Time Perception Embodied: The Effect of Yogic Posture and Meditation on Retrospective Time Estimations

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Time Perception Embodied

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Abstract

The current study aims to integrate models of embodied and cognitive time perception by investigating the role of attention allocation, physiological arousal, and arm length on retrospective time estimations. We operationalize attention through an open monitoring meditation and physiological arousal through expansive and contractive yogic postures. Arm length was analyzed as a covariate. Participants (N=60) reported estimated time spent on a brief attention task after either listening to music or meditating and the adoption of an expansive or contractive yogic posture. We found that the expansive posture lengthened time estimations in comparison to the contractive posture, and that this effect was accentuated for individuals with longer arms. No significance was found for the effect of meditation on retrospective time estimations. Interactive effects of posture and arm length feed into embodied models of time perception, emphasizing the idea that our spatial relationship to the external world directly influences our internal perceptions.

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A common complaint is that time is "slipping through our fingers." Hidden in this metaphor is a curious tension between time as an abstract flow requiring higher-order cognitive processes and time as situational framing that we grasp through our embodiment of the world around us. The current study aims to address this tension by examining retrospective time perception through attentional and motoric manipulations, using mindfulness meditation and energizing yoga posture, respectively. This work will seek to bridge a gap between our experience of time as stipulated by internal mental models and as an emergent property of how our bodies coordinate with extended spatial contexts.

The present work aims to understand retrospective time estimation as depending on a confluence of attentional and bodily resources. After outlining some of the theoretical and applied stakes for developing our understanding of time perception, this work highlights how cognitive, abstract models of time perception have begun to acknowledge the role of embodiment. This thesis will use meditation and yoga to operationalize the relatively mentalist and relatively embodied aspects of time perception.

Time Perception as a Lens into Psychological Experience

The study of our instantaneous time perception holds various potential applications in the realm of psychology. Studying one's experience of time offers a unique lens to understanding key topics such as attentional capacities, impulsivity and or even broader personality characteristics. Time perception plays a role in attentional capacities, as focused attention renders time irrelevant to the participant, accelerating rate of time (Linares Gutiérrez et al., 2022) while divided attention and boredom create awareness of time, slowing it down (Behm & Carter, 2020). Differences in felt sense of time result in variations in impulse control, having repercussive impacts on cognitive capacities such as decision making (Wittman & Paulus, 2008). For instance, those higher in addictive tendencies seem to process time differently (Paasche et al. 2019). For instance, stimulant-dependent individuals overestimated time durations, an effect which coincides with higher impulsivity (Wittman et al., 2007). The Zimbardo Time Perspective Inventory sorts an individual's general sense of time by given personality traits (Wittman et al., 2015). This idea, called "time perspectives", is summarized by Wittman et al. (2015) by exemplifying the "future" time perspective as people who perceive time to move faster and are therefore goal directed, future focused and less impulsive.

Time perception is the root of many essential functions for humans. For example, embodied time mechanisms align our bodies with external environments in the form of circadian rhythms, syncing us with the cyclic shift from day to night. While clock time is standardized, objective and universal, our momentary experience of time speed is individual and changing from moment to moment. Time perception research has identified factors which impact our perceived speed of time, such as our mood and cognitive states (Wittman & Wassenhove, 2009). We may thus use individual's perceived rate of time as a mechanism to explore a multitude of avenues within the field of psychology. The current study focuses on how awareness of the body—as with meditation and body posture— impacts our mental state and therefore perceived rate of time.

When analyzing time perception, it is, essential to distinguish between time estimation and experienced rate of time. The current study examines retrospective time estimation, which does not allow us to conclusively make claims regarding perceived rate of time due to the uncertain relationship between time speed and time estimation. There exists two opposite ways of interpreting retrospective time estimates in terms of perceived time rate. Assumptions that underestimations indicate a faster rate of time and overestimations indicate a slower rate of time are in alignment with a colloquial conceptualization, however, are not consistent with pacemaker models of time perception. The cognitive timer model reflects a pacemaker which accumulates "tics" over a given period (Berkovich-Ohana et al., 2011). So, one who has overestimated time, experienced a higher accumulation of "tics" relative to the given amount of time. Thus, according to the cognitive timer model, one who overestimates has experienced time faster. The oppositional interpretations cause us to veer from making statements involving perceived time speed as claims regarding experienced rate of time cannot be made with only the knowledge of one's retrospective time estimation.

Theories of Time Perception

Resolving a theoretical approach to time perception will involve balancing the abstract with the physical underpinnings of subjective experience. Prevailing theories of time perception stem from an internal clock-like mechanism, which tracks the number of subjective pulse rates. Cognitive theory proposes that we have an internal "pacemaker" which represents time duration through number of pulses accumulated over a specific period (Wittman & Paulus, 2008). Time perception, although seemingly abstract and difficult to objectively measure, relies on our direct experience of physical, embodied aspects of our experience. The cognitive timer model (CTM) builds on the elementary pacemaker theory by taking states of both mind and body into account, stating that attention and arousal are definitive intersecting factors in pulse rate estimation (Berkovich-Ohana et al., 2011). The current study aims to find further support for the cognitive timer model, operationalizing attention through meditation and manipulating physiological state through two various yoga postures. Fundamentally, this approach aims to extend the cognitive timer model to make the embodied roots of time perception more explicit.

Cognitive Timer Model: Attention Through the Lens of Meditation & Flow

The experience of a given moment is shaped by the focus of our attention. Consciousness of time, such as in states of boredom (Zakay, 2014) slows time (Behm & Carter, 2020). However, allocating attention away from time, causes time to "fly" (Linares Gutiérrez et al., 2022) as with engaging in a challenging (Im & Varma, 2018) or enjoyable task (Nuyens et al., 2019). Csikszentmihalyi (1990) proposed the idea of "flow" or total engrossment in which attention is entirely devoted to an activity at hand. Since these states of flow are enjoyable and goal oriented, time-duration is often underestimated (Nuyens, 2019). Flow states are of popular research interest due to their production of optimal experience and desirable lengthening of attention spans (Yang et al., 2019). Measuring time perception is one way to identify a flow state (Hancock et al., 2019) as it reflects the nature of one's experience. Studying perceived rates of time thus becomes an important lens for understanding how we may lengthen attention spans and enable flow.

Meditation is a compelling avenue to explore the effects of time perception due to its inception of state of presence, akin to states of flow. Undesirable states, such as boredom, coincide with a resistance to what exists in the present moment. Meditation loosens this resistance by eliciting unconditional acceptance of the present, thus altering the perceived rate of time (Thönes & Wittman, 2016). Goleman (1988) and later Lutz et al. (2008), identified two types of meditation. The first, a focused attention (FA) approach, involves gaining control of attention and continually redirecting it toward a stable object such as an image or breath counting (Berkovich-Ohana et al., 2011). On the other hand, open monitoring (OM) meditation brings awareness to the internal state, such as with a systematic relaxation which demands focus on sensations within the body (Lin et al., 2020). Berkovich-Ohana et al. (2011) compared each method and found the OM condition retrospectively estimated longer time durations while focused attention meditation exhibited no significant impact on time estimation. OM prompts a stronger state of presence by reducing self-narrative and by activating momentary awareness (Berkovich-Ohana et al., 2011; Fujino et al., 2018), as opposed to FA, which fails to produce time dilation because it activates memory and self-concept (Berkovich-Ohana et al., 2011; Fujino et al., 2018).

