THE EFFECTS OF ISOMETRIC EXERCISE ON TIME PERCEPTION BETWEEN YOUNGER AND OLDER ADULTS: A RANDOMIZED CROSSOVER TRIAL

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Abstract

Time is a concept that we cannot escape from – it exists in everything we do. Not only does time pass physically, it is a relative measure. Areas where time is crucial such as sport, work, and fitness, may be seriously impacted by changes in time perception. Specifically, time perception may play a vital role in exercise adherence; if people find time to pass by slowly, they may become disinterested in exercise and experience low physical active levels. The Pacemaker-Accumulator Model and the Striatal Beat-Frequency Model are two models that attempt to explain the human perception of time. Respectively, they explain the perception of the number of events in a given period of time and how neurotransmitters activate and coordinate cortical structures. Several factors have been studied for their effects on time perception, such as age, exercise intensity, trained state, psychological and emotional factors, heart rate, and body temperature. These factors can be considered to be exercise-related/induced, meaning future research exploring these topics from an exercise-focused lens is very important. This literature review aims to explore exercise-related factors on the human perception of time and the underlying physiological processes that control time perception and its distortion with activity.

General Summary

The human perception of time changes depending on the type of situation you are in. When exercising, there are a number of different factors that may influence your perception of time, such as exercise intensity, trained state, psychological and emotional factors, heart rate, and body temperature. Age is a factor that has been studied with respect to time perception, however, no studies have used exercise to investigate age-related differences in time perception. When you are exercising, you may find time to pass by either slowly or quickly – this has to do with how engaged you are with the activity (both mentally and physically). Scientists have created two models to explain human's subjective experience of time, the Pacemaker-Accumulator Model and the Striatal Beat-Frequency Model.

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List of Abbreviations

HR – Heart Rate

MD – Mean Difference

MSN – Medium Spiny Neurons

MVIC – Maximal Voluntary Isometric Contraction

PAM – Pacemaker Accumulator Model

PSD – Power Spectral Density

RPE – Rating of Perceived Exertion

SB-FM – Striatal Beat-Frequency Model

SD – Standard Deviation

s-EMG – Surface Electromyography

s – Seconds

Chapter 1: Review of Literature

Introduction

Time is a construct that has intrigued scientists and philosophers alike for many centuries. It is considered by many to be a very precise and objective measure through the use of precision clocks. However, Einstein's theory of special relativity suggests that time is relative (Einstein, 1905). More recently, research has emerged that has studied the human interpretation of time, which explores how humans experience time subjectively. This is an important area of research as we are always experiencing time. Being able to manipulate our subjective experience of time would have major implications for success in professions such as professional sports and military. One of the fundamental factors for time perception is arousal (Gibbon et al., 1984; Allman & Meck, 2012; Gill & Droit-Volet, 2012; Allman et al., 2014; Cheng et al., 2016; Turgeon et al., 2016; Driot-Volet & Berthon, 2017), which is associated with different environmental, physiological, and psychological states (Wittman, 2013; Allman et al., 2014).

Many scientists consider that changes in physiological arousal via activation of the sympathetic nervous system (SNS) account for changes in time perception (Gibbon et al., 1984; Allman & Meck, 2012; Gill & Droit-Volet, 2012; Allman et al., 2014; Cheng et al., 2016; Turgeon et al., 2016; Droit-Volet & Berthon, 2017). Two models are commonly used to describe the process of time perception; the pacemaker accumulator model (PAM) and the striatal beat-frequency model (SB-FM). Both theories highlight that time perception is influenced by arousal (Allman & Meck, 2012; Allman et al., 2014). High arousal speeds up the internal clock, causing people to over-estimate and under-produce time intervals (Gill & Droit-Volet, 2012). While these theories provide biologically plausible mechanisms, the exact neural basis for subjective time perception is still unknown (Wittman, 2013).

Exercise is a form of physiological arousal and can lead to changes in time perception (Dormal et al., 2017). Vercruyssen et al. (1989) first proposed this possibility, yet few studies have directly investigated and found any relationship between exercise-induced arousal and changes in time perception. Studies have investigated exercise intensity (Edwards & McCormick, 2017), heart rate (Lambourne, 2012; Vercruyssen et al., 1989), body temperature (Tamm et al., 2014; 2015), perceived fatigue (Tamm et al., 2014; 2015), and attentional effects (De Bourdeaudhuij et al., 2002). There is a limited body of literature on these factors, some of which present conflicting results. Other factors include age, sex, and mental concentration. This literature review investigates exercise-related factors on the perception of time.

Time Perception Models

The Pacemaker Accumulator Model (PAM)

The PAM of time perception, also known as the scalar expectancy theory, is the dominant and most cited model regarding the effects of arousal on time perception (Allman & Meck, 2012). This theory proposes that an internal clock judges time and divides temporal processing into a clock, memory, and decision stages (Gibbon et al., 1984). The onset of a "to-be-timed interval" is the beginning of the clock stage. Here, a "mode-switch" controlled by attention processes closes, and an accumulator collects pacemaker pulses where they will exist for some time. You may think of these pulses as a tally, where they accumulate in the accumulator in a linear fashion, however, they are not necessarily stored or remembered as such, which is thought to contribute to the subjective nature of time perception. The accumulator is a theoretical region as it is unknown what specific brain locations are involved in time perception (Allman et al., 2014) as is the pacemaker and switch. The pacemaker-switch-accumulator complex is thought to be the "clock" of the timing system.

The memory stage is responsible for the important memory component of the Pacemaker Accumulator Model. A common tactic for interval timing is using previously stored timing information (as described next in the decision stage). If information (in the form of pacemaker pulses) is determined to be significant by the system, the temporal information from the accumulator will move from the working memory to reference memory to be used in the future timing of similar length durations.

