010; Church 1984).

In conclusion, according to the internal clock-like models, the pacemaker speed is influenced by factors such as arousal, mood, and emotions. The pulses are encoded in a pattern by the accumulator. The pulse pattern is further encoded in memory at a certain speed (k^* parameter). Duration-based and beat-based are the two ways by which pulse patterns are stored. When duration judgments are required, the encoded pulse patterns are compared against saved patterns in the reference memory.

Duration Judgements

Judging an interval involves cognitive effort. Cognitive effort is any cognitive activity that is required to accomplish a goal and is constrained by the availability of cognitive resources (Block, 2003). Working memory, executive functioning, and attention are all considered cognitive resources that play a role in the quality and quantity of cognitive effort (Baars, 2013). Working memory plays a crucial role in temporal encoding.

Human brains are very well adapted to their temporal environments (Damasio, 2017). We have a working memory capacity that is justified for us to make reasonably well decisions as dictated by evolution (Damasio, 2017). Judging the *speed* (timing function) of an approaching animal and planning our action is "hard-wired." We use temporal predictions to modify our behavior in the present moment. In an interesting study performed on the elderly population, those with walking difficulties were asked to judge the time for crossing a busy intersection. Then researchers asked these elders to physically walk across the intersection while objectively measuring their crossing time. Those with walking difficulties *overestimated* the time it would take them to cross the intersection compared to the real time. Naveteur, Delzenne, and Dupuy (2013) reasoned that the elderly with walking disabilities overestimated the expected time to cross an intersection as a protective measure.

Four measurement methods exist in the time perception literature to quantify temporal perception: verbal estimates, duration production, reproduction and comparison (Zakay & Block, 1997). In verbal estimation tasks, participants are presented with a stimulus, and immediately following the stimulus, participants are asked to estimate the duration of the stimulus in standard units of time (e.g., seconds, minutes). Verbal estimates are a standard method used to measure the length of the presented stimulus (Grondin, 2010) when durations are perceived to have last longer than real-time, verbal estimates are generally biased towards overestimation (Grondin, 2010).

Two timing paradigms are used in time perception literature: prospective timing and retrospective timing (Block, Hancock, & Zakay, 2010). Prospective judgments are used to estimate the passage of time starting from the present moment into the future (Bakhurin, Goudar, Shobe, Claar, Buonomano, & Masmanidis, 2017). In prospective timing, the person is aware that a duration *judgment* must be made after an *experienced* interval. Duration judgments in the prospective paradigm are dependent on the allocation of attentional resources between temporal information processing and non-temporal information processing. Non-temporal processing is any other cognitive process that is being performed simultaneously as temporal processing is being performed (Zakay & Block, 2004). For example, college students taking an exam must allocate attentional resources to the test questions (non-temporal task) while keeping track of the elapsed duration (temporal task).

In contrast, retrospective timing is used to estimate the passage of time from some moment in the past up until the present (Bakhurin et al., 2017). Retrospective timing is not an actual timing task as it attempts to infer the passage of time by reconstructing some past event from memory. It is suggested that prospective timing and retrospective timing are distinctly separate cognitive processes, requiring different brain regions for processing each type of timing (Buonomano, 2014; Zakay & Block, 2004, 2010).

Khan, Sharma, and Dixit (2006) manipulated levels of a cognitive load by increasing the number of items to be remembered while performing a prospective timing task. The results suggested that prospective time estimates systematically decreased (underestimation bias) as cognitive demand increased. The experience of an interval seems to speed up while performing a cognitively demanding task, which results in an underestimation of an elapsed duration (Brown and Harkins, 2016; Khan et al., 2006; Zakay, 1993). Presumably less temporal information is encoded due to attention being diverted to performing a cognitive task, leading to underestimation errors.

On average, an interval timing is an automatic process, and we are more or less accurate in our judgments. However there are acceptions, Lovett and Lewandowski (2015) examined the effects of *time-related anxiety* in students with attentional disabilities. They concluded that students with attentional difficulties experience more episodes of mind-wandering which disrupts their timing mechanism (attentional gate of internal clock model) and leads to poor performance on The Scholastic Aptitude Test (SAT). It is clear that executive control and working memory capacity play an essential role in the encoding of time and recalling encoded information to use as a referential template. Can temporal coding and recall ability of temporal information be improved? The answer may lie in yet another cognitive process: Mindful Meditation.

Mindful Meditation

The concept of mindfulness eludes an all-encompassing definition. Generally, it involves bringing attention to the present experience of the moment and non-judgmentally observing the flow of thoughts (Carmody, 2009). A mindful state can be induced by short-mindfulness interventions during which participants are trained to focus on the moment-to-moment experience of sensations, emotions, and thoughts (Wallace, 1999). Mindfulness meditation has been scientifically researched for several decades and has shown promising results in improving the well-being of a person. Research suggests mindfulness meditation can help with mood regulation such as control of depression (Hofmann, Sawyer, Witt, and Oh, 2010) and anxiety (Hofmann et al., 2010). It has been shown to improve immune function (Carlson, Speca, Faris, & Patel, 2007) and reduced blood pressure and cortisol levels (Jacobs et al., 2010). Additionally, research suggests that by practicing mindfulness meditation one can improve working memory capacity (Chambers, Lo, & Allen, 2008; Jha, Stanley, Kiyonaga, Wong, & Gelfand, 2010; Kramer et al., 2013; Arnell, Stokes, MacLean, & Gicante, 2010). Mindfulness interventions have also been successfully used to improve working memory capacity via better attentional control (Jha & Stanley, 2010).

Being mindful is conceptualized as being consciously aware of events that are changing from moment-to-moment. These events can be cognitions, emotions, and behaviors. *When* we are mindful *of* ongoing changes in cognition, *then* we can change those cognitions. Being mindful requires some cognitive effort. Remaining in a *mindful state* is a cognitively demanding task. It requires sustained attention to the events that are being experienced at the moment — formation of thoughts and emotions. Neuroimaging studies suggest processing in frontal and posterior parietal cortex increases while performing a task that requires sustained attention (Baars, 2013).

