Temporal Perception distorted by Submaximal and Maximal Isometric Contractions of the Knee Extensors in Young Healthy Males and Females: A randomized controlled trial.

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A thesis submitted to the

School of Graduate Studies

In partial fulfillment of the requirements for the degree of

Master of Science in Kinesiology

School of Human Kinetic and Recreation

Memorial University of Newfoundland

St. John's, Newfoundland, and Labrador

October 2022

St. John's Newfoundland & Labrador

Abstract

Time perception has been of interest in neuropsychology research for decades. However, in recent years the topic has gained interest in exercise physiology. Research has shown that time perception can be distorted by multiple factors: sex, vital signs, exercise intensity, and attentional effects. Conflict in the literature exists as studies have found the perception of time to be underestimated or overestimated as these factors interplay with exercise. As only a few studies have analyzed exercise and time perception, there are gaps in understanding what truly influences time perception. Additionally, many studies have not investigated sex differences in time perception while performing a bout of exercise. Additional research is needed to grasp time perception's psychological and physiological interplay. The findings of this study highlight a significant time underestimation during 20 and 30-s intervals during submaximal and maximal exercise, with the greatest underestimation being at 30-s undergoing a maximal intensity contraction.

Keywords: Time Processing, Arousal, Verbal Time Estimation, Intensity

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.

Acknowledgments

I would like to thank the faulty and fellow students on helping me carry out this challenging but rewarding process.

I wish to thank Dr. David Behm for his guidance and support every step of the way.

Thank you to Dr. Shahab Alizadeh for the patience and taking the time to answer my questions. Additionally, I would like to thank Andrew Graham for helping me with data collection, communication, and analysis.

Lastly, I would like to thank my father as he always lends a helping hand. I miss you every day.

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List of Abbreviations

HR- Heart rate

MD- Mean difference

MVIC- Maximal voluntary isometric contraction

RPE- Rate of Perceived Exertion

SBF- Striatal Beat Frequency

SET- Scalar Expectancy Theory

SD- Standard deviation

SBF- Striatal Beat Frequency

-s- seconds

Chapter 1: Review of Literature

Introduction

Fundamental human movements and behaviours are continually influenced by one's perception of time. For example, catching a baseball requires a judgement of time to align the hand with an airborne ball for a successful catch. *Time perception* is defined as an individual judgement of a predetermined chronological interval (Wittmann, 2009). The chronological time on a clock compared to one's perception has been of interest in many research fields, including physics, psychology, and, recently, exercise science.

Albert Einstein (1905) theorized that the passage of time is independently determined by a reference time (clock); in other words, time is a relative concept. Different theories have argued that gravitational forces generate one's perception of time, and the reference time initiates from the Big Bang Theory (Hawking & Hartle, 1972). However, two main theories within the literature, Scalar Expectancy Theory and Striatal Beat Frequency, give insight into the neural mechanisms of time perception. Although neurobiological studies suggest that specific areas of the brain feed into one's perception of time, it remains unclear if performing tasks in concert with perceiving time will distort time (Wittmann, 2009). A common finding in the time perception literature is that as an additional task is endured when attempting to estimate fixed timing intervals, one's perception of time is distorted (Hanson & Buckworth, 2016; Edwards & McCormick, 2017). The combination of perceiving or estimating time intervals with exercise may distort time perception due to the demand for attentional resources. However, exercise-induced alterations to time perception have been under-researched and inconclusive. Studies have highlighted that physiological and psychological factors influence one's notion of time (Tobin & Grondin, 2012; Tamm et al., 2014; Hanson & Buckworth, 2016; Edwards &

McCormick, 2017; Hayashi & Ivry, 2020). These physiological factors, such as sex, body temperature, and fatigue mechanisms, have been shown to distort individuals' time perception. Psychological aspects of time include attentional and emotional influences. Physiological and psychological mechanisms within exercise environments are altered, which can distort time.

The perception of time is an essential skill within time-dependent sports (figure skating, basketball, ice hockey, dancers, and others) and daily tasks or professions (i.e., walking across a busy street and emergency professionals). Moreover, the perception of exercise time may influence adherence to programs for overall wellbeing. Those who deem an exercise routine prolonged may refrain from exercising, whereas those who underestimate time may be inclined to exercise. Sex differences and time perception is an area of limited research. However, one study examining sex differences in time perception during an endurance activity reported that women consistently underestimated time intervals (Hanson & Buckworth, 2016). The biggest caveat to this study is that women worked at a higher intensity than men; vigorous work may result in the underestimation of chronological time. Understanding time perception's physiological and psychological influence will contribute to human experience and performance. This literature review examines the two neural mechanisms and physiological and psychological factors that may distort time perception.

Prospective & Retrospective Time

James (1890) suggested that temporal experiences differ when various environmental variables are manipulated, such as timing awareness to influence temporal judgments. He categorized differences in temporal expression as prospective and retrospective time. Prospective timing or experienced duration is when an individual is informed prior that they will have to judge a temporal event, while retrospective timing is when individuals are unaware of temporal estimation until after the task is completed. Both prospective and retrospective time concepts have been used in research to understand the human cognitive experience of temporal estimation. Hicks, Miller, and Kinsbourne (1976) compared prospective and retrospective timing to understand these two categories' relevancy by sorting playing cards with zero bits, one bit, or two bits of information and estimating the time it took to complete the task. One group was aware (prospective time), and the other was unaware (retrospective) after the task was completed, they would be asked to guess the time it took them to complete sorting the cards. Results showed that the prospective group was more successful in completing the sorting task as the bits of information increased. There were no significant findings for the retrospective group; responses had low variability when estimating the time, it took to complete the task. The additional bits of information increased the cognitive resources allocated to the task, which increased the participants' attention. Block (1992) found that when participants performed several memory-based tasks, retrospective timing caused an overestimation, while prospective timing was accurate to chronological time. A possible explanation for this difference in timing from just informing the participants about temporal judgment may be due to resource allocation and cognitive pathways. Prospective timing may increase when participants have to allocate more attentional resources. Retrospective timing increases when there is a demand for memory processing. Taking these results into account when designing temporal experiments, one should consider the two forms of temporal judgments as they may influence results. Research in the exercise and time perception scope has focused on the prospecting timing approach in the research design. Prospective timing models have attempted to explain human attention through physiological and psychological explanations, Scalar Expectancy Theory and Striatal Beat Model.

Scalar Expectancy Theory

For over three decades, the Scalar Expectancy Theory (SET) has been recognized as one of the most accepted theories to explain time perception. First developed to understand learning in animals, the SET was successfully proposed in humans by dividing the experience of time into three components; a clock, memory, and decision (Gibbon and Church, 1984; Meck and Aimee, 2002). This mathematical theory proposes that time is mediated by an internal clock composed of a pacemaker. The internal pacemaker releases Poisson distribution-like pulses to express the probability of a given number of events that are likely to occur during a fixed interval in space. The determined probability of a particular time interval becomes ingrained in memory and past experiences (Meck and Church, 1983; Gibbon, Church and Meck, 1984; Allman and Meck, 2012) and then extrinsically or intrinsically announced when one assumes the interval is terminated.

The temporal pacemakers are proposed to be neural circuits that create loops where structures communicate to make decisions, or create memories, or perform tasks. Action potentials drive the neural loop, and as one loop is achieved, this represents one pulse to be admitted to the pacemaker; increased time would result in more neural loops achieved and more pulses (Thatcher & John, 1977). An external cue or timed signal initiates the internal clock, and the pacemaker pulses gather into an accumulator. If this signal gains significance (environmental changes or feedback), the information collected by the accumulator is transferred to working memory and then solidified to reference memory (Brody et al., 2003). The excitable or inhibitory feedback can alter the electrical activity and the number of pulses to distort one's previous experience or decision. SET uses a reference memory containing a distribution of stored accumulator values from an internal clock reading to interpret chronological timing intervals to which a source of scalar variability occurs (Gibbon and Church, 1984; Rakitin et al., 1998). In other words, SET promotes an explanation for the perception of time when an individual encounters a similar timing situation from the past. As the time of an event increases, the distortion of that time interval is likely to occur (Gibbon and Church, 1984).

When manipulating arousal levels, many studies have reported distortion of time. For instance, exposure to a stressor or aerobic activity increases body temperature (Killeen & Fetterman, 1993). The Arrhenius equation proposed a chemical reaction velocity increase (cortisol and adrenaline during stress) with elevated body temperature, which occurs in many biological processes (Bell, 1966). The equation predicts that small elevations in temperature will increase neuromodulators' activation reaction, leading to an increased rate of pulses of the internal clock. Thus, when arousal increases body temperature, the pacemaker speeds up to cause the internal clock to tick faster (Wearden et al., 1999).

Furthermore, Wearden (2003) explained that time distortion occurs with increased arousal as the rapid timing interval pulses are compared to the initially encoded control condition. The number of pulses is achieved sooner due to the increased rate of addition arousal. For this reason, increased arousal by performing exercise may compress the perception of time. In addition to exercise arousal, external feedback from the sensory system is thought to influence temporal perception. When exercising or performing a demanding task, the increase in arousal by the increase in physiological processes and external feedback work in concert with one another to have a global effect on time perception.

Auditory and visual stimuli can influence the SET's reliability, primarily as aging occurs (Lustig & Meck, 2011). These findings stem from the reality that memory declines with age. As a result, recalling past events may not be as quick or easy as younger individuals, distorting time to a greater extent. For example, Coelho and colleagues (2004) developed a time perception measure tool to understand the plasticity of time perception. Older adult participants were instructed to perform two tasks; to verbally announce and estimate the duration of the neuropsychological evaluation. The verbal estimation task resulted in participants hearing auditory beeps in intervals of 7, 32, and 58-s, then asked to estimate the duration of the intervals between the auditory signals. The neurophysiological test analyzed global time where the researcher asked the participant to draw a clock, then immediately after the task was complete, the researcher would ask how much time elapsed when the participant put pen to paper. Furthermore, at the end of the study, the researcher asked how long the participants thought the study took. Results showed their measure was an ecologically valid test to measure time perception. A positive correlation was found between age and the interval clock; as one ages, the internal clock seems to tick faster to produce underestimations of chronological time. Although the technique was deemed valid, more research is needed to create accurate and reliable time perception test protocols.