The decision stage includes the final processes of this model. During a separate trial, a ratio-decision rule functions to determine if the accumulator's contents reach a threshold selected from the reference memory (Allman & Meck, 2012; Gibbon et al., 1984). In other words, the current information from the timing task is compared to stored information from other timing tasks. When different information is selected as a reference, variable estimates in time perception occur. It is a common belief that the human timing mechanism revolves around sympathetic arousal (Droit-Volet & Berthon, 2017; Cheng et al., 2016; Fayolle et al., 2015; Gill & Droit Volet, 2012). In the case of this model, arousal affects the mode switch in the clock stage. Heightened arousal is thought to increase the rate at which the pacemaker processes information, resulting in extended perceptions of time intervals. Differences in attention, pacemaker speed, memory, and decision-making skills result in time perception differences (Allman & Meck, 2012). According to Dormal et al. (2017), exercise-induced arousal can produce this effect and generate distortion in time perception during exercise.

The Striatal Beat-Frequency Model (SB-FM)

The SB-FM suggests that time perception is estimated based on the coincidental detection of oscillatory processes in cortico-striatal circuits (Matell & Meck, 2000, 2004; Matell et al., 2003; Buhusi & Meck, 2005). This theory differs from the pacemaker accumulator model as it highlights connections between the striatum, cortex, and thalamus, with the dorsal striatum (Meck, 2005), thus attempting to identify the linkages of specific anatomical components (Merchant et al., 2013). The model says that clock speed is determined by levels of dopamine-glutamate activity in the substantia nigra compacta and ventral-tegmental area-cortical pathways.

Our internal timekeeping mechanism begins with a phasic release of dopamine from dopaminergic midbrain projections to the cortex and dorsal striatum (Matell & Meck, 2004) at the onset of the “to-be-timed” interval. This causes groups of cortical neurons to reset, synchronize their firing, and begin oscillating at their respective periods in the dorsal striatum (Allman & Meck, 2012). These oscillating neurons are essentially the clock mechanism, whereas the rate of oscillatory activity is what determines how time is perceived in the brain.

Ten thousand (10,000) to 30,000 of these oscillating neurons converge on a single striatal medium spiny neuron (MSN) (Matell & Meck, 2004). The MSNs are responsible for monitoring activation patterns and creating an output based on the oscillatory information from the many oscillatory neurons to be sent to the striatum. MSNs are affected by glutamate, and can be reset by phasic dopaminergic input (as mentioned at the beginning of this model). Glutamatergic pyramidal neurons oscillate with varying intrinsic frequencies and their oscillations fall out of phase after the initial synchronizing action of dopamine.

Different frequencies cause input activation patterns to striatal neurons that vary with the time elapsed from the cortical synchronization event (Murai et al., 2016). The MSNs in the striatum integrate the oscillatory input based on previous knowledge from long-term potentiation. It is thought that the MSNs interpretation of the frequency of oscillatory firing incorporated with previous task-related knowledge creates our ability to subjectively experience time.

Both the memory aspect and oscillations are important to time perception. In the absence of task-related memory, striatal output projects to the thalamus and then back to the striatum completing the cortico-thalamic-striatal-loop (Buhusi & Meck, 2005). The basal ganglia is thought to be involved with starting, stopping, and resetting timing activity (Wiener et al., 2008). Lusk et al. (2016) included the cerebellum in this model and postulated that it plays a role in feedback and fine-tuning timing processes. Further investigations of this model have suggested further cortical regions that are thought to be involved in controlling our sense of time, including the cerebral cortex, hippocampus, striatum, thalamus, prefrontal cortex, and basal ganglia (Fontes et al., 2016; Meck 2005; Lusk et al., 2016; Turgeon et al., 2016). More studies investigating moderating variables (e.g., physiological, environmental) are necessary to better understand the neurophysiology behind time perception (Fontes et al., 2016).

Factors that Influence Time Perception

Aging Effects

“Time flies as you get older.” This common phrase implies that people find time to pass more quickly with age and is familiar to the point where it is accepted as true in society. Researchers have investigated this saying and results suggest that time perception is affected by age (Block et al., 1999; Bherer et al., 2007; Turgeon et al., 2016), possibly due to long-term cognitive and physical changes across the lifetime. Older adults tend to estimate short intervals less accurately and with more variability compared to their younger counterparts (Wittmann & Lehnhoff, 2005). According to Coelho et al. (2004), the internal clock speeds up with age, though Turgeon & Wing (2012) suggests that it ticks more slowly with age. This lack of consensus in the literature highlights the complex nature of the underlying timing mechanism. The effects of aging on time perception are not well known and often attributed to cognitive changes (Jual & Barron, 2017). Turgeon et al. (2016) reviewed age-related effects on time perception and noted that fundamental age-related changes in the functioning of cortico-thalamic-basal ganglia circuits cause impairments in time perception.

No studies have investigated the effect of exercise-induced arousal in an elderly population (Behm, 2020). To hypothesize how older adults may experience time during exercise, existing literature that uses other arousal-induced mechanisms must be discussed. Wittmann & Lehnhoff (2005) analyzed time awareness in 499 participants aged 14-94 and found a low to moderate positive correlation between age and perceived passing of time, such that older adults tended to estimate short intervals less accurately and with more significant variability than their younger counterparts. According to the pacemaker accumulator model of time perception, these results are likely due to age-related changes in attention, working memory, or information processing speed (Wittmann & Lehnhoff, 2005).