Being in a mindful state has been shown to influence temporal judgments. Kramer, Weger, and Sharma (2013) had participants complete a temporal bisection task before and after a meditative session and suggested that participants in the meditative group overestimated the duration. In a temporal bisection task, participants are trained to distinguish between “short” and “long” durations. Kramer et al. (2013) presented visual stimuli (shapes and colors of circle/square) on a computer screen, and the duration for presentation ranged from 400 ms to 1600 ms. For inducing a state of mindfulness, they had participants sit in a quiet room and listen to an audiobook designed to focus their attention on the movement of the breath in the body (Holzel et al., 2007). The control group listened to an audiobook version of ‘The Hobbit.' Kramer et al. (2013) reported that "long" responses were significantly higher after the mindfulness session than the story session, indicating overestimation error.

In the current experiment, we employed a verbal estimation task, which has been widely used in time perception research to test the predictions of clock-based models (Block & Zakay, 1992, 1995). An advantage of the verbal estimation task is that participants are not primed for any intervals. Kramer et al. (2013) used only a visual stimulus to probe for the temporal distortions in their study. We used a video version of the mindfulness meditation with both visual and audio stimuli to induce a state of mindfulness. Additionally, to control for ‘visual and audio noise signal,' the control group watched the same video without the guided mindfulness component.

Current Study

The first aim of the study was to determine if mindfulness meditation distorts the perception of time as would be expected by its modulating effects on the pacemaker activity of the internal clock. The oscillatory nature of cortical neurons is hypothesized to generate pulses that are subsequently detected by the medium spiny neurons in the striatum. EEG data suggests that during mindful meditation the electrical activity originating from the cerebral cortex is reduced. The second aim was to determine if increased cognitive load distorts the duration judgment of the to-be-timed interval. The third aim was to examine the effects of mindful meditation could improve the distortions experienced during the increased cognitive load. The fourth aim was to determine if mindful meditation enhances the performance of working memory.

Mind State: In the experimental condition, participants watched a guided mindfulness video for ten (10) minutes and subsequently made a duration estimate (i.e., the duration of the video). In the control condition, participants watched a music video for ten (10) minutes and subsequently made a duration estimate. The musical and visual components were kept constant between both videos. In other words, both videos were identical concerning music and visual aesthetics but differed on the meditation content.

Cognitive load: In the experimental condition, participants completed a 3-back working memory task in three (3) blocks: block 1 had 60 trials, block 2 had 50 trials and block 3 had 40 trials. In the control condition, participants completed a 1-back working memory task.

Hypothesis 1

We predicted that participants in the mindful meditation condition would overestimate the duration compared to the control condition.

Hypothesis 2

Performing a demanding cognitive task requires significant cognitive effort. We predicted that participants performing a demanding cognitive task would underestimate the duration relative to those performing an easy cognitive task.

Hypothesis 3

If the temporal contraction is experienced during a strenuous mental activity then perhaps the temporal dilation experienced by mindful meditators can be beneficial. We hypothesized meditators performing a 3-back task would experience less distortion of time as reflected by duration estimates closer to real-time.

Hypothesis 4

Mindful meditation has been shown to improve working memory (Jha et al., 2010). We hypothesized that working memory performance would be significantly better for the mindful meditators.

CHAPTER 2: METHOD

Participants and Design

An *a priori* power analysis produced a required sample size of 124 participants, assuming a medium effect size of .25, an alpha of .05, and power of .80. Two important studies that examined the role of mindfulness meditation on the perception of time did not publish the effect sizes (Kramer et al., 2013; Droit-Volet et al., 2014). Initially, 128 participants were recruited through the Department of Psychology's subject pool website (Sona) at the University of Texas at Arlington. Five participants were removed from the final sample. Three of the five were excluded because they fell asleep during the mindful video session and two did not complete the task. The final sample included 123 participants (see Figure 3).

Written informed consent was obtained from every participant. Each participant was allowed to read instructions and ask related questions. Participants were informed that their participation in the experiment was voluntary and they could withdraw at any time during the experiment. Course credit was offered for completion of the study.

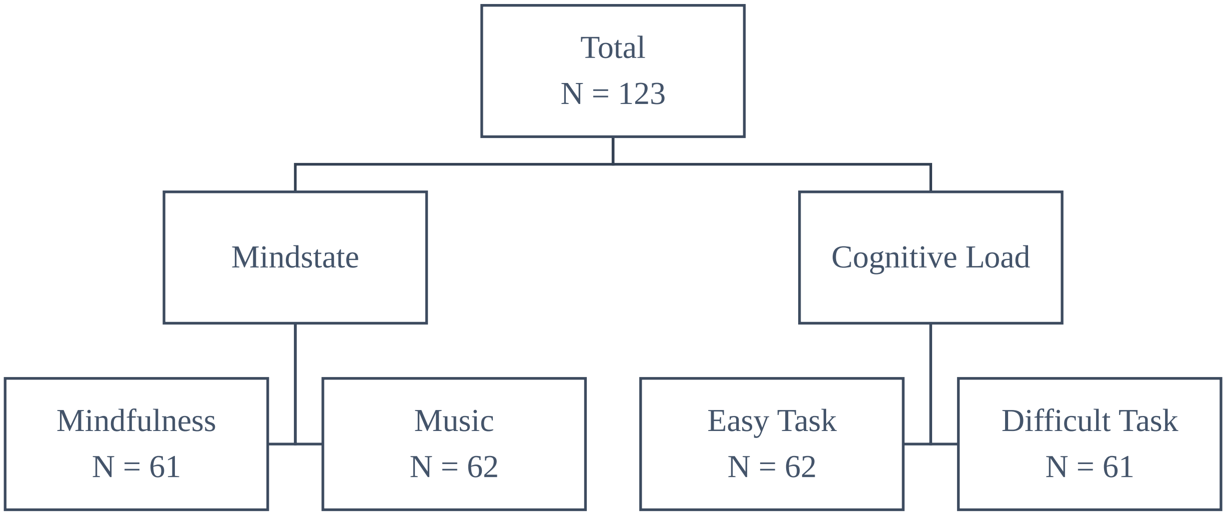

Figure 3: Participant distribution among the four experimental conditions.

2 (Mind-state: mindfulness versus music) X 2 (Cognitive load: easy versus difficult) between-subjects design was used. Participants were assigned a case number, and each case number was paired with a randomly selected condition. Participants in the mindful condition watched a guided mindful meditation video for ten minutes without being told how long the video clip was. The video was downloaded from the YouTube channel hosted by, "The Honest Guys" (https://www.youtube.com/watch?v=jobVHhlMmRo&list=WL). The script for the meditation was written by Sian Lloyd-Pennell and narrated by Rick Clarke. Participants in the control (music) condition watched the same video clip without the guided meditation content. After the video clip ended, participants were asked to estimate the duration of the clip.

