THE EFFECTS OF PHYSICAL AND MENTAL FATIGUE ON TIME PERCEPTION

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Abstract

Overview: The subjective perception of time holds a foundational significance within the realm of human psychology and our conceptualizations of reality. It forms an intrinsic component of the cognitive framework through which we elucidate the chronological progression of events within our lives. While some studies have examined the effects of exercise on time perception during the exercise period, there are no studies investigating the effects of fatiguing exercise on time perception after the exercise intervention. Thus, this study aimed to investigate the effects of physical and mental fatigue on time estimates over 30-seconds (5-, 10-, 20-, and 30-seconds) immediately after the exercise intervention and 6-minutes after the post-test.

Participants: Seventeen healthy and recreationally active volunteers (14 males, 3 females) were subjected to three conditions: physical, mental fatigue, and control.

Methods: All participants completed a familiarization and three experimental conditions (control, physical fatigue (cycling at 65% peak power output for 30 minutes), and mental fatigue (Stroop task for 1100 trials for 30 minutes) on separate days. Heart rate and body temperature were recorded at the pre-test, the start, 10-, 20-, 30- minutes of the intervention, post-test, and follow-up. Rating of perceived exertion (RPE) was also recorded during the intervention four times. Time perception was measured prospectively (at 5-, 10-, 20-, and 30-seconds) at the pre-test, post-test, and 6-minute follow-up.

Results: Physical fatigue significantly ($p=0.001$) underestimated time compared to mental fatigue and control conditions at the post-test and follow-up, with no significant differences between mental fatigue and control conditions. Heart rate, body temperature, and RPE were significantly higher in the physical fatigue compared to the mental fatigue and control conditions during the intervention and also at the post-test.

Conclusion: This study demonstrated that cycling fatigue led to time underestimation compared to mental fatigue and control conditions. It is crucial to consider that physical fatigue has the potential to lengthen an individual's perception of time when estimating durations in sports or work environments.

Land Acknowledgement

We respectfully acknowledge the territory in which we gather as the ancestral homelands of the Beothuk, and the island of Newfoundland as the ancestral homelands of the Mi'kmaq and Beothuk. We would also like to recognize the Inuit of Nunatsiavut and NunatuKavut and the Innu of Nitassinan, and their ancestors, as the original people of Labrador. We strive for respectful relationships with all the peoples of this province as we search for collective healing and true reconciliation and honour this beautiful land together.

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List of Abbreviations

HR – Heart Rate

MD – Mean Difference

NASA-TLX – The National Aeronautics and Space Administration Task Load Index

BT – Body Temperature

PPO – Peak Power Output

PAM – Pacemaker Accumulator Model

RPE – Rating of Perceived Exertion

SD – Standard Deviation

Min – Minutes

S – Seconds

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Chapter 1: Literature Review

1.1 **Introduction**

People have been fascinated by time for centuries; however, philosophers and scientists from ancient times have yet to fully agree on its definition and qualities (Bunnag, 2019). The concept of time is one of the experiences that are essential for how we experience the world (Wittmann, 2009). Our behavioral and cognitive systems depend heavily on duration perception, which allows us to interact with the outside world (Jia et al., 2020). Serious consequences can result from changes in how one perceives time spent at work, exercising, and participating in sports. An accurate perception of time is an indispensable part of many time-constrained sports (i.e., North American football, basketball, figure skating, and others) and work environments (Behm & Carter, 2020). It is well known that our subjective perception of time can be manipulated and distorted under certain circumstances (Eagleman, 2005); however, little is known about how physical and mental fatigue affects how people perceive time.

People who engage in physical activity as part of training or rehabilitation frequently complain about fatigue. Numerous research articles have been written about fatigue and how it impacts physiological and bodily functions. Physical or mental fatigue can result in difficulty starting or continuing voluntary tasks (Chaudhuri & Behan, 2004). Failure of one or more physiological processes that enable the contractile proteins to produce force causes fatigue (Abd-Elfattah et al., 2015). Physical fatigue can be divided into peripheral (distal to the synaptic neuromuscular junction) and central (prior to the neuromuscular synaptic junction including all aspects of the corticospinal system) components (Chaudhuri & Behan, 2004). Boyas and Guével (2011) have developed a principle known as "exercise-induced fatigue" to describe muscular fatigue resulting from physical activity.

As a psychobiological condition, mental fatigue results from extended periods of demanding cognitive activity (Job & Dalziel, 2000). Mental fatigue is a state of tiredness that sets in when your brain's energy levels are depleted. Mental fatigue is usually the result of prolonged stress. Research has evaluated people's subjective reports of fatigue to measure mental fatigue before, during, and after challenging cognitive tasks (Ackerman, 2011). One objective way to examine how behavioral performance changes over time while performing various cognitive activities is to investigate mental fatigue. After finishing the mentally exhausting task, another approach is to look at behavioral performance deficiencies on a subsequent task (Helm, 2021). The best explanation for behavioral changes during such tasks is a reduction in top-down (i.e., cerebral cortex to periphery) processing, which results in an inability to focus and meet task demands (Taylor et al. 2010). The Stroop, continuous attention or vigilance mental performance test, psychomotor vigilance, and other tasks has been used to induce mental fatigue (Tran et al., 2020). As a result, when a person is experiencing mental fatigue, the skills needed for these tasks become less effective.

Exercising for a long time in a hot environment impairs physical and mental performance (González-Alonso et al., 1999). Timing behaviour is sensitive to changes in body temperature; hence it has been suggested that there is a temperature-sensitive time mechanism (Tamm et al., 2015). Studies examining the influence of different temperatures on how people perceive time have revealed discrepancies. Some studies claim that a rise in temperature causes time to hasten, but others contend that this effect only happens once a certain threshold of perceived fatigue has been reached (Tamm et al., 2014, 2015).

The perception of time by individuals during exercise and whether or not sex-related factors play a role in this perception are both unknown (Hanson & Buckworth, 2016). The experience of time during exercise may be influenced by intensity level, physical and mental fatigue, or sex-related factors. In addition, how physical and psychological fatigue affects how much time seems to pass has yet to be determined.

The aim of the present study is to explores whether physical and mental fatigue impacts the perception of time elapsed after the exhaustive cycling and Stroop task test to determine if any sex-related differences are present. Furthermore, we aimed to investigate whether heart rate and temperature have an impact on the perception of time. Specifically, the experiment will test the hypothesis of whether exhaustive cycling (which leads to physical fatigue) and the Stroop task test (which leads to mental fatigue) distorts perception of time. We hypothesize that physical and mental fatigue protocol will lead to an underestimation of the time.

1.2 Time Perception

The experience of time is one aspect of human life that remains largely unknown, with scientists still struggling to understand its neural basis (Brown, 2008). While both short and long-duration activities are judged in terms of their perceived length, it is evident that some may be viewed as too brief or not lasting enough (Edwards & McCormick, 2017). In cases when a person engages in an enjoyable task that requires attention, time may seem to pass quickly. However, when working on a less pleasurable task, time can appear to drag on slowly (Wittmann & Paulus, 2008). In some situations, involving increased temporal awareness, such as anticipation, boredom, and impatience, time appears to move more slowly (Fraisse, 1984). Therefore, the experience of time is a result of the intricate relationships between specific cognitive functions and momentary mood states (Wittmann, 1999).

The sensation of time is particular among our senses (Wittmann & van Wassenhove, 2009). Recent studies have examined how individuals' perceptions, decision-making processes, and perceived exertion are affected by timed exercise (Smits et al., 2014), there is currently limited evidence showing whether or not exercise has an impact on how time seems to pass (Lambourne, 2012). One aspect of a person's unique relationship to their environment is their temporal experience. Time can be perceived as moving quicker or slower than objective measures depending on the situation and the person (Hanson & Buckworth, 2016). This integration, which is necessary for this experience of time, which is an integration of parallel chains of internal and external events, is only possible in a neurological system that is highly functional (Eson & Kafka, 1952).

Several cognitive and emotional elements influence the accuracy and precision of time estimation in the seconds-to-minutes range (Wittmann & van Wassenhove, 2009). In terms of the feeling of time about seconds, minutes, and hours, our subjective well-being has a significant impact on how time is perceived: time flies when engaging in enjoyable activities but drags when experiencing mental distress (Bschor et al., 2004; Flaherty, 1999; Wittmann et al., 2006). Everyday choices we all make, like taking the stairs or waiting for the elevator, are influenced by how we perceive the passing of time (Wittmann, 2009).

It is well known that, in some situations, the way that time is seen (subjective time) can be manipulated and distorted (Eagleman, 2005). This is unexpected because studying temporal illusions reveals the neurological foundations of time perception, which are essential for the proper timing of human performance (Abbiss et al., 2016). Time distortion may occur due to exercise, especially during high-intensity, self-regulated exercise where physical discomfort is severe (Edwards & Polman, 2013). The study of Edwards and McCormick (2017) as the first empirical proof showed that exercise intensity affects perception of time, especially during maximal exercise. In this study participants were asked to verbally indicate when they perceived (subjective time) 1) 25%, 2) 50%, 3) 75% and 4) 100% of each bout's measured (chronological) time had elapsed. The results showed that in response to the Wingate task, there was no significant difference between the durations of subjective time at the 25%, and 50% interval. However, at the 75% and 100% intervals, the estimate for the rating of perceived exertion (RPE) of 20 was the shortest (Edwards & McCormick, 2017).

The findings of Hanson and Buckworth (2016) revealed that women's overall time estimates were significantly lower than men's, indicating that women perceived time to be moving more slowly than men. In this study twenty-two recreational runners (11 men and 11 women) took part in a treadmill run in which they were given the option to choose their own intensity level. Before, during (at 33%, 66%, and 90% of the completed distance), and after the run, 60-second prospective time estimates were taken. Additionally, the entire time, heart rate (HR) was measured (Hanson & Buckworth, 2016). The main finding of this study was the distinction in how men and women participants perceived time during a bout of self-paced exercise. Time seems to pass more rapidly when the prospective time estimation ratio is higher than 1.0, while time seems to move more slowly when the ratio is lower than 1.0. The average time estimation ratio for women was .895 (SD =.162), whereas the average for men was 1.054 (SD =.172). According to these ratios, the average 60-second time estimates for men and women were 63 and 54 seconds, respectively. The results showed that the women in this study experienced time passing more slowly than the males did; these differences were present before, during, and after each run. If these findings applied to the entire exercise bout, women would have perceived the typical 30-minute exercise session as taking more than 3 minutes longer than it actually did, but men would have perceived the same session as taking almost 1.5 minutes less time than it actually did (Hanson & Buckworth, 2016).

The purpose of the study of Tonelli et al (2022) was to investigate the effects of moderate physical activity (cycling) on a temporal estimation task in a group of adult volunteers under three different conditions: (1) baseline, (2) during the physical activity phase, and (3) roughly 15 to 20 minutes later, when participants were seated and returned to a resting heart rate (POST). They discovered that exercise directly alters how people perceive time, causing them to overestimate durations in the millisecond range. Notably, the impact lasted during the POST session, ruling out either the heart rate or cycle rhythmicity as the primary contributors (Tonelli et al., 2022). In addition, Tamm et al. (2015) studied the effects of heat acclimation and factors contributing to time perception under heat stress. Following a 10-day heat acclimation program, twenty young, healthy male subjects performed three exercise tests on a treadmill: H1 (at 60% VO2peak until exhaustion at 42 °C), N (at 22 °C; duration equal to H1), and H2 (walk until exhaustion at 42 °C). Their result revealed that after 60 minutes of exercise, compared to the pre-trial coefficients, there were noticeable distortions (which means they perceive time to have passed by a faster rate than chronological time) in the produced intervals prior to heat acclimation, indicating accelerated temporal processing. However, this effect was not present in subjects who had already acclimated.

1.3 Theories of Time Perception

1.3.1 Scalar Expectancy Theory

Scalar expectancy theory, also known as the pacemaker accumulator model, is the model that is most frequently used when discussing how arousal affects time perception (Allman & Meck, 2012; Grondin, 2010). As illustrated in figure one, the scalar expectancy theory uses the clock, memory, and decision stages to divides the temporal processing system (Allman & Meck, 2012; Behm & Carter, 2020).