Electroencephalogram (EEG) is a common technique used to measure corticospinal excitability by assessing event-related potentials (ERP). These ERPs are produced in response to motor and cognitive events such as time perception when completing other tasks. The ERPs are elicited by the summation of post-synaptic potentials in the brain to communicate with other neural structures to help activate memory and decision processes (Walter et al., 1964). If a similar experience occurs on a separate occasion, the brain utilizes a decision ratio pre-determined by ERPs to compare the accumulator's current information to past experiences (Meck et al., 1987). This experience may be inferior, similar, or exceed the threshold memory created, which entails the decision stage.

The SET theory indicates that a possible internal clock is ingrained in humans to perceive time. An internal clock estimates time from pulses elicited to a pacemaker developed from neural loops. As neural chemistry changes from increased arousal or aging or other factors, time perception can change throughout life and different experiences. Future research is needed to investigate SET's neural physiology and measurement tools.

Striatal Beat Frequency Model

The Striatal Beat Frequency (SBF) model is inspired by neurobiology from the interactivity of neural networks. The alterations to cortico-striatal networks influence the theoretical internal clock to cause temporal distortion (Meck and Church, 1983). Neural structures deemed critical for temporal discrimination are the suprachiasmatic nucleus (SCN) and neuronal oscillators, specifically managing day-to-day and second-to-minute durations (Fontes, 2016). Neuronal oscillators communicate through electrical currents. To determine a timing interval, oscillator neurons within the SCN fire at similar frequencies to communicate with neostriata GABAergic medium spiny neurons. Research has theorized that large amounts of input arrive at the medium spiny neurons (from the basal ganglia, specifically the dorsal striatum) (Matell & Meck, 2004).

The neurotransmitters, dopamine, and glutamate, influence the clock's speed due to the influence of the substantia nigra compacta and ventral tegmental area-cortical pathways. The first engagement in a timing interval will cause the oscillating connections to fire at a particular frequency and terminate when the interval has stopped from an external cue. If the event occurs on another occasion, the neostriata GABAergic spiny neurons compare the activation pattern to the past knowledge, determining one's perceived time (Merchant et al., 2013). The output of cortical beat elicits excitatory postsynaptic potentials to increase the current to medium spiny neurons, where timing intervals are decided. Twenty percent (20%) of the temporal-specific firing rate is activated around 10 seconds, and others activate around 40 seconds (Matell & Meck, 2004). The input toward the medium spiny neurons increases strength by solidifying connections of the oscillators and medium spiny neurons. Researchers have shown that neurons that activate at lower frequencies encode for longer durations (Miall, 1989). The SBF mechanism is complex, however, studies have credited the SBF model to explain time perception alterations and sensory feedback (Matell and Meck, 2004).

Based on the present knowledge, SBF can attempt to explain the altered time perception when enduring a physically demanding task. The SBF is influenced by a change in neural activity and given the neural changes that occur with exercises such as motor neuron recruitment, rate coding, synchronization, increased motor neuron connections, and intermuscular coordination that alter the intensity and duration of exercise, time perception is also influenced (Taylor et al., 2016). Thus, it is hypothesized that exercise can alter time perception by the brain's neurobiological and chemical processes. The predominant psychological time perception model has been applied to human physiology since neural circuits and structures are more active than others throughout the day, depending on the task needed. Communication between neural networks and the associated GABAergic spiny neurons is the model's basis for contributing to one's sense of time. However, future research is needed to provide greater detail on the contribution of neural structures.

Factors that influence time perception:

Sex Differences

Despite the curiosity about time perception throughout history, many studies have underreported possible sex differences. Over a century ago, MacDougall (1904) found that females tended to judge timing intervals with more significant variability than men. However, Swift and McGeoch (1925) opposed the sex difference in perceived timing. Block et al. (1999) review concluded that perceived time differs in magnitude when analyzing the different sexes. Presently, only one study has attempted to investigate sex differences in temporal processing during an exercise condition. This experiment instructed 22 active recreational runners (11 male and 11 female) to perform a self-paced exercise (Hanson & Buckworth, 2016). Additionally, prior, during, and after the run, the participants were required to verbally estimate 60 seconds. The study found that temporal estimation was distorted when engaging in exercise. Furthermore, females and males differed during a self-paced exercise; females tended to underestimate time throughout the run, while males overestimated the temporal intervals. However, in this study, women were reported to have lower cardiorespiratory fitness and ran shorter distances than men, which influenced temporal distortion. Taking these caveats into account, the findings suggest that women may experience time moving more slowly when compared to their male counterparts. A theoretical explanation to explain this difference uses the SET that females focus on the cognitive task to count time more than the intensity of exercise than males, which causes the accumulator to collect pulses at a more rapid rate.

Physiologically, men and women differ in many aspects, such as concentrations of sex hormones. This difference in hormone concentration may lead to a disruption in time perception in animal and human studies. Sandstorm (2007) stated that when injecting rats with estradiol (a form of the female dominant hormone estrogen) 30 minutes before the demanding temporal protocol, perceived time was compressed. The SET would support this by suggesting that the estradiol increased the speed of the pacemaker. Estradiol has been shown to enhance dopaminergic synthesis and release rate, thereby increasing dopamine concentration (Reimers et al., 2014).

The SBF of time perception can also help explain the speculated mechanism. Estrus has increased dopamine levels for females as female rats show greater sensitivity to dopamine activity within the striatal (Yoest et al., 2018). The increase in extracellular dopamine may increase the firing rate of oscillating neurons affecting the internal clock. Since estradiol is a dominant primary sex hormone in females, one can expect that females may perceive time as passing quicker than males.

Trained State

Current literature proposes that highly trained individuals have a better perception of time during exercise than sedentary individuals (Edwards & Polman, 2013). As the old saying goes, "practice makes perfect," which may be why trained individuals perform better on temporal perception tasks than untrained individuals. Performing tasks from practice or routine can develop knowledge about the task's duration. When asked to recall the duration of a task, there is a tendency to have better accuracy, perhaps due to the repetition from practice, often seen in athletes. For example, competitive lane swimming's goal is to finish the course faster than the other opponents while performing different strokes. Tobin and Grondin (2012) instructed elite swimmers to complete their strongest and weakest strokes while estimating the time to complete each stroke. The swimmers were more precise at estimating time completion with their strongest stroke and tended to overestimate the weaker stroke. Athletes often get feedback about their timing when performing an event, allowing them to develop timing knowledge of the task. Conclusions of this study suggest that knowledge of task from feedback or self-discovered knowledge improved time judgement intervals as it was ingrained in memory. Therefore, knowledge of the task could cause time perception discrepancies in trained and untrained individuals depending on the participant's past knowledge and the task at hand. Although literature around memory and timing tasks is limited, results have been skewed when participants experience the interference effect; rehearsing a task to be easily accessed in memory compared to not training for the task to have no recollection in memory. Brown (2008) explains that it is important for participants to have the same amount of training around the timing task as it will reduce the attenuation of robustness between participants and the interference effect.

Two popular training types differ in the body's intensity, duration, and physiological processes; aerobic training utilizes oxygen to sustain a continuous rhythmic-like movement, and anaerobic training is an intense short burst of activity with less dependence on oxygen utilization (American College of Sports Medicine, 2013). The body navigates and switches between anaerobic and aerobic demands to produce energy to complete a task. The demands on both training types have global effects on the body and could interfere neurobiology of time perception. Edwards & McCormick (2017) recruited twelve healthy, trained participants to complete a 30-second Wingate test (anaerobic) and a 1200-second rowing exercise (aerobic). Participants completed a temporal familiarization session before the protocol. The protocol resulted in participants verbally identifying 25%, 50%, 75%, and 100% of their perceived time during an anaerobic or aerobic test. Results show that participants perceived time more accurately for the Wingate test. The temporal distortion for the aerobic exercise may occur as discomfort awareness increases and terminating exercise would allow the body to return to a homeostatic state. The temporal distortion could also result from differences in training status between participants. For example, if the participant is trained anaerobically, then the Wingate test may be ingrained to perform better than an aerobic test. Presently, no study has investigated that dominantly trained anaerobic or aerobic participants differ in temporal perception or judgments. Another mechanism proposed for this temporal distortion in trained and untrained populations is the experience of fatigue; trained individuals often experience fatigue later or with a lower perception of intensity than untrained (Halin, 2002). Therefore, greater underestimation of time intervals is likely to occur with untrained participants due to the uncomfortable onset of fatigue. During exercise and time perception studies, temporal distortion may be underestimated and cause cessation of exercise due to lack of motivation or discomfort (Marcora, 2008).

Trained individuals have been shown to increase the expression of dopamine receptors after an exercise intervention to increase dopamine concentrations in the striatum (Tanaka et al., 2009). This upregulation of dopamine with training may improve memory, resulting in more accurate temporal estimation (Lin & Kuo, 2013a, b). In rodents, chronic exercise has increased both striatal dopamine concentration and dopamine receptor binding sites. This increase in binding sites leads to greater connectivity between neural circuits to increase memory. Since the SBF model of time perception is sensitive to alterations in dopamine concentrations, this could lead to a better understanding of temporal intervals. Time perception intervals are perceived by synchronizing oscillating modulation of dopaminergic neurons in the basal ganglia. Therefore, an increase in dopamine from muscle contractions increases receptors, which may enable greater memory storage to lead to greater success when recalling time intervals (Matell & Meck, 2004).

Furthermore, vigorous intense exercise alters neurotransmitters such as dopamine. Considering the SBF is sensitive to dopamine concentrations, an increased concentration will fire the oscillating neurons at a higher rate. Higher frequency firing of neurons will result in the rapid completion of neural loops and compression or underestimation of temporal intervals.

The current literature presumes that time perception does not rely on fitness level but instead of knowledge of the task. However, the limited research on fitness level and time perception encourages further high-quality studies. Understanding an individual's fitness and perception of time can help trainers prescribe exercise to promote long-term exercise adherence.

Exercise intensity

Intensity is critical to determining physical demand during work, such as exercise or demanding occupations. Furthermore, intensity is often categorized as low, moderate, or vigorous (Physical Activity Guidelines Advisory Committee, 2008). In a fast-paced work environment such as the emergency room, the frontline workers perceived a cardiac arrest scenario as 42.6-seconds longer than reality (Eisen et al., 2007). An emergency room can be physically and mentally demanding where decisions must be rapid, like sport or exercise. Exercising at different intensities has led to widespread consequences on cognitive tasks (Davey, 1973; Lyons et al., 2008). Various studies found greater time distortion as work intensity increases (Edwards & McCormick, 2017; Eisen et al., 2007). There are a few mechanisms that attempt to explain distorted time.