The more plausible explanation is that the internal clock becomes slower with age (Block et al., 1999; Bherer et al., 2007). This causes people of advanced age to both underestimate and over-produce intervals relative to chronological time (i.e., a person with a slow internal clock may perceive a five-second stimulus as lasting only three seconds, and when asked to produce a three-second interval, instead produces a five-second one). Finger tapping at a self-selected pace has been assumed to be a natural measure of the internal clock (McAuley et al., 2006), such that slower and more variable tapping is associated with a slower internal clock. Turgeon & Wing (2012) noted that older adults tended to self-select slower intervals than their younger counterparts. In addition, the oldest fifteen participants had nearly twice the variability as the youngest fifteen participants (SD old = 21%; young = 12%, of the mean). Slowing of the internal clock may result in changes in the hundredths of the milliseconds-to-minutes range and may be attributed to the cortico-thalamic-basal ganglia circuits. In these circuits, MSN's interpret "time information" in the form of oscillatory neurons more unpredictably, and create a signal that is more variable and less reliable with age. Furthermore, cognitive aging of the ventral tegmental area has been shown to decrease dopamine levels, which could also explain why older adults seem to have a slower internal clock (Peterson et al., 2017). Dopamine is thought to speed up the internal clock and make time perception more accurate (Lusk et al., 2016; Mitchell et al., 2018).

Turgeon et al. (2016) noted that older adults compensate for age-related changes by utilizing cortico-cerebellar or hippocampal regions that are less affected by age to take over for the loss of functioning. These researchers also challenged the idea that aging-related deficits in time perception are attributed to impairments in working memory and attention. Both factors undoubtedly play an important role in time perception. However, many studies produce only trivial effects when comparing aging with time perception. Researchers hypothesize that the trivial effects are due to older adults' ability to mask age-related declines using different neural circuits (Reuter-Lorenz & Cappell, 2008). Older adults seem to use additional cognitive resources and external cues to increase their reliance on their internal timing networks, their reliance on feedback, and adaptive corrections to perform well at time perception tasks. When interrupting older adults' ability to use these systems, the actual age-related deficits in time perception become more apparent (Turgeon & Wing, 2012).

Understanding the neurological changes in the timing mechanisms warrant studies that investigate aging effects of time perception during exercise. With an increasing median age in population, maintaining a healthy population of older adults will help increase quality of life, longevity, and reduce strain on the healthcare system, which according to Jual & Barron (2017) should be a public health priority. Knowing whether or not time perception is affected differently in older adults during exercise may have major implications on physical activity and exercise adherence. Further research should investigate this relationship to help eliminate barriers associated with reduced physical activity and aging, to help older adults live happier, healthier, and more fulfilled lives. Furthermore, there are no studies investigating time perception differences in children and thus an examination of time perception differences across the lifespan is warranted.

Exercise Intensity

People often find that the last few minutes or seconds of high-intensity exercise appear to drag on, and it has been shown that the intensity at which one engages in exercise may impact whether or not time perception is affected. Exercise-induced arousal is thought to influence time perception as high-intensity exercise causes the secretion of adrenal catecholamines that increase sympathetic activity (Jansen et al., 1995). Therefore, it was proposed that exercise-induced arousal could speed up the internal clock and cause time intervals to appear longer relative to physical time (Vercruyssen et al., 1989).

A study by Edwards & McCormick (2017) was the first study to empirically demonstrate that exercise intensity distorts time perception during maximal and submaximal exercise. They found that time duration estimate was the shortest during very high-intensity rowing (> 75% of maximum). These results were attributed to the awareness of the exercise-induced physical discomfort felt at high intensities, due to high catecholamines causing hyperarousal (Jansen et al., 1995). This hyperarousal causes additional pulses to be accumulated in the accumulator (Gill

& Droit-Volet, 2012), causing chronological time to feel slow and time estimates to be underestimated.

Similar results were found by Hanson & Lee (2020), who investigated exercise intensity in running and time perception. They found that slower chronological time estimates were positively correlated with higher exercise intensity, measured by the rating of perceived exertion. These results suggest that high-intensity exercise shortens subjective time, making chronological time seem slow. This supports the arousal hypothesis (Droit-Volet & Berthon, 2017), which suggests time perception is not affected until arousal reaches a certain degree, causing the internal clock to speed up and the overestimation of time intervals.

Evident in the existing studies regarding exercise and time perception is that researchers have chosen whole-body type exercise. No study has attempted to isolate singular joints during isometric or dynamic muscle contractions (concentric versus eccentric). Breaking exercise down into its individual and core components may allow researchers to gain a better knowledge of the relationship between exercise and our perception of time. The ability to recommend exercise intensity and duration to optimize our perception of time and improve our experience during exercise may help many people not fond of physical activity adopt and stick to an exercise routine.

Trained State

Due to more practice at training in high-affect states, one may assume that a highly-trained individual may have a more accurate perception of time during exercise compared to their untrained counterparts (Edwards & McCormick, 2017). According to Tobin & Grondin (2012), this may be due to an increase in task-duration knowledge, which refers to the ability to derive and apply duration information from the past after years of training. Athletes often receive comments about their timing and duration which they use to make minor adjustments and fine-tune their task-duration knowledge, making them more effective at estimating time (Edwards & McCormick, 2017).

This effect of task-duration knowledge has been analyzed in a group of elite swimmers (Tobin & Grondin, 2012). Athletes were told to choose two strokes, one of which was their strongest stroke, in which they were assumed to have a high task-duration knowledge, and the other was their weakest stroke, in which they were considered to have a low task-duration knowledge. It was hypothesized that the athletes would be able to estimate time more accurately in their strongest stroke and less accurately in their weakest. After completing the trials of both strokes, a significant relationship was found between time estimation and stroke, such that the athlete's best stroke time was estimated very accurately and with little error. The duration of the weaker stroke was found to be less accurate. These results suggest that better task-duration knowledge is associated with a more accurate perception of time. This finding may be explained through attentional resources, where the swimmer's best stroke is well-learned through more practice. This could lead to less attention directed toward the stroke and more directed toward the timing aspect (Edwards & McCormick, 2017).

Only task-duration knowledge has been investigated with respect to time perception. There have been no studies on whether trained individuals have a more accurate perception of time compared to untrained individuals in an unaccustomed exercise or activity. Trained individuals may be more accustomed to functioning in a highly associated state (Edwards & McCormick, 2017), suggesting they will perceive time more accurately than their untrained counterparts. Athletes are often in situations where time is restricted or constrained and they must complete their action or task within a specified time period (e.g., 20-seconds after the last point, to initiate the first serve in tennis). While no evidence suggests a more accurate perception of time perception improves athletic performance (Tobin & Grondin, 2012), results from studies comparing trained and untrained individuals may help with prescribing an exercise that best suits the individual and helps to modulate their perception of time such that the exercise is most enjoyable, helping to improve exercise adherence and improve overall physical activity level.