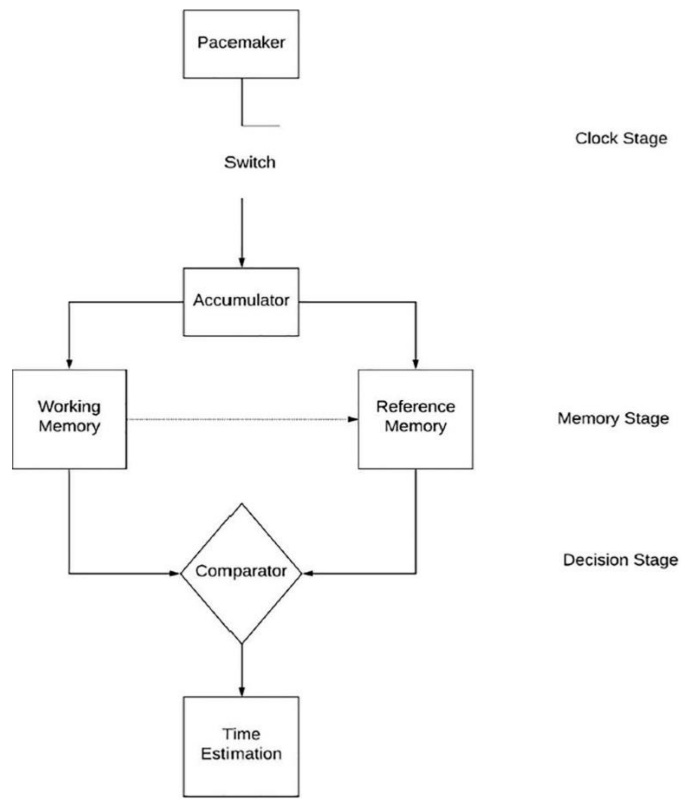

Figure 1 Adopted from Behm and Carter (2020)

When a signal first appears, an attention-controlled switch closes, and pacemaker pulses are collected into an accumulator (a hypothetical but unidentified function of the brain), the clock stage begins (Allman & Meck, 2012). The contents of the accumulator are transferred from working memory to reference memory for long-term storage if, after some time, the signal gains some additional relevance (such as feedback or changes in the environment). This involves the memory stage (Allman & Meck, 2012).The perception of our time is formed by this process.

1.3.2 Striatal Beat Frequency Model

The striatal beat frequency model (SBF) describes the way in which timing networks are interactive (Merchant et al., 2013). As outlined in the figure two, this model is better equipped to address timing behavior because it not only discusses the timing behaviors, but also identifies which neural regions of the brain are involved (Merchant et al., 2013).

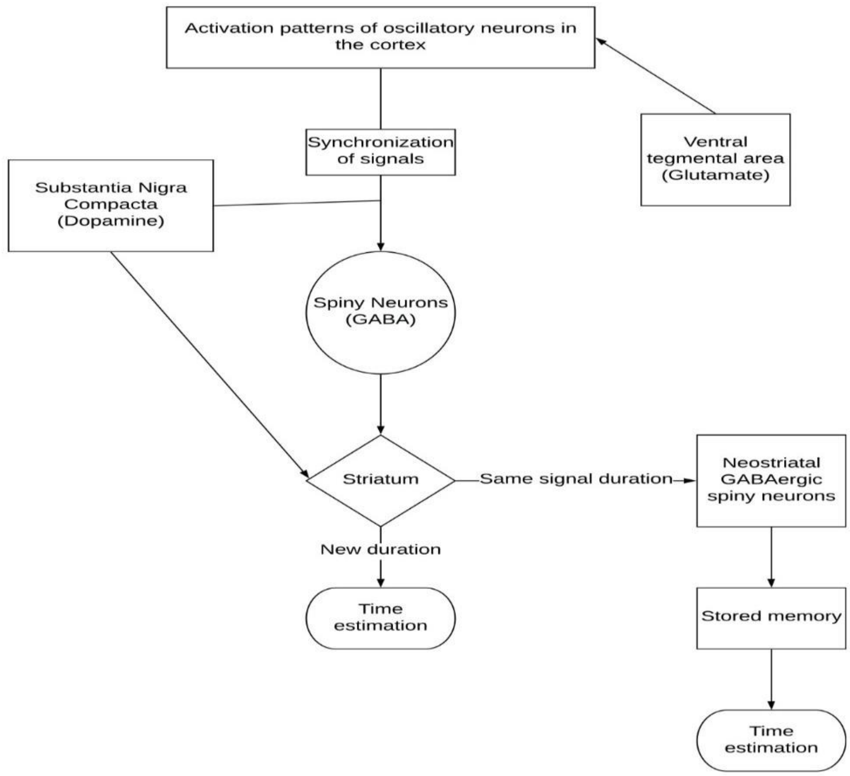

Figure 2 The neural regions associated with time perception and timing behavior (Adopted from Behm & carter, 2020)

The model suggests that the speed of a clock is determined by levels of dopamine and glutamate activity in regions near the substantia nigra and ventral tegmental area. The timing process starts with striatal spiny neurons that monitor activation patterns in the cortex's oscillatory neurons, which are controlled by glutamate action (Meck, 2005).The oscillating neurons synchronize when an interval starts, and the spiny neurons are reset by phasic dopaminergic input. A dopamine pulse is released when the target duration is attained, strengthening the synapses that are active in the striatum (Meck, 2005). Time is perceived in the mind according to the oscillatory activity rate. Similar to how long-term potentiation and depression mechanism are used to strengthen and weaken synaptic weights in order to create a memory of the target duration (Matell & Meck, 2004). Once the same signal duration has been timed once more, neostriatal GABAergic spiny neurons compare the current activation pattern to the stored pattern to determine when the duration has been reached; when they match, spiny neurons fire to indicate that the period has passed (Matell & Meck, 2004; Meck, 2005; Merchant et al., 2013).

This hypothesis attributes the distortion of time to context-dependent activation dynamics, but these dynamics are still largely unknown (Merchant et al., 2013). This temporal distortion effect is thought to result from timing-interfering neural activity in various neural networks. This was seen in experiments where emotionally charged stimuli caused time perception to be altered because of activity in the emotion and association networks (Dirnberger et al., 2012; Merchant et al., 2013). This animal model has been used to explain differences in time perception between the sexes, but it has not yet been used to explain exercise-induced arousal alteration of time perception (Pleil et al., 2011; Sandstrom, 2007). Since the neural activity linked to exercise varies depending on the intensity, duration, and type of activity (Behm & Sale, 1993), it is possible to expect activity-specific changes in time perception (distortion) (Behm & Carter, 2020).

1.4 Physical Fatigue

We know much about the physiological impairments that might lead to muscular fatigue. Muscle fatigue is a term that describes a temporary decline in one's ability to perform physical activity (Enoka & Duchateau, 2008). Muscle fatigue is one of the uncomfortable sensations, making performing a physical task more difficult than usual. When you begin work, you first feel robust and tenacious before your muscles become tired and weaken. One definition of fatigue is the inability to maintain the necessary or expected force (Edwards, 1981). Therefore, fatigue is not measured at the start or just when muscles reach failure. Instead, fatigue gradually increases after the beginning of a physical task (Enoka & Duchateau, 2008). It is believed that an impairment of the contractile mechanism of the muscle fibers is one of the causes of muscle fatigue. This might be brought on by the accumulation of metabolic waste in active muscles or the depletion of energy reserves. Several mechanisms have been proposed, including the buildup of intracellular lactate and hydrogen ions, ionic changes in the action potential, the failure of sarcoplasmic reticulum (SR) Ca2+ release, and the reduced calcium sensitivity of myofibrillar proteins (Allen et al., 2008; Olsson et al., 2020; Reid, 2008). There is no known significant cause for fatigue; fatigue can cause temporary impairment of voluntary activation and force production and is categorized as either local or global (Rattey et al., 2006). Fatigue is generally believed to have a significant impact on sports performance, attributable primarily to physical fatigue caused by ametabolic and neuromuscular factors.

1.4.1 Central fatigue

Before the central neural drive reaches the neuromuscular junction, events in the brain, spinal cord, and motor neurons are involved (Gandevia, 2001). Central fatigue is the processes in which the function of neurological systems that send signals to the muscle fibers, including the motor cortex and the neural pathways that descend the spinal cord to innervate motor neurons is compromised (Ashley-Ross, 2005). Reducing voluntary activation during tasks requiring both maximal and submaximal exertion has been identified as a measurement of central fatigue. Although numerous studies have investigated how central fatigue affects different aspects, including grip strength and MVCs, the precise cause of central fatigue is still unknown. Exercise performance may be hampered by a variety of factors, including central fatigue, which is a complex phenomenon (Meeusen, 2006). Glutamate, acetylcholine, adenosine, and GABA are just a few of the many neurotransmitters that the brain uses to transmit signals, but they have all been linked to central fatigue (Meeusen, 2006). Additionally, it's likely that the interactions between several factors, including the cerebral metabolic, thermodynamic, and hormonal reactions to exercise, contribute to reducing the amount of communication between the brain and the peripheral muscles (Meeusen, 2006).

Central fatigue has also been found to be induced by demanding cognitive tasks (Bray et al., 2008). Because of changes in neurotransmitter concentrations, hormonal responses to cognitive exercise, and an impaired ability to designate resources to activities, central fatigue impairs the signal transmission from the brain to the muscle, which decreases the muscle's ability to maintain optimal muscle contraction (Alder et al., 2021; Decorte et al., 2012; Meeusen, 2006; Nordlund et al., 2004; Wan et al., 2017) which contributes to the decreased grip, plantar flexor muscles and quadriceps muscle maximal voluntary contraction values in participants.

Furthermore, because it interacts with pre-motor regions and is involved in movement planning and decision-making, activation of the prefrontal cortex has been proposed as a sign of central fatigue (Thomas & Stephane, 2008). It has been shown that mental fatigue increases prefrontal cortex activation, which is a sign of increased cerebral perfusion caused by a buildup of exercise by-products and enhanced somatomotor activation in the brain. This increase in blood flow to the prefrontal cortex may result from additional neural activation required to produce efferent motor commands, which may be one of the reasons why central fatigue can have an impact on physical performance (Mehta & Parasuraman, 2014; Nobrega et al., 2014). Previous studies have shown that the way in which central fatigue manifests depends on the task specific, with continuous low-intensity exercise frequently leading to greater central fatigue (Kennedy et al., 2013; Place et al., 2009). Both maximal and submaximal voluntary contractions have the potential to cause central and peripheral alterations; however, central fatigue is more frequently linked to low-intensity continuous exercise, whereas peripheral fatigue is more frequently linked to high-intensity maximal exercise (Kennedy et al., 2013).

To sum up, central fatigue involves CNS-related processes and decreases voluntary muscle activation during physical tasks. Although the precise causes of central fatigue are not fully known, research has shown that it may be caused by alterations in neurotransmitter levels, hormonal responses to exercise, and a decreased capacity to allocate resources for task completion (Alder et al., 2021; Kennedy et al., 2013; Meeusen, 2006; Wan et al., 2017).

1.4.2 Peripheral Fatigue

Events that originate outside the central nervous system, particularly those that occur distal to the motor neurons and within the muscle fibers, are referred to as peripheral aspects of fatigue (Wan et al., 2017). After prolonged or repetitive muscle contractions, neuromuscular fatigue can occur in, impairing physical performance by preventing sufficient blood flow to the muscle and causing metabolites to accumulate (Sjøgaard et al., 1986). This is seen in research by Merton (1954), which found that even after peripheral fatigue occurred, if the blood supply was cut off by a blood pressure cuff, twitch force did not recover, and participants were unable to exert MVCs to their fullest capacity. According to Merton (1954), this shows that fatigue is caused by peripheral causes as well as the central nervous system and that voluntary strength might not recover until peripheral blood flow to the muscles is restored. Additional peripheral aspects of fatigue include inhibitory reactions to metabolite accumulations, such as hydrogen ions and inorganic phosphates (Pi), which slow the excitation process that starts at the neuromuscular junction (Kent-Braun, 1999) and muscle contractile function will be impaired as well (Kent-Braun, 1999). The neural signal might not reach the muscle fibers, or else the postsynaptic area might lose sensitivity to the neural signal (Kent-Braun, 1999). There is a decrease in muscle force output as a result of these, which have been seen during both high and low intensity exertion (Kent-Braun, 1999). The depletion of neurotransmitters released in the synapse, which may occur due to a decrease in the number of accessible vesicles as well as a decrease in the neurotransmitter's vesicle content, is a contributing factor to the failure of neuromuscular transmission (Wu & Betz, 1998). Even when a neuronal signal, enough acetylcholine, and calcium are available, post-synaptic potential failure (also known as synaptic depression) can still take place. This is because long-term exposure to neurotransmitters desensitizes the receptors, which prevents even sufficient amounts of ACh or calcium from binding to the tropomyosin complex from binding to the receptors.

1.5 Mental Fatigue

The feeling of mental fatigue happens after or during extended periods of cognitive work, and it has been linked to a temporary decline in cognitive performance (Borghini et al., 2014). Compared to normal functioning levels, mental fatigue is characterized by a decline in alertness and impaired performance (Ackerman & Kanfer, 2009). Mental fatigue may result from increased mental effort. Prior to, during, and after challenging cognitive tasks, research has assessed people's subjective reports of fatigue to measure mental fatigue (Ackerman, 2011). If changes in task performance do not occur or when objective measurement may not be practicable, these types of assessments can be helpful (Smith et al., 2019). Although, there is some evidence that subjective ratings reflect mental fatigue in an individual before they begin to experience impairments during task performance (Kanfer, 2011), People can be inaccurate or dishonest when reporting their experiences of mental fatigue, as they may not accurately reflect what is happening in their minds. As a result, researchers have used more objective techniques to study mental fatigue.