Inconsistent results pertaining to the exact directional influence of meditation on time perception direct us towards other possible mechanisms. Perhaps perceived rate of time is dependent on the body's state of arousal, type of meditation (Berkovich-Ohana et al., 2011) or extent of meditation experience. One study consisting of primarily inexperienced meditators, found meditation accelerated felt time (Thönes & Wittman, 2016), while experienced meditators experience a slowed rate of time (Berkovich & Ohana et al,, 2011; Wittman et al., 2015), suggesting meditation experience plays a strong role in time perception effects of meditation. Broader time perception theory appears consistent with these findings. Theoretically, meditation allocates attention away from time, as it demands bodily awareness, causing time to speed (Linares Gutiérrez et al., 2022), whereas awareness of time produces a slowed down effect (Behm & Carter, 2020). However, time perception appears context-dependent, making definitive statements about expected effects of internal pacemakers difficult.

Embodied Foundations of Time Perception: Complementing Meditation with Yoga

Though far removed from the internal unfolding of mental factors, the physical embodiment at the whole-body scale may also have a role to play in time perception (Berkovich-

Ohana et al., 2011). The current study examines the potential postural interaction combined with open monitoring meditation in mixed experience meditators. The physiological and psychological impacts of the ancient practice of yoga will provide a presumably more holistic avenue to examine how time perception reflects a strong connection between the body and the mind. Yogic practices involve a syncing of movement and breath, which necessitates attention to turn inward, toward the body. Bodily sensations induced by physical practices such as yoga can facilitate meditation. In previous research, regular yoga practice over six weeks functioned similarly to an antidepressant, by greatly improving mood and general life satisfaction (Imboden et al., 2020). The effects of yoga and whole body stretching expand beyond mood, permeating cognitive capacities, seeming to improve selective attention (Hotting et al., 2011) and cognitive performance (Sudo & Ando, 2020).

Stepping Towards Embodiment: Role of Physiology

The connection between cognitive factors and embodiment begins to become apparent through the internal physiological dynamics supporting and responding to neural events. Our experience of a particular moment depends on a host of perceptual factors interacting across multiple scales. Our perception of the passage of time is directly intertwined with our emotional and physiological state. Just as low energetic levels can alter the anticipation of a challenge ahead (Schnall et al., 2010), aroused states such as fear and exertion tend to accelerate our experience of time (Fayolle, 2015; Schwarz, 2010), while unaroused states, such as boredom, depression or relaxation seem to slow our experience of time (Zakay, 2014; Thönes & Oberfeld, 2015; Thönes & Wittman, 2016). Isolating the physiological factors that influence time perception serves to further understand this relation between arousal and time perception. For instance, our perception of time appears dependent, in part, on the temperature of our bodies

(Behm & Carter, 2020). One perspective on this relationship theoretically intertwines with the pacemaker model of time perception, suggesting that perceived time runs faster at a higher body temperature due to our internal pacemakers pulsing at a higher rate (Tamm et al., 2014). Hormones, such as cortisol, seem to also play role in temporal sensitivity, seen with a spike in stress, decreasing temporal sensitivity, or the ability to differentiate varying time durations (Yao et al., 2016). States of high arousal tend to speed our internal clock, while states of low arousal may slow our experience of time.

Embodiment at the Whole-Body Scale: Role of Posture

Whereas many fine-grained physiological dynamics of the body can play their own role in psychological experiences of time, the whole-body movement coordination that yoga emphasizes may contribute to the organization of how we relate to time in a way that the fine-grained dynamics may not address (Kugler & Turvey, 1987). Physical manipulations of the body produce varying bodily states, causing either high or low arousal. Hence, yoga allows us to depart from the molecular factors and offers us a whole-body lens on how physiology might influence time perception. A one-minute stretch of a singular arm muscle can activate the parasympathetic nervous system (Inami et al., 2014), suggesting the influence of bodily geometry on our physiological states and guiding us to question the perceptual effects of these internal changes. Another example, involving yoga, demonstrated the effect of a yoga pose, bhujangasana (cobra), which lead to an increase in testosterone and a decrease in cortisol (Minvaleev et al., 2004). Yet again, we see the whole-body impact of singular muscular manipulations. Time perception has already shown dependence on full-body posture, (Baurés & Hecht, 2011) and perception of body movement (Nather et al., 2011). We plan to build on this literature by using yoga poses as postural manipulation in the current study.

Yoga may be a crucial vehicle for exploring embodied theories of time perception. Previous "power posing" research demonstrates the meaningful role that body posture plays in our perception of time. Duffy and Fiest (2017) found that an expansive body posture led participants to conceptualize time as something they moved "through" while a contractive posture led participants to feel as though time was moving "toward" them. The intriguing implications of power posing research gained popularity, but the findings have not always been consistent (Garrison et al., 2016). We propose that the deeper historical traditions governing yogic practice may suggest an even more robust route for examining mind-body relationships in time perception. Certainly, yoga has not developed through explicit evidence-based scientific practice, but compared to novel "power pose," yoga practice has aimed at enriching mind-body relationships long before embodiment came into psychological-scientific vogue. Succeeding literature introduced yogic postures as a potentially more fruitful line to pursue due to its more technical nature. Yogic postures further embodiment by incorporating more specific bodily placement and breath. Findings within this line indicate that yogic postures produce higher states of self-esteem in comparison to power posing (de Zavala et al., 2017). While the literature on power posing provides useful and fascinating ramifications, the current study focuses on yogic postures due to their comparatively stronger effects.

If our body posture impacts our perception of time, so too might our body size and shape. Postural influences on time perception may reflect a role of bodily dimensions (e.g. height or arm span), giving a spatial mediation of our relationship with time. For instance, much of our experience of time may depend on how we can use our bodies to move through space and learn to time our movements according to our ability to get from one point to another. Since clocking behavior of a pendulum can depend on its mass distribution, Kugler and Turvey (1987) raised the possibility that our ability to coordinate with time depended on the pendular aspects of our bodily posture and their preferred modes of oscillation. Taller or longer pendula whose mass is distributed farther from their hinge have longer, slower oscillations. For instance, it appears that taller people with longer limbs appear to have heightened perceptual abilities for estimating longer time intervals (Gilden & Mezaraups, 2022). Our bodies constitute distributed tensional networks in which pendular limbs coordinate within a web of connective tissue, balancing the need for muscular effort with a reliance on the length-dependent resonant wavelength of our limbs (Turvey & Fonseca, 2014). So, yoga posture may be recruiting different networks of tension and inertia, thereby engendering new time-perceptual modes.