During exercise, one's brain chemistry alters to result in deviations in task performance (Basso & Suzuki, 2017). A memory solidifying enzyme, P300, has been shown to reduce concentration after vigorous exercise. Kunar and colleagues (2012) stated that the relationship between exercise and P300 is U-shaped; moderate intensities increase memory, while vigorous activity may decrease. The SET would state that any variable that reduces memory retrieval would influence the temporal accumulator's pulses to distorted timing decisions. As a result, during or after a bout of vigorous exercise would lead to poor timing recall due to P300 being unable to process memories properly. In contrast, moderately intense exercise may improve or not change time perception since P300 are sufficient to undergo the memory processes needed to access knowledge on time intervals, and time distortion would not be altered (Kunar et al., 2012). Future research is needed in this area to assess the influence of neural enzymes on time perception.

One of the first studies of time perception during submaximal exercise utilized a cycle ergometer. Participants were instructed to perceive 10 seconds at a cadence of 72rpm at 30% and 60% of their VO2max (maximal oxygen consumption) on two different days (Vercruyssen et al., 1989). This study found that exercise at 30% and 60% VO2max resulted in temporal underestimation, however, 60% VO2 resulted in greater variability. This finding contributes to the idea that the higher exercise intensity, the greater variability of temporal underestimation. The submaximal intensity, in combination with exercise, alters the temporal mechanism physiology where the "ticks" of the internal clock increase and meet the threshold of the accumulator at a faster rate—working at a high intensity with a low rest period (70% and 90% heart rate reverse) distorted perception of time (Duncan et al., 2013). These studies suggest that exercise at a high intensity will distort temporal perception.

Hanson and Lee (2020) reported a higher rate of perceived exertion (RPE) score resulting in a compressed perception of time. Participants were instructed to run on a treadmill for 30 minutes for three sessions that varied in intensity and perceived time intervals: 10-, 20-, and 30-

minutes. During the 10-, 20-, and 30-minutes, participants were instructed to estimate 1-, 3-, 7-, and 20-s timing intervals. The participants reported a high-intensity RPE level of 17 to produce temporal compression. They attributed this finding to an increased intensity which caused neurological alterations, which may have accelerated the proposed internal clock (SET). A previously mentioned study by Edwards and McCormick (2017) compared different exercise intensities to chronological time using an anaerobic Wingate test and a rowing endurance task. The findings of this study highlighted that as exercise intensity increases, time "slowed."

Exercise-induced changes in dopamine concentrations from altered intensities have also been shown to take a U-shape; dopamine increases to a certain point and decreases when work is excessive (Cools & D'Esposito, 2011). Alterations in neurotransmitters concentrations from exercise attempt to explain time perception distortions. SBF is sensitive to dopamine since oscillating connections pulse at a particular frequency which causes the timing interval to be perceived once a particular dopamine concentration is attained. Therefore, increased dopamine concentration would increase the GABAergic spiny neurons' firing rate to communicate within the medium spiny neurons. The increased firing rate would achieve the cortical timing interval compared to the encoded (past) experience quicker and compression of temporal judgement underestimation.

Another explanation for the change in cognitive task performance when performing exercise is the catastrophe model (Hardy & Parfitt, 1991). This model is related to the U-inverted stress model which states that performance is dependent on physiological and cognitive components. The study concluded that basketball free-throw caused an increase in physiological and cognitive resources to decrease temporal performance. Similarly, Duncan and colleagues (2016) used four protocols to investigate the influence of incremental exercise with increasing anxiety or low anxiety situations and incremental exercise with decreasing anxiety and high anxiety. The research team completed this by manipulating conditioned anxiety by stating intense instructions and physiological arousal by a treadmill. The high anxiety and physiological stress resulted in poor performance compared to the other three protocols that were not as demanding. Time perception is a cognitive task that, when paired with exercise, can be high stress for the body; as a result, performance would likely decrease.

The current literature indicates that focus and attentional resources are allocated to higher-intensity tasks. Higher arousal shows greater neural activity to allude to the SET. The increased neural activity from both cognitive and physiological tasks enhances the number of pulses collected in the accumulator to speed up the internal clock and distort time intervals.

Type of Contractions and Movements

From present knowledge, there have been limited studies directly comparing contraction or movement type on time perception. The type of contraction (isometric, dynamic, isotonic) and movement (cyclical, rhythmic) have been accepted to influence fatigue and force production (Halperin et al., 2015). Fatigue and force production modifies arousal levels to alter neural circuits and the internal environment to impact time perception (Taylor, 2016). One study manipulated visceroreceptors from isometric contractions to see a possible influence on time perception (Di Lernia et al., 2018). The visceroreceptors report the internal chemical environment of the muscle to the insula of the brain, where self-awareness information is received (Craig, 2009). Although research remains unclear, it is hypothesized that the insula integrates signals to communicate with other brain structures for cognitive tasks (Üstün et al., 2017). Participants were instructed to estimate 10, 15, and 20 seconds when performing a hand-grip test for nine pseudo-randomized sequences. Another trial consisted of the same task with an additional inflatable cuff to cause arm occlusion. The researchers found that overstimulation of visceroreceptors from isometric contractions can distort temporal intervals (Benko & Cimrová, 2018).

Related to Aristotle's classic physics equation of velocity derived from distance divided by time, it is seen that the quicker the movement, the increased temporal perception. On the other hand, a slow contraction would indicate a slower perception of time. The intent to perform a slow or fast movement initially develops through the brain's thought processes to increase neural activity that travels down to the periphery. A rapid, intense contraction increases motor unit recruitment, rate coding, intermuscular coordination, and other factors than a slow contraction that results in a greater force development (Behm and Sale, 1993). The increase in arousal and change in visceroreceptors potentially increases the internal clock's pace and skewed perception of time (Gibbon and Church, 1984).

Different types of contraction with additional sensory manipulation may manipulate temporal judgment. Static and vibrotactile stimulations to the finger influence time perception, as demonstrated by Jones & Ogden (2015). The researchers found that stimulation to the fingers in a vibrotactile protocol increased perceived time intervals. Tomassini et al. (2016) investigated the influence of motor planning on timing using stimulation. Participants were instructed to compare the temporal separation of three tasks: rapid movement, isometric contraction of the right arm, and hand with additional stimulation to the right hand. When moving the hand at a rapid, intense pace, time was significantly underestimated compared to when the hand was static. Furthermore, temporal intervals were greatly distorted when the participant received stimulation to the rapidly moving hand. The study summarized that movements requiring high speeds with motor preparation, much like a maximal voluntary contraction, result in greater time distortion. Tomassini and colleagues concluded that motor processing influences temporal processing during motor execution. The stimulation and rapid movement increase arousal to the ascending and descending motor tracts, where the motor efferences are sent toward the muscle(s) of interest to initiate movement. The SET would assume that since there was an increase in arousal, the internal clock would speed up, and the time interval would be compressed.

Perceived timing is influenced by movement-related disorders that affect the motor system and rely on the proper functioning of neural structures. Clinically, movement disorders such as Parkinson's disease influences temporal processing. Individuals with Parkinson's disease have low dopamine concentrations and deteriorating basal ganglia, both critical in time processing (Triarhou, 2003). The tapping to a tone in individuals with early Parkinson's tended to be asynchronous compared to healthy participants. When performing different muscle contraction through exercise, neural alterations occur, which may distort time perception (see Exercise Intensity). There is a limited number of studies that directly investigate time perception and contraction type from the literature. Additionally, there is no independent analysis of different contraction types and time perception to the present knowledge. For this reason, future studies should directly compare contraction type in relation to time perception as it may be beneficial to the development of exercise programs.

Heart Rate

Heart rate is often accepted as a reliable physiological measure for arousal (Coutinho & Cangelosi, 2011; Sforza, Jouny, & Ibanez, 2000; Thayer, 1970). An increase in heart rate equates with increased arousal producing a greater number of pulses transmitted to the accumulator in the brain to accelerate perceived timing and distort time. Therefore, heart rate has been proposed to serve as a predictor of time perception due to the functional pulse for the neural pacemaker in the SET. However, evidence on this topic remains inconclusive.

Hawkes and colleagues (1962) reported a low correlation between temporal judgments and heart rate (up to 0.44) to conclude that the temporal interval recall sped up when heart rate increased. Increases in heart rate from holding breath while performing a task also led to underestimations of temporal judgment compared to holding breath while thinking about performing the same task (Jamin et al., 2004). Ostao and colleagues (1990) found that a low heart rate overestimated temporal intervals compared to conditions that produced higher heart rates. Similarly, Cellini and colleagues (2015) reported that estimating temporal intervals with higher heart rates were more accurate than slowing the heart rate.

Contradictory, other researchers have questioned whether time distortion can be explained by variability in heart rate. Smokers tend to have a higher resting heart rate than non-smokers. However, no significant temporal difference was seen between these two populations (Carroasco et al., 1998). Independently manipulating heart rate and arousal, Schwarz et al. (2012), highlighted that heart rate was not a good predictor of time perception, but somewhat subjective arousal may have a better indication of time perception. These studies indicate that the relationship between time perception and heart rate is not novel. When considering temporal recall, heart rate may not influence time perception. However, there is evidence to suggest that heart rate may influence temporal judgments. The variability of heart rate and time perception findings requires greater attention to understand if relationships exist. Presently, minimal studies have yet to measure heart rate consistently during a bout of exercise in combination with a timing interval.

Body Temperature

Bodily temperature oscillates throughout the day and can vary depending on the environment, emotional, or physical state. These fluctuations in body temperature have been shown to manipulate temporal distortion. First studies regarding time perception and physiological influence were reported by Pieron (1923 &1945), which predicted that "the speed organic processes are modified, by variation and temperature, for instance, mental time will increase or decrease proportionally." In 1933, Hoagland studied time intervals regarding the circadian body temperature fluctuations and found many individuals overestimated the time in the afternoon when body temperature is naturally at its peak. He called these day-to-day chemical clock changes, later termed the circadian rhythm. Presently, body temperature was manipulated by submerging participants in a hot tub (36 and 38 degrees Celsius), and participants estimated the time a circle was on a screen (van Maanen et al., 2019). The results from this study revealed that the water at 38 degrees increased core temperature and underestimated time intervals. Several processes have explained the manipulation of temporal intervals.