One way to measure mental fatigue is by assessing how a person's performance changes over time during various cognitive tasks. Another way to look at deficits in performance following a mentally challenging task is by examining how well people perform on subsequent tasks (Helm, 2021). Mental fatigue can be induced through various tasks, including the n-back test, Go/No-Go task, Flanker Task, psychomotor vigilance, Oddball Paradigm Test, Stroop Task, and Continuous Performance Test. Behavioral performance changes during difficult tasks can be explained by a decrease in top-down processing, which results in difficulty focusing and meeting task demands (Tran et al., 2020). As a result, when a person is experiencing mental fatigue, their skills for performing tasks such as these become less efficient.

The ideal task duration to induce mental fatigue in young adults is currently unclear in the literature, thus it is not known how long it takes for a change in task performance to become significant. Previous studies have employed tasks that continue for several hours. However, new research indicates that 60 to 90 minutes is sufficient to cause mental tiredness (Helm, 2021). Individual differences may also be a significant factor in the onset of mental fatigue and the length of time required to induce it. Little research, however, has looked at individual variations in the emergence of mental fatigue. Tasks lasting between two and four hours are used in several experimental procedures to induce mental fatigue (Arnau et al., 2017; Boksem et al., 2005; Tanaka et al., 2012; Wang et al., 2016; Wascher et al., 2014). However, evidence from these and other studies suggests that shorter task durations may be sufficient to cause mental fatigue as significant declines in cognitive function were seen after only 30 minutes (Slimani et al., 2018), 45 minutes (Smith et al., 2019), 60 minutes (Wascher et al., 2014) or 90 minutes (Wang et al., 2016). Overall, evidence from biological, behavioral, and self-report measures suggests that mental fatigue can occur during various task durations requiring high cognitive abilities. Vrijkotte et al (2018) in their studies used 90 minutes of Stroop task to induce mental fatigue. The primary conclusion of this research is that in trained, young, healthy athletes, mental fatigue had no impact on physical or cognitive performance during the second exercise bout of the two-bout exercise protocol (Vrijkotte et al., 2018). They found that when no mentally fatiguing task was being conducted, the initial maximal exercise test increased mental fatigue. This indicates that individuals were unable to distinguish between physical and mental fatigue (Vrijkotte et al., 2018). Slimani et al (2018), in their study showed that performing the Stroop task for 30 min successfully induced mental fatigue.

Human-Computer interaction involves substantial mental activities in every workplace. The need for a tool to measure or quantify mental activity is critical, as it provides a more objective means of assessing one's cognitive abilities. Any mental activity alters physiological elements as well. The Stroop test is based on the idea of associations and inhibitions (or interference). It measures how much effort it takes to name the color associated with a word that is written in another color (Hakim et al., 2022). The "Stroop effect" is a term used to describe the interference caused by irrelevant information while performing a cognitive task. Several theories have been proposed to explain the phenomenon known as "Stroop effect." The processing speed theory suggests that the brain reads words faster than it can detect colors, while the theory of selective attention claims that people are largely unaware of color differences. And finally, automaticity refers to color recognition not being an automatic process for most individuals (Stroop, 1935). It has been demonstrated that the Stroop task, which demands prolonged attention and response inhibition, induces a state of mental fatigue (Smith et al., 2016). The Stroop Color and Word Exam (SCWT), a widely used neuropsychological test, measures a subject's capacity to suppress cognitive interference, often known as the Stroop Effect, which happens when the processing of one stimulus attribute interferes with the concurrent processing of another (Stroop, 1935). The most popular form of the SCWT, which Stroop first put forth in 1935, asks participants to read three different tables as quickly as possible. Two of them stand for the "congruous condition," which requires participants to read color names (hence known as color words) printed in black ink (W) and identify various color patches (C). The third table, known as the color-word (CW) condition, on the other hand, prints color words in inconsistently colored ink (for example, the word "red" is printed in green ink). Participants are, therefore instead of reading the word, asked to identify the color of the ink under this incongruous circumstance. In other words, participants must complete a task that is less automated (identifying the color of ink) while preventing interference from a task that is more automated (Ivnik et al., 1996; MacLeod & Dunbar, 1988). The Stroop effect is a term used to describe the difficulties in preventing the more automated procedure (Stroop, 1935). The result of Skala and Zemková (2022) study showed that mental fatigue caused by at least 30 min of the smartphone application exposure and Stroop color-word task caused a decline in cognitive performance in sport-specific tests (Loughborough Soccer Passing Test) and directly in soccer games (Decision Making Index) (Skala & Zemková, 2022). According to a different study which was conducted by Slimani et al (2018), the result demonstrated that in active male endurance athletes, mental fatigue induced by prolonged periods of a mentally demanding activity (i.e., a 30-minute Stroop task) decreased cognitive and aerobic performance in terms of selective attention and estimated VO2max. Additionally, the mentally fatigued condition had greater subjective ratings of mental fatigue and ratings of perceived exertion (RPE) than the control condition did. They suggested that strength and conditioning coaches can employ the Stroop task to induce mental fatigue and to avoid mentally fatigued tasks before the competition (Slimani et al., 2018).

1.6 Factors affecting Time Perception

1.6.1 Sex differences

There has only been one study that examined how men and women perceive time differently when exercising. Hanson and Buckworth (2016) examined eleven men and eleven women recreational runners, who were asked to run at a speed they chose for themselves for 75% of their daily average run distance. The participants were only informed when they arrived at the distance endpoint and were unaware of any time or distance intervals that had passed. The results showed that women produced significantly lower time estimates while running at a greater self-selected pace than men. Therefore, compared to males, women perceived time was moving more slowly (Behm & Carter, 2020; Hanson & Buckworth, 2016). It should be noted that these differences in time perception existed before, during, and following each run. These findings might support the scalar expectancy theory, which states that women during exercise pay greater attention to the passage of time than do males, leading to a higher rate of pulse accumulation in the accumulator (Hanson & Buckworth, 2016). As it was a self-selected intensity assessment, there is still an issue with this study because the men and women exercised at different intensities. The fact that women consistently chose greater intensities than men may perhaps have contributed to some of the difference in time perception (Hanson & Buckworth, 2016).

Studies on the influences of sex-related factors on how people perceive time have produced contradictory results (Block et al., 2000; Espinosa-Fernández et al., 2003; MacDougall, 1904). For instance, according to Hanson and Buckworth's (2016) findings, women estimated total time in a significantly lower range than men, indicating that they perceived time to be moving more slowly than men.

1.6.2 Body Temperature

Throughout the course of the day, changes in body temperature are common due to a variety of causes, including psychological stress, physical exertion, disease (such as fever), and environmental factors like temperature (Nybo, 2012). Exercising for a long time in a hot environments impairs physical and mental performance (González-Alonso et al., 1999). Timing behaviour is sensitive to changes in body temperature; hence it has been suggested that there is a temperature-sensitive time mechanism (Tamm et al., 2015). This is supported by animal timing research, in which the scalar timing theory is used to explain the timing processes (Gibbon, 1977; Gibbon et al., 1984). When core temperature rises, time compression (the perception of time as being shorter than it is) frequently happens. This is because the pacemaker emits pulses more quickly, in a manner similar to how many physiological processes accelerate at higher temperatures (Tamm et al., 2014).

The mechanics underlying this effect can also be explained in terms of classical physics: a rise in enthalpy (temperature) causes a rise in entropy, which is consistent with the observation that time moves more quickly as entropy increases (Ghaderi, 2019). This is also in accordance with the 2nd law of thermodynamics' prediction that time moves in a particular direction as entropy rises. Since time is a psychologically interpreted concept, the brain might be considered the system. It has been demonstrated in animal models that the cortex temperature can vary daily by 0.5 C, and it is assumed that people will experience a similar range. These oscillations, which naturally occur throughout the day in response to a variety of physiological stimuli, can be achieved by cooling processes involving cerebrospinal fluid, heat exchange with the surroundings (scalp and skulls), and circulating blood (Nybo, 2012). It is hypothesized that when environmental and brain entropies are different, there will be a mismatch between the two time-systems, resulting in differences between perceived and actual time (Behm & Carter, 2020; Ghaderi, 2019). However, in humans, brain temperature rises concurrently with body core temperature, making it challenging to study the effects of cerebral temperature alone in many contexts. Due to this phenomena, an increase in core body temperature brought on by exercise would result in hyperthermia, which would affect the experience of time (Behm & Carter, 2020; Nybo, 2012). However, there is no research performed on the effects of exercise-related changes in cerebral temperature.

Numerous studies have been done on the relationship between body temperature and time by changing the environment's temperature, which then affects the body's temperature (Tamm et al., 2014, 2015). Studies examining the influence of different temperatures on how people perceive time have revealed discrepancies. Some studies claim that a rise in temperature causes time to hasten, but others contend that this effect only happens once a certain threshold of perceived fatigue has been reached (Tamm et al., 2014, 2015). One study found that time distortion effects may be influenced by heat acclimatization (Tamm et al., 2015). Because this study was conducted in the winter, the subjects were not accustomed to being in extremely hot conditions. Participants were required to walk for 30 minutes on a treadmill in a room that was kept at 42 degrees Celsius. The 10-day experiment gave the participants time to gradually get used to the hot and dry environment. Time was found to have a substantial main effect of core temperature, indicating that prolonged exercise in the heat can alter how people perceive time, but that alterations can be countered by acclimation to the heat (Tamm et al., 2015). This is due to the fact that following heat acclimatization, the rate of increase in core temperature during exercise in hot settings was greatly reduced (Tamm et al., 2015). No studies were conducted to ascertain whether the problems with time perception were due to the external heat alone or whether the exercise-induced rise in body temperature was a contributing factor.

1.6.3 Exercise Intensity

It has been shown that the type and intensity of exercise performed affects time perception (Edwards & McCormick, 2017; Hanson & Lee, 2020; Karşılar et al., 2018). Despite limited research on this subject, Edwards and McCormick (2017) showed how time perception distortion was affected by various exercise intensities. In this study, the Wingate anaerobic cycling test (at 25%, 50%, 75%, and 100% intensities) and an endurance exercise (rowing ergometry) were compared. The study's findings revealed that higher intensity exercise caused time to seem to pass more slowly than chronological time. There appears to be a multiplicative impact (Behm & Carter, 2020; Edwards & McCormick, 2017; Edwards & Polman, 2013). This impact is ascribed to the increased sensory awareness of physical discomfort experienced during high-intensity or maximal exercise (Edwards & Polman, 2013) as a result of catecholamines' release, which creates a state of hyperarousal (Jansen et al., 1995). Hyperarousal increases the amount of brain information processed, giving the impression that more time has passed than has really happened (Behm & Carter, 2020). When performing high-intensity or maximal exercise, this experience is once again compressed into a shorter time frame, resulting in increased arousal and awareness and temporal distortion. The fact that this experiment was conducted on recreationally active people means that the findings of this study only apply to this group of people (Edwards & McCormick, 2017). These findings are consistent with those of an experiment done by Hanson and Lee (2017), where time seemed to slow down as a higher intensity was performed and a higher RPE was reported. Another study that looked at walking speed as a measure of intensity found that as walking speed increased, time seemed to pass more slowly (passed more slowly) (Karşılar et al., 2018).

1.7 Conclusion

Physical fatigue and mental fatigue have both been extensively researched individually, but their effects on time perception are relatively unexplored. Therefore, we hypothesized that physical and mental fatigue might lead to an underestimation of time; further study into their effects on how we perceive time is necessary. Reduced muscle performance due to neuromuscular fatigue can be attributed to central fatigue, which affects how signals are transmitted from the brain to the muscle and involves central nervous system related processes and decreases voluntary muscle activation during physical tasks, however peripheral fatigue, which may be due to inhibitory reactions to metabolite accumulation or the depletion of neurotransmitters in the neuromuscular junction. The finding of a study showed that mental fatigue caused by at least 30 min of the smartphone application exposure and Stroop color-word task caused a decline in cognitive performance in sport-specific tests. Therefore, when a person is experiencing mental fatigue, their skills for performing mental tasks become less efficient.

Time distortion may occur due to sex differences, hot environment, and exercise, especially during high intensity, a self-regulated exercise where physical discomfort is severe. There is little research has been done on how people perceive time when engaging in maximal cycling exercise. It is also unknown whether or not sex-related factors may affect how people perceive time.

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1.8 Objectives

The objectives of this study are:

I. To investigate the effects of physical and mental fatigue on time perception by testing at different time conditions (5-, 10-, 20-, and 30-seconds) immediately after the intervention and 6 minutes after the post test.

II. To investigate if the heart rate and temperature of the body play a role in the perception of time.

1.9 Hypothesis

Based on pilot studies in our laboratory it is hypothesized that physical fatigue will result in the underestimation of time.

Based on the pilot study results in our laboratory it is hypothesized that mental fatigue protocol will lead to an underestimation of time.