The Current Study

The current study examined the effects of meditation and yoga practices on time perception. A 2 (mindfulness/music) x 2 (energizing/relaxing) between subjects design tested adult participants on a retrospective time-estimation task. We randomly assigned participants to engage in either a mindfulness-meditation practice or in a music-listening task. They then adopted either an expansive or contractive pose, stimulating the sympathetic and parasympathetic nervous system, respectively. After each yoga pose, participants completed a brief attention task and then reported how long they thought the task took.

The present work blended meditation with yoga poses to examine time perception as both an abstract and embodied experience. The meditation condition is based on prior research conducted by Thönes and Wittman (2016) from which we derived the duration of meditation condition and operationalization of the control. The yogic postures and length of time maintaining them are adapted from de Zavala et al. (2017).

We had three hypotheses. Hypothesis 1 was that we would replicate the previous finding of a main effect of meditation leading participants perceive time as running faster (Thönes & Wittman, 2016), as we expected a majority of participants to have minimal meditation experience. Hypothesis 2a was that yoga poses would alter time perception, such that expansive poses would lead to faster time perception while contractive poses will lead to slower time perception, respectively. We expected the expansive posture to cause physiological arousal, causing rate of time to appear to move faster (Baurés & Hecht, 2011). Arm length is an important covariate of this effect because an expansive posture would require greater effort for longer arms with more distal center of mass (Hypothesis 2b). We expected that individuals with longer arms and taller heights would perceive time to move faster in the expansive posture condition, due to the higher level of exerted effort (Kugler & Turvey, 1987). Finally, Hypothesis 3 was that the meditation condition would accentuate predicted perceptual effects of each yoga posture, with mindfulness accentuating the perception of time as faster or slower with expansive or contractive poses, respectively. So, if we expect the expansive posture to quicken perceived time speed, the meditative condition will accelerate perceived time speed further, and produce an opposite effect in the contractive condition.

In considering modeling strategy for the present analysis, it is important to highlight the potential of a non-Gaussian distribution given constraints of individual differences producing variations in participant engagement in the Digital Vigilance Task (Brown & Steyvers, 2009; Kuznetsov & Wallot, 2011; Stephen & Dixon, 2011; Mangalam et al., 2023). The avoidance of repeated measures reduces the threat of non-ergodicity to linear modeling (e.g., Molenaar, 2008). That said, the anticipation of a non-Gaussian response profile across participants may require testing predictions in regression strategies that generalize linear modeling to non-Gaussian outcome variables and that control for relationships between exogenous manipulation (e.g., posture) with endogenous variation (e.g., in attention and consequent variation in time spent on the DVT). Respecting the count-like quality of time estimates that participants will make in as counts of seconds, we will also attempt to fit these predictions into a generalized linear model for count variables.

Method

Participants

60 Participants were recruited from SUNY New Paltz's SONA system, which allows students to receive credit towards graduation or a class upon participation in other students' studies. Participants were of varied yoga and meditation experience.

Design

The present research consists of a 2 (mindfulness/music) x 2 (expansive/contractive) between subjects design. Participants first lay down on a mat and listened to either a guided meditation or classical music, each 13 minutes and 20 seconds in duration. The meditation script was adapted from Thönes & Wittman (2016) and voice recorded by the female researcher. The audio for both the meditation and music condition were played from laptop speakers. Participants were then shown a video on a laptop of an expansive or contractive posture to adopt for one minute. Participants then completed the Digital Valence Task (DVT), in which they were presented with a randomized series of numbers and instructed to cancel out the numbers "6" and "9". Following the task, participants filled out a six-questions survey intended to capture estimated time spent on the DVT task, a relaxation measure which served as a meditation manipulation check and questions about previous experience with meditation and yoga.

Materials

The current study used the yoga room in the Athletic and Wellness Center and an empty room in Lenape Hall to provide space for the meditation and yoga poses. Measuring tape was used to measure participant's arm span length. Participants in the meditative condition followed a guided meditation recording (see Appendix A). Participants in the control condition listened to Sonata in D Major for Two Pianos, by Mozart, K.448. The experimenter recorded a video of herself explaining and demonstrating each the contractive and expansive yogic posture (https://osf.io/c9fu6/). A printed sheet with the DVT task was provided to participants to fill out with a pen. The six-question survey was provided on a separate sheet of paper.

Procedure

Participants' arm length and height were measured prior to the start of yogic and meditative tasks. Random assignment sorted each participant into either a meditative or music (control) condition and expansive or contractive yogic pose condition. In all conditions, the researcher instructed participants to lie facing up (supine) on a yoga mat. Instructions then guided participants to relax and move as little as possible. A recorded guided, open monitoring meditation played through speakers for participants in the meditative condition. The control condition listened to Sonata in D Major for Two Pianos, by Mozart, K.448 (Thönes & Wittman, 2016) through speakers. Both the meditative condition and the control lasted 13 minutes and 20 seconds, to suit individuals with limited meditative experience (Thönes & Wittman, 2016).

After the meditation or music listening task, participants adopted an expansive yogic posture or a contractive yogic posture in a randomly assigned order for counterbalancing. For each pose, the researcher showed participants an instructional video that demonstrated the yoga postures. Participants then maintained each posture for one minute. The expansive posture, urdhva hastasana (i.e., “upward salute”) involves reaching arms up, with feet hip width apart. The contractive posture, garudasana (“eagle pose”) involves crossing the arms while standing up straight. While the yoga poses intend to manipulate posture, it is of note that the contractive posture demands more complexity in the crossing of arms.

After the yoga posture, participants then performed the Digital Vigilance Test (DVT). The DVT developed by Kelland and Lewis (1996) provided participants with a mildly cognitively stimulating task designed to measure sustained attention (Ganpat et al., 2013). The DVT presented randomly arranged numbers 1-9 in rows. It includes 30 digits per row and 50 rows per sheet, the current study modified this to 21 rows per sheet. Participants received instructions to cross out digits 6 and 9 with a pen as quickly as possible (Ganpat et al., 2013). Researchers noted the total time participants spent on the task. The number of errors were also recorded. Participants then filled out a 3-part survey. First, participants were prompted to report how much time they thought they spent on the number counting task (DVT). Second, participants responded to three questions on a 1-7 scale to gauge relaxation state to serve as a meditation manipulation check (Thönes & Wittman, 2016). Finally, the survey asked participants to report how much experience they have with meditation and yoga.

Data Analysis

ANCOVA

The current study analyzed the impact of meditation and yogic posture on accuracy of retrospective time estimations, while controlling for the influence of arm length and height. Our initial analysis consisted of a two-way between subjects Analysis of Variance (ANOVA), which analyzed the difference between participant’s time estimations and actual time spent on the DVT task (Actual time – Estimated time). Arm length and height are measured as covariates. Yoga experience, meditation experience, DVT errors and relaxation state served as manipulation checks.