Participants in the easy task completed a *1*-back working memory task. For the *1*-back condition, target letter (K) was displayed on a computer screen for 3 seconds followed by a blank screen for 0.5 seconds, and then a second letter was displayed (K or E) for additional 3 seconds. Participants were required to press (Y) if the displayed letter was the target letter (K) or press (N) if the displayed letter was not the target letter (E). *1*-back is a relatively easy task as it only requires retaining a target letter in working memory for a shorter duration. Participants in the difficult task were presented with letters in a similar fashion, but they were required to retain the target letter for a longer period (7.5 seconds) while distractor letters were introduced (see Figure 4).

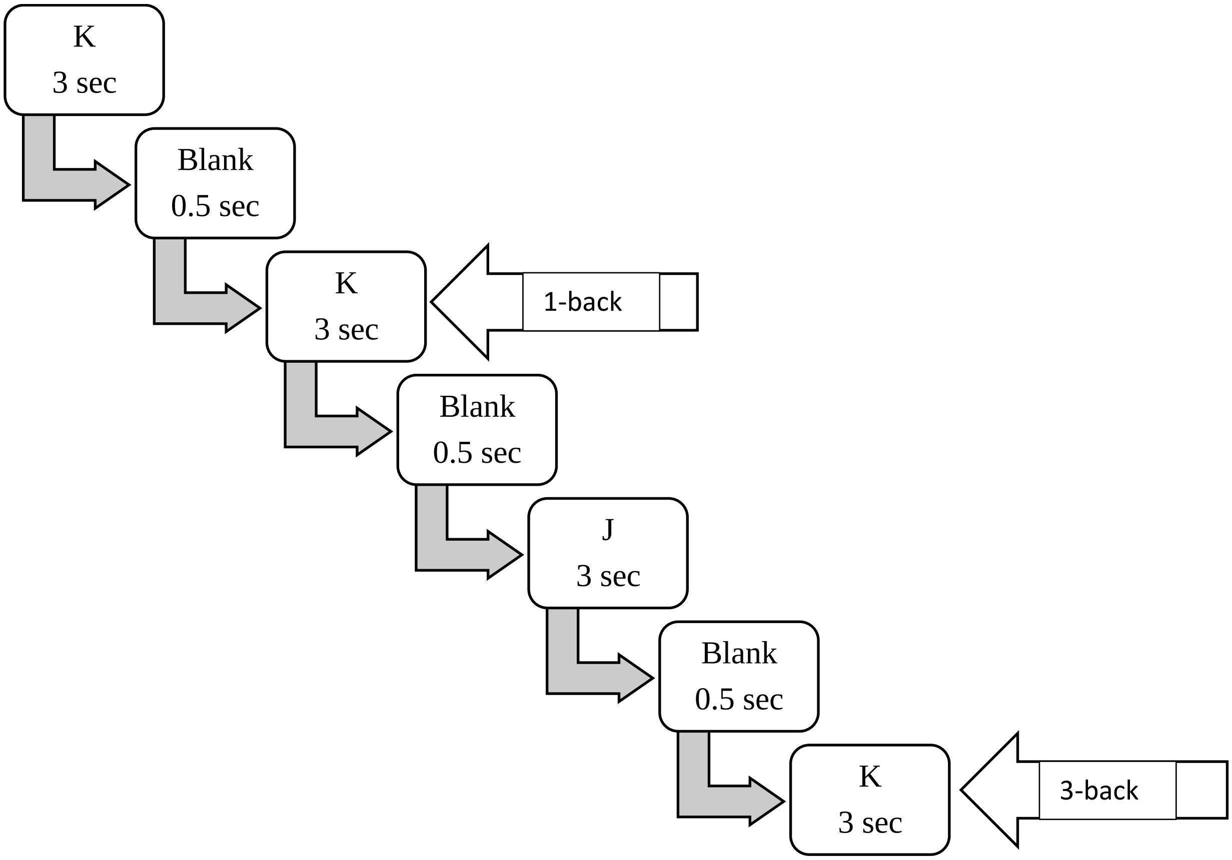

Figure 4: 1-back condition requires the retention of information for 0.5 seconds. The 3-back condition involves the retention of data for 7.5 seconds.

Measurements

Verbal Duration Judgements. As this was a prospective timing task, all participants were explicitly informed before each task that duration judgment would be required several times during an experiment. Participants watched either the guided mindfulness video or the music video and subsequently made a judgment regarding the duration of the video. Participants then completed either an easy task or a difficult task and estimated the length of their respective task. These verbal time estimates were then converted to duration judgment ratios (DJR). DJR is widely used in time perception research to determine directional errors in temporal estimation (Block et al., 2010). DJR is a computed ratio of subjective duration to objective duration; DJR = $\frac{verbal\ estimate}{Clock-time}$. Thus a DJR of one (1) indicates a perfect performance on the prospective timing task. A directional error of *underestimation* is indicated by DJR being less than 1 and *overestimation* is indicated by DJR being greater than 1.

Directional error example:

>1 : 12 min / 10 min = 1.2 overestimated directional error.

<1 : 8 min / 10 min = 0.8 underestimated directional error.

The *degree* of error was computed by subtracting one from DJR (Block et al., 2010).

Degree of overestimation error 1.2 - 1 = .2

Degree of underestimation error .08 - 1 = -.2

As shown in the example above, the degree of estimation error can be equivalent, but the direction of error differs as indicated by a positive and a negative sign.

n-back Task Accuracy

In an *n*-back task, individuals are shown letters on a computer screen (target letter), and their task is to keep the stimulus active in working memory over a specified *duration*. During this "delay period," distractor letters are presented, and the participant's task is to identify if the currently presented letter on the screen is the target letter. The *n*-back task was initially developed by Wayne Kirchner (1958) to test short-term memory capacity. The *n*-back task is a continuous performance task that is commonly used to measure part of working memory and working memory capacity (Gazzaniga et al., 2009). Participants were presented with a sequence of letters on a computer screen, one at a time, each letter was displayed for 3 seconds. For each letter except for the first letter, participants choose between Y or N on the keyboard. For a *1*-back task, the correct response was Y if the displayed letter matched the target letter and N if the letter was not the target letter. Likewise for the *3*-back condition participants were required to identify if the displayed letter matched the target letter that was displayed two letters earlier.