Chapter 2: The Effects of Physical and Mental Fatigue on Time Perception

Abstract

Overview: The subjective perception of time holds a foundational significance within the realm of human psychology and our conceptualizations of reality. It forms an intrinsic component of the cognitive framework through which we elucidate the chronological progression of events within our lives. While there have been some studies examining the effects of exercise on time perception during the exercise period, there are no studies investigating the effects of fatiguing exercise on time perception after the exercise intervention. Thus, this study aimed to investigate the effects of physical and mental fatigue on time estimates over 30-seconds (5-, 10-, 20-, and 30-seconds) immediately after the exercise intervention and 6-minutes after the post-test.

Participants: Seventeen healthy and recreationally active volunteers (14 males, 3 females) were subjected to three conditions: physical fatigue, mental fatigue, and control.

Methods: All participants completed a familiarization and three experimental conditions (control, physical fatigue (cycling at 65% peak power output), and mental fatigue (Stroop task for 1100 trials) on separate days. Heart rate and body temperature were recorded at the pre-test, the start, 10-, 20-, 30- minutes of the interventions, post-test, and follow-up. Rating of perceived exertion (RPE) also was recorded during the intervention four times. Time perception was measured prospectively (at 5-, 10-, 20-, and 30-seconds) at the pre-test, post-test, and 6-minute follow-up.

Results: Physical fatigue significantly ($p=0.001$) underestimated time compared to mental fatigue and control conditions at the post-test and follow-up, with no significant differences between mental fatigue and control conditions. Heart rate, body temperature, and RPE were significantly

higher in the physical fatigue compared to the mental fatigue and control conditions during the intervention and also at the post-test.

Conclusion: This study demonstrated that cycling-induced fatigue led to time underestimation compared to mental fatigue and control conditions. It is crucial to consider that physical fatigue has the potential to lengthen an individual's perception of time estimating durations in sports or work environments.

2.1 Introduction

People have been fascinated by time for centuries; however, philosophers and scientists from ancient to modern times have yet to fully agree on its definition and qualities (Bunnag, 2019). The concept of time is one of the experiences that are essential for how we experience the world (Wittmann, 2009). Our behavioral and cognitive systems depend heavily on duration perception, which allows us to interact with the outside world (Jia et al., 2020). An accurate perception of time is an indispensable part of many time-constrained sports (i.e., North American football, basketball, figure skating, and others) and work environments (Behm & Carter, 2020). It is well known that our subjective perception of time can be manipulated and distorted under certain circumstances (Eagleman, 2005); however, little is known about how physical and mental fatigue affects how people perceive time.

There are two prominent theories pertaining to time perception: the Pacemaker Accumulator Model (PAM), alternatively referred to as the Scalar Expectancy Theory (SET) (Gibbon et al., 1984b), and the Striatal Beat Frequency Model (SB-FM) (Meck, 1983; Meck & Church, 1983). Both theoretical frameworks elucidate that time perception is significantly impacted by arousal (Allman & Meck, 2012; Grondin, 2010). The scalar expectancy theory uses a clock, memory, and decision stages to divide the temporal processing system. The SB-FM not only discusses the timing behaviors, but also identifies which neural regions of the brain are involved (Merchant et al., 2013). The model suggests that the speed of a clock is determined by levels of dopamine and glutamate activity in regions near the substantia nigra and ventral tegmental area. The timing process starts with striatal spiny neurons that monitor activation patterns in the cortex's oscillatory neurons, which are controlled by glutamate action (Meck, 2005). The oscillating neurons synchronize when an interval starts, and the spiny neurons are reset by phasic dopaminergic input. A dopamine pulse is released when the target duration is attained, strengthening the synapses that are active in the striatum (Meck, 2005). Time is perceived in the mind according to the oscillatory activity rate. Once the same signal duration has been timed once more, neostriatal GABAergic spiny neurons compare the current activation pattern to the stored pattern to determine when the duration has been reached; when they match, spiny neurons fire to indicate that the period has passed (Matell & Meck, 2004; Meck, 2005; Merchant et al., 2013).

Physical and mental activity can impact arousal levels pacemaker accumulator model or Scalar Expectancy Theory (PAM or SET) and impact our perception of time. Arousal involving elevated heart rate, increased muscle activation (e.g., motor unit recruitment and firing frequency), thermoregulation, and other physiological or external signals, have the potential to alter time perception (Graham et al., 2023). The increased activity gives rise to additional events within the temporal processing system, leading to an accelerated perception of time in response to higher-intensity contractions. Given the cerebellum's involvement in both movement and temporal processing (Ivry et al., 1988), exercise-induced arousal may exert more influence on time perception compared to other forms of arousal. The heightened demands in terms of frequency of events during sensory afferent processing may also play a role in impacting time perception (Graham et al., 2023).

As a psychobiological condition, mental fatigue (e.g., difficulty in maintaining focus, attention, cortical excitability) results from extended periods of demanding cognitive activity (Job & Dalziel, 2000). It has been shown that mental fatigue increases prefrontal cortex activation, cerebral perfusion, and somatomotor activation. This increase in blood flow to the prefrontal cortex may result from additional neural activation required to produce efferent motor commands, which may be one of the reasons why central fatigue can have an impact on physical performance (Mehta & Parasuraman, 2014; Nobrega et al., 2014). Previous studies have shown that the way in which central fatigue manifests depends on the specific task, with continuous low-moderate intensity exercise frequently leading to greater central fatigue (Iannetta et al., 2022; Kennedy et al., 2013; Krüger et al., 2019; Place et al., 2009). After finishing a mentally exhausting task, an approach is to look at behavioral performance deficiencies on a subsequent task (Helm, 2021). The best explanation for behavioral changes during such tasks is a reduction in top-down processing, which results in an inability to focus and meet task demands.

Exercising for a long time in a hot environment impairs physical and mental performance (González-Alonso et al., 1999). Timing behaviour is sensitive to changes in body temperature; hence it has been suggested that there is a temperature-sensitive time mechanism (Tamm et al., 2015). Some studies claim that a rise in temperature causes time to hasten, but others contend that this effect only happens once a certain threshold of perceived fatigue has been reached (Tamm et al., 2014, 2015). Exercise encompasses a wide range of forms, with differences in intensity, duration, and movement types. However, time perception research often overlooks the significance of contraction types, such as dynamic contractions. Additionally, the impact of varying fatigue protocol on time perception remains relatively unexplored, representing an understudied factor that could potentially affect time perception positively or negatively.

Since no studies have compared physical and mental fatigue on time perception, the objective of this study was to compare the effects of physical (exhaustive cycling exercise protocol) and mental fatigue (Stroop task test) on the time perception. It was hypothesized that physical and mental fatigue protocol will lead to an underestimation of the time.

2.2 Methods

2.2.1 Participants

An "a priori" statistical power analysis (software package, G * Power 3.1.9.7) was conducted based on the time perception of related studies (Tonelli et al., 2022) to achieve an alpha of 0.05, an effect size of 0.4, and a statistical power of 0.8 using the F-test family. The analysis indicated that between 12-14 participants per condition should be sufficient to achieve adequate statistical power. Seventeen (17) healthy and recreationally active participants took part voluntarily in this study. Exclusion criteria included: participants who have neurological conditions, knee injuries, presence of medical issues that prevent high-intensity exercise, or injuries to the quadriceps muscles that could affect pedaling. Inclusion criteria included that participants need to be healthy, and recreationally active.

Table 1 Participant anthropometrics

Participants	Age (years)	Mass (kg)	Height (cm)
Male (n=14)	28.57 ± 4.92	80.46 ± 11.22	175.71 ± 2.65
Female (n=3)	24 ± 2.64	69.06 ± 10.96	157.33 ± 2.30

Prior to their lab visit, participants were given instructions to avoid intense activity (24 hours prior to participating) and to stop drinking alcohol, smoking, and using caffeine (12 hours). Each participant completed the physical activity readiness questionnaire plus (PAR-Q+ 2020), read and signed the informed consent form prior to testing and after a brief explanation of the study and the experiment's procedures. During their first visit to the lab, every participant became familiar with all psychological measurements. The Institutional Health Research Ethics Board (ICEHR #20231533-HK) gave its approval for this study, which was carried out in accordance with the most recent version of the Helsinki Declaration.

2.2.2 Experimental design

The effects of physical and mental fatigue on time perception were investigated using a randomized crossover study design. The participants became familiar with a basic orientation to the testing procedures and equipment during the initial familiarization session and, they performed an incremental cycling test using Velotron ergometer (Velotron RacerMate, Seattle, USA) to determine their peak power output (PPO). The participants then came to the lab for three distinct testing sessions, physical fatigue, mental fatigue, or control. Each session was randomized and separated by at least 48 hours.

2.2.3 Measures

Prior to the intervention, participants watched a digital clock count to 30-seconds, twice, followed by four trials of time estimate practice of 30-seconds duration (estimate 5-, 10-, 20- and 30-seconds) with feedback. Then, for the pre-test data collection participants sat in a chair to estimate the time intervals of 5-, 10-, 20-, and 30-seconds, six times without feedback. We chose to execute the intervals six times as individuals can ingrain this into memory (as stated by the Scalar expectancy theory). Thirty seconds was chosen as this approximate time restriction is common in a number of sports including basketball, tennis, North American football, and others. This procedure has also been used successfully in prior experiments conducted in this lab with intraclass correlation coefficients (ICC) of 0.75-0.85 (Gardner et al., 2023; Graham et al., 2023). In the present study, a high degree of reliability was found between time perception measurements, with an ICC of 0.802 with a 95% confidence interval from .628 to .916 ($F^{(16,176)} = 5.058$, $p<0.001$). With the six 30-second time estimate attempts for each testing time, the mean scores were analyzed, for the pre-test, immediately post-test, and 6-minute follow up. Since six 30-second time estimates equals 3-minutes, it was decided to be consistent and permit a 3-minute recovery before the next 3-minute testing period (6 minutes in total). To estimate time, a hand dynamometer (custom built design) connected to a BioPac AcqKnowledge data acquisition system (Massachusetts, USA) was used.

Heart rate was monitored (T31, Polar, Kempele, Finland), tympanic temperature (IRT6520CA ThermoScan, Braun, Germany) and rating of perceived exertion (RPE) (Borg, 1998) were recorded in the pre-test, during the experimental protocols (start, 10-, 20-, and 30-minutes), and at the post-test. The heart rate monitor was fixed using an elastic belt secured around the participant's sternum. Tympanic temperature was acquired with a thermometer's probe, fitted with a disposable plastic covering, which was gently inserted into the right ear canal.

2.2.3.1 Rate of Perceived Exertion (RPE)

The RPE Borg Scale (Borg, 1998) was used as a tool for assessing the intensity of participants' activity during the intervention, utilizing a graduated scale ranging from 6 to 20. Throughout the physical, mental fatigue, and control conditions, participants were prompted to provide their RPE ratings. The main aim of using the RPE Borg Scale was to gain valuable insights into whether participants were engaging in the prescribed activity at the desired intensity (Graham et al., 2023).

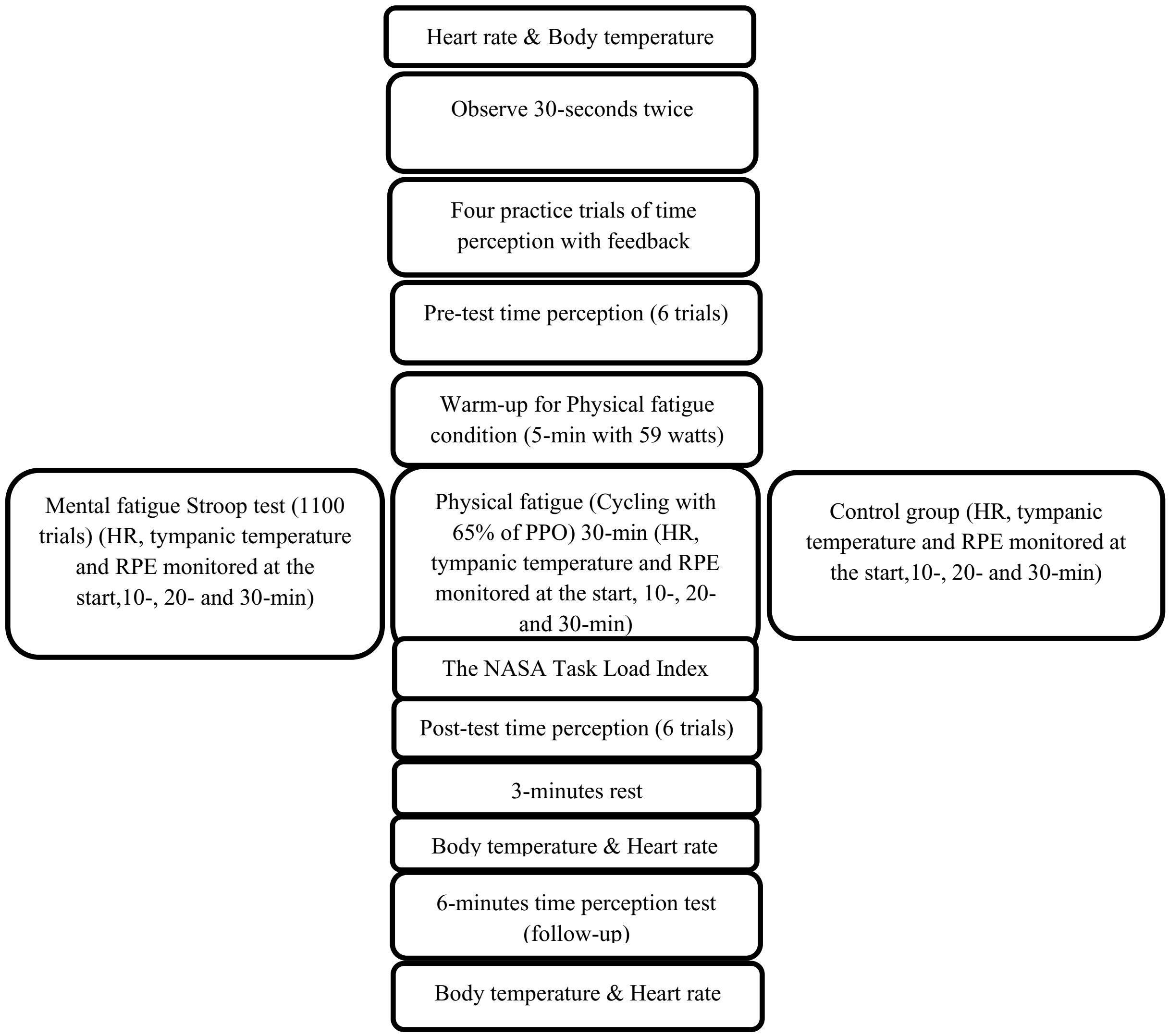

Figure 3 Experimental Design: PPO: peak power output, RPE: rating of perceived exertion