Negative Binomial

We also applied a negative binomial model to respect the fact that our time-estimate response variable was a strongly non-Gaussian count variable. A negative binomial regression is an elaboration of a Poisson regression, both of which are generalized linear models (GLM) used to model whole-number response measures. The negative binomial model elaborates Poisson regression modeling for count variables with overdispersion, i.e., with variance greater than the mean. GLMs use a link function to convert a non-linear response measure into a linear modeling space--a prevalent example of this link-function is the logit link allowing logistic regression to model a linear relationship between predictor variables and logarithmic odds of change in a dichotomous variable. Instead of using a logit link, Poisson and negative-binomial modeling alike use a logarithmic link to model the linear relationship between predictor variables and logarithmic probability of a unit increase in the count variable.

Negative binomial modeling estimates a *B* coefficient for each predictor to express the average difference in logarithmic probability with a unit increase in each predictor. Thus, *B* indicates the unstandardized effect size of the predictor variable, and analogously to how exponentiating a predictor's *B* coefficient in logistic regression yields an odds ratio for that predictor, exponentiating a *B* coefficient in negative binomial regression yields an estimate of proportional ratio. Specifically, for each predictor variable's *B* coefficient, $\exp(B)-1$ is proportional change: for $B = 0$, $\exp(B) = 1 = 100\%$, i.e., indicating that the predicted count with unit increase of the predictor is 100% of the predicted count without the unit increase--that is, the unit increase has no effect on the predicted count. For $B > 0$, $\exp(B) > 1$, and the excess beyond

100% amounts to a predicted increase of the count. For $B < 0$, $\exp(B) < 1$, and the difference below 1 amount to a predicted decrease of the count.

A benefit of this regression strategy is that it allows us to model the raw time-estimation scores using the actual time spent on the DVT as a predictor and allowing the remaining predictors to address the deviations of time estimates above and beyond the actual DVT time. It thus allows modeling time estimates while avoiding having to subtract the actual time spent on the DVT task before analysis.

We ran our analysis with R studio using the function (GLM.nb). Our dependent variable was the retrospective time estimate Time_{Est} measured in seconds. Our predictors included Posture (0 = contractive, 1 = expansive), time spent on the DVT task TimeDVT_Time_{DVT} measured in seconds, and arm length Arm in inches. We included two interactions Posture×Arm Posture×Time_{DVT}. Additional predictors exceeded the recommended ratio of one predictor per ten observations for proper statistical power in regression methods (Babyak, 2004). Furthermore, alternate models with different predictors (e.g., for the meditation variable) showed no significant effects in this model.

Results

ANCOVA Results

Our results were non-significant for the main effect of meditation ($F(1, 50) = 0.85$, $p = 0.36$) and yogic posture ($F(1, 50) = 0.40$, $p = 0.53$) on accuracy of retrospective time estimation while controlling for covariates, arm length and height. There were also no significant effects when adjusting for the influence of arm length ($F(1, 50) = 0.14$, $p = 0.71$, height ($F(1, 50) = .55$, $p = .46$), yoga experience ($F(1, 50) = 0.17$, $p = 0.69$), meditation experience ($F(1, 50) = 0.10$, $p =$

0.75), relaxation state ($F(1, 50) = .12$, $p = 0.73$) and number of errors on the DVT task ($F(1, 50) = 2.38$, $p = 0.13$). These effects failed to be significant even when each was entered alone.

Negative Binomial Results

Our negative binomial model analyzed the interactions Posture×Arm and Posture×$Time_{DVT}$ and their component main effects on time estimation, the regression is demonstrated by Figure 1. Arm length was analyzed as opposed to height as the two are highly correlated, and we expect arm length is to play a stronger role in pendular aspects of body posture and time perception. Meditation was left out of the analysis as it did not improve model fit. Estimating this model through Poisson regression does indeed leave the residuals overdispersed, [$x^2(54) = 2101.00$], ($p < .001$), but the negative binomial model shows no such overdispersion, [$x^2(54) = 61.31$],($p = .230$). The actual time spent on the DVT task was included in the model ($Time_{DVT} B = 0.01$, $p < .001$), leaving all subsequent effects on $Time_{Est}$ to reflect deviations from accurate time estimation. Expansive yogic posture (Posture; $B = -4.59$, $p = .016$) reduced time estimations. This effect was even stronger for participants spending longer on the DVT task (Posture×$Time_{DVT}$; $B = -0.005$, $p = 0.04$). Arm length on time estimation had no main effect ($B = -.02$, $p = 0.21$) but increased time estimates for participants who held the expansive posture ($B = 0.09$, $p = 0.003$).

In summary, the expansive posture condition accentuated time estimates $Time_{Est}$ for participants with longer arms. Comparing the third and first quartile of Arm (i.e., 67 and 62, respectively), participants in the expansive posture prompted ($\exp(B_{Posture}+67\times B_{Posture\times Arm}) - 1 = \exp(-4.59+67\times 0.09) - 1 = 367\%$) higher time estimations than individuals in the contractive posture condition. Meanwhile for the participants with shorter arms, the expansive posture prompted a 237% increase in time estimation scores from the expansive to the contractive posture condition. In the expansive condition, individuals in the first quartile for arm length (people with shorter arms) were 4331.27% more likely to estimate one more second. Individuals in the third quartile for arm length (people with longer arms) were 5988.32% more likely to estimate another second. In the contractive condition, participants in the first quartile for arm length (people with shorter arms) were 1772.63% more likely to estimate another second. Participants in the third quartile for arm length were 1557.52% more likely to estimate one more second. Figure 2 demonstrates these percent differences among the first and second quartiles of arm length.

There was no significant effect found for meditation. The relaxation measure which served as a manipulation check, demonstrated significant ($p < .05$) differences between meditation ($M = 5.71$) and music ($M = 5.15$). Participants' experience in meditation was varied; 7 ($N = 7$) reported they had no experience, 21($N = 21$) reported they had minimal experience, 19 ($N = 19$) reported they had some experience, 10 ($N = 10$) reported they had moderate experience and 3 ($N = 3$) reported having a lot of meditation experience.