The behaviour of timing and manipulation of body temperature has been explained by physics and neural physiology. The second law of thermodynamics states that entropy (energy) increases as enthalpy increases (temperature) in an isolated system. For an open system, a decrease in enthalpy results in decreases in entropy. Entropy is known as an arrow of time, where humans can remember events in the past, not the future. When there is an elevated temperature in the system, the perception of the event “speeds up.” The Second Law of thermodynamics drives neural activity. The brain acts as an open system in which volume, number of particles, and pressure remain relatively constant to output the perception of time (entropy). Temporal processes require neural activity, which increases heat production to increase temperature. Thermodynamics would state that increased temperature would speed the projection of time forward to cause a compression of perceived time to one’s original state. Animal and human models have highlighted that the cortex temperature fluctuates (0.5) throughout the day. These changes are explained by blood circulation, brain metabolism, exchange of heat within the environment, and many daily physiological processes. The mismatch in temperature from the brain to the environment changes alterations in timing intervals. Psychophysics proposes the SET as the neural process to contribute to this explanation. At heightened arousal states, temporal pulses occur at a faster rate than total in the accumulator, leading to the number of pulses to the dedicated time interval received from memory to be compressed. Heightened arousal such as exercise can cause the body temperature to increase. Tamm and colleagues (2014) found that aerobic exercise in a hot environment accelerates subjective time and arousal. Twenty-four males endured an exercise protocol consisting of walking on a treadmill at 22 or 42 degrees Celsius at 60% of the VO2 maximal. Temporal tasks on a computer resulted in estimating 0.5, 0.75, 1, 2, 3, 5, and 10 s at random occurred pre, during (10 minutes and 60 minutes), and post-test. During the post-test, participants tended to distort time during both conditions. However, exercising in a hot environment caused a greater compression of temporal recall. The researchers concluded that exercise durations of 10 and 60 minutes could compress estimated timing intervals by 13% and 23%, respectively.

Similarly, Tamm et al. (2015) found that temporal compression was present as the core body temperature increased as participants ran in a warm, humid environment. The cause of humid environment caused a shift in the body to increase the core temperature to promote sweating. Control conditions in the above studies that limit manipulating the external environment have shown that exercising increased body temperature parallel to brain temperature increases the complexity of isolating neural influence on the rest of the body. Minimal studies have analyzed neural exercise-induced temperature alterations for this reason. Therefore, it is accepted, though, that exercise-induced body temperature elevations increase brain temperature resulting in a distortion of temporal intervals.

Perceived Fatigue

Performing continuous or concurrent demanding tasks can lead to mental fatigue and has been shown to reduce physical performance measures (Halperin et al., 2015). Recently, when mentally fatigued, it has been demonstrated that time intervals were distorted (Hayashi & Ivry, 2020). Vice versa, physically demanding tasks have been shown to decrease cognitive performance. The literature states that a mentally challenging or frustrating task that results in higher fatigue and lower motor control contributes to distorted time perception (Filipas et al.,2019). Experiencing a cortical fatiguing protocol from a mental task before enduring a cycling physical task reduced performance (Filipas et al., 2019). This repercussion in task performance when enduring a physical task may result from the constant attention required to complete the task, creating a successful fatigue scenario. Continuous exercise may cause discomfort where the participant may resist the urge to terminate the task, resulting in a lack of attention. Therefore, it is proposed that the demanding task of exercise can distort timing intervals.

The BORG scale rate of perceived exertion (RPE) is often utilized to quantify fatigue. As participants undergo a physically demanding task, they rate their perceived fatigue level on a scale of 6-20 (BORG, 1982); 6 indicates minimal exertion, and 20 indicates an all-out effort. In relation to heart rate, multiplying the BORG scale number by approximately 10 ($HR = 8.88 \times RPE + 38.2$) provides an estimate of heart rate (beats per minute) (Chen et al. 2013). When performing a physical task in conjunction with a mental task, there is a higher amount of neural activity resulting in a higher time processing rate. The RPE would perhaps increase due to the increased cortical and physical demand. The increase in the RPE scale would indicate greater stress on the body leading to a distortion of time perception. Tamm and colleagues (2014) investigated the effects of fatigue as determined by RPE and time perception by instructing the participants to exercise in a hot environment to induce stress-induced arousal. Current research has proposed that stress-induced arousal increases time perception by increasing and achieving the correct number of pulses for a timing interval to be emitted to the accumulator. Future research is needed to determine the influence of fatigue and time perception.

Analysis of time perception and fatigue can influence exercise and sporting performance. Performing a mental task before exercise may cause the perception of time to be distorted, where exercise programs may “drag” or decrease performance. Current results must consider that only a handful of studies have analyzed the influence of time perception and perceived fatigue. Future investigation on fatigue and time perception is recommended to strengthen the findings above.

Attentional and Emotional Effects

Humans are shown to be poor multi-taskers. When managing two tasks, one allocates more attention resources to one task over the other (Madore & Wagner, 2019). A common multitasking situation is performing a cognitive task with a physical task. Hanson and Lee (2017) found a mismatch in performance where the cognitive task was given less attention than the physical task resulting in the perception of time increasing while the physical task also reduced performance. The attentional influence of time perception has also been investigated with age, sex, temperature, and physiological and trained states.

Horváth & Winkler (2010) constructed a study that suggests distraction from timing tasks impacts temporal perception. Participants were asked to listen to a sound and when the sound was turned off the participant must press a trigger as quickly as possible. The second condition was similar to the first, with a distraction during the protocol that participants were told to ignore. Despite this, participants delayed their event-response timing. Lontz (2013) presented similar findings when participants had to complete a computer task with and without auditory stimulus. Participants altered their perception of time when an auditory stimulus was present. These studies suggest that when performing a temporal task, auditory stimuli can slow down a participant's temporal response. Although not all auditory stimuli show this same response to human time perception. Often music is utilized in exercise and is seen to alter psychomotor stimuli to excite or calm the body. Therefore, music can influence one's attention to a task by promoting rhythmic output, enhancing mood, increasing work output, and decreasing focus on other tasks. For example, during a cycle condition at 80% VO2max with music (130bpm), participants exercised longer than cycling without music. The longer exercise time with music resulted from a buildup of metabolites (e.g., blood lactate). However, this study did not directly investigate time perception, demonstrating that exercise in combination with sensory stimuli shows attentional deficits.

Interestingly, Fillingim et al., (1989) concluded that distraction from exercise did not distort behavioural fatigue perception taken from the BORG Scale. Participants were instructed to cycle at a cadence of 50 revolutions per minute at 300 kiloponds and took part in 3 conditions: high, low, and no distraction. During the high distraction condition, screens were set up, and participants were asked if the first letter they saw on the screen came before the first letter of the word in the alphabet and whether the second letter they see comes before the last letter of the word in the alphabet. The low distraction condition task had participants verbally announce if the first letter they see comes before the first letter of the word in the alphabet and whether the second letter they see comes before the last letter of the word in the alphabet. Results showed the minimal significance of fatigue alteration from the distraction task. However, more research is needed to analyze the perception of fatigue while performing a distraction such as exercise.

The attention to a task can be influenced by emotion to influence time perception. For example, if a task is deemed boring, a greater amount of attention is allocated, and the perception of time slows (Watt, 1991). With explanation in the SET theory, if the task is not stimulating to the body, the pulses to the pacemaker are reduced to perceive the time slowly (Droit-Volet, 2017). In contrast, when the environment or body is stimulating, the pacemaker is likely to perceive temporal intervals quickly.

Emotional states that present negativity, such as fear or anxiety, have been shown to slow down time perceived. Hammond (2012) found that time was overestimated when participants with arachnophobia analyzed photos of spiders. Similarly, when participants were presented with angry and upset facial expressions, they overestimated time when looking at happy faces. The temporal accuracy from experiencing pleasant emotions promoted participants to have greater self-awareness and consciousness of the passage of time.

Despite these studies not analyzing time perception discrepancies between trials, the findings display that perception has the potential to be influenced by emotions and attention to a task. These findings can play an essential role in rehabilitation and exercise programs. Those that are happier performing exercise may be more inclined to return to the exercise program. In contrast, unhappy individuals may deem that the exercise program is prolonged than the actual time to reduce adherence. Furthermore, future research should expand the role of time perception and attentional effects concerning increasing or decreasing performance when exercising.

Conclusion

Time perception has been shown to be distorted by exercise intensity and sex differences, with possible explanations by the SET and SBF models. Participants' fitness and time perception judgment studies have shown that there may not be a significant effect. Rather, differences are caused by attention toward a task. Although many studies have highlighted the sex difference in exercise and maximal intensities, very few have analyzed exercise related to temporal perception. Therefore, further investigation of time perception during an intense task would benefit demanding professions, exercise, and sports environments.

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Research Objectives

The objectives are:

i) Examine chronological time with perceived time to determine a possible distortion of time caused by exercise.

ii) Assess the possible distortion of time when the participants undergo knee extension at varying intensities.

iii) Examine possible sex differences with the distortion of time.

Hypothesis

The researchers hypothesize that time estimations will be distorted to a greater degree as chronological time increases. Additionally, maximal intensity knee extension will cause greater time distortion compared to the submaximal, distraction, and control protocols. Further, females will have a greater distortion of time which has been a trend in past research.

Chapter 2: Temporal Perception is distorted by Submaximal and Maximal Isometric Contractions of the Knee Extensors in Young Healthy Males and Females: A randomized controlled trial

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Running Head: Temporal Perception with Exercise

Abstract

The objectives of this study were to examine chronological time and a participant's perceived time of 5- , 10-, 20-, and 30-s intervals to determine a possible distortion of time caused by varying intensity isometric contractions. Additionally, to investigate any possible sex differences on time perception that may exist. In a computer-generated randomized control study, 19 participants (10 F, 9M) endured two sessions which consisted of a cognitive task of estimating time intervals while performing an isometric knee extension at maximal, submaximal (60%), and distraction (10%) intensities and control. The main findings of this study were that exercise at a submaximal and maximal intensities resulted in an underestimation in time perception at 20 and 30-s intervals. For the 20-s time interval a post hoc pairwise comparison reported that the maximal condition was underestimated by an average of 1.813 seconds ($P=0.013$) compared to the control condition. Additionally, a 30 second interval post hoc pairwise test for time, practice and post protocols found that the mean difference for time was underestimated by 2.043 seconds. There was a significant difference ($p<0.05$) between sexes during the 5-s interval, which was more pronounced at the distraction protocol to which females underestimated time to a greater degree than males. For the other 10-, 20-, 30-s intervals, there was no significant sex difference in time perception. There was greater integrated knee extensor EMG during the maximal mean of contractions to suggest more physiological and psychological events that may influence time perception. This work adds to the growing literature of time perception during exercise to state that time is significantly underestimated when performing moderate to vigorous intensity exercise.