2.2.4 Protocol

Prior to the pre-test, during the intervention (start, 10-, 20-, and 30-minutes), after the time perception test, and after the 6-minutes time perception test (follow-up) participants' body temperatures and heart rates were recorded. The rating of perceived exertion was also recorded at the start, 10-, 20-, and 30-minutes during the intervention for the three conditions.

Maximal incremental cycling test protocol: The maximum cycling exercise protocol was used to determine the maximum wattage (W_{max}) for the incremental test on a cycle ergometer (Velotron RacerMate, Seattle, USA). Each participant's ideal seat height on the cycle ergometer was determined, recorded, and used for the following sessions. Participants warmed up with 59 watts with the RPM of 70 for 5-minutes and then participants began cycling at 80 watts for 3-minutes with RPM of 70, then raised their resistance by 40 watts every 3-minutes until they reached exhaustion (a cadence of less than 60 RPM for more than 5-seconds despite intense verbal encouragement). The researcher verbally encouraged participants during the test to perform a true all-out effort. The W_{max} (i.e., peak power output (PPO)) was calculated with the formula: $W_{max} = W_{out} + (t/180) \times 40$ [W_{out}: workload of the last completed stage; t: time (seconds) in the final stage] (Barzegarpoor et al., 2020).

2.2.4.1 Exhaustive cycling exercise protocol

Following the orientation practice time estimate sessions (two observations of a clock showing 30-seconds followed by four estimates of 30-seconds with feedback) and pre-tests, participants warmed up on the cycle ergometer for 5-minutes (with 59 watts) and then cycled at 65% PPO for 30-minutes. On the cycle ergometer, participants' positions were adjusted to replicate their maximum cycling exercise. After the exhaustive cycling exercise protocol, participants filled out the NASA Task Load Index and then they were tested with six-time estimate trials immediately as well as six minutes after the immediate post-test time estimates.

2.2.4.2 Stroop Task

The Stroop Colour-word test, a widely used neuropsychological test, measures a subject's capacity to suppress cognitive interference, which happens when the processing of one stimulus attribute interferes with the concurrent processing of another (Stroop, 1935). It has been demonstrated that the Stroop task, which demands prolonged attention and response inhibition, induces a state of mental fatigue (Smith et al., 2016). The participant was asked to identify the colour of the word without regard for its actual meaning. Fifty percent (50%) of the trials were congruent (matched word and color), whereas 50% were incongruent, according to a pseudo-random sequence that was used to govern the trials (with all incongruent word-color combinations). The participants were then instructed to push the key on the keyboard that matches the color of the text that is displayed on the screen. The computer screen was 33 cm, and all participants used this laptop to observe 30-second time estimate and Stroop tasks throughout the study. For 1000 ms, each word appeared on the screen in font size 34, and then the screen remained blank before the next word appeared (Barzegarpoor et al., 2020). In this investigation, we conducted a total of 1100 trials to induce mental fatigue, requiring an approximate duration of 30 minutes for its completion. Slimani et al (2018), in their study showed that performing the Stroop task for 30 min successfully induced mental fatigue.

2.2.4.3 NASA-TLX

The NASA-TLX was implemented for all three conditions. It is a tool for measuring mental workload that aims to record workers' subjective perceptions of complex socio-technical systems that involve humans and machines. Due to its multidimensional nature and ease of administration, the NASA-TLX is perhaps the most commonly used mental workload scale (Colligan et al., 2015). NASA-TLX has six subscales that measure mental demand, physical demand, temporal demand, performance, effort, and level of frustration (Hart & Staveland, 1988). Following the implementation of interventions in each experimental condition, participants manually completed the NASA-TLX questionnaire. Participants were required to rate each item using a scale consisting of 20 equidistant intervals delineated by bipolar descriptors (e.g., high/low). Subsequently, the computed score was scaled by a factor of 5, yielding a resultant score ranging from 0 to 100 for each of the subscales (Barzegarpoor et al., 2020).

2.2.4.4 Control Condition

The control condition executed the six trials (pre-test), watched a documentary film "When We Left Earth: The NASA Missions – Episode 6: A Home in Space" (Discovery Channel, USA) for 30-minutes (Barzegarpoor et al., 2020), and then they filled out the NASA Task Load Index (NASA-TLX).

2.2.5 Statistical Analysis

Statistical analyses were calculated using SPSS software (Version 28.0, SPSS, Inc., Chicago, IL). The Shapiro-Wilk and Mauchly's Tests were used to assess the normality of the distribution and assumption of sphericity, respectively ($P>0.05$). The data for time perception were analyzed using the means of six trials. A 3 testing times (pre-test, post-test, and 6-min follow-up) × 3 conditions (control, mental and physical fatigue) with repeated measures analysis of variance (ANOVA) was conducted to determine significant differences for time perception for each time estimate (5-, 10-, 20-, and 30-seconds) separately (within time estimate analysis). One-way repeated measures were conducted to determine significant differences between testing times (pre-test, post-test, and follow-up). A 3 conditions (control, mental and physical fatigue) × 4 time estimates (5-, 10-, 20-, and 30-seconds) with repeated measures (ANOVA) was conducted to determine significant differences between time estimates. The mean difference (MD) (measures the absolute difference between the mean value in two groups) has been used for the analysis, and it estimates the amount by which the experimental intervention changes the outcome on average compared with another condition. To analyze body temperature and heart rate, an ANOVA with repeated measures were used for 7 testing times (pre-test, start, 10-, 20-, and 30-minutes, post-test, and follow-up) × 3 conditions (control, physical, and mental). To examine RPE during the intervention, a 4 testing times (start, 10-, 20-, and 30-minutes) × conditions (control, mental, and physical fatigue) ANOVA with repeated measures was used. To analyze the NASA Task Load Index, a one-way repeated measures ANOVA was used for mental and physical demand subscales. If the interactions were significant, the Bonferroni post hoc test was conducted to detect the significant differences between conditions for each test. The effect sizes of each variable were tested using partial eta squared (η_p^2) (0.01= small effect, 0.06= medium effect, 0.14= large effect). The statistical significance level was set at P<0.05. Cohen's d effect sizes were calculated for individual post-hoc comparisons with effect sizes as trivial (d = <0.2), small (0.2 - ≤0.5), medium (d = 0.5 - ≤0.8), and large (d = ≥0.8) (Cohen 1988)

2.3 Results

2.3.1 Time estimates

2.3.1.1 Five seconds

The results of the 5-seconds time estimates revealed a significant main effect for the conditions ($F_{(1.63,26.11)}$ =8.44, p=0.003, η_p^2=0.346) as well as an interaction of testing times and conditions ($F_{(4,64)}$=10.08, p=0.001, η_p^2=0.387). However, there was no significant main effect for the testing times ($F_{(2,32)}$=3.20, p=0.054, η_p^2=0.167). There were no significant differences in the interaction of condition * testing time between conditions at the pre-test, but there was a significant large magnitude, underestimation of time for the physical fatigue condition compared to the mental (MD= -0.706 s, p<0.001, d=1.25) and control (MD= -0.577, p<0.001, d=1.45) conditions at the post-test and the follow-up (mental fatigue (MD= -0.842 s, p<0.001, d=1.59), and control (MD= -

0.698 s, $p<0.001$, d=1.71)). While physical fatigue demonstrated an underestimation of time at post-test and follow-up compared to mental and control conditions, the underestimation with physical fatigue at post-test (MD= -0.539 s) and follow-up (MD= -0.590 s) was also significantly greater than the pre-test, but there was no significant difference between the post-test and follow-up. Additionally, there were no significant differences between the mental fatigue and control conditions during pre-test, post-test, and follow-up. The significant main effect for conditions showed an underestimation of time in the physical fatigue condition compared to mental fatigue ($p<0.011$, MD= -0.500 s) and control ($p<0.001$, MD= -0.469 s) conditions. There were no significant differences between mental fatigue and control conditions (Table 2).

2.3.1.2 Ten seconds

There were significant main effects with the 10-seconds time estimates for condition ($F_{(1.40,22.39)}$ =12.57, p=0.001, η_p^2=0.440), and testing time ($F_{(2,32)}$=4.75, p=0.016, η_p^2=0.229) as well as a significant interaction of testing time and conditions ($F_{(4,64)}$=16.91, p=0.001, η_p^2=0.514). The interaction of condition * testing time showed that there were no significant differences at the pre-test, but there was a significant, large magnitude, underestimation of time in the physical fatigue condition compared to the mental fatigue (MD= -1.612 s, $p<0.001$, d=1.78) and control (MD= -1.366 s, $p<0.001$, d=2.0) conditions at the post-test as well as with the mental fatigue (MD= -2.067 s, $p<0.001$, d=1.90) and control conditions (MD= -1.609 s, $p<0.001$, d=1.95) at follow-up. There were no significant differences between mental fatigue and control conditions at the pre-test, post-test, and follow-up. There was a significant (main effect for conditions) underestimation of time in the physical fatigue condition compared to mental fatigue (p=0.001, MD= -1.246 s) and control conditions ($p<0.001$, MD= -1.077 s). Furthermore, the main effect for the testing time

($F_{(2,32)}$=65.93, p<0.001, η_p^2=0.805) showed a significant underestimation of time in the follow-up (MD= -1.308 s) and post-test (MD= -1.244 s) compared to the pre-test (Table 2).

2.3.1.3 Twenty seconds

Furthermore, the 20-seconds time estimates revealed a significant main effect for fatigue condition ($F_{(1.35,21.64)}$ =17.12, p=0.001, η_p^2=0.517), testing time ($F_{(1.44,23.03)}$=4.27, p=0.037, η_p^2=0.211), and as well as for the interaction of testing time and conditions ($F_{(4,64)}$=17.12, p=0.001, η_p^2=0.519). There was a significant, large magnitude, underestimation of time in the interaction of condition * testing time in physical fatigue compared to mental fatigue (MD= -3.418 s, p<0.001, d=2.11) and control (MD= -2.708 s, p<0.001, d=2.39) at the post-test and mental fatigue (MD= -3.726 s, p<0.001, d=1.93) and control (MD= -2.976 s, p<0.001, d=2.13) conditions in follow-up, but there were no significant interactions of condition * testing time at the pre-test among conditions. The main effect for conditions revealed a significant underestimation of time with the physical fatigue condition compared to mental fatigue (MD= -2.436 s, p<0.001) and control (MD= -2.093 s, p<0.001) conditions, but there were no significant differences between mental fatigue and control conditions. The main effect for the testing time demonstrated a significant underestimation of time in the follow-up (MD= -2.314 s) and post-test (MD= -2.376 s) compared to the pre-test, but there were no significant differences between post-test and follow-up (Table 2).

2.3.1.4 Thirty seconds

Thirty seconds showed a significant main effect of fatigue condition ($F_{(1.28,20.58)}$=15.65, p=0.001, η_p^2=0.495), testing time ($F_{(1.27,20.46)}$=5.01, p=0.029, η_{p2}=0.239), and as well as for interaction of testing time and conditions ($F_{(4,64)}$=15.90, p=0.001, η_p^2=0.499). The interaction of condition * testing time revealed that there were no significant differences between conditions at the pre-test, but there was a significant, large magnitude, underestimation of time with physical fatigue compared to mental fatigue (MD= -4.763 s, d=1.89) and control (MD= -3.829 s, d=2.45) conditions at the post-test and mental fatigue (MD= -5.218 s, d=1.82) and control (MD= -3.700 s, d=2.01) conditions in follow-up. Additionally, there were no significant differences between mental fatigue and control conditions at the pre-test, post-test, or follow-up. The main effect for conditions revealed an underestimation with the physical fatigue compared to mental fatigue (MD= -3.458 s, $p<0.001$) and control (MD= -2.786 s, $p<0.001$) conditions, but there were no significant differences between mental fatigue and control conditions. A significant main effect for the testing time showed a significant underestimation of time in the follow-up (MD= -3.208 s) and post-test (MD= -3.399 s) compared to the pre-test, but there were no significant differences between post-test and follow-up (Table 2).