The *3*-back task is much more cognitively demanding than the *1*-back task. There are two reasons for this: (a) in the 1-back condition, the information needed to be retained in working memory is for a shorter duration (0.5 seconds) without any distractors; (b) for the *3*-back condition, the information needed to be retained in working memory is for more extended period (7.5 seconds) with distractors.

Participants individual reaction time within three blocks was collapsed across trials. The summed values were used as a measure of the actual time for each participant. The performance on the *n*-back task was measured by summing correct responses per block and dividing them by total opportunities for correct answers. Percentage of correct responses was used for statistical analysis.

Arousal Scale

Each participant completed a 24-item perceived arousal scale after watching the video. The arousal scale has been developed by Anderson et al. (1995). Each scenario asks the participant to "indicate to what extent do you feel this way right now, that is, at the present moment…". The items included were: active, drowsy, exhausted, lively, sleepy, vigorous, alert, dull, fatigued, powerful, slow, weak, aroused, energetic, forceful, quiet, sluggish, weary, depressed, excited, inactive, sharp, tired, and worn-out. Below each scenario participants were required to respond to five-point Likert scale questions ranging from "very slightly or not at all" as 1, "moderately" as a 3, and "extremely" as a 5. Fourteen of the twenty-four items were reverse coded. Total scores from the 24 items after correcting for reverse coding were computed. A higher score on the scale indicated a higher level of arousal.

Procedure

Participants were brought into the lab and instructed to remove their watches and place any other electronic devices that displayed time in their bags. Participants were informed that this study was related to time perception and they would be making duration judgments throughout the experiment. Participants were then randomly assigned to one of the two conditions (mindfulness or control). Participants were seated in a dimly lit room with a computer screen. Participants watched their assigned video clip and subsequently made a duration judgment regarding the length of the video. Participants were then given instructions on how to complete the *n*-back task. During trial runs, they had an opportunity to practice both *1*-back and *3*-back conditions before beginning the second part of the study. For the second part of the experiment, participants were randomly assigned to either a *1*-back task or a *3*-back condition. Participants completed three blocks of the *n*-back task: the first block consisted of 60 trials followed by a second block with 50 trials and concluded with the third block of 40 trials. Blocks were randomized, and participants were required to make three duration judgments, one for each block.

The video clip and *n*-back task were administered using E-prime 2.0 and the time counter for the video was made invisible to the participant. The time clock counter on each computer was switched to invisible mode; therefore there were no temporal cues available within the experimental room.

CHAPTER 3: RESULTS

Data Screening

Before formal hypothesis testing, data were screened for statistical assumptions. The verbal estimates were used to compute DJR. DJR for the variable mind-state was slightly positively skewed with three outliers that were higher than three standard deviations from the mean. DJR for the video was log transformed which corrected for the skewness. This variable met the assumption of normality after transformation. DJR for the cognitive load conditions were also calculated, and this variable was positively skewed as well. DJR for the cognitive load conditions were log transformed which resolved the outliers and normalized the distribution. The performance variable for the *n*- back condition were negatively skewed and had to be cube transformed to meet the assumption of normality. The arousal variable was normally distributed and did not require any transformations. All continuous predictor variables were centered before regression analysis.

Statistical Analysis

The purpose of this study was to observe how different mind-states and levels of mental effort affect the perception of time and subsequently the duration judgments. Additionally, we were interested in assessing the benefits of mindfulness meditation on working memory performance.

Hypothesis 1:

Participants watching the meditation video clip would overestimate the duration relative to the control condition. A one-way between subjects Analysis of Variance (ANOVA) was conducted to compare the effects of mindfulness and music on duration judgment. No significant difference was found between conditions on duration judgement between conditions *F*(1,121) = .85, *p* = .357. These results suggest that the duration judgments made regarding the perceived duration remain unchanged between the mindfulness and the control condition. The first hypothesis there was not supported.

Hypothesis 2:

Participants performing a *3*-back cognitive task will underestimate the duration of the task relative to *1*-back condition. A one-way between subjects Analysis of Variance (ANOVA) was conducted to compare the effect of cognitive load on duration judgments. No significant effect of cognitive load on duration judgement was noted between the two conditions $F(1,121) = 3.08$, $p = .082$. These results suggest that the duration judgments made concerning the duration of cognitive work were unaffected by the task difficulty (see Table 1). The second hypothesis, therefore, was not supported.

Hypothesis 3:

As expected, the duration estimates made after watching the video were significantly correlated with duration estimates made after performing a cognitive task, $r = .38$, $p < .05$. To test the hypothesis that mindful meditation will buffer the temporal distortion experienced during the increased mental effort condition, a 2 (mind-state: mindful/control) X 2 (cognitive load: easy/difficult) between-subjects factorial ANCOVA was used. DJR of the video used as a covariate. No main effect of videos on duration judgment for a cognitive task. F(1,117) = .67, p = .415. partial-eta sq = .006. These results suggest that the videos did not affect the temporal judgments made during a cognitive task. No main effect of cognitive task on duration judgement was noted F(1,117) = .84, p = .361, eta sq = .007. These results suggest that both easy and difficult cognitive conditions made similar duration judgments. There was no significant interaction between videos and cognitive task, F(1,117) = .85, p = .359, et sq = .007. These results suggest that duration estimates made after performing a difficult cognitive task were unaffected by mindful moment (see Table 1). The third hypothesis was not supported.

Hypothesis 4:

As expected working memory performance significantly differed between the 1-back and 3-back condition $F(1,120) = 20.74$, $p < .001$, $\eta_p^2 = .15$. Participants in the 1-back condition ($M = .68$, $SE = .04$) did significantly better than participants in the 3-back condition ($M = .45$, $SE = .04$).

Linear regression was performed to determine if the perception of time during meditation could predict working memory performance. The continuous variable of duration estimate was centered before regression analysis. The categorical variable of mindset conditions was dummy coded such that mindful condition (1) compared with the control condition (0).