Key Words: Time Processing, Arousal, Verbal Time Estimation, Intensity

Introduction

Temporal perceptions are critical for everyday behavior and survival (Wittmann & Paulus, 2008), yet the perception of time is underexplored. Time estimation can influence movement decisions and determine whether the individual is successful at their goal, for example, the 25-second time restriction for a tennis serve. *Time perception* is an individual judgment of a predetermined chronological interval (Wittmann, 2009). Evaluating one's perception of time can be achieved by comparing chronological time (objective time) to one's perception (subjective time). The Scalar Expectancy Theory (SET) and the Striatal Beat Frequency (SBF) model attempt to explain the human experience of time perception. The neurobiology of the SBF model uses alterations to cortico-striatal networks to influence the theoretical internal clock to cause temporal distortion (Meck and Church, 1983). The SET proposes that a pacemaker produces a series of pulses, and an accumulator counts the number of pulses emitted over time. The monitoring of pulses determines the duration experienced. This is known as a clock phase, followed by a memory stage where the value of pulses in the accumulator is compared to previously stored durations leading to a temporal decision and response (Gibbon et al., 1984). However, both the SBF and SET are influenced by arousal, which can result in temporal distortions (physiological or psychological) (Penton-Voak et al., 1996; Lambourne, 2012; Schwarz et al., 2013; Droit-Volet and Berthon, 2017).

The psychological factor of attentional effect plays a critical role in time perception when encountering a dual-task; the ability to perform two tasks simultaneously. Dual-tasking measures a component of executive function as participants must coordinate their attention to both tasks performed (MacPherson, 2018). Hanson and Lee (2017) found a mismatch in performance during a dual-task; the cognitive task was given less attention than the physical task. The conclusion was that the perception of time increased while the physical performance of the task decreased. Presently, studies have found conflicting evidence for temporal distortions as it seems to depend on the distraction. For example, Lontz (2013) found that an auditory distraction altered the perception of time. In contrast, the distraction of music has shown that participants can perform tasks for longer durations (De Bourdeaudhuij et al., 2002; Maddigan et al., 2019). To our knowledge, limited studies have investigated time perception during a distraction; therefore, future research is needed in this area.

Exercise has been shown to increase physiological and psychological arousal, such as increased heart rate, temperature, and neuromuscular responses such as increased motor unit recruitment and rate coding (Pitcher & Miles, 2002) Although, the influence of exercise on temporal perception is currently limited. However, researchers have found that temporal perceptions are distorted when increasing arousal. For instance, researchers found high-intensity scenarios, similar to exercise arousal levels, such as front-line healthcare workers overestimated time to aid a cardiac arrest case (Eisen et al., 2007). Competing athletes require continuous accurate temporal estimations to succeed at their sport, such as executing a martial arts technique or performing a forceful forehand hit in tennis. When asked to recall the duration of a task, there is a tendency to have better accuracy. This accuracy of temporal events often seen in sports may be due to the practice and thus knowledge of the task. Tobin and Grondin (2012) instructed elite swimmers to complete their strongest and weakest strokes while estimating the time to complete each stroke. The swimmers were more precise at estimating time completion with their strongest stroke and overestimated the weaker stroke. From this, knowledge of the task increases time performance in participants. One's perception of time may be easily influenced by the environment and related to their awareness of the task's psychological and physiological factors (Wittmann & van Wassenhove, 2009).

Exercise can take many forms, varying in intensity, duration, and movement type. The difference in contraction type, dynamic, and isometric, has been underreported in time perception research. A single study has concluded that performing an isometric grip test can distort time intervals (Benko & Cimrová, 2018). Varying exercise intensity has been an under-researched factor that may improve or impair time perception. The rate of perceived exertion (RPE) scale has been reported to be an indicator of how hard the participant is working. Hanson and Lee (2020) reported a higher RPE score resulting in a compressed perception of time during a 30-minute treadmill protocol. As participants work at a higher intensity, RPE increases, and temporal perceptions are distorted.

Additionally, exercise can interact with many factors such as age, sex, and fitness level. Presently, only one study conducted by Hanson & Buckworth (2016) has attempted to investigate sex differences and temporal distortion during an exercise condition. The study found that females and males differed during a self-paced exercise; females underestimated time while males overestimated the temporal intervals. The intensity of exercise and perception of time research is limited. Hanson and Lee (2020) reported a higher RPE score resulting in a compressed perception of time during a 30-minute treadmill protocol. These factors can help understand the physiological and psychological influence of time perception that will contribute to human experience and performance.

The goal of this study is to analyze time perception in intervals of 5, 10, 20, and 30 seconds when performing isometric knee extensions at varying intensities (maximal, 60%

maximal, and 10% maximal). Furthermore, this study also aims to explore sex differences in time perception. We hypothesize that time perception (estimates) will be impaired to a greater degree with longer chronological time. Additionally, it is hypothesized that maximal and submaximal exercise intensities may distort temporal perception to a greater extent due to increased arousal than the control and distraction conditions due to the attentional demands required. Lastly, we hypothesize that females will tend to distort time intervals to a greater extent than male participants.

Methods

Participants

Based on an “a priori" statistical analysis (G*power version 3.1.9.2, Dusseldorf Germany) and a pilot project (11 participants), it was determined that approximately 15 participants were needed to achieve an alpha of 0.05 and a power of 0.8. A convenience sample of 19 (9 males, 10 females) health physically active participants between the ages 18-30 years were recruited. The participants had no history of lower limb injuries in the last 6 months and resistance trained more than twice a week for over two years. Prior to completion of the study, participants read, signed an informed consent document, and completed the Physical Activity Readiness Questionnaire-Plus (Canadian Society for Exercise Physiology, 2020). A COVID-19 pre-screening test was submitted before entry into the laboratory. The study adhered to the approval process of the institution’s Interdisciplinary Committee on Ethics in Human Research (20210782-HR) in accord with the Declaration of Helsinki.

Table 1: Anthropometric data between male and female participants, listed as M (SD).

	Age (years)	**Height (m)**	**Mass (kg)**	**BMI (kg/m^2)**
Males	23 ± 2.8	1.80 ± 6.3	76.5 ± 8.4	23.7 ± 2.3
Females	23 ± 1.9	1.64 ± 6.9	67 ± 14.7	25.1 ± 5.8
Total	23 ± 4.4	1.71 ± 10.3	72 ±12.7	24.4 ± 4.29

(M=9, F=10)

Experimental Design

A computer-generated randomized control study design was used to examine the effect of time perception when performing at varying intensity isometric contractions, further, to investigate a possible sex difference in the perception of time. Participants attended two sessions on two different occasions, separated by 48 hours, based on the American College of Sports and Medicine (ACSM) recommendations for exercise recovery (ACSM, 2009). The two sessions were randomized (generated by Microsoft Excel) as Session A (control, and 30 second maximal contraction protocols) or Session B (submaximal contraction at 60% MVC and distraction using 10% MVC, protocols). Each session included data collection of the quadriceps (force and electromyography) and focused on the participant's perception of time at intervals of 5, 10, 20 and 30 seconds. During the timing protocol, Rate of Perceived Exertion (BORG Scale) was used to deter the participant from consciously counting and to determine how hard the person feels like they were working. Heart rate and tympanic temperature were also recorded pre- and post-learning components and pre- and post-protocol. For the first session, anthropometric data were recorded for each participant.

Session Preparation

Participants underwent six repetitions of the 30-second time perception familiarization protocol for each testing session. The time perception familiarization allowed the participant to focus on the 30 seconds duration. During the familiarization protocol, participants were seated while they observed the passage of 30 seconds on a computerized digital clock twice. Then, participants were asked to recall chronological temporal intervals of 5, 10, 20, and 30 seconds without viewing the digital clock, for 6 repetitions. Their perception or estimate of intervals was identified when the participant squeezed a hand dynamometer to indicate the temporal passage of the interval. The hand dynamometer was connected to the computer software acquisition system (BioPac AcqKnowledge) to document the participants' time perceptions. An average of the participant's perception of time was determined to compare to chronological time.

Time familiarization was followed by electromyography (EMG) electrodes preparation and a warm-up on a cycle ergometer (Monark Inc., Sweden) for five minutes at a cadence of 70 rpm at one kilopond. Participants were then seated in a leg extension machine via a custom-built apparatus (Technical Services Memorial University of Newfoundland), with the knee fixed at 110°, to perform four warm-up isometric knee extensions. A strap was placed around the waist to eliminate upper body movement, and participants were instructed to cross their hands across their chest while holding a hand dynamometer. The dominant ankle, determined by which foot the participant would kick a ball with, was inserted into a padded ankle cuff attached to a strain gauge (Omega Engineering Inc., LCCA 250, Don Mills, Ontario). The strain gauge inhibited the quadriceps muscle group from changing length. Differential voltage from the strain gauge, sampled at a rate of 2,000-Hz, was amplified, digitally converted (Biopac Systems Inc. DA 100 and analog to digital converter MP100WSW; Holliston, MA), and monitored on a computer. A commercial software program (AcqKnowledge III, Biopac Systems Inc., Holliston, MA) was used to analyze the digitally converted analog data.

Participants performed two maximal voluntary isometric knee extensions for four seconds with one-minute rest. If the difference between the two MVICs was more than 5%, a third contraction was performed to ensure the participant's maximal force was achieved. Prior to performing each MVIC, the participant was told to contract their knee extensors as hard and fast as possible. The subsequent steps for the session were pre-determined by randomizing the two sessions.

Session A

For the control protocol, a researcher verbally announced a “GO” signal to initiate the protocol. Participants did not perform muscle contractions as they sat in the custom-built apparatus (Technical Services Memorial University of Newfoundland) as they estimated 5, 10, 20, and 30 seconds by squeezing the hand dynamometer for each interval. Simultaneously, participants announced their Rate of Perceived Exertion (BORG scale) after each time estimate. The maximal contraction protocol followed the same procedure except the participant contracted as fast and hard as possible while 5, 10, 20, and 30 seconds and stated their RPE after every estimation.