Figure 1

Predicted Change in Time Estimation by Time Estimation in second

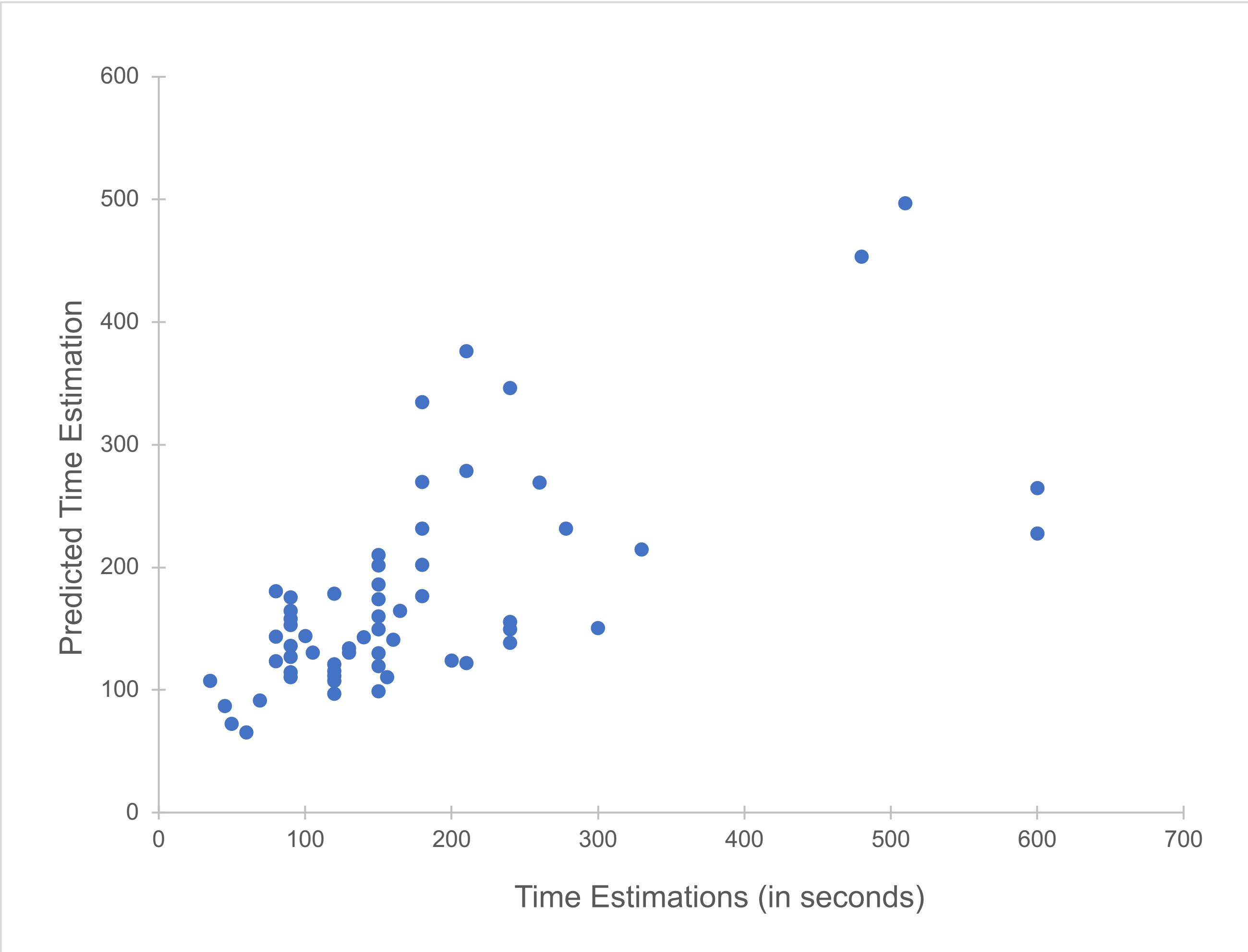
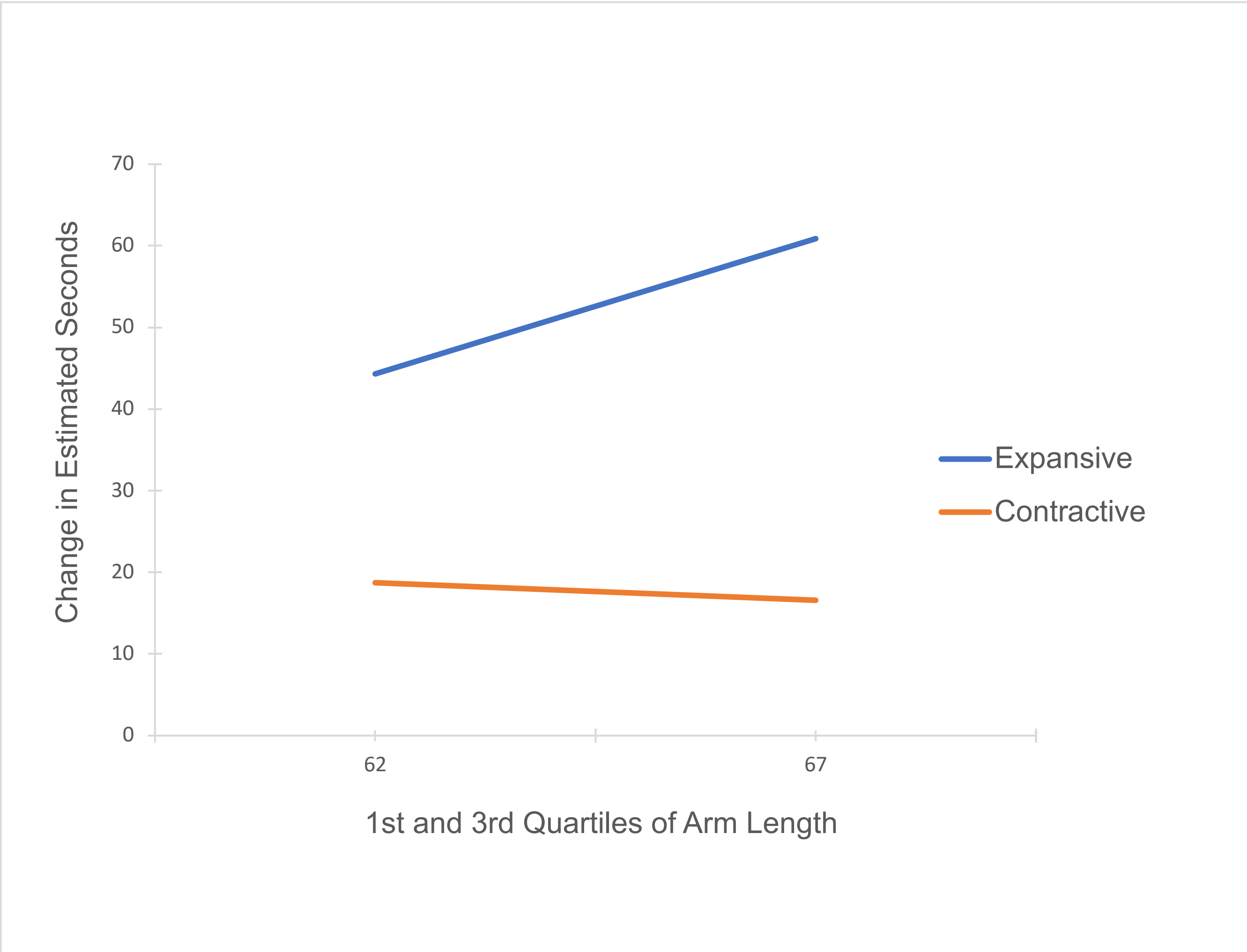


Figure 2

Likelihood of Another Estimated Second in 1st and 3rd Quartiles of Arm Length



Discussion

The current study examined the effect of meditation, yogic posture, and arm length on retrospective time estimations. We first predicted that meditation would accelerate perceived rate of time (Hypothesis 1). No significant effect of meditation was found, which is likely due to the wide variance in participant's prior meditation experience. We also predicted that the expansive yogic posture would lead to faster perceived rate of time (Hypothesis 2a), and that this effect would be accentuated for participants with longer arms (Hypothesis 2b). We found significant effects of posture on retrospective time estimation, such that the expansive posture lengthened time estimations. We found no main effect of arm length but discovered that longer arms further lengthened time estimations, revealing an interaction between posture and arm length. Given the lack of significant effects of meditation, no significance was found for Hypothesis 3 regarding the predicted interaction between meditation and posture. The significant effect of posture and interactive effect of posture and arm length lend new credence to the embodied roots of the cognitive timer model.