Psychological and Emotional Factors

There are often misconceptions about common phrases, yet the saying "time flies when you're having fun" may hold more truth than myth. Gable & Poole (2012) investigated this age-old saying and found that time appears to speed up when you are having fun during goal-motivated tasks. In this positive emotional state, time appears to be accelerated for the individual. This difference in temporal processing can be explained by attentional effects, as highlighted in the Pacemaker Accumulator Model (Droit-Volet & Gil, 2009). This positive affective state may cause distraction away from the concept of time, causing the collection pulses in the accumulator to begin at a later time (Droit-Volet & Gil, 2009, Hanson & Lee, 2020). According to the Striatal Beat Frequency model, the oscillating neurons may synchronize and fire at a faster rate (Merchant et al., 2013). Both models suggest this state would cause the individual to estimate intervals of time to be longer than chronological time (retrospective timing), and to produce intervals of time that are shorter than chronological time (prospective timing).

This common phrase also implies the opposite. It has been noted that negative emotional states such as, fear or fatigue caused the overestimation of time, meaning participants experience time passing by more slowly (Kent et al., 2019; Fayolle et al., 2015). These findings may be attributed to an increase in attention to the passing of time (Droit-Volet & Gil, 2009), which causes an earlier accumulation of pulses (Droit-Volet & Gil, 2009, Hanson & Lee, 2020) or a slower rate of firing of oscillatory neurons (Merchant et al., 2013).

This spectrum of emotion and its apparent effect on the perception of time has not been investigated with respect to exercise or exercise-related changes in time perception, yet it may be an interesting and important area to investigate. Many people have different reasons why they exercise. Some people have a high intrinsic motivation to exercise and may therefore find time to pass by quickly while exercising. Could it be possible that this motivational state may create a sort of positive-feedback loop that pushes people to engage in more and more physical activity? On the other hand, people who exercise for other reasons might find time to pass by more slowly during exercise and find engaging in activity more difficult. Regardless of possible interactions, no studies have analyzed this hypothesis yet.

Emotional arousal has been shown to affect time perception (Droit-Volet & Berthon, 2012). Sympathetic activity due to negative arousal appears to be a critical component of time perception. Subjects who viewed high-arousal pictures (disgust, sad, and fear emotions) systematically found the duration of viewing these pictures to be longer compared to low-arousal or neutral pictures (Gill & Droit-Volet, 2012). These researchers hypothesized that hyperarousal induces the ability to process information at a much faster rate, making it feel like chronological time has slowed down. This idea has been supported in the pacemaker accumulator model, which states heightened arousal speeds up the internal clock (Gibbon et al., 1984) so that more “ticks” or “oscillations” (i.e., time information) can be processed per unit of time.

Droit-Volet & Berthon (2017) investigated the effects of high, moderate, and low arousal groups on time perception, and found that significant differences in time perception only occur once a sufficient level of arousal has been reached. A faster clock compared to physical time will cause over-estimation and under-production of intervals relative to physical time (Turgeon et al., 2016). Fayolle et. al (2015) had a similar protocol and found that negative arousal induced by electric shock caused participants to perceive time intervals as being longer than chronological time. These results support the consensus that time perception is mediated by emotion-related arousal levels (Droit-Volet & Berthon, 2017; Cheng et al., 2016; Fayolle et al., 2015; Gill & Droit Volet, 2012).

In contrast to positive and negative highly aroused states, researchers have investigated the lack of arousal, or boredom on the perception of time (Danckert & Allman, 2005; Hanson & Lee, 2020; Zakay, 2014). Defined by the low demand for information processing (Zakay, 2014), Danckert & Allman (2005) found boredom to affect time perception in the 15-60 second range where time was felt to pass by more slowly as more attention can be directed to the passing of time. Related to exercise and physical activity, no studies have investigated the effects of boredom on time perception. Studies are warranted as understanding how to optimize arousal/boredom may help trainers develop more individualistic and well-rounded exercise programs that work to maintain a perception of time that will promote the best relationship with exercise.

Heart Rate

In addition to emotional arousal, arousal can also be physiological. Heat rate can be considered a measure of physiological arousal, such that the higher the heart rate, the greater the arousal level (Dormal et al., 2017). One possible meaning of this is that an increase in heart rate during exercise may affect the perception of time. According to the internal clock, an increase in heart rate may increase the number of pacemaker pulses in the accumulator, causing one to overestimate the duration of time passing by (Droit-Volet & Meck, 2007; Wearden, 2005). While Lambourne (2012) and Vercruyssen et al. (1989) suggest that heart rate can affect one's perception of time, the supporting literature remains inconclusive.

Lambourne (2012) and Vercruyssen et al. (1989) both investigated time perception during exercise. Participants experienced exercise-induced physiological arousal which researchers measured using heart rate. It was determined that an arousal increase (increase in heart rate) caused participants to overestimate and underproduce time intervals. In both cases, time appears to slow down during exercise, supporting the hypothesis from the pacemaker accumulator model. Hawkes et al. (1962) and Surwillo (1982) found low correlations between heart rate and perception of time, such that people with higher heart rates produced time estimates that were shorter than people with low heart rates.

It also appears that heart rate variability may be a key aspect that connects heart rate and time perception. Participants of Cellini et al. (2015) completed a temporal bisection task and a finger-tapping task, where they found heart rate variability to affect time perception. They determined that a higher heart rate variability was related to lower error during the bisection task, meaning that a higher heart rate variability was associated with higher temporal accuracy. In another study, researchers found that individuals with a higher resting heart rate variability were more accurate in a duration reproduction task (Pollatos et al., 2014). Fung et al. (2017) found that a low-frequency component of heart rate variability was associated with a less accurate perception of time. Together, these results suggest that autonomic function plays an important role in time perception (Cellini et al., 2015; Fung et al., 2017). Because heart rate variability increases with training due to improved cardiovascular health (Kemp & Quintana, 2013), this may explain why physically trained individuals may experience a more accurate perception of time. A study that compares activity level and heart rate variability during a time perception task may help to explore this hypothesis.

On the contrary, some studies conclude that there does not appear to be an association between heart rate and time perception. In fact, Schwartz et al. (2013) do not believe heart rate to be a measure of physiological arousal. The researchers concluded that an increase in subjective arousal leads to higher time estimates, and that heart rate itself has no significant impact on time perception.

Body Temperature

During the day, body temperature exists within a range where it may rise and fall depending on internal and external factors. According to Ghaderi et al. (2012), our innate ability to perceive time can be affected by variations in our body temperature, and there are several mechanisms as to why this relationship may exist.

Tamm et al. (2015) suggest that body temperature's effect on time perception can be explained through the scalar expectancy theory. When core temperature is increased, time compression may occur, such that a time interval produced is shorter than chronological time. This is due to the pacemaker emitting pulses at a faster rate, similar to other physiological systems that accelerate when exposed to high temperatures (Tamm et al., 2014).

Ghaderi (2019) went on to explain this mechanism through the use of classical physics. Increasing enthalpy (temperature) leads to increased entropy, which matches the suggestion that time passes by more quickly with increased entropy. As we physiologically interpret time, our brain and body can be considered to be a timing system. With it being shown in animal models that the cortex temperature can fluctuate by 0.5°C, it can be estimated to be similar in humans. It is predicted that when brain entropy differs from environmental entropy, there is a difference in the timing systems causing a disparity between perceived and chronological time (Ghaderi, 2019). Since brain temperature increases with body temperature in humans, it is often difficult to measure cerebral temperature in isolation. Due to exercise-induced hyperthermia, an increase in core temperature would also yield an increase in brain temperature, possibly distorting the timing system (Nybo, 2012). These effects of exercise-induced increases in cortical temperature have not yet been investigated.

Circadian changes in body temperature have been shown to affect time perception, such that intervals of time were overestimated in the afternoon when body temperature is at typically highest (Hoagland, 1933). More recent studies have attempted to study body temperature and time perception by manipulating environmental temperature to modulate body temperature (Tamm et al., 2014, 2015). Tamm et al., (2015) found that heat acclimation appeared to be a factor in time distortion effects. This study was conducted in a 42°C room in the winter time when subjects were no longer habituated to extreme heat. Throughout the 10-day experiment, participants completed a 30-minute walk on a treadmill each day which allowed them gradually acclimate to the hot and dry conditions. Researchers found a significant main effect on core temperature on time, meaning that time perception was affected by the exercise in the heat, however, these effects can be overcome with heat acclimation. This finding was attributed to the fact that core temperature increased much more slowly during exercise in hot and dry conditions after heat acclimation (Tamm et al., 2015). No distinction was made whether the increase in body temperature caused by exercise was a factor in addition to the increase in body temperature caused by the hot and dry environmental conditions. Researchers also attributed results to hormone responses caused by heat stress on the body. In addition, time distortions were only evident once a certain level of fatigue was reached.

Tamm et al., (2014) used the same treadmill protocol where a group of young males completed time reproduction tasks in varied environmental temperatures. The results of this study also support the hypothesis that temporal compression is related to a higher core body temperature. As the aforementioned studies have investigated time perception in warmer environments, some researchers have used colder environments, with the results of these studies being more conflicting such that some report time acceleration and others deceleration (Baddeley, 1966; Fox et al., 1967; Tamm et al., 2015).

Conclusions

Time perception is a relative measure that appears to be impacted by exercise and related factors such as age, exercise intensity, trained state, psychological and emotional factors, heart rate, and body temperature. These changes may be explained through the Pacemaker-Accumulator Model and the Striatal Beat-Frequency Model. Most notably, arousal appears to be a key component underlying how humans perceive and experience time. Increased arousal and frequency of physiological events can serve to increase the internal clock, thus accelerating the perception of time. More research is needed that individually investigates these factors and their role in time perception during exercise.

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Research Objectives

The objectives of this research are:

i. Investigate how prospective time perception changes during exercise
ii. Investigate time perception during varying exercise intensities
iii. Examine possible age differences in “i and ii”.

Hypotheses

It was hypothesized that prospective time estimates during exercise will be shorter than pre-trial/non-exercise time estimates in both cohorts (Edwards & McCormick, 2017; Hanson & Lee, 2020). It was also hypothesized that younger adults will be more accurate in their time estimation compared to older adults, who would be less accurate and more variable in their time estimation (Wittmann & Lehnhoff, 2005).

Chapter 2: The Effects of Isometric Exercise on Time Perception Between Younger and Older Adults: A Randomized Crossover Trial.

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Abstract

Overview: Our perception of time is often overlooked, yet it plays a critical role in nearly all daily activities. Literature surrounding exercise effects on time perception is scarce, and there have been no studies that have investigated time perception during exercise in older adults. Thus, this study aimed to compare the effects of exercise on time perception between a younger and older adult population.

Participants: Thirty-three recreationally active participants were recruited and assigned to either the younger (university students, 9 males and 10 females) or older adults (aged 60 and above, 8 males and 6 females).

Methods: All participants completed four exercise conditions over two sessions on separate days: control (no contraction), knee extensors maximal voluntary isometric contraction (MVIC), 60%, and 10% knee extension MVICs. Time perception was measured prospectively (at 5, 10, 20, and 30-seconds) at the beginning of each session and while performing the exercise. A 4x4x2 (four conditions, four times, and two age categories) repeated measures ANOVA was used to analyze the data.

Results: A main effect was found for condition ($F_{(3, 71.241)} = 8.721$, $p < 0.001$, $d = 1.06$) whch indicated participants significantly underestimated time in all three exercise conditions compared to the control. No significant differences between the two age cohorts were identified.

Conclusion: This study demonstrated that exercise impacted time perception regardless of intensity. This questions the postulated intensity-dependent relationship between exercise and time perception. Older adults were expected to be less accurate and more variable in their time estimates. It is possible that older adults were able to compensate for age-related changes in their internal clock, resulting in no difference in time perception between the two age cohorts.

Introduction

Time is a construct that is considered by many to be a very precise and objective measure. However, Einstein's theory of special relativity suggested that time is relative (Einstein, 1905). More recently, research has studied the human subjective interpretation of time. Being able to manipulate our subjective experience of time would have significant implications for success in professions such as professional sports and the military. A fundamental factor affecting time perception is arousal (Gibbon et al., 1984; Allman & Meck, 2012; Gill & Droit-Volet, 2012; Allman et al., 2014; Cheng et al., 2016; Turgeon et al., 2016; Droit-Volet & Berthon, 2017), which is associated with different environmental, physiological, and psychological states (Wittman, 2013; Allman et al., 2014).

Two models are commonly used to describe the process of time perception; PAM and the SB-FM. The PAM proposes that an internal clock judges time and divides temporal processing into a clock, memory, and decision stages (Gibbon et al., 1984). The onset of a "to-be-timed interval" is the beginning of the clock stage. Here, a "mode-switch" controlled by attention processes closes, and an accumulator collects pacemaker pulses where they will exist for some time. The memory stage is responsible for the vital memory component of the PAM, as a common tactic for interval timing is referring to previously stored timing information to judge a new interval. The decision stage includes the final processes of this model. Here, a ratio-decision rule determines if the accumulator's contents reach a threshold selected from the reference memory (Allman & Meck, 2012; Gibbon et al., 1984). In other words, the current information from the timing task is compared to stored information from other timing tasks. The SB-FM is similar in theory. It suggests that our internal timekeeping mechanism begins with a phasic release of dopamine from dopaminergic midbrain projections to the cortex and dorsal striatum (Matell &

Meck, 2004) at the onset of the “to-be-timed” interval. This causes groups of cortical neurons to reset, synchronize their firing, and begin oscillating at their respective periods in the dorsal striatum (Allman & Meck, 2012). These oscillating neurons are essentially the clock mechanism, whereas the rate of oscillatory activity determines how time is perceived in the brain. While these theories provide biologically plausible mechanisms, the exact neural basis for subjective time perception is still unknown (Wittman, 2013).

A simple way to understand both theories is through the frequency of neural events (Matell & Meck, 2000). A greater frequency of neural events causes more pacemaker pulses to accumulate, or oscillatory neurons to oscillate at a faster rate. These actions speed up the internal clock, causing people to overestimate and under-produce time intervals (Gill & Droit-Volet, 2012). When bored, few events are encoded into your timing system. This means that your experience of time will slow down and you feel like time is dragging by.

In contrast, “time flies when you’re having fun.” When you are engaged in an activity, you process more events in a specified period of time. To allow for this, your internal clock speeds up, causing your perception of time to increase. In fact, many scientists consider that changes in physiological arousal via activation of the sympathetic nervous system (SNS) are the foundation for changes in time perception (Gibbon et al., 1984; Allman & Meck, 2012; Gill & Droit-Volet, 2012; Allman et al., 2014; Cheng et al., 2016; Turgeon et al., 2016; Droit-Volet & Berthon, 2017). Both time perception theories highlight that time perception is influenced by arousal (Allman & Meck, 2012; Allman et al., 2014). High arousal speeds up the internal clock, causing people to overestimate and under-produce time intervals (Gill & Droit-Volet, 2012).

Exercise is a form of physiological arousal and is thought to influence time perception as adrenal catecholamines release with high-intensity exercise increases sympathetic activity (Jansen et al., 1995). With muscular contractions, you have increased motor unit recruitment and firing frequency. This increased activity is encoded as additional events in the timing system, further speeding up the perception of time with higher-intensity contractions. With the cerebellum overlapping both movement and timing (Ivry et al., 1988), exercise-induced arousal may have more of an effect on our perception than other forms of arousal.

The increased demands (frequency of events) with sensory processing may also affect time perception. Processing both internal (physiological) and external (e.g., video monitors) events may negatively affect exercise performance as it may cause hyperarousal and disengagement in exercise. Being distracted from adverse internal events may cancel out their deleterious effect on timing, or perhaps even slow down your internal clock as your arousal level may decrease. Processing increased frequencies of internal events such as increased heart rate, muscle activation (e.g., measured by EMG), thermoregulation and other physiological or external signals may distort time regulation.

Sensory processing and memory are important factors of time perception and exercise and are also aspects of the human brain that tend to decline with age. The common phrase “time flies as you get older” implies that people find time to pass more quickly with age. Researchers have investigated this axiom, and results suggest that time perception is indeed affected by age (Block et al., 1999; Bherer et al., 2007; Turgeon et al., 2016), possibly due to long-term cognitive and physical changes. Older adults tend to estimate short intervals less accurately and with more variability compared to their younger counterparts (Wittmann & Lehnhoff, 2005). According to Coelho et al. (2004), the internal clock speeds up with age, though Turgeon & Wing (2012) suggests that it ticks more slowly with age. This lack of consensus in the literature highlights the complex nature of the underlying timing mechanism. The effects of aging on time perception are not well known and often attributed to cognitive changes (Jual & Barron, 2017). Turgeon et al. (2016) reviewed age-related effects on time perception. They noted that fundamental age-related changes in the functioning of cortico-thalamic-basal ganglia circuits cause impairments in time perception. Interestingly, no studies have investigated the effect of exercise-induced arousal in an elderly population (Behm, 2020). The purpose of this study was to investigate whether there are age-related differences in time estimation during varying intensities of isometric exercise. It was hypothesized that prospective time estimates during exercise will be shorter than pre-trial/non-exercise time estimates in both cohorts (Edwards & McCormick, 2017; Hanson & Lee, 2020). It was also hypothesized that younger adults will be more accurate in their time estimation compared to older adults, who would be less accurate and more variable in their time estimation (Wittmann & Lehnhoff, 2005).

Methods

Participants

Two cohorts of participants were recruited for this study. A sample of 14 healthy (absence of knee and hip pain for the past six months) recreationally active (at least 150 minutes of moderate physical activity per week) older adults were recruited as participants for this study (8 males: 173.8 ± 3.8 cm, 85.8 ± 16.2 kg, 64.9 ± 5.4 years; 6 females: 160.3 ± 6.9 cm, 60.6 ± 6.9 kg, 64.3 ± 4.4 years). In addition, 19 healthy and recreationally active (as defined above) young adults (aged 18-30) were also recruited (9 males: 180 ± 6.3 cm, 76.5 ± 8.4 kg, 23 ± 2.8 years; 10 females: 164 ± 6.9 cm, 67 ± 14.7 kg, 23 ± 1.9 years).

Table 1: Participant Anthropometrics

	Cohort	Age (years)	Height (cm)	Mass (kg)
Males	Young (n=9)	23 ± 2.8	180 ± 6.3	76.5 ± 8.4
	Old (n=8)	64.9 ± 5.4	173.8 ± 3.8	85.8 ± 16.2
Females	Young (n=10)	23 ± 1.9	164 ± 6.9	67 ± 6.9
	Old (n=6)	64.3 ± 4.4	160.3 ± 6.9	64.3 ± 4.4

The experimental protocol was verbally explained to all participants, who then completed the Physical Activity Readiness Questionnaire (CSEP Path: Canadian Society for Exercise Physiology, 2011), and read and signed an informed consent form. All participants were determined to be right-leg dominant (Oldfield, 1971). This research was approved by the Institutional Health Research Ethics Board (ICEHR #20210782) and conducted according to the latest version of the Declaration of Helsinki. Testing of participants was completed at the same time each day, with a minimum of two days between sessions to allow for muscle recovery (American College of Sports Medicine, 2009).

Experimental Design

Following recruitment and signing the informed consent form, participants attended the Biomechanics Lab at the School of Human Kinetics and Recreation (Memorial University) twice over two weeks with at least 48 hours between sessions. One session consisted of the control and maximal voluntary isometric contractions (CON+MAX) conditions, and the other consisted of the 10% and 60% submaximal (SUBMAX) contractions. The two sessions were completed in a randomized order for all participants. Height and mass were recorded at the beginning of the first session. Upon arrival for both sessions, participants were first fitted with a heart rate monitor with both values being recorded for the first time. The following tasks were performed in sequential order for both sessions: the familiarization stage where they watched a timer count up to 30-seconds twice, which was immediately proceeded by recording heart rate and body temperature, the learning phase (which consisted of six trials where participants were asked to prospectively estimate when 5, 10, 20, and 30-seconds had elapsed). No instructions were given to the participants on how they should go about timing, only that they should try to be as accurate and consistent as possible. After each of the six trials, the time estimates were read aloud to the participants. After the sixth trial, the learning phase was complete, and the participant's heart rate and temperature were recorded for the second time.

The electromyography (EMG) preparation followed the learning phase. Following the learning phase and EMG preparation, the participants completed a five-minute warm-up on a cycle ergometer, where they cycled at approximately 1 kilopond (kP) at a rate of 70 revolutions per minute. When five minutes of cycling was completed, heart rate and temperature were taken for the third time.

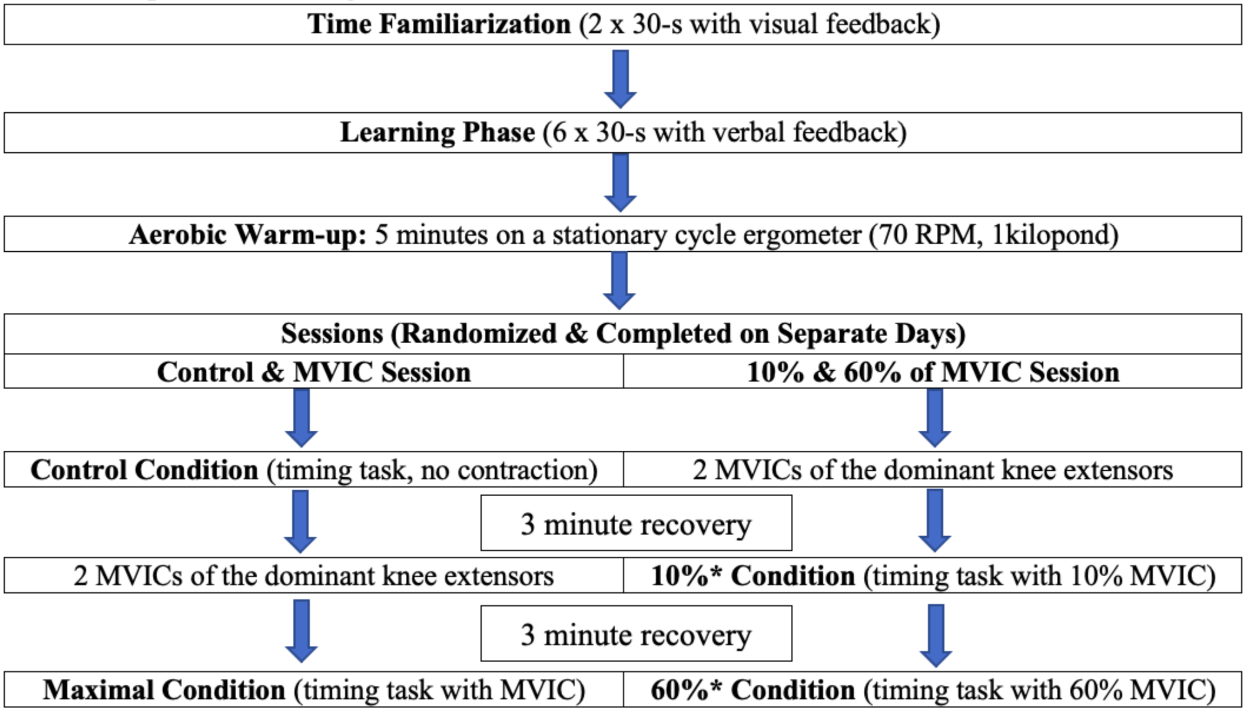
Participants were then instructed to sit in a chair designed specifically for isometric knee extension contractions (constructed by Technical Services: Memorial University of Newfoundland). Once seated, they were fixed to the chair with chest straps to reduce extraneous movement during the experiment. The EMG leads were connected to the electrodes, and the noise was measured to ensure it was less than five kilo-ohms (5 k Ω). The researchers then inserted the participant's ankle into a leather cuff attached by a chain to the force dynamometer to measure force production. A goniometer was used to achieve a knee angle of 110° for all participants.

Next, participants completed maximal voluntary isometric contractions (MVICs) of the dominant knee extensors. To warm up, they were instructed to try to extend their knee at about 50% of maximal intensity and to sustain it for five seconds. This was completed twice before the actual testing MVICs commenced. During the MVICs, participants were instructed to contract their quadriceps as fast and as hard as possible as they heard the “GO” signal from the researcher. They continued this contraction while the researchers provided verbal encouragement until they heard the “STOP” signal, which occurred after four seconds. The value was recorded for the first MVIC. If the value for the second MVIC was 5% greater than the first, a third MVIC was completed to ensure the participant reached their maximum force production.

The two experimental protocols were the last components to be completed for each session. Both sessions were completed in random order. For the SUBMAX session (10% and 60% of MVIC), the two protocols were also randomized. For the CON+MAX session, the control was always completed first before any MVICs commenced to ensure no fatigue effects impacting the control condition. The protocol was similar to the learning phase completed at the beginning of each session. Participants prospectively estimated when 5, 10, 20, and 30 seconds had elapsed, which they indicated by squeezing a trigger with their hand. The trigger provided a signal to the computer software to determine the deviation in the estimation of time.

While the participants were engaged in this timing, they also completed two other activities. When one of the researchers visually observed the participant squeeze the trigger, rating of perceived exertion (RPE) was asked, which prompted the participant to give a value between 6-20 from the Borg scale (Borg, 1998), which was previously explained to them. During the 30-seconds time periods, participants were either asked to relax (CON) and then after a three-minute rest period perform a single MVIC (CON+MAX session) or during the SUBMAX session, in random order perform 10% and 60% of MVIC with three-minutes of rest between protocols. During the submaximal contraction trials, their targeted force was indicated on a video monitor in front of participants, and they were instructed to do their best to hold the contraction around that value. If participants repeatedly (two times) deviated by more than approximately 10%, the trial was stopped and repeated again after two-minutes of rest. Once the timing protocols were completed, heart rate and temperature were taken one last time.

Table 2: Experimental Design



*Note: MVIC = Maximal Voluntary Isometric Contraction; * indicates that the 10% and 60% conditions were also randomized.*

Measures

This study utilized electromyography (EMG) to measure muscle activity and the Borg Scale as a psychophysical measure of perceived exertion. The Mini-Mental State Exam (MMSE) (Mini-Mental State, 1975) was also used as a measure of cognition, which was incorporated to ensure that any differences in time perception were not attributed to ageing-related deficits in cognition. No subjects were excluded from this study based on their MMSE score. Other tools include a heart rate monitor (T31, Polar, Kempele, Finland, manufactured in Guangzhou, China) and an eardrum thermometer (IRT6520CA ThermoScan, Braun, Germany) to collect heart rate and body temperature, respectively, four times during each condition; first entering the lab, post-learning, post-warmup, and post-protocol.

Surface Electromyography (s-EMG) was used in this study to record muscle activity of the dominant rectus femoris. Self-adhesive Cl/AgCl bipolar electrodes (MeditraceTM 130 ECG conductive adhesive electrodes, Syracuse, USA) were used in parallel with the muscle fibres and systematically placed according to Seniam (2020) guidelines. Before electrodes were placed on the skin, investigators prepared the area by shaving, abrading, and cleaning the skin with an isopropyl alcohol swab before letting it dry (Seniam, 2020). The ground electrode was placed on the lateral epicondyle of the femur, and all leads were taped to the skin to help minimize any movement artifacts in the s-EMG signal. Before beginning the experiment, a check was performed to assess the inter-electrode noise, which had to be less than five kilo-ohms (5 kΩ). EMG signals were amplified 1000x (CED 1902 Cambridge Electronic Design Ltd., Cambridge, UK) and filtered with a 3-pole Butterworth filter with cut-off frequencies of 10-500 Hz. Analog signals were digitally converted at a sampling rate of 5 kHz with a CED 1401 interface (Cambridge Electronic Design Ltd., Cambridge, UK) and sampled at 2000 Hz. EMG integral was measured during the first and last 5-seconds of each experimental condition to calculate an EMG Fatigue Index. The Power Spectral Density (PSD) was also analyzed for each condition, and the median and maximal frequency were recorded for the first 50 Hz.

The Borg Scale of Rating of Perceived Exertion (RPE) (Borg, 1998) was used to measure the intensity/level of fatigue the participants felt during the isometric contractions. This value was recorded at the end of each 5, 10, 20, and 30-second time estimates during all four contraction trials (control, maximal, 10%, and 60% of MVIC). This measure ensured researchers that the participants were contracting at the proper exertion level and interrupts any possible counting maneuvers participants may have used as a strategy to estimate time.