Table 2 Means and standard deviations of the time estimates of 5-, 10-, 20-, and 30-seconds from the chronological time at the pre-test, post-test, and follow-up

Time estimates	Mental fatigue (M±SD)	Physical fatigue (M±SD)	Control (M±SD)
Deviation from 5-seconds from chronological time			
Pre-test	-0.059 ± 0.416	-0.011 ± 0.288	0.121 ± 0.478
Post-test	0.155 ± 0.751	-0.550 ± 0.255	0.026 ± 0.500
Follow-up	0.240 ± 0.677	-0.601 ± 0.314	0.096 ± 0.483
Deviation from 10-seconds from chronological time			
Pre-test	0.360 ± 0.734	0.301 ± 0.549	0.555 ± 0.927
Post-test	0.669 ± 1.228	-0.942 ± 0.350	0.423 ± 0.898
Follow-up	1.061 ± 1.446	-1.006 ± 0.524	0.603 ± 1.040
Deviation from 20-seconds from chronological time			
Pre-test	0.581 ± 1.154	0.417 ± 1.136	1.014 ± 1.542
Post-test	1.458 ± 2.219	-1.958 ± 0.538	0.748 ± 1.502
Follow-up	1.830 ± 2.570	-1.896 ± 0.898	0.748 ± 1.502
Deviation from 30-seconds from chronological time			
Pre-test	0.846 ± 1.938	0.452 ± 1.733	1.281 ± 2.322

Post-test	1.815 ± 3.459	-2.947 ± 0.839	0.881 ± 2.042
Follow-up	2.461 ± 3.790	-2.756 ± 1.413	0.943 ± 2.175

2.3.1.5 Relative (%) Time Changes between each Time Estimate

With the post-test, relative time changes showed a significant main effect of conditions ($F_{(1.27,20.43)}$=16.83, p=0.001, η_{p2}=0.513), and testing time ($F_{(1.36,21.89)}$=4.12, p=0.044, η_p^2=0.205), but there was no significant interaction for testing time and conditions ($F_{(2.60,41.63)}$=0.628, p=0.579, η_p^2=0.038). The main effect for fatigue condition showed that physical fatigue had a significant relative underestimate of time compared to mental fatigue (MD= -0.158 s, p<0.001,) and control (MD= -0.129 s, p<0.001) conditions. There was no significant relative time change between time estimates (5-, 10-, 20-, and 30-seconds) at the post-test with all conditions combined (Figure 4).

With the follow-up, relative time changes showed a significant main effect of testing time ($F_{(1.72,27.53)}$=3.70, p=0.018, η_p^2=0.188), conditions ($F_{(2,32)}$=18.09, p=0.001, η_{p2}=0.531), as well as for testing time and conditions ($F_{(2.32,27.22)}$=25.01, p=0.001, η_p^2=0.610). The main effect for testing time (all conditions combined), revealed relative time changes between 5-, 10-, 20-, and 30-seconds in the follow-up with 10- (MD= 0.040 s, p=0.005) and 20-seconds (MD= 0.044 s, p=0.039) time estimates significantly, relatively higher overestimates than 5-seconds ($F_{(1.72,27.53)}$=3.70, p<0.043, η_p^2=0.188). There were no significant differences between the 30 seconds with other time estimates (5-, 10-, and 20-seconds) in the follow-up testing period (Figure 5). The main effect for conditions showed that the relative time changes with physical fatigue were significantly underestimated compared to mental fatigue (MD= -0.110 s, p=0.002) and control (MD= -0.125 s, p=0.001) conditions. The interaction of testing time and conditions relative time changes showed that in the mental fatigue, 30-seconds was underestimated compared to the

5- (MD= -0.140 s, p=0.005), 20- (MD= -0.183 s, p<0.001), and 10-seconds (MD= -0.198 s, p<0.001). The results of relative time changes for the physical fatigue revealed that 30-seconds was overestimated compared to the 20- (MD= 0.126 s, p<0.001), 10- (MD= 0.132 s, p<0.001), and 5- (MD= 0.152 s, p<0.001) seconds. Additionally, there was no significant relative time change in the control condition.

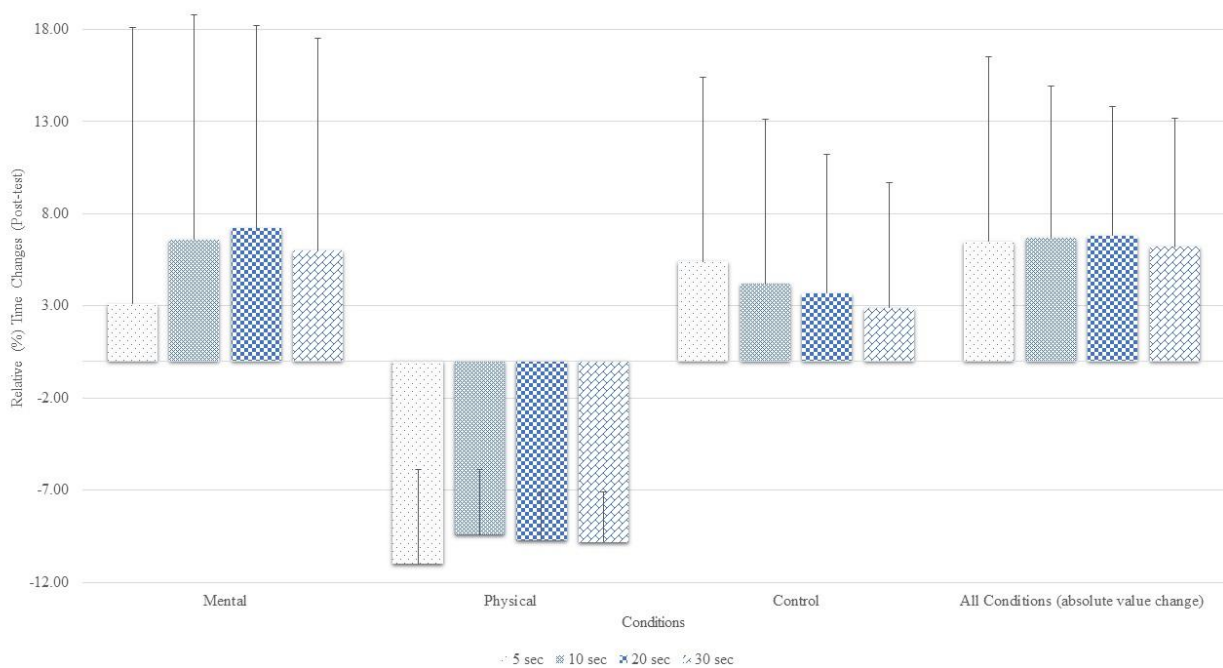

Figure 4 Relative (%) time change for the time estimates at the post-test (mean % ± SD). Only the physical fatigue condition underestimated time (bolded)

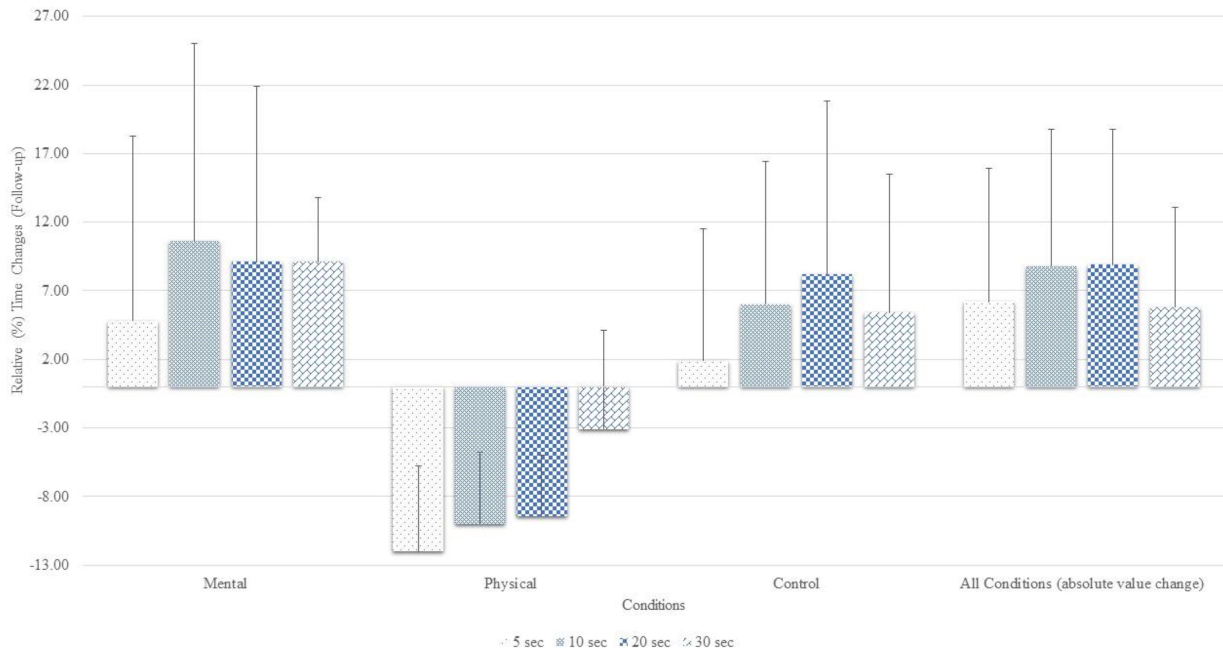

Figure 5 Relative (%) time change for the time estimates at the follow-up (mean % ± SD). Only the physical fatigue condition underestimated time (bolded)

2.3.2 Heart Rate

Analysis revealed significant main effect for the testing time ($F_{(3.69,59.09)}$ =193.12, p=0.001, η_p^2=0.923) and conditions ($F_{(1.42,22.77)}$ =286.40, p=0.001, η_p^2=0.947) as well as a significant interaction of testing time and conditions ($F_{(4.23,67.73)}$ =158.18, p=0.001, η_p^2=0.908). The condition * testing time interaction showed that there were no significant differences between conditions at the pre-test, but physical fatigue condition (p<0.001) had a significantly higher heart rate compared to the mental fatigue and control conditions at the start,10-, 20-, 30- minutes, post-test, and follow-up (Figure 6). Additionally, there were no significant differences between mental fatigue and control conditions at all testing times. The main effect for conditions showed a significantly large magnitude, higher heart rate for physical fatigue than the mental (MD= 54.513, p<0.001) and control (MD= 56.126, p<0.001) conditions. There was no significant difference between mental fatigue and control condition. The main effects for testing time showed a significant difference ($p<0.001$) between pre-test, start, 10-, 20-, 30-minutes, and follow-up, except for 20-and 30-minutes ($p=0.184$) and between post-test and follow-up ($p=0.207$) (Figure 6).