We hesitate to make claims regarding the perceived rate of time among participants, given two various potential interpretations of the relationship between length of estimates and perceived rate of time. It is unclear whether a shorter time estimation translates to faster or slower experienced rate of time as there appears to be inconsistencies, dependent on unknown factors. In Thönes & Wittman (2016), participants who reported shorter time estimations rated their felt rate of time as faster, and participants who reported longer time estimations rated their felt rate of time as slower. However, research by Chambon (2008) references an internal clock model, which states that shortened time estimations reflect a slowing of perceived time speed. Aside from this uncertainty, we find significant results of posture and the interaction between posture and arm length worthy of discussion and further research. In measuring retrospective time estimates, we suggest that subsequent studies use an additional measure which prompts participants to rate speed of time on a Likert scale, as used in Thönes and Wittman (2016).

The interactive effects of posture and arm length feed into embodied models of time perception. The significant effect of arm length on retrospective time estimations in the expansive posture condition supports Gilden & Mezaraups' (2021) finding that experience of time is scaled to one's capacity for oscillation. Kugler and Turvey (1987) considered the complex tensional network which coordinates the distribution of weight throughout our bodies, producing various physiological shifts. These physiological shifts seem to generate aspects of our experience which inevitably dictate our perceptual reality.

Kugler and Turvey's (1987) proposition of bodily mass distribution playing a role in perceptual capacities states that our ability to coordinate with time depends on the pendular aspects of our body. Longer pendula have further mass distribution and therefore longer oscillations, giving taller individuals longer units for tiling perceived time. Taller individuals may then have weaker sensitivity to finer details of time estimation and be more likely to overestimate time. We find support that body size interacts with body posture, tapping into a special inertial network within the body, altering perceived rate of time.

We acknowledge the potential of biological sex to act as a confound in the current study as males tend to be taller than females. However, we rule this out by consulting prescreening survey responses on the participant pool administration software which indicates that our sample comprised participants predominantly female (59) rather than male (11), suggesting there were not many males to skew the distribution of arm lengths.

Future Directions: Elaborating postural effects and revisiting meditation

We found no significant effect of meditation on time perception. We were motivated to understand the role of attention allocation and, more specifically, the effect of bodily awareness using open monitoring meditation. The high variation of participants' meditation experience in the current study likely canceled out significant effects in respect to meditation. Inexperienced meditators have more difficulty entering a meditative state, especially with open monitoring (Fujino et al., 2018), and may have thus experienced excessive boredom or mind wandering in the meditative condition. The influence of meditation on time perception appears to directionally vary depending on one's extent of practice. Meditation tends to slow time for experienced meditators (Berkovich & Ohana et al., 2011; Wittman et al., 2015) and accelerate time for inexperienced meditators (Thönes & Wittman, 2016). This raises the possibility that repetitive mindfulness practice may alter one's global relationship with time. Future research could compare time perspectives between meditators and non-meditators using the Zimbardo Time Perspective Inventory (Wittman et al., 2015). Given our lack of significant results in our attempt to test attentional effects on time perception, we suggest that future researchers either require a minimum level of meditation experience for recruitment or explore alternative routes to induce states of relaxation for naïve meditators.

Time perception should be more widely researched due to its ability to uniquely capture the nature of one's reality, both instantaneously and longitudinally. In this way, temporal sense serves as an unconscious, but inescapable structure of every moment we experience. We orient ourselves with reality through our perception of time. Understanding the role of embodied time allows us to further grasp the nature of our bodily coordination with reality and the strong relationship between internal mechanisms on our external realities. There exists an intersection of fixed variables, such as body size and malleable factors, such as body posture, which work together to influence our sense of time. We are thus guided to consider the potential to leverage malleable factors and test effects of altering time perception on observed correlated aspects such as attention or impulsivity. Alternatively, and especially if this attempt fails, we may be led to explore other emerging factors which influence our perception of time.

References

Babyak M. A. (2004). What you see may not be what you get: a brief, nontechnical introduction to overfitting in regression-type models. *Psychosomatic medicine*, *66*(3), 411–421. https://doi.org/10.1097/01.psy.0000127692.23278.a9

Baurès, R., & Hecht, H. (2011). The effect of body posture on long-range time-to-contact estimation. *Perception*, *40*(6), 674–681. https://doi.org/10.1068/p6945

Behm, D. G., & Carter, T. B. (2020). Effect of exercise-related factors on the perception of time. *Frontiers in Physiology*, *11*, 770. https://doi.org/10.3389/fphys.2020.00770

Berkovich-Ohana, A., Glicksohn, J., & Goldstein, A. (2011). Temporal cognition changes following mindfulness, but not transcendental meditation practice. *Fechner Day 2011: Proceedings of the 27th Annual Meeting of the International Society for Psychophysics* (pp. 245-250).

Brown, S. D., & Steyvers, M. (2009). Detecting and predicting changes. *Cognitive psychology*, *58*(1), 49–67. https://doi.org/10.1016/j.cogpsych.2008.09.002

Chambon, M., Droit-Volet, S., & Niedenthal, P. M. (2008). The effect of embodying the elderly on time perception. *Journal of Experimental Social Psychology, 44*(3), 672–678. https://doi.org/10.1016/j.jesp.2007.04.014

Csikszentmihalyi, M. (1990). Flow: The psychology of optimal experience. New York, NY: Harper & Row.

de Zavala, A. G., Lantos, D., & Bowden, D. (2017). Yoga poses increase subjective energy and state self-esteem in comparison to 'power poses'. *Frontiers in Psychology, 8,* Article 752.