After statistically controlling for the effects of arousal on performance, the *n*-back task significantly predicted task performance, $\beta = .23$, $t(121) = 4.37$, $p < .001$. The *n*-back task also explained a significant proportion of variance in working memory performance, $R^2 = .14$, $\Delta F(2,119) = 9.55$, $p < .001$. Using unweighted effects code, it was determined that duration perception did not significantly predict task performance, $\beta = .17$, $t(119) = 1.01$, $p = .314$. Furthermore, we had an interaction that was approaching significance between duration judgement and mindsets on performance, $\beta = -.31$, $t(119) = -1.82$, $p = .07$.

After statistically controlling for the effects of arousal and the *n*-back condition, we had a significant interaction between duration judgement and mindsets on performance, $\beta = -.90$, $t(116) = -2.77$, $p = .007$. Results suggest that perceived time during mindfulness and control period could predict the performance of a working memory task. After probing the interaction further, we found a significant simple effect of time estimate on performance for participants within music group, β

= .55, *t*(116) = 2.31, *p* = .023. For every unit change in duration estimate, there was a .55 increase in performance (See Figure 5). Additionally we found that there were no simple effects of duration estimate on performance for participants within mindfulness group, *β* = -.346, *t*(116) = -1.63, *p* = .107.

In sum, participants who underestimated the duration of the music video performed worse on a working memory task compared to those who overestimated. Again, underestimating a period suggests that the memory storage constant was less than 1.0 which lead to each moment being perceived as being shorter than real time. Participants who underestimated the duration of mindfulness video did not significantly differ on performance when compared to over estimators. The fourth hypothesis was therefore partially supported.

Arousal statistic:

All the participants completed a perceived arousal scale after watching the videos to control for effects of arousal level on the internal clock. There were no statistical differences on the level of arousal between conditions *F*(1,117) = .04, *p* = .85. Results suggest that, as intended, arousal level was equivalent after both conditions.

CHAPTER 4 : DISCUSSION

Distortions in the perception of time are experienced when the subjective duration of elapsed time feels different from a clock-measured time (Block & Zakay, 1997; Eagleman, 2015; Buonomano, 2017). A single "internal-clock" model is a useful theoretical framework that describes the processes and mechanisms involved in the perception of time (Church, 1984; Treisman, Faulkner, Naish, & Brogan, 1990) along with an attentional gate model (Zakay & Block, 1997). Temporal encoding and its ability to bind events are crucial for the formation of episodic memories (Tsao, Sugar, Lu, Wang, Knierim, Moser, 2018). Disruptions in temporal encoding results in memory recall errors and the neural correlate for temporal encoding are proposed to involve the entorhinal cortex (ongoing debate on the precise region, lateral entorhinal cortex or dorsal entorhinal cortex or both) (Tsao et al., 2018). The perception of time itself impacts the behavior of an individual as seen in previous studies. When each moment is perceived as being shorter than the real moment, the verbal estimates are biased towards underestimation (temporal contraction). When each moment is observed to last longer than the actual moment, the verbal estimates are biased towards overestimation (temporal dilation). The perception of each moment is dependent on the processed content within that moment. Performing a cognitively demanding task result in contraction of the moment. While decreasing the cognitive demand results in dilation of the moment (Eagleman, 2015; Buonomano, 2017).

In the current study, we attempted to manipulate the quantity of content processed within the mind. More specifically, the mindful and the relaxation music condition tried to decrease the amount of content processed. Control condition would require minimal content to be processed. Mindful meditation would require more content to be processed, specifically content concerning awareness of the moment and the bodily sensations. We similarly increased the quantity of content processed by having participants perform a working memory task. We were particularly interested in determining the effects of mindfulness on the perception of time and the role of temporal perception on cognitive performance.

We did not find any temporal biases in verbal estimates. Participants in all four conditions estimated the duration that was within an acceptable range. The groups did not differ among each other, i.e., mindful group and relaxation group both made similar estimates. These results suggest that participants were more or less accurate when asked to make explicit judgments regarding an interval. Using explicit decisions as a proxy for the perception of time during an interval, we successfully predicted cognitive performance. Participants in the music group that underestimated the duration performed poorly on a working memory task. Recall that verbal underestimate reflects the contraction of each moment. In accordance with previous research, participants experiencing temporal contraction performed poorly. Those in a music group who overestimated the duration (perceived temporal dilation) performed better than underestimators. Interestingly we did not find this pattern in the mindful condition. No statistically significant difference was found on cognitive performance within mindful condition between overestimators and underestimators. In conclusion, results suggest that cognitive performance is attenuated by temporal contraction for the relaxation condition but not for the mindful condition.

Future studies should attempt to replicate and extend these findings. Moreover, manipulating the attributes of the content rather than the quantity of the content may explain the beneficial effects of mindfulness. There were several limitations in this study, lack of measurement to conclusively determine if watching a mindfulness video induced a mindful state. Nevertheless, it is difficult to explain why the non-mindful underestimators performed poorly considering the only difference between the groups was the mindfulness content. Lack of the control group was a significant drawback of this study. Future studies should remedy these limitations.

APPENDIX A

Condition	*n*	*M*	*SE*	95% CI
Mindset				
Mindful	61	-.04	.02	[-.08, .01]
Relaxed	62	-.06	.02	[-.10, -.02]
Cognitive Load				
1-back	62	.03	.03	[-.03, .09]
3-back	61	-.05	.03	[-.11, .02]

Table 1: Descriptive statistics for duration judgement ratio.

APPENDIX B

Condition	*n*	*M*	*SE*	95% CI
Mindset				
Mindful	61	.59	.04	[.52, .67]
Relaxed	62	.54	.04	[.46, .63]
Cognitive Load				
1-back	62	.68	.04	[.60, .77]
3-back	61	.45	.03	[.38, .51]

Table 2: Descriptive statistics for working memory performance.