Session B

With the distraction and submaximal protocols, 10% and 60% of the participant's MVIC was determined respectively, and a range band of the relative MVIC force (+/-10%) was shown to the participant on the computer screen (AcqKnowledge III, Biopac Systems Inc., Holliston, MA) to gauge the intensity throughout the protocol. Before counting, the participant performed a knee extension ordered to achieve approximately 10% or 60% of their MVIC. Once this was sustainable, the participant started to estimate the time intervals by pressing the hand dynamometer for the 5,10, 20, and 20-s intervals. RPE ratings were asked after each time estimate. Three minutes of rest was given prior to beginning the following protocol.

Electromyography

EMG of the dominant quadriceps was monitored using self-adhesive 3.2 cm diameter Ag/AgCl bipolar electrodes (MeditraceTM 130 ECG, Syracuse, USA. The electrodes were placed parallel and edge-to-edge for an inter-electrode spacing of 20 mm. Before electrode placement, the skin was shaved, abraded, and cleansed with an isopropyl alcohol swab to reduce EMG recording impedance (Hermens et al., 2000). EMG activity was collected from the rectus femoris mid-belly, midway between the anterior superior iliac spine and the patella's superior edge. A ground electrode was placed on the femoral lateral epicondyle. Following electrode placement, electrodes were taped to minimize movement and tested for inter-electrode impedance noise (<5 kOhms). All EMG signals were amplified ((Biopac System Inc., DA 100: analog-digital converter MP150WSW; Holliston, Massachusetts) and recorded with a sampling rate of 2000 Hz using AcqKnowledge III, Biopac System Inc software. EMG activity was filtered with a Blackman -61 dB band-pass filter between 10-500 Hz, amplified (bi-polar differential amplifier, input impedance = 2MΩ, common-mode rejection ratio > 110 dB min (50/60 Hz), gain x 1000, noise > 5 μV), and analog-to-digitally converted (12 bit) and stored on a personal computer for further analysis.

Tympanic Temperature

Tympanic temperature was obtained and recorded by a tympanic thermometer (IRT6520CA ThermoScan, Braun, Germnay). The thermometer probe with a disposable plastic covering was inserted into the right ear canal to record the tympanic temperature. For each participant, the disposable plastic was changed. This procedure was performed on four occasions for each protocol: pre- and post-time familiarization protocol, pre-and post-test protocols.

Heart Rate

A heart rate monitor (T31 Heart Rate Sensor, Polar, USA) was used to obtain heart rate during pre-and post-time familiarization sessions and protocol. The heart rate monitor was fixed using an elastic belt to be secured around the participant's third sternum.

Rate of Perceived Exertion (RPE)

The RPE Borg Scale was used to rate the participant's physical activity intensity for each protocol on an increasing scale of 6-20. RPE was reviewed and asked during the control, maximal, submaximal, and distraction protocols to give insight if the participant was working at the correct intensity and to prevent participants from internal counting of time (seconds).

Data Analysis

Statistical analysis was completed using the SPSS software (Version 24.0, SPSS, Inc. Chicago, IL). First, normality (Kolmogorov-Smirnov) and homogeneity of variances (Levene) tests were conducted for all dependent variables. If the assumption of sphericity was violated, then the Greenhouse-Geisser correction was employed. Significance was established as $p \leq 0.05$. A repeated-measures ANOVA was used to analyze the four conditions and time perception. Time estimation ratios were analyzed with 3-way ANOVAs, involving four conditions (control, maximal, submaximal, and distraction) x 4 times (5, 10, 20, 30 seconds) and a between factor of sex (female and male). Additionally, a 3-way ANOVA was conducted to analyze the difference between participant perception of time to chronological time, four conditions (control, maximal, submaximal, and distraction), and a between factor of sex. Additionally, a 3-way ANOVA was conducted to analyze the difference between participant perception of time to chronological time, four conditions (control, maximal, submaximal, and distraction), and a between factor of sex. Normalized EMG signal was analyzed by conducting a repeated measure ANOVA, activation of the dominant quadricep for the three exercising conditions x first and last 5 seconds.

For heart rate and temperature, a two-way repeated-measured ANOVA was completed involving four conditions (Heart rate Pre-Session, Post-Session, Pre protocol, and post-protocol) and a between factor of sex. Paired t-tests with Bonferroni corrections were used to decompose significant interactions, and Bonferroni post hoc tests were used to determine main effect differences. Cohen's d effect sizes (ES) were calculated to compare all measures. Effect sizes (d) represent the magnitude of change and are reported as trivial (<0.2), small (0.2-0.49), medium (0.5-0.79), or large (≥0.8) effect size (d) (Cohen, 1988). Inter-session reliability responses were assessed with Cronbach's alpha intraclass correlation coefficient (ICC). Data reported as mean ± SD.

Results

5 seconds

A significant main effect of time for the pre-and post-conditions (F *(1,17) =18.644, p=0.0005,* n^2*=0.523)* showed greater deviations (underestimation of time) for the post-intervention at 5-s (Mean Difference (MD):.401, p=0.0005). Additionally, a significant interaction effect for Time x Sex was highlighted (*F (1,17) =6.476, p=0.021,* n^2*=0.276),* only for the 5-s time interval, with females demonstrating a greater misinterpretation that fell short of 5 seconds for post-test than males (see Table 2).

Table 2: Average estimated 5-seconds for males, females, and total for each condition during practice and Post-protocol (Mean ± SD). P-P: Post-protocol.

Italics indicates pronounced differences in time perception between meles and females

	Control		**Maximal**		**Submaximal**		**Distraction**	
	Practice	**P-P**	**Practice**	**P-P**	**Practice**	**P-P**	**Practice**	**P-P**
Males	4.67 ± .11	4.68 ±.16	4.67 ±.12	4.49 ±.26	4.75 ±.16	*4.61* *± .27*	4.73 ± .14	*4.39* *± .23*
Females	4.76 ± .10	4.46 ± .15	4.93 ± .11	4.38 ±.25	4.74 ±.15	*3.97* *± .26*	4.79 ±.14	*3.86* *± .22*
Average	4.72 ± .10	4.57 ±.16	4.80 ± .12	4.43 ± .26	4.75 ±.16	4.29 ± .27	4.76 ± .14	4.13 ±. 23

A significant 3- way interaction between conditions, time, and sex, (*F (3, 51) = 2.791, p=0.00497,* $n^2=0.141$), showed an underestimation of 0.445-s (p=0.006) between the control and maximal conditions. Figure 1 illustrates that time estimations for the 5-s interval were underestimated for each protocol, while the practice time estimations remained stable for each condition. The post-protocol for the maximal, submaximal, and distraction conditions estimations differed to chronological time, where the distraction condition temporal estimation reported a greater variability of underestimation of time compared to the other three conditions.

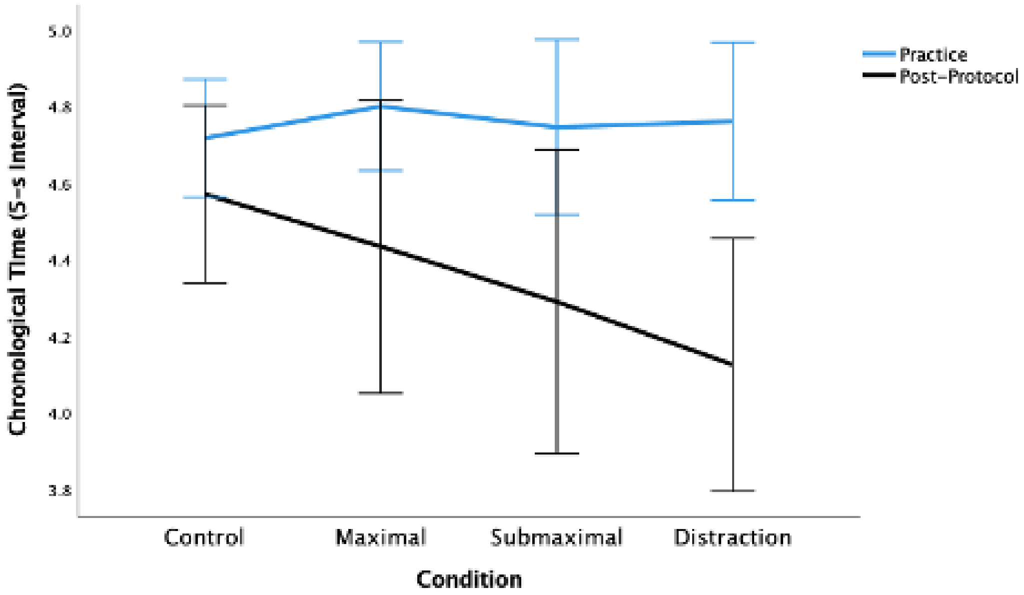

Figure 1: Subjective mean estimations for each condition for the five-second interval

10 seconds

There were no significant main effects or interactions between conditions, time, or sex.

20 seconds

There was a main effect for time during pre-and post-protocols, (F *(1,17) =8.153, p=0.011,* n^2*=0.324).* Post hoc pairwise test found a significant mean difference between the control and maximal conditions (*MD=0.937, p=0.0007),* where time was underestimated to a greater degree than the control condition. In Figure 2, the practice time estimations were relatively near the 20-s interval as indicated by the blue line, while the post-protocol was estimated to be shorter for the maximal, submaximal, and distraction conditions. Additionally, Figure 2 demonstrates that the control condition had low variation in pre-and post-protocol (Pre-Mean: 20.334 seconds, Post mean: 20.431 seconds). There was a significant interaction between the difference between conditions, time, and sex, (F (3,51) =2.854, p=0.046, n^2=0.144), highlighting a greater difference between female time estimations compared to men. A post hoc pairwise comparison showed that the maximal condition for time interval of 20 seconds was underestimated by an average of 1.813 seconds (P=0.013) compared to the control condition, seen in Figure 2 by asterisk.