Duffy, S. E., & Feist, M. I. (2017). Power in time: The influence of power posing on metaphoric perspectives on time. *Language and Cognition*, *9*(4), 637–647. https://doi.org/10.1017/langcog.2016.33

Fayolle, S., Gil, S., & Droit-Volet, S. (2015). Fear and time: Fear speeds up the internal clock. *Behavioural Processes*, *120*, 135–140. https://doi.org/10.1016/j.beproc.2015.09.014

Fujino, M., Ueda, Y., Mizuhara, H., Saiki, J., & Nomura, M. (2018). Open monitoring meditation reduces the involvement of brain regions related to memory function. *Scientific Reports*, *8*(1), 9968. https://doi.org/10.1038/s41598-018-28274-4

Ganpat, T., Sheela, & Nagendra, H. R. (2013). Efficacy of Yoga for sustained attention in university students. *AYU (An International Quarterly Journal of Research in Ayurveda)*, *34*(3), 270. https://doi.org/10.4103/0974-8520.123117

Garrison, K., Tang, D., and Schmeichel, B. (2016). Embodying power: a preregistered replication and extension of the power pose effect. *Soc. Psychol. Personal. Sci.* 7, 1–8. doi: 10.1177/1948550616652209

Gilden, D. L., & Mezaraups, T. M. (2022). Allometric scaling laws for temporal proximity in perceptual organization. *Psychological Review*, *129*(3), 457–483. https://doi.org/10.1037/rev0000307

Goleman, D. (1988). The meditative mind–the varieties of meditative experience. New York: GP Putnam & Sons.

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

Hötting, K., Reich, B., Holzschneider, K., Kauschke, K., Schmidt, T., Reer, R., Braumann, K.-M., & Röder, B. (2012). Differential cognitive effects of cycling versus stretching/coordination training in middle-aged adults. *Health Psychology*, *31*(2), 145–155. https://doi.org/10.1037/a0025371

Im, S., & Varma, S. (2018). Distorted Time Perception during Flow as Revealed by an Attention-Demanding Cognitive Task. *Creativity Research Journal*, *30*(3), 295–304. https://doi.org/10.1080/10400419.2018.1488346

Imboden, C., Gerber, M., Beck, J., Holsboer-Trachsler, E., Pühse, U., & Hatzinger, M. (2020). Aerobic exercise or stretching as add-on to inpatient treatment of depression: Similar antidepressant effects on depressive symptoms and larger effects on working memory for aerobic exercise alone. *Journal of Affective Disorders*, *276*, 866–876. https://doi.org/10.1016/j.jad.2020.07.052

Inami, T., Shimizu, T., Baba, R., & Nakagaki, A. (2014). Acute Changes in Autonomic Nerve Activity during Passive Static Stretching. *American Journal of Sports Science and Medicine*, *2*(4), 166–170. https://doi.org/10.12691/ajssm-2-4-9

Kelland, D. Z., & Lewis, R. F. (1996). The Digit Vigilance Test: reliability, validity, and sensitivity to diazepam. *Archives of clinical neuropsychology : the official journal of the National Academy of Neuropsychologists*, *11*(4), 339–344.

Kugler, P. N., & Turvey, M. T. (1987). *Information, natural law, and the self-assembly of rhythmic movement.* Lawrence Erlbaum Associates, Inc.

Kuznetsov, N. A., & Wallot, S. (2011). Effects of accuracy feedback on fractal characteristics of time estimation. *Frontiers in Integrative Neuroscience, 5,* Article 62. https://doi.org/10.3389/fnint.2011.00062

Lin, Y., Gloe, L. M., Louis, C. C., Eckerle, W. D., Fisher, M. E., & Moser, J. S. (2020). An electrophysiological investigation on the emotion regulatory mechanisms of brief open monitoring meditation in novice non-meditators. *Scientific reports*, *10*(1), 14252. https://doi.org/10.1038/s41598-020-71122-7

Linares Gutiérrez, D., Schmidt, S., Meissner, K., & Wittmann, M. (2022). Changes in Subjective Time and Self during Meditation. *Biology*, *11*(8), 1116. https://doi.org/10.3390/biology11081116

Lutz, A., Slagter, H. A., Dunne, J. D., & Davidson, R. J. (2008). Cognitive-emotional interactions: Attention regulation and monitoring in meditation. Trends in Cognitive Sciences, 12, 163-169.

Mangalam, M., Kelty-Stephen, D. G., Sommerfeld, J. H., Stergiou, N., & Likens, A. D. (2023). Temporal organization of stride-to-stride variations contradicts predictive models for sensorimotor control of footfalls during walking. *Plos one*, *18*(8), e0290324.https://doi.org/10.1371/journal.pone.0290324

Minvaleev, Nozdrachev, A. D., Kir'yanova, V. V., & Ivanov, A. I. (2004). Postural influences on the hormone level in healthy subjects: I. the cobra posture and steroid hormones. *Human Physiology*, *30*(4), 452–456. https://doi.org/10.1023/B:HUMP.0000036341.80214.28

Molenaar P. C. (2008). On the implications of the classical ergodic theorems: analysis of developmental processes has to focus on intra-individual variation. *Developmental psychobiology*, *50*(1), 60–69. https://doi.org/10.1002/dev.20262

Nather, F. C., Bueno, J. L. O., Bigand, E., & Droit-Volet, S. (2011). Time Changes with the Embodiment of Another's Body Posture. *PLoS ONE*, *6*(5), e19818. https://doi.org/10.1371/journal.pone.0019818

Nuyens, F. M., Kuss, D. J., Lopez-Fernandez, O., & Griffiths, M. D. (2020). The Potential Interaction Between Time Perception and Gaming: A Narrative Review. *International Journal of Mental Health and Addiction*, *18*(5), 1226–1246. https://doi.org/10.1007/s11469-019-00121-1

Paasche, C., Weibel, S., Wittmann, M., & Lalanne, L. (2019). Time perception and impulsivity: A proposed relationship in addictive disorders. *Neuroscience and Biobehavioral Reviews, 106,* 182–201. https://doi.org/10.1016/j.neubiorev.2018.12.006

Schnall, S., Zadra, J. R., & Proffitt, D. R. (2010). Direct Evidence for the Economy of Action: Glucose and the Perception of Geographical Slant. *Perception*, *39*(4), 464–482. https://doi.org/10.1068/p6445

Schwarz, M. A., Winkler, I., & Sedlmeier, P. (2013). The heart beat does not make us tick: The impacts of heart rate and arousal on time perception. *Attention, Perception, & Psychophysics*, *75*(1), 182–193. https://doi.org/10.3758/s13414-012-0387-8

Stephen, D. G., & Dixon, J. A. (2011). Strong anticipation: Multifractal cascade dynamics modulate scaling in synchronization behaviors. *Chaos, Solitons & Fractals*, *44*(1-3), 160-168.https://www.sciencedirect.com/science/article/abs/pii/S0960077911000105

Sudo, M., & Ando, S. (2020). Effects of Acute Stretching on Cognitive Function and Mood States of Physically Inactive Young Adults. *Perceptual and Motor Skills*, *127*(1), 142–153. https://doi.org/10.1177/0031512519888304

Tamm, M., Jakobson, A., Havik, M., Burk, A., Timpmann, S., Allik, J., Oöpik, V., & Kreegipuu, K. (2014). The compression of perceived time in a hot environment depends on physiological and psychological factors. *Quarterly journal of experimental psychology*, *67*(1), 197–208. https://doi.org/10.1080/17470218.2013.804849

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

Thönes, S., & Wittmann, M. (2016). Time perception in yogic mindfulness meditation—Effects on retrospective duration judgments and time passage. *Psychology of Consciousness: Theory, Research, and Practice*, *3*(4), 316–325. https://doi.org/10.1037/cns0000088

Turvey, M. T. & Fonseca, S. T. (2014) The Medium of haptic perception: A tensegrity hypothesis, *Journal of Motor Behavior*, *46*(3), 143-187, https://doi.org/10.1080/00222895.2013.798252

Wittmann, W., Leland, D. S., Churan, J., Paulus, M. P. (2007). Impaired time perception and motor timing in stimulant-dependent subjects. *Drug and Alcohol Dependence, 90*(2–3), 183-192.