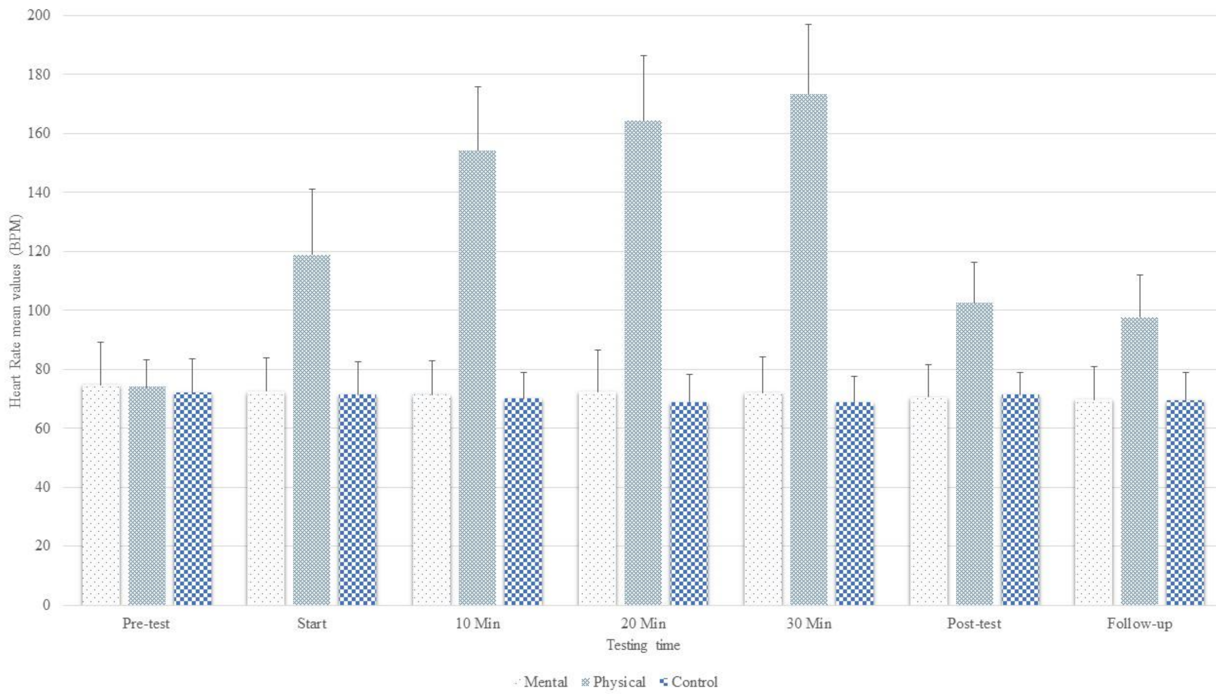

Figure 6 The means and standard deviations of heart rate for the three conditions at the seven time stages

2.3.3 Body temperature

A significant main effect was evident for testing time ($F_{(2.74,43.84)}=27.18$, $p=0.001$, $\eta_p^2=0.629$) and conditions ($F_{(2,32)}=13.35$, $p=0.001$, $\eta_p^2=0.455$) as well as the interaction of testing time and conditions ($F_{(4.70,75.32)}=8.925$, $p=0.001$, $\eta_p^2=0.358$). The interaction of condition * testing time showed that there were no significant differences between conditions at the pre-test and start, but there was significantly elevated body temperature with physical fatigue ($p=0<.001$) compared to mental fatigue and control conditions at the 10-, 20-, and 30-minutes (Figure 7). There was no significant difference between mental fatigue and control conditions at these testing times (10-, 20-, and 30-minutes). In addition, there was a significantly higher body temperature with physical fatigue ($p=0.006$) compared to mental fatigue in the post-test. There was no significant difference among conditions at follow-up. The main effect for conditions showed that physical fatigue had significantly, large magnitude, higher body temperature compared to mental fatigue (p=0.001) and control (p=0.008) conditions. Additionally, there were no significant differences between mental fatigue and control conditions. The main effects for a testing time showed a significantly higher body temperature difference in pre-test (p<.001) compared to (start, 10-, 20-, 30-minutes, and post-test), start (pre-test, 10-, 20-, and 30-minutes), 10-minutes (pre-test, start, 20-minutes, and follow-up), 20-minutes (pre-test, 10-, 20-minutes, post-test, and follow-up), 30-minutes (pre-test, start, post-test, and follow-up), post-test (pre-test, 20-, and 30-minutes), and follow-up (10-, 20-, and 30-minutes) (Figure 7).

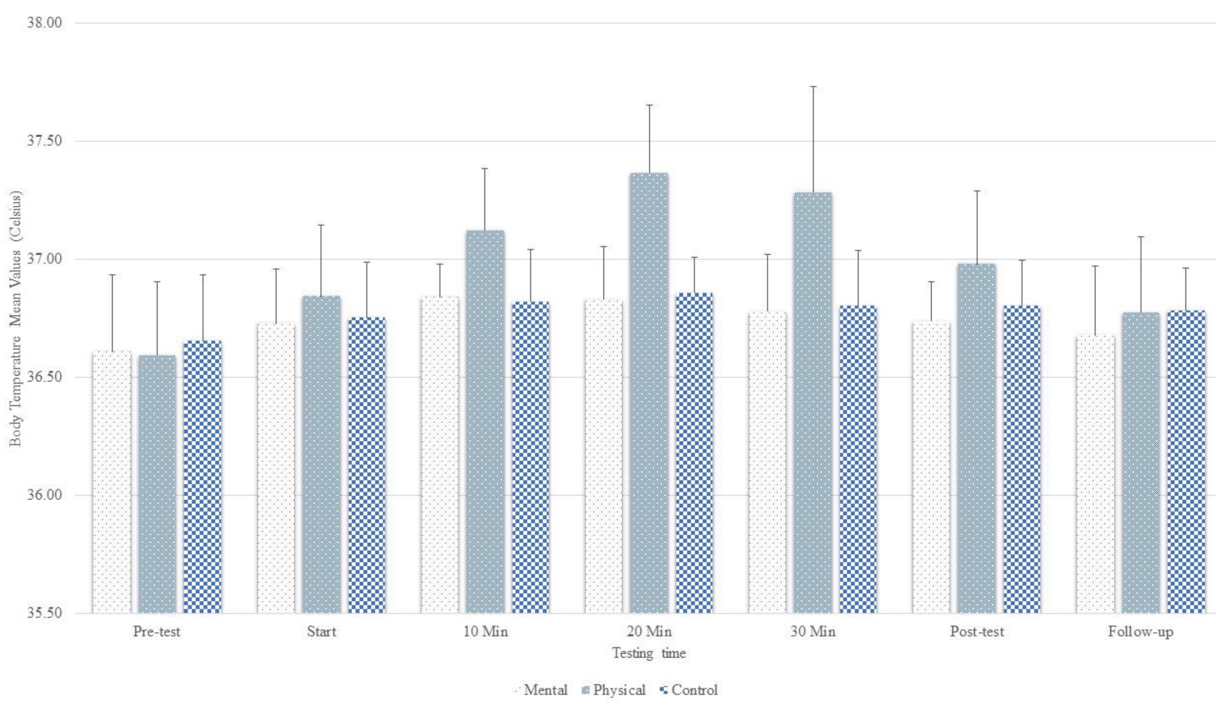

Figure 7 The means and standard deviations of body temperature at the three conditions at the seven time stages

2.3.4 Rating of Perceived Exertion (RPE)

A significant main effect was evident for testing times ($F_{(1.78,28.51)}$ =170.51, p=0.001, η_p^2=0.914) and conditions ($F_{(2,32)}$ =106.80, p=0.001, η_p^2=0.870) as well as the interaction of testing times and conditions ($F_{(3.04,48.63)}$=24.72, p=0.001, η_p^2=0.607). The interaction of condition * testing time showed that physical fatigue (p<0.001) had a higher RPE than mental fatigue and control conditions at the start. Physical fatigue (p=0.021) also had a higher RPE than mental fatigue, and mental fatigue (p<0.001) had a higher RPE than control conditions at 10- and 20-minutes (Figure 8). The results revealed that physical fatigue and mental fatigue (p<0.001) had a higher RPE than control conditions, but there were no significant differences between physical fatigue and mental fatigue (p=0.157) at 30-minutes. The main effect for the fatigue condition showed significantly higher RPE scores for physical fatigue versus mental fatigue and control conditions (p<0.001). The main effects for testing time showed a significant difference between RPE (p<.001) the start, 10-, 20-, to 30-minutes (Figure 8).

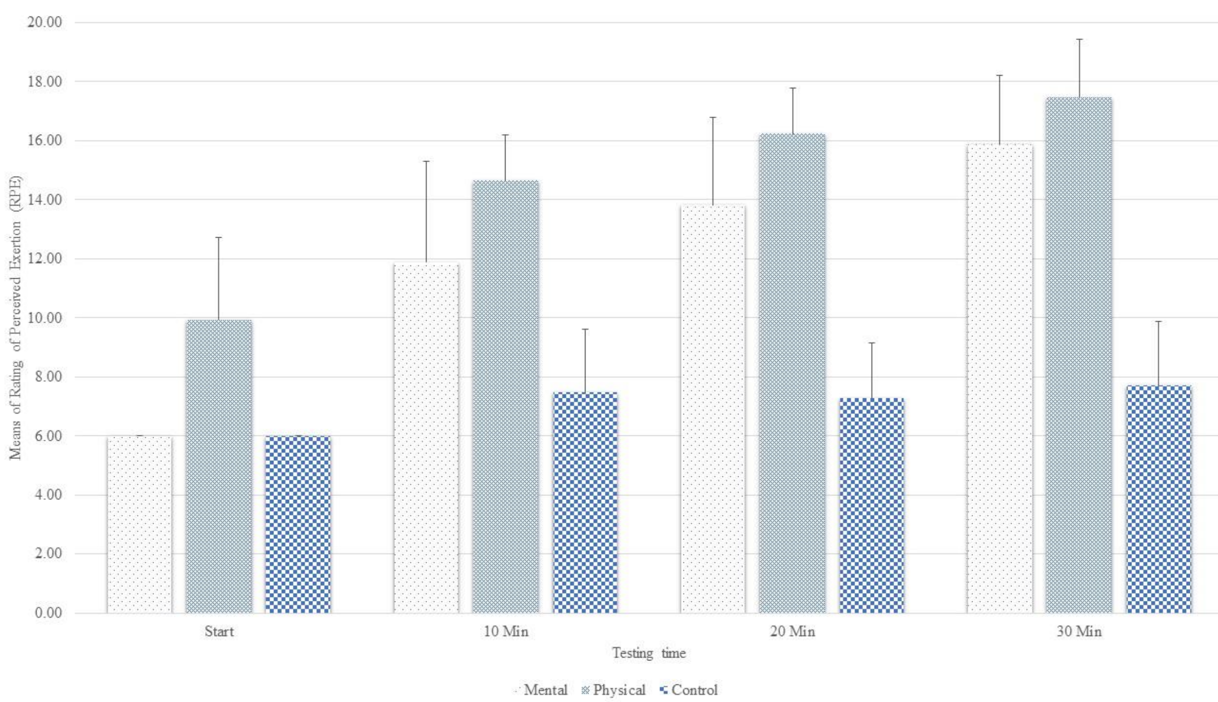

Figure 8 The means and standard deviations of Rating of Perceived Exertion (RPE)

2.3.5 The NASA Task Load Index

2.3.5.1 Mental demand

The one-way repeated measure ANOVA ($F_{(2,32)}$=41.87, p<0.001, η_p^2=0.724) revealed that the mental fatigue condition had a large magnitude, mental demand compared to physical fatigue and control conditions. Additionally, there were no significant differences between physical fatigue and control conditions (Table 3).

Table 3 The means and standard deviations for the mental demand

Conditions	Mean	Standard deviation
Mental fatigue	80	18.28
Physical fatigue	34.11	20.63
Control	23.23	25.18

2.3.5.2 Physical demand

Physical fatigue had a large magnitude, significant ($F_{(1.23,19.69)}$=167.241, p<0.001, η_p^2=0.913), and higher physical demand compared to mental fatigue and control conditions, but there were no significant differences between mental fatigue and control conditions (Table 4).

Table 4 The means and standard deviations for the physical demand

Conditions	Mean	Standard deviation
Mental fatigue	14.41	14.45
Physical fatigue	81.17	14.09
Control	11.67	17.31

2.4 Discussion

To the best of our knowledge, this is the first study to compare the impacts of mental and physical fatigue on the perception of time. The major findings of this research revealed that participants subjected to physical fatigue exhibited a significant underestimation of time intervals during the post-test and follow-up when compared to those in the mental fatigue and control conditions. In addition, physical fatigue had a significantly higher relative (%) underestimation of time change in comparison to mental fatigue and control conditions. Moreover, physical fatigue induced significantly higher tympanic temperatures and heart rates during the intervention and post-test compared to the mental fatigue and control conditions. The NASA Task Load Index demonstrated the efficacy of both the physical and mental fatigue protocols in inducing states of physical and mental fatigue.

The underestimation of time at 5-, 10-, 20- and 30-s with the physical fatigue condition were in line with the hypothesis predicting significant time underestimations (estimated time was shorter than chronological time) compared to the mental fatigue and control conditions. Moreover, the results for the physical fatigue (underestimation of time) were congruent with Graham et al. (2023), as their results showed an underestimation of time in all three exercise conditions (30-seconds of knee extensors 100%, 60% and 10% of maximum voluntary isometric contraction) with all time estimates (5-, 10- 20- and 30-s) compared to the control condition. In addition, the findings of the present study were generally consistent with Gardner et al. (2023), who revealed that maximal contractions induced significantly greater time underestimations at 5-, 20-, and 30-s than control condition. Moreover, their study showed that submaximal (60% of maximal voluntary isometric contractions) contractions also contributed to time underestimation at 30-seconds. Furthermore, Edwards and McCormick (2017) utilized cycling wherein participants were asked to estimate the completion of 25%, 50%, 75%, and 100% of the trial duration under various RPE conditions. Notably, they observed that at the 75% and 100% intervals, time estimates for the RPE 20 condition, representing maximal exertion, exhibited the shortest durations when compared to those of RPE 11 (light intensity) and RPE 15 (moderate intensity). Additionally, the participants also completed a rowing task, wherein they found similar intensity-dependent results (A. M. Edwards & McCormick, 2017). Similarly, the RPE findings indicated that participants, upon the end of the physical fatigue intervention, reported an average RPE score of 17. This finding was aligned with the Edwards and McCormick (2017) and suggested that the perceived level of exertion experienced during the physical fatigue condition might be an indicator of underestimation of time in the physical fatigue condition.