APPENDIX C

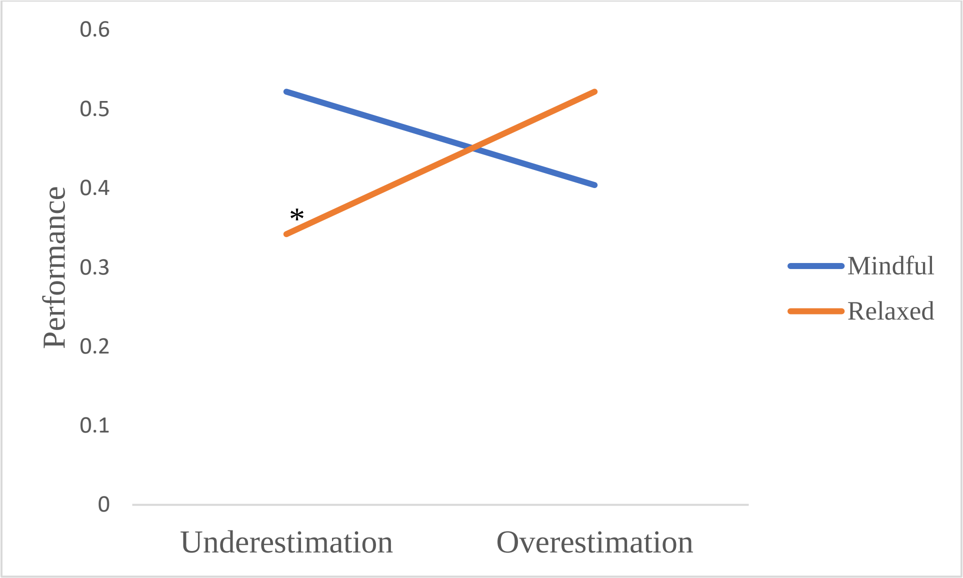

Figure 5: Under estimators in relaxation mindset performed significantly poorer than over estimators. No significant difference in performance between underestimators and over estimators for the mindful mindset.

REFERENCES

Allman, M. J., Teki, S., Griffiths, T. D., & Meck, W. H. (2014). Properties of the internal clock: First- and second-order principles of subjective time. *Annual Review of Psychology*, *65*, 743–771. https://doi-org.ezproxy.uta.edu/10.1146/annurev-psych-010213-115117

Arnell, K. M., Stokes, K. A., MacLean, M. H., & Gicante, C. (2010). Executive control processes of working memory predict attentional blink magnitude over and above storage capacity. *Psychological Research*, *74*(1), 1-11. doi:10.1007/s00426-008-0200-4

Baars, B. J. (1988). Momentary forgetting as a 'resetting' of a conscious global workspace due to competition between incompatible contexts. In M. J. Horowitz, M. J. Horowitz (Eds.), *Psychodynamics and cognition* (pp. 269-293). Chicago, IL, US: University of Chicago Press.

Baars, B. J. (1993). How does a serial, integrated and very limited stream of consciousness emerge from a nervous system that is mostly unconscious, distributed, parallel and of enormous capacity? In, *Experimental and theoretical studies of consciousness* (pp. 282-303). Oxford, England: John Wiley & Sons. doi:10.1002/9780470514412.ch14

Baars, B. J., Banks, W. P., & Newman, J. B. (2003). *Essential sources in the scientific study of consciousness*. Cambridge, MA, US: MIT Press.

Baars, B. J., Ramsøy, T. Z., & Laureys, S. (2003). Brain, conscious experience and the observing self. *Trends In Neurosciences*, *26*(12), 671-675. doi:10.1016/j.tins.2003.09.015

Benson, H., Greenwood, M. M., & Klemchuk, H. (1975). The relaxation response: Psychophysiologic aspects and clinical applications. *International Journal of Psychiatry* *in Medicine*, *6*(1–2), 87–98. https://doi-org.ezproxy.uta.edu/10.2190/376W-E4MT-QM6Q-H0UM

Block, R. A. (2003). Psychological timing without a timer: The roles of attention and memory. In H. Helfrich (Ed.), *Time and mind II: Information processing perspectives* (pp. 41–49). Gttingen, Germany: Hogrefe & Huber.

Block, R. A., Hancock, P. A., & Zakay, D. (2010). How cognitive load affects duration judgments: A meta-analytic review. *Acta Psychologica*, *134*(3), 330-343. doi:10.1016/j.actpsy.2010.03.006

Bakhurin, K. I., Goudar, V., Shobe, J. L., Claar, L. D., Buonomano, D. V., & Masmanidis, S. C. (2017). Differential encoding of time by prefrontal and striatal network dynamics. *The Journal Of Neuroscience*, *37*(4), 854-870. doi:10.1523/JNEUROSCI.1789-16.2016

Buonomano, D. V. (2014). The neural mechanisms of timing on short timescales. In V. Arstila, D. Lloyd, V. Arstila, D. Lloyd (Eds.), *Subjective time: The philosophy, psychology, and neuroscience of temporality* (pp. 329-342). Cambridge, MA, US: MIT Press.

Block, R. A., Hancock, P. A., & Zakay, D. (2010). How cognitive load affects duration judgments: A meta-analytic review. *Acta Psychologica*, *134*(3), 330-343. oi:10.1016/j.actpsy.2010.03.006

Brown, A. J., & Harkins, S. G. (2016). Threat does not make the mind wander: Reconsidering the effect of stereotype threat on mind-wandering. *Motivation Science, 2*(2), 85-96. doi:10.1037/mot0000032

Brown, K., & Ryan, M. (2003). The benefits of being present: Mindfulness and its role in psychological well-being. *Journal of Personality and Social Psychology, 84*, 822–848.

Botta, F., Ródenas, E., & Chica, A. B. (2017). Target bottom-up strength determines the extent of attentional modulations on conscious perception. *Experimental Brain Research*, *235*(7), 2109-2124. doi:10.1007/s00221-017-4954-z

Cai, M. B., & Eagleman, D. M. (2015). Duration estimates within a modality are integrated sub-optimally. *Frontiers In Psychology*, *6*

Carmody, J. Evolving conceptions of mindfulness in clinical settings. *Journal of Cognitive Psychotherapy, 23* (3) (2009), pp. 270-280, 10.1891/0889-8391.23.3.270

Chaston A, Kingstone A (2004). Time estimation: the effect of cortically mediated attention. *Brain and Cognition 55*: 286–289.

Church RM. 1984. Properties of the internal clock. *Ann. N.Y. Acad. Sci.* 423:566–82

Chen, S., Sun, P., Wang, R., & Fang, J. (2011). Moderating role of time management disposition to the relationship between stress and anxiety. *Chinese Journal Of Clinical Psychology*, *19*(5), 660-662.