Wittmann, M., & Paulus, M. P. (2008). Decision making, impulsivity and time perception. *Trends in Cognitive Sciences*, *12*(1), 7–12. https://doi.org/10.1016/j.tics.2007.10.004

Wittmann, M., Rudolph, T., Linares Gutierrez, D., & Winkler, I. (2015). Time Perspective and Emotion Regulation as Predictors of Age-Related Subjective Passage of Time. *International Journal of Environmental Research and Public Health*, *12*(12), 16027–16042. https://doi.org/10.3390/ijerph121215034

Wittmann, M., & Van Wassenhove, V. (2009). The experience of time: Neural mechanisms and the interplay of emotion, cognition and embodiment. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1525), 1809–1813. https://doi.org/10.1098/rstb.2009.0025

Yang, X., Cheng, P.-Y., Lin, L., Huang, Y. M., & Ren, Y. (2019). Can an Integrated System of Electroencephalography and Virtual Reality Further the Understanding of Relationships

Between Attention, Meditation, Flow State, and Creativity? *Journal of Educational Computing Research*, *57*(4), 846–876. https://doi.org/10.1177/0735633118770800

Yao, Z., Zhang, L., Jiang, C., Zhang, K., & Wu, J. (2016). Stronger cortisol response to acute psychosocial stress is correlated with larger decrease in temporal sensitivity. *PeerJ*, *4*, e2061. https://doi.org/10.7717/peerj.2061

Zakay, D. (2014). Psychological time as information: The case of boredom. *Frontiers in Psychology*, *5*. https://doi.org/10.3389/fpsyg.2014.00917

Appendix A
Subject of the Appendix

Meditation Script

Getting ready for a short relaxation exercise. This systematic relaxation may help if are you feeling exhausted or find yourself needing to relax. You may begin by lying on your back. Making sure that your whole body is straight, your legs are in a straight line allowing for space between your legs and between your feet. Allow for some space between your arms and the sides of the body. Turning your palms upwards and relaxing your fingers. You may close your eyes and keep them closed until the end of the exercise. Let your lips lie loosely on top of each other. Allow your tongue to loosen from the roof of the mouth and release any tension in your jaw. Orient your awareness to the facial muscles. Sense the very fine muscles of the eyelids, allow them to be heavy. Be aware of the whole body. If you would like to change your position, do so now, as the body should lie still during this exercise. Try your best to stay awake during the whole exercise, even if it is tempting to fall asleep. Intend to allow the body to rest deeply.

And now bring your attention toward the internal state of the body, being aware of the whole body from head to toe. -- Start to bring attention to sensations throughout the body. Now, bring your awareness to your feet, feeling your heels sink into the floor. And bringing your awareness to your legs and releasing each muscle, allowing the ground to carry your weight. Take your awareness to your contact with the ground. Now take your awareness to the shoulder blades, feeling them relax against the floor. Allow yourself to release the muscles throughout your whole back and all along your spine. Take your awareness to the right hand, releasing any remaining tension in the hand, and taking your awareness throughout the right arm, allowing the weight of it to fall into the ground. Take your awareness to the left hand, releasing any remaining tension in the hand, and taking your awareness throughout the left arm, allowing the weight of it to fall into the ground. Turn your awareness to the back of the head, sense how the ground supports your head, and allows for the muscles in your neck to release and relax. Bring your awareness of the whole backside of the body and sense all points contacting the ground. Body and ground.

The right leg becomes heavy. The left leg becomes heavy. The right arm becomes heavy. The right hand, every single finger becomes heavy. The left arm becomes heavy. The left hand, every single finger becomes heavy. Feel the weight of your shoulders sinking into the ground. Every time you breathe out, your shoulders sink a bit further. Allowing all the weight you carry on your shoulders to drop off into the ground. Tensions in the shoulders lead to back pain. Say to yourself a few times as you breathe out: “Release” and keep watching your physical and mental tensions flowing out of your body. “Release.” Turn your awareness to the right side of the body. Feel the weight of it. Feel the weight of the whole right side of the body. It sinks into the ground.

Turn your awareness to the left side of the body. Feel the weight of the left side of the body. Feel it becoming very heavy. Allow it to sink down to the ground, further and further. If thoughts want to disturb you, replace them with observing your breath. I breathe in, I breathe out; and turn back to the systematic relaxation. Eyelids are heavy, and the whole head is heavy. The whole body is heavy. You are awake and you listen to my voice and at the same time you keep watching your body becoming heavier, sinking deeply to the ground. All your muscles become heavy as lead. Feel how gravity pulls every single part of the body to the ground. You are awake and you keep watching your body becoming more motionless and relaxed.

Turn your awareness to the darkness behind your closed eyes. Be aware of the emptiness of the space behind your eyes. Spread your awareness throughout the dark space, surrounded by emptiness. Allow yourself to slides more and more into the emptiness. You are awake and watch.

Gradually, the body sinks deeper and deeper. You Keep on sinking. Like a leaf falling from a tree. It sinks down to the depth of infinity. You are awake. You keep watching how your body sinks more and more into the emptiness. Watch your body lying on the ground. Feel the contact with the ground again and, simultaneously, observe your natural breath. Keep watching your natural and spontaneous breath. This differs from trying to breathe deeply. Just watch it. Keep on watching and make sure that you breathe in vital energy and breathe out all heaviness, tensions, toxins, sorrows, anger, and pain. Watch your breath very attentively. It will give you power and energy and you will get rid of all your heaviness. Do not ignore any of your breaths. Do not get disturbed by any of your thoughts. Be aware of your whole body again. Be aware of how your body lies on the ground and relaxes. Turn your awareness back outwards. Visualize your body and the room you are lying in. Pick up the noises of the environment, noises from the outside. Turn all your attention back outwards, come back to the outer world. Get ready for your tasks and duties, which are waiting for you. You feel calm and peaceful. Also refreshed, energetic and full of life. Be aware of your whole body. The meditation is complete.