In some studies, it has been suggested that an increase in body temperature affects temporal perception (Piéron, 1923; van Maanen et al., 2019). Brinnel & Cabanac (1989), suggested that tympanic temperature as measured in the present study, when measured accurately, is a good index of core temperature and that its variations may reflect variations in brain temperature. Two studies showed that core temperature increased (with running in a warm, humid environment) corresponding to an underestimation of time (Tamm et al., 2014, 2015). Similarly, in the present study, the core temperature was significantly higher in the physical fatigue condition compared to mental fatigue and control during the intervention and the post-test. This finding diverges from the Graham et al. (2023) study, who reported an absence of significant increase in tympanic temperature. Similarly, Gardner et al. (2023) documented that tympanic temperature remained unaffected by the contraction intensities. One possible reason for the observed disparity in outcomes between the present study and the prior investigation lies in the dissimilarities in methodological approaches. Notably, they employed isometric contraction as the primary exercise modality, while we opted for a 30-minute cycling at 65% PPO, which induced a rise in tympanic temperature higher compared to Graham et al. (2023), and Gardner et al. (2023) studies. Moreover, it is pertinent to acknowledge that the duration of their experimental protocol was comparatively shorter than ours, which may have further contributed to differences in physiological reactions and subsequent findings of the two studies.

Another notable finding in this study pertains to the heart rate, which exhibited a significant elevation during the physical fatigue condition at the stages of intervention, post-test, and follow-up in comparison to both the mental fatigue and control conditions. This finding aligns with the findings of Gardner et al. (2023), who reported lower heart rate values for the control condition (75.3 ± 11.6) in contrast to the maximal (92.5 ± 13.9), 60% submaximal (92.2 ± 14.4), or distraction (90.5 ± 14.7) conditions. Similarly, the results obtained by Graham et al. (2023) were consistent with our study, as they demonstrated that the control condition exhibited lower heart rate values (beats per minute) (74.6 ± 10.6) compared to the maximal (91.6 ± 12.4), 60% MVIC (92.5 ± 13.8), or 10% MVIC (90.7 ± 13.5) conditions.

Contrary to our initial hypothesis, the results of our analysis in the mental conditions did not align with our hypothesis, as participants did not exhibit a tendency to underestimate perception of time in this condition. The ideal task duration to induce mental fatigue in young adults is currently unclear in the literature, thus it is not known how long it takes for a change in task performance to become significant. Previous studies have employed tasks that continue for several hours. However, new research indicates that, 30 to 90-minutes is sufficient to cause mental fatigue (Helm, 2021). Individual differences may also be a significant factor in the onset of mental fatigue and the length of time required to induce it. Evidence from some studies suggests that shorter task durations may be sufficient to cause mental fatigue as significant declines in cognitive function were seen after only 30-minutes (Slimani et al., 2018), 45-minutes (Smith et al., 2019), 60-minutes (Wascher et al., 2014) or 90-minutes (Wang et al., 2016). Vrijkotte et al (2018) in their studies used 90-minutes of Stroop task to induce mental fatigue. The primary conclusion of this research is that in trained, young, healthy athletes, a large magnitude of mental fatigue as determined by the NASA task load index had no impact on physical or cognitive performance (accuracy and reaction times) during the second exercise bout of the two-bout exercise protocol (Vrijkotte et al., 2018). They found that when no mentally fatiguing task was being conducted, the initial maximal exercise test also increased mental fatigue. The individuals were unable to distinguish between physical and mental fatigue (Vrijkotte et al., 2018). Slimani et al (2018), showed that performing the Stroop task for 30-minutes successfully induced mental fatigue. Although the NASA-TLX showed that Stroop task induced mental fatigue for the participants, the 1100 trials (approximately 30-minutes) might not have been enough to affect time perception or had a shorter duration of impact after the mental fatigue protocol. Another possible mechanism is that mental fatigue and physical fatigue might have different physiological and psychological mechanism that affect time perceptions differently. Our findings for the physical fatigue condition were not consistent with Tonelli et al. (2022,) study, who investigated the effects of moderate physical activity (cycling) on a temporal estimation task in a group of adult volunteers under three different conditions: (1) baseline, (2) during the physical activity phase, and (3) roughly 15 to 20-minutes later, when participants were seated and returned to a resting heart rate (POST). They discovered that exercise directly alters how people perceive time, causing them to overestimate durations in the millisecond range. Notably, the impact lasted during the POST session, ruling out either the heart rate or cycle rhythmicity as the primary contributors (Tonelli et al., 2022).

It was anticipated that when participants estimated the four successive times (5-, 10-, 20-, and 30-seconds), gradually time variability would increase. Naturally, you would anticipate more time variability as time goes on because minor time estimate errors made early in the trial can become more amplified as time goes on (Graham et al., 2023). However, it was intriguing that the relative results showed that 5-, 10-, and 20-seconds intervals demonstrated relatively higher underestimation of time in the physical fatigue condition compared to the 30-seconds.

The findings that physical fatigue can lengthen an individual's subjective experience of time can be elucidated from the perspective of the Pacemaker-Accumulator Model (PAM) as posited by Gibbon et al. (1984), Grondin (2010), and Allman and Meck (2012). Specifically, in the physical conditions, participants were cycling at 65% of PPO. This physical exertion induced muscle fatigue and discomfort attributed to factors such as tension, partial blood occlusion, and metabolite accumulation, among others. According to Edwards and Polman (2013), this adverse sensation functions as a type of physiological arousal. Arousal has been found to elevate the speed of the pacemaker, resulting in an increased number of pulses accumulated in the accumulator (Gil & Droit-Volet, 2012; Lambourne, 2012). This heightened arousal contributes to a perceived distortion of time, leading to a specific lengthening of perceived time intervals (Gil & Droit-Volet, 2012). Importantly, this time distortion effect exhibits a multiplicative characteristic, wherein the extent of distortion intensifies with longer stimulus durations (Zakay & Block, 1997). Consequently, it is plausible to hypothesize that arousal induced by exercise could engender a time distortion effect (Behm & Carter, 2020; Dormal et al., 2018). In the present study, the heightened state of arousal post-exercise can be attributed to the sustained increase in heart rate and body temperature during the post-test phase. This suggests that the distortion in perception of time persists even after the cycling activity has concluded. The study findings indicate that mental fatigue led to a slight overestimation of time when compared to chronological time; however, the observed difference did not reach statistical significance. Possible reasons for this outcome can be attributed to the limited number of trials employed in the Stroop task, which might not have been sufficient to induce a notable distortion in time perception. Additionally, it is plausible that mental and physical fatigue operate through distinct mechanisms, which could contribute to differential effects on the perception of time. Further investigation and a more comprehensive experimental design are warranted to delve deeper into these intricacies and better comprehend the underlying factors influencing temporal perception in the context of mental and physical fatigue.

2.5 Limitations

This research investigation, akin to any other studies, was not devoid of limitations. One of the hypotheses of the study aimed to compare time estimates between male and female cohorts. However, due to challenges in recruiting an adequate number of female participants, this objective remained unfulfilled. Consequently, the sample primarily consisted of male students engaged in recreational physical activities. An additional limitation of this study pertains to the substantial standard deviations in relation to the mean values, reflecting considerable heterogeneity among the various individual outcomes. Future studies should investigate how mental and physical fatigue might affects perception of time in males and females differently. Additionally, how might time perception be different for endurance exercise above the lactate threshold (e.g., >80-85% max aerobic power)?

2.6 Conclusions

This study's findings highlight the impact of physical and mental fatigue on participants' perception of time. Specifically, under the physical fatigue condition, participants underestimated time during the post-test and follow-up, as compared to the mental fatigue and control conditions, across various time intervals (5-, 10-, 20-, and 30-seconds). Moreover, the investigation revealed no significant differences between the mental fatigue and control conditions concerning time estimates. In addition, the results showed that physical fatigue condition demonstrated significantly higher heart rates and body temperatures during both the intervention and post-test, as compared to the mental fatigue and control conditions. Furthermore, participants reported significantly higher RPE under the physical fatigue condition compared to the mental fatigue and control conditions. Additionally, mental demand was significantly higher in the mental fatigue condition than in the physical fatigue and control conditions. The physical demand was significantly greater in the physical fatigue condition relative to both the mental fatigue and control conditions. Overall, these findings contribute valuable insights to the expanding body of research on the relationship between exercise-induced fatigue and time perception. The present study suggests that individuals engaged in physically demanding activities, such as sports, drivers, and work settings, among others may experience alterations in time perception due to the influence of physical fatigue. Accordingly, it is recommended that these individuals engage in deliberate exercises aimed at enhancing their time perception abilities during periods of physical fatigue. Such practices are hypothesized to facilitate the development of an enhanced sense of timing under physically demanding conditions.

Furthermore, there is another practical aspect to consider: how can we offer feedback or modify exercise routines for individuals who perceive themselves as having limited time available for improvement in order to enhance adherence? This question holds significant relevance, particularly for the general populace that may not find exercise enjoyable. Moreover, the prospective time estimation ratio could also have a notable influence on endurance athletes or time restricted athletes (e.g., tennis, basketball, North American football) who require precise pacing or timing. This factor carries substantial implications, as an athlete who underestimates the time may perform too slowly, jeopardizing their chances of winning a race, whereas an overestimation of time might lead them to push too hard and experience premature fatigue.

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2.8 Appendix

MEMORIAL UNIVERSITY

Interdisciplinary Committee on Ethics in Human Research (ICEHR)

St. John's, NL Canada A1C 5S7
Tel: 709 864-2561 icehr@mun.ca
www.mun.ca/research/ethics/humans/icehr

ICEHR Number:	**20231533-HK**
Approval Period:	March 24, 2023 – March 31, 2024
Funding Source:	NSERC [RIS# 20171793]
Responsible Faculty:	Dr. David Behm School of Human Kinetics and Recreation
Title of Project:	*The Effects of Physical and Mental Fatigue on the Time Perception*

March 24, 2023

Mr. Reza Goudini
School of Human Kinetics and Recreation
Memorial University

Dear Mr. Goudini:

Thank you for your correspondence addressing the issues raised by the Interdisciplinary Committee on Ethics in Human Research (ICEHR) for the above-named research project. ICEHR has re-examined the proposal with the clarifications and revisions submitted, and is satisfied that the concerns raised by the Committee have been adequately addressed. In accordance with the *Tri-Council Policy Statement on Ethical Conduct for Research Involving Humans (TCPS2)*, the project has been granted *full ethics clearance* for **one year**. ICEHR approval applies to the ethical acceptability of the research, as per Article 6.3 of the *TCPS2*. Researchers are responsible for adherence to any other relevant University policies and/or funded or non-funded agreements that may be associated with the project. If funding is obtained subsequent to ethics approval, you must submit a Funding and/or Partner Change Request to ICEHR so that this ethics clearance can be linked to your award.

The *TCPS2* **requires** that you **strictly adhere to the protocol and documents as last reviewed** by ICEHR. If you need to make additions and/or modifications, you must submit an Amendment Request with a description of these changes, for the Committee's review of potential ethical concerns, before they may be implemented. Submit a Personnel Change Form to add or remove project team members and/or research staff. Also, to inform ICEHR of any unanticipated occurrences, an Adverse Event Report must be submitted with an indication of how the unexpected event may affect the continuation of the project.

The *TCPS2* **requires** that you submit an Annual Update to ICEHR before **March 31, 2024**. If you plan to continue the project, you need to request renewal of your ethics clearance and include a brief summary on the progress of your research. When the project no longer involves contact with human participants, is completed and/or terminated, you are required to provide an annual update with a brief final summary and your file will be closed. All post-approval ICEHR event forms noted above must be submitted by selecting the ***Applications: Post-Review*** link on your Researcher Portal homepage. We wish you success with your research.

Yours sincerely,

James R Drover

James Drover, Ph.D.
Vice-Chair, Interdisciplinary Committee on
Ethics in Human Research

JD/bc

cc: Supervisor – Dr. David Behm, School of Human Kinetics and Recreation

2.8.1 Peak Power Output (PPO)

Table 3 The peak power outputs of the participants

ID	$W_{(out)}$	Time (Seconds)	$W_{(max)}$	$W_{(65\%)}$	$HR_{(Max)}$
1	120	58	132.88	86.37	176
2	200	92.6	220.57	143.37	167
3	120	34	127.55	82.91	150
4	120	170	157.77	102.55	182
5	200	113	225.11	146.32	198
6	240	52.5	251.66	163.58	171
7	240	116	265.77	172.75	180
8	120	1	120.22	78.14	210
9	200	25.9	205.75	133.74	150
10	120	76.3	136.95	89.02	178
11	240	122.6	267.24	173.70	168
12	200	106	223.55	145.31	188
13	120	140	151.11	98.22	194
14	160	8.41	161.86	105.21	182
15	200	10.41	202.31	131.50	188
16	200	164	236.44	153.68	190
17	200	156	234.66	152.53	201