Cheng RK, MacDonald CJ, MeckWH. 2006. Differential effects of cocaine and ketamine on time estimation: implications for neurobiological models of interval timing. *Pharmacol. Biochem. Behav.* 85:114–22

Cheng RK, Meck WH. 2007. Prenatal choline supplementation increases sensitivity to time by reducing non-scalar sources of variance in adult temporal processing. *Brain Res.* 1186:242–54

Chambers, R., Lo, B. Y., & Allen, N. B. (2008). The impact of intensive mindfulness training on attentional control, cognitive style, and affect. *Cognitive Therapy And Research*, *32*(3), 303-322. doi:10.1007/s10608-007-9119-0

Chavez, B. R. (2004). *Effects of stress and relaxation on time perception*. *Dissertation Abstracts International: Section B: The Sciences and Engineering*. ProQuest Information & Learning.

Damasio, A (2017). The strange order of things. New York, U.S.: Pantheon.

Davis, D. M., & Hayes, J. A. (2011). What are the benefits of mindfulness? A practice review of psychotherapy-related research. *Psychotherapy*, *48*(2), 198-208. doi:10.1037/a0022062

Droit-Volet, S., Lamotte, M., & Izaute, M. (2015). The conscious awareness of time distortions regulates the effect of emotion on the perception of time. *Consciousness And Cognition: An International Journal*, *38*155-164. doi:10.1016/j.concog.2015.02.021

Droit-Volet, S., & Meck, W. H. (2007). How emotions color our perception of time. *Trends In Cognitive Sciences*, *11*(12), 504-513. doi:10.1016/j.tics.2007.09.008

Dehaene, S. (1998). The development of delayed response: Parallel distributed processing lacks neural plausibility. *Developmental Science*, *1*(2), 194-196. doi:10.1111/1467-7687.00025

Dehaene, S., Changeux, J., Naccache, L., Sackur, J., & Sergent, C. (2006). Conscious, preconscious, and subliminal processing: A testable taxonomy. *Trends In Cognitive Sciences*, *10*(5), 204-211. doi:10.1016/j.tics.2006.03.007

Dusek, J. A., Hibberd, P. L., Buczynski, B., Chang, B.-H., Dusek, K. C., Johnston, J. M., … Zusman, R. M. (2008). Stress management versus lifestyle modification on systolic hypertension and medication elimination: A randomized trial. *The Journal of Alternative and Complementary Medicine*, *14*(2), 129–138. https://doi-org.ezproxy.uta.edu/10.1089/acm.2007.0623

Faber, M., & Gennari, S. P. (2017). Effects of learned episodic event structure on prospective duration judgments. *Journal Of Experimental Psychology: Learning, Memory, And Cognition*, *43*(8), 1203-1214. doi:10.1037/xlm0000378

Finnerty, G. T., Shadlen, M. N., Jazayeri, M., Nobre, A. C., & Buonomano, D. V. (2015). Time in cortical circuits. *The Journal of Neuroscience*, *35*(41), 13912–13916. https://doi-org.ezproxy.uta.edu/10.1523/JNEUROSCI.2654-15.2015

Gazzaniga, M. S., Bizzi, E., Chalupa, L. M., Grafton, S. T., Heatherton, T. F., Koch, C., … Wandell, B. A. (2009). *The cognitive neurosciences, 4th ed*. (M. S. Gazzaniga, E. Bizzi, L. M. Chalupa, S. T. Grafton, T. F. Heatherton, C. Koch, … B. A. Wandell, Eds.). Cambridge, MA: Massachusetts Institute of Technology.

Gibbon, J., Church, R. M., & Meck, W. H. (1984). Scalar timing in memory. *Annals of the New York Academy of Sciences, 423* (1), 52–77. doi:10.1111/j.1749-6632.1984.tb23417.x

Gupta, S., & Cummings, L. L. (1986). Perceived speed of time and task affect. *Perceptual And Motor Skills*, *63*(2, Pt 2), 971-980. doi:10.2466/pms.1986.63.2.971

Hartman, M., Bolton, E., & Fehnel, S. E. (2001). Accounting for age differences on the Wisconsin Card Sorting Test: Decreased working memory, not inflexibility. *Psychology And Aging*, *16*(3), 385-399. doi:10.1037/0882-7974.16.3.385

Iwamoto, Y., & Hoshiyama, M. (2011). Alteration of time perception in young and elderly people during jigsaw puzzle tasks with different complexities. *Occupational Therapy International*, *18*(4), 194-200. doi:10.1002/oti.322

Jha, A. P., Stanley, E. A., Kiyonaga, A., Wong, L., & Gelfand, L. (2010). Examining the protective effects of mindfulness training on working memory capacity and affective experience. Emotion, 10, 54–64.

Jha, A. P., Stanley, E. A., Kiyonaga, A., Wong, L., & Gelfand, L. (2010). Examining the protective effects of mindfulness training on working memory capacity and affective experience. *Emotion*, *10*(1), 54-64. doi:10.1037/a0018438

Kabat-Zinn, J. (2003). Mindfulness-based interventions in context: Past, present, and future. *Clinical Psychology: Science and Practice*, *10*, 144–156

Karmarkar UR, Buonomano DV. 2007. Timing in the absence of clocks: encoding time in neural network states. *Neuron* 53:427–38

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

Larson, E., & von Eye, A. (2010). Beyond flow: Temporality and participation in everyday activities. *American Journal Of Occupational Therapy*, *64*(1), 152-163. doi:10.5014/ajot.64.1.152

Laje R, Buonomano DV. 2013. Robust timing and motor patterns by taming chaos in recurrent neural networks. *Nat. Neurosci.* 16:925–33

Lovett, B. J., & Lewandowski, L. J. (2015). Timing and scheduling accommodations. In, *Testing accommodations for students with disabilities: Research-based practice* (pp. 93-119). Washington, DC, US: American Psychological Association. doi:10.1037/14468-005

Lomas, T., Medina, J. C., Ivtzan, I., Rupprecht, S., Hart, R., & Eiroa-Orosa, F. J. (2017). The impact of mindfulness on well-being and performance in the workplace: An inclusive systematic review of the empirical literature. *European Journal Of Work And Organizational Psychology*, *26*(4), 492-513. doi:10.1080/1359432X.2017.1308924