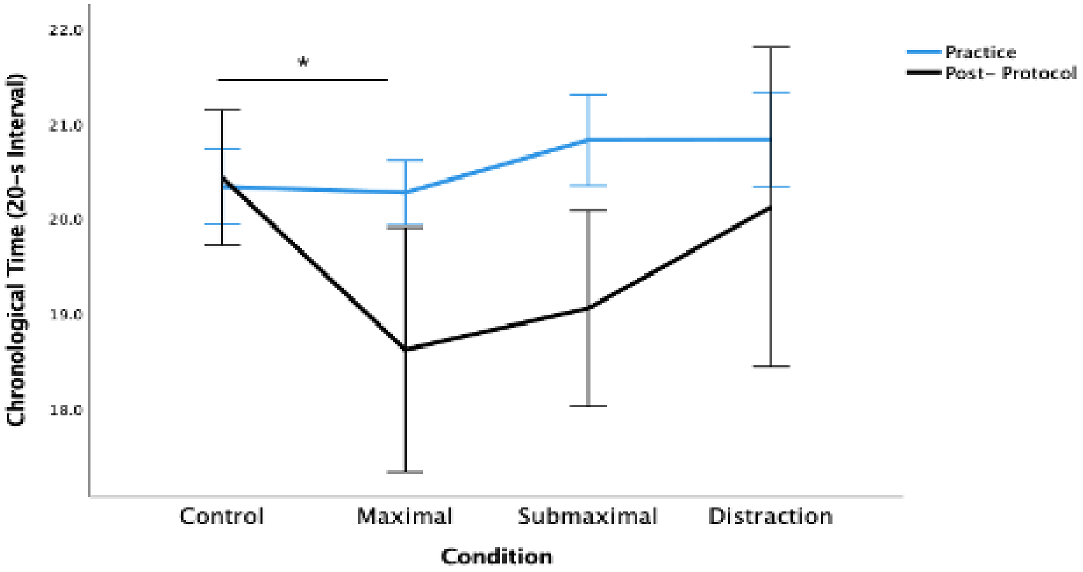

Figure 2: Subjective mean estimations for each condition for the 20-second interval. Horizontal lines with asterisks mark significant differences (p<0.05).

30 seconds

A significant main effect of condition, (*F (3,51)* =5.038, p=0.004, n^2=0.229) revealed a significant difference between the control and maximal conditions (MD=1.528, p=0.003). In Figure 3, time interval estimations for the maximal and submaximal conditions were shorter than the control and distraction. The control condition had similar time estimations for the practice and post-protocol trials. Time demonstrated a main effect of practice and post protocols, (*F*

(1,17) =13.075, p=0.002, n^2*=0.435).* Post hoc pairwise test for time, practice and post protocols found that the mean difference for time was underestimated (MD=2.043, p=0.002).

A significant main effect for the difference in time, condition, and sex was found, (F *(3.51) =5.763, p=0.002,* n^2*=0.253).* A post hoc pairwise comparison showed a significant difference between the control and submaximal (EM=3.065, p=0.004) and maximal condition (EM=3.089, p=0.005). The maximal condition had the greatest difference in temporal estimation compared to the chronological time.

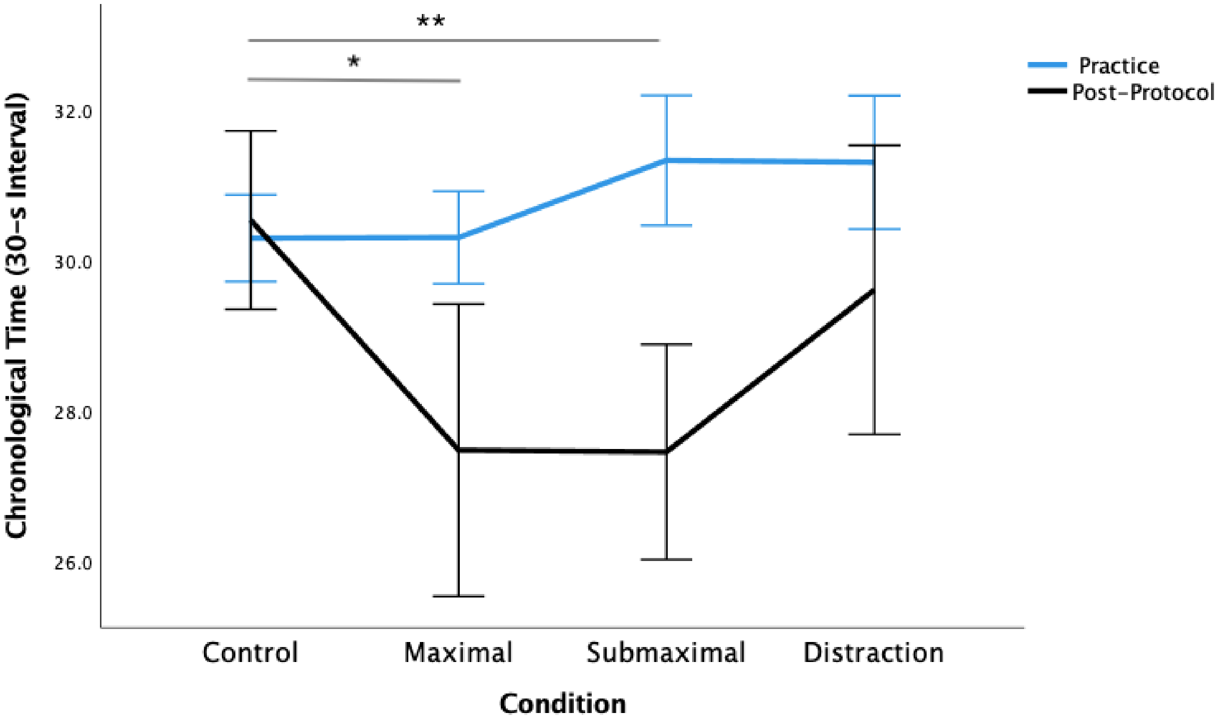

Figure 3: Subjective mean estimations for each condition for the 30-second interval. Horizontal lines with asterisks mark significant differences (p<0.05).

*: Maximal

**: Submaximal

Heart Rate

There was a significant main effect of heart rate for the Practice vs. Protocol, (F (1,17) =268.942, p=0.0001, n^2=0.941), and Condition * Practice vs Protocol: (F (3,51) =72.652, p=0.0001, n^2=0.812). There was a significant effect for Condition *time: (F (3, 51) =138.412, p=0.0001, n2=0.812). Additionally, a main significant effect was computed for the Practice vs Protocol *Time: (F (1,17) =114.037, p=0.0001, n^2=0.870). A post hoc pairwise comparison showed a main effect for heart rate in each condition. The test indicated a significant main effect (p= 0.0001) between the control and submaximal protocols and between the submaximal condition compared to the distraction condition (p=0.0001), indicating a higher heart rate for the submaximal condition. Furthermore, the post hoc pairwise test revealed a greater mean difference between the submaximal and distraction protocol (MD= 17.199, p=0.000016), which indicates the heart rate was higher in the submaximal condition. There was a main effect for the post hoc pairwise test when comparing pre-protocol to post-protocol heart rate (MD=29.929, p=0.0001), to indicate a higher heart rate reported post-protocol.

Body Temperature

A repeated-measures ANOVA found that there was a significant main effect of body temperature for Practice vs. Protocol, (F (1,17) =50.402, p=0.00002, n^2=.7), and time, (F (1,17) = 32.192, p=0.000027, n^2=0.654). As expected, body temperature also had a significant main effect for Practice vs Protocol * Time, (F (1,17) =24.337, p=0.00013, n^2=0.589). A post hoc pairwise test was conducted and found a main effect when comparing practice to post-protocol temperature and for time. A mean difference of 0.344 (p=0.000002) indicates that the body temperature was higher post-protocol than resting. A mean difference of 0.219^0C (p= 0.00003) concluded that temperature was higher after estimating time. For Practice vs Protocol * Time, the body temperature was higher for the protocol and estimating time intervals (M=36.8 SD=0.054) compared to practice and before performing the protocol.

Relative (normalized) EMG

A repeated-measures ANOVA found that there was a significant main effect for dominant leg EMG x condition (F (2, 36) = 45.794, p=0.001, $n^{2=}$ .718), which showed a lower activation of the dominant quadriceps during the 10% protocol than the maximal and submaximal condition. Normalized EMG signal was greater for the maximal and submaximal condition compared to the distraction condition. A pairwise comparison test reported that the mean difference was 2.41 mV.s (p=1.6127E-7) between the maximal and distraction conditions. Additionally, a mean difference between the submaximal and distraction reported to be 1.707 mV.s (p=0.000003). There was no significant difference between the condition * first and last 5 seconds.

Discussion

To our present knowledge, this is the first study to investigate the temporal perception of time intervals in humans while performing varying intensity isometric contractions and whether or not there were any sex-differences. The purpose of the present study was to analyze time perception of chronological intervals while performing varying contraction intensities of an isometric knee extension. Additionally, this study analyzed if there was a possible sex difference in temporal perception while performing an exercise. The primary findings include that as chronological time increases, time perception is distorted where time in underestimated during submaximal and maximal exercise. The integrated EMG signal was reported to be greater during the maximal and submaximal contractions than the distraction condition, possibly inducing a greater bodily arousal. The maximal (at 5-, 20-, and 30-s) and submaximal (30-s) isometric contractions impaired time perception more than the control and distraction conditions. Time perception distortion was most evident during the maximal condition at the 30-s interval. The distortion of time due to exercise has been a similar finding in past research (Edwards & McCormick, 2017; Hanson & Lee, 2017; Benko & Cimrová, 2018). Furthermore, there was no significant sex differences. To our present knowledge, this is the first study to investigate the temporal perception of time intervals in humans while performing varying intensity isometric contractions.

The variation of time estimates was most pronounced at the 30-s interval while performing a dual-task. Gazes et al. (2010) found a reduction in cognitive and motor tasks when performed together. Similarly, Polti and colleagues (2018) found a significant underestimation of time for 30-s to 90-s intervals when participants performed a dual-task. The present study had participants encounter a cognitive-motor dual-task that revealed an influence on time perception. The cognitive-motor interference has shown to distort time intervals as the two tasks are simultaneously being performed, where one or both performances are impaired. (Al-Yahya et al., 2011). In comparison, Brown (1998) concluded that when performing a dual-task, the judgment of the time interval varied to a greater degree with prolonged chronological time. The attentional gate model can explain the misjudgment of time, a model relating attentional allocation and estimating time from the SET (Zakay & Block, 1995). When the task's priority is temporal processing, the attentional gate allows pulses to enter cognition for an accurate estimation. Conversely, when a non-temporal processing task is devoted, such as exercise, the attentional gate is narrowed, allowing fewer pulses to enter and impairing time perception.

Time variation tended to be more pronounced with the maximal and submaximal intensity contraction conditions, particularly 30-s, where estimates were shorter than chronological time. Normalized EMG signals resulted in a greater amplitude during the maximal and submaximal contraction resulting in increased corticospinal excitability and motor unit activation (Behm 2004). During muscle contractions, research has shown that neural output increases (motor unit recruitment, rate coding synchronization, muscle action potential conduction velocity, and increased hormones such as dopamine) to reinforce the muscle for proper performance (Liu et al., 2003; Basso & Suzuki, 2017). In turn, this increases in neurophysiological events within the given time frame will increase the proposed mechanisms of time perception SET or SBF to underestimate time intervals.

Edwards & McCormick (2017) reported similar findings, as participants that exercised at a higher intensity (RPE 20) underestimated time to a greater degree. Findings from this study state that at the five and 10-s interval mark, time perception did not significantly differ between exercising conditions. However, at 20 and 30-s, there was a significant difference between the exercising conditions, where the maximal protocol ($p=0.003$) caused an underestimation to a greater extent. Likewise, Benko and Cimrová (2018) instructed participants to estimate 10, 15, and 20-s when performing a hand-grip test for nine pseudo-randomized sequences, with and without an inflatable cuff to cause arm occlusion. The researchers found that overstimulation of visceroreceptors from isometric contractions can distort temporal intervals. Therefore, time underestimation was distinct in response to maximal efforts and longer time intervals. At higher intensities of exercise, catecholamines release into the blood where there is greater sensory awareness of physical discomfort. As a result, neural networks will have greater activity, which may result in a time distortion, as explained by the SET. The SET would depict that the increase in arousal and change in visceroreceptors potentially increases the internal clock's pace and skewed perception of time (Gibbon and Church, 1984).

The results from the control condition showed that a dual-task of estimating time and reporting RPE have less time estimation variation compared to the other three conditions. A non-temporal task, such as exercise, can result in hyperarousal, where the body experiences greater sensory awareness of physical discomfort. A possible explanation is that an MVIC such as a knee extension is an intense contraction that will increase motor unit recruitment, rate coding, intermuscular coordination, and other factors that result in greater force development (Behm & Sale, 1993). During the exercise conditions, participants focused on working at the correct intensity while concurrently estimating time intervals. The body experiences hyperarousal from the intense isometric contraction. The hyperarousal would result in a greater amount of processing in the brain, and attention to the alternate task is distorted. The control condition was not as physically taxing to the body compared to the other three exercising conditions allowing more focus on the cognitive task. Though deviations were reported in the practice and post-protocol estimations, this may be due to arousal experienced as researchers asked participants to perform a task. Wearden (2003) reported similar findings, in that the distortion of time occurs with increased arousal. Furthermore, they conclude that this time distortion may be due to the SET as the rapid timing interval pulses are compared to the initially encoded control condition.

There was only a sex difference reported for temporal estimations at 5-s compared to the other time intervals (10-20-30-s). Rather, the present study suggests females and males produce relatively similar time estimations while exercising at varying intensities. However, the sample size achieved by a prior statistical analysis of 15, and a sample size of 19 may have been underpowered to depict the sex differences within time perception. Previous literature has shown differences in females and males while others have not (MacDougall, 1904; Block et al., 2000; Hanson & Buckworth, 2016). Hanson & Buckworth, (2016) found that females tend to underestimate time more than males during a self-paced run. Although, females ran at a higher self-pace resulting in the two groups exercising at different intensities. As well, our study analyzed intervals of 5-10-20-30-s before and during an isometric knee extension while, Hanson & Buckworth performed assessments before, during, and after a running protocol. Further investigation into sex differences in time perception during exercise is needed to add to the small pool of research.

This study had limitations. Participants were trained young females and males; therefore, the results may not be representative of untrained or older individuals. Likewise, as this study was conducted in a laboratory where participants underwent isometric knee extension contractions, it is unknown whether these findings would translate into real-like tasks or competitions.

Conclusions

This study found that time perception was impaired when exercising at maximal (at 5-, 20- and 30-s) and submaximal (30-s) intensities. The deficits were most evident during the maximal contraction intensity condition at 30-s. These results add to the growing body of literature on time perception and exercise. With many athletes competing at a high intensity, this may suggest that their perception of time is negatively skewed (typically underestimated). Likewise, exercise programs may be more enjoyable with high-intensity exercises for a 30-second interval, as individuals may believe that time is “flying by” (accelerated). Future research should aim to investigate time perception on types of contractions, sex differences, and compare athletic to non-athletic populations. This study is a great foundation for understanding time perception in humans when enduring a short bout of isometric exercise.

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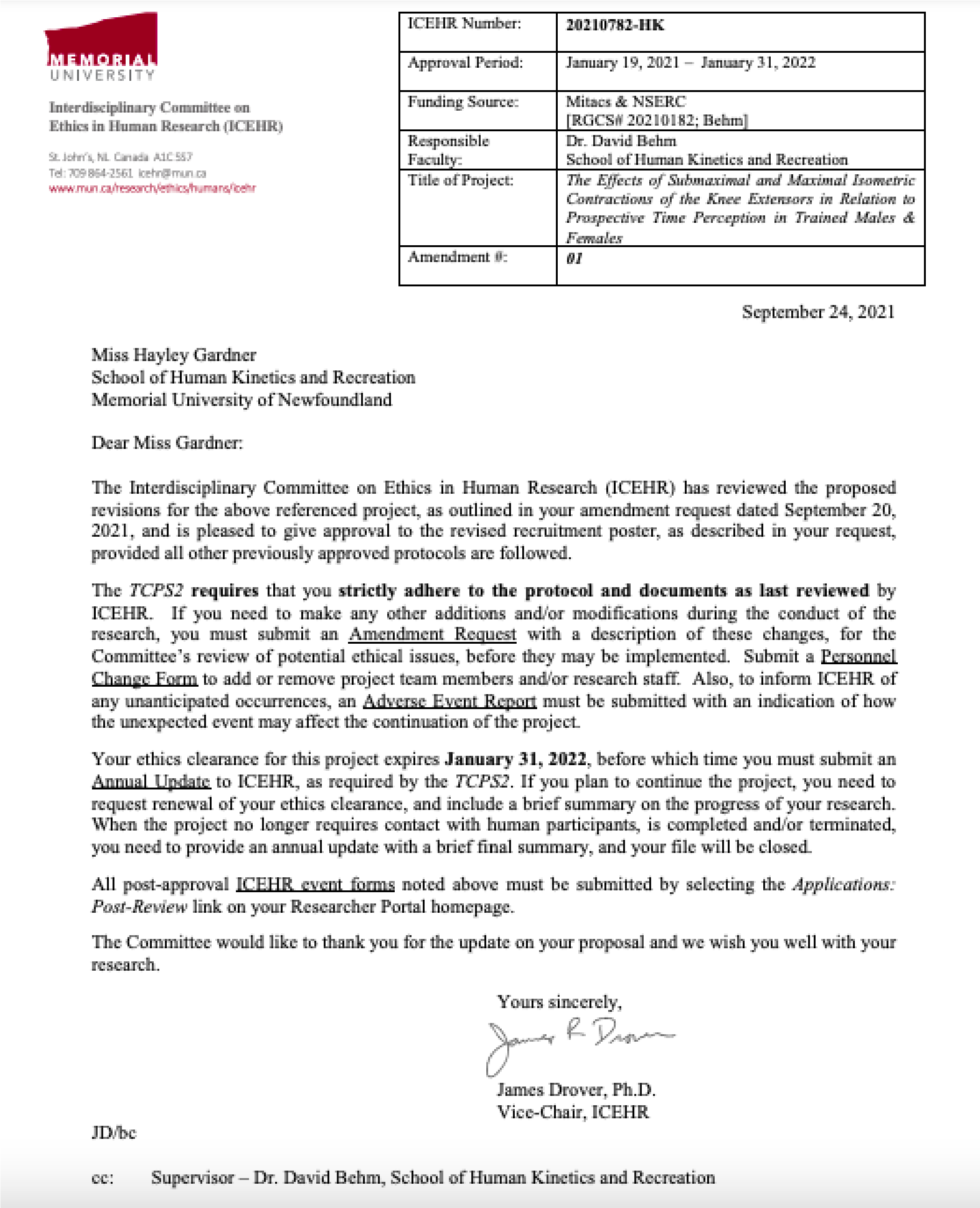
Chapter 3: Summary & Future Directions

As there is limited research to understand how exercise influences time perception, this thesis adds to the growing body of knowledge. This study was the first to explore time perception intervals while performing lower body isometric contractions. It was found that as time progresses, the perception of time distorts to a greater degree. Additionally, this study concluded that time perception distorts when performing contractions at a greater intensity, as seen from the submaximal and maximal knee extensions. As many sports are time orientated, such as basketball, football, and others, performing movement is also time dependent such as a tennis serve, understanding how exercise influences time perception is critical for athletic performance.

Future studies should compare dynamic and isometric contractions while estimating timing intervals. Additionally, further investigation of sex differences in time perception as conflict still exists in the literature. This work would give greater insight into how different life factors influence time perception.

This research found no significant difference between males and females during the 10,20,30-s intervals. Significant sex differences were seen at the 5-s interval. Although the intervals of interest were only seconds, it may be of interest for future research to investigate longer time intervals. Additionally, perhaps further studies can explore 5-s intervals and sex differences with a greater number of participants that are equal of both sexes.

Appendix A



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ICEHR Number:	**20210782-HK**
Approval Period:	January 19, 2021 – January 31, 2022
Funding Source:	Mitacs & NSERC [RGCS# 20210182; Behm]
Responsible Faculty:	Dr. David Behm School of Human Kinetics and Recreation
Title of Project:	*The Effects of Submaximal and Maximal Isometric Contractions of the Knee Extensors in Relation to Prospective Time Perception in Trained Males & Females*
Amendment #:	***01***

September 24, 2021

Miss Hayley Gardner
School of Human Kinetics and Recreation
Memorial University of Newfoundland

Dear Miss Gardner:

The Interdisciplinary Committee on Ethics in Human Research (ICEHR) has reviewed the proposed revisions for the above referenced project, as outlined in your amendment request dated September 20, 2021, and is pleased to give approval to the revised recruitment poster, as described in your request, provided all other previously approved protocols are followed.

The *TCPS2* **requires** that you **strictly adhere to the protocol and documents as last reviewed** by ICEHR. If you need to make any other additions and/or modifications during the conduct of the research, you must submit an Amendment Request with a description of these changes, for the Committee's review of potential ethical issues, 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.

Your ethics clearance for this project expires **January 31, 2022**, before which time you must submit an Annual Update to ICEHR, as required by the *TCPS2*. 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 requires contact with human participants, is completed and/or terminated, you need 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.

The Committee would like to thank you for the update on your proposal and we wish you well with your research.

Yours sincerely,

James R Drover

James Drover, Ph.D.
Vice-Chair, ICEHR

JD/bc

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