Lim, E. C., Kum, D., & Lee, Y. H. (2015). Understanding how changes within service experiences impact prospective vs. retrospective time judgments. *Journal Of The Academy Of Marketing Science*, *43*(6), 730-745. doi:10.1007/s11747-014-0415-4

Matell MS, Bateson M, Meck WH. (2006). Single-trials analyses demonstrate that increases in clock speed contribute to the methamphetamine-induced horizontal shifts in peak-interval timing functions. *Psychopharmacology* 188:201–12

Matell MS, King GR, Meck WH. (2004). Differential adjustment of interval timing by the chronic administration of intermittent or continuous cocaine. *Behav. Neurosci.* 118:150–56

Meck WH. (1984). Attentional bias between modalities: effect on the internal clock, memory, and decision stages used in animal time discrimination. *Ann. N.Y. Acad. Sci.* 423:528–41

Meck WH. (1986). Affinity for the dopamine D2 receptor predicts neuroleptic potency in decreasing the speed of an internal clock. *Pharmacol. Biochem. Behav.* 25:1185–89

Meck WH. (1996). Neuropharmacology of timing and time perception. *Cogn. Brain Res.* 3:227–42

Meck WH. (2006a). Frontal cortex lesions eliminate the clock speed effect of dopaminergic drugs on interval timing. *Brain Res.* 1108:157–67

Meck WH. (2007). Acute ethanol potentiates the clock-speed enhancing effects of nicotine on timing and temporal memory. *Alcohol. Clin. Exp. Res.* 31:2106–13

Newman, J., Baars, B. J., & Cho, S. (1997). A neural global workspace model for conscious attention. *Neural Networks*, *10*(7), 1195-1206. doi:10.1016/S0893-6080(97)00060-9

Naveteur, J., Delzenne, J., Sockeel, P., Watelain, E., & Dupuy, M. A. (2013). Crosswalk time estimation and time perception: An experimental study among older female pedestrians. *Accident Analysis And Prevention*, *60*42-49. doi:10.1016/j.aap.2013.08.014

Ogden, R. S., Moore, D., Redfern, L., & McGlone, F. (2015). The effect of pain and the anticipation of pain on temporal perception: A role for attention and arousal. *Cognition And Emotion*, *29*(5), 910-922. doi:10.1080/02699931.2014.954529

Ogden, R. S., Moore, D., Redfern, L., & McGlone, F. (2015). The effect of pain and the anticipation of pain on temporal perception: A role for attention and arousal. *Cognition And Emotion*, *29*(5), 910-922. doi:10.1080/02699931.2014.954529

Ruotsalainen, S., Miettinen, R., MacDonald, E., Riekkinen, M., & Sirviö, J. (1998). The role of the dorsal raphe-serotonergic system and cholinergic receptors in the modulation of working memory. *Neuroscience And Biobehavioral Reviews*, *22*(1), 21-31. doi:10.1016/S0149-7634(96)00065-6

Raffone, A., Srinivasan, N., & Barendregt, H. P. (2014). Attention, consciousness, and mindfulness in meditation. In N. N. Singh, N. N. Singh (Eds.), *Psychology of meditation* (pp. 147-166). Hauppauge, NY, US: Nova Science Publishers.

Smythies J, Edelstein L, Ramachandran V. (2012). Hypotheses relating to the function of the claustrum. *Front. Integr. Neurosci.* 6:53

Sucala, M., & David, D. (2013). Mindful about time in a fast forward world. The effects of mindfulness exercise on time perception. *Erdélyi Pszichológiai Szemle*, *14*(2), 243-253.

Srinivasan, N., & Baijal, S. (2007). Concentrative meditation enhances preattentive processing: A mismatch negativity study. *Neuroreport: For Rapid Communication Of Neuroscience Research, 18*(16), 1709-1712. doi:10.1097/WNR.0b013e3282f0d2d8

Teki, S., Griffiths, T. (2016). Brain bases of working memory for time intervals in rhythmic sequences. *Frontiers in Neuroscience*, 10:239. Doi: 10.3389/fnins.2016.00239

Treisman, M. (1993). On the structure of the temporal sensory system. *Psychologica Belgica*, *33*(2), 271-283.

Treisman M. (1963). Temporal discrimination and the indifference interval: implications for a model of the “internal clock.” *Psychol. Monogr.* 77(13):1–31

Treisman M. (1984). Temporal rhythms and cerebral rhythms. *Ann. N.Y. Acad. Sci.* 423:542–65

Treisman M. (2013). The information-processing model of timing (Treisman, 1963): its sources and further history. *Timing Time Percept.*

Treisman, M., Cook N., Naish PL., Mac Crone JK. (1994). The internal clock: electroencephalographic evidence for oscillatory processes underlying time perception. *Q. J. Exp. Psychol. A* 47:241–89

Treisman, M., Faulkner A., Naish PLN., Brogan D. (1990). The internal clock: evidence for a temporal oscillator underlying time perception with some estimates of its characteristic frequency. *Perception* 19:705–43

VanRullen, R., Reddy, L., & Koch, C. (2006). The Continuous Wagon Wheel Illusion Is Associated with Changes in Electroencephalogram Power at ∼13 Hz. *The Journal Of Neuroscience*, *26*(2), 502-507. doi:10.1523/JNEUROSCI.4654-05.2006

VanRullen, R., & Koch, C. (2003). Is perception discrete or continuous? *Trends In Cognitive Sciences*, *7*(5), 207-213. doi:10.1016/S1364-6613(03)00095-0

Wallace, B. A. (1999). The Buddhist tradition of Samatha: Methods for refining and examining consciousness. *Journal Of Consciousness Studies*, *6*(2-3), 175-187.

Zakay, D., & Block, R. A. (1997). Temporal cognition. *Current Directions in PsychologicalScience*, *6* (1), 12–16. doi:10.1111/1467-8721.ep11512604

Zakay, D., & Block, R. A. (2004). Prospective and retrospective duration judgments: An executive-control perspective. *Acta Neurobiologiae Experimentalis*, *64*(3), 319-328.

Zeidan, F., Gordon, N. S., Merchant, J., & Goolkasian, P. (2010). The effects of brief mindfulness meditation training on experimentally induced pain. *The Journal of Pain*, *11*(3), 199–209. https://doi-org.ezproxy.uta.edu/10.1016/j.jpain.2009.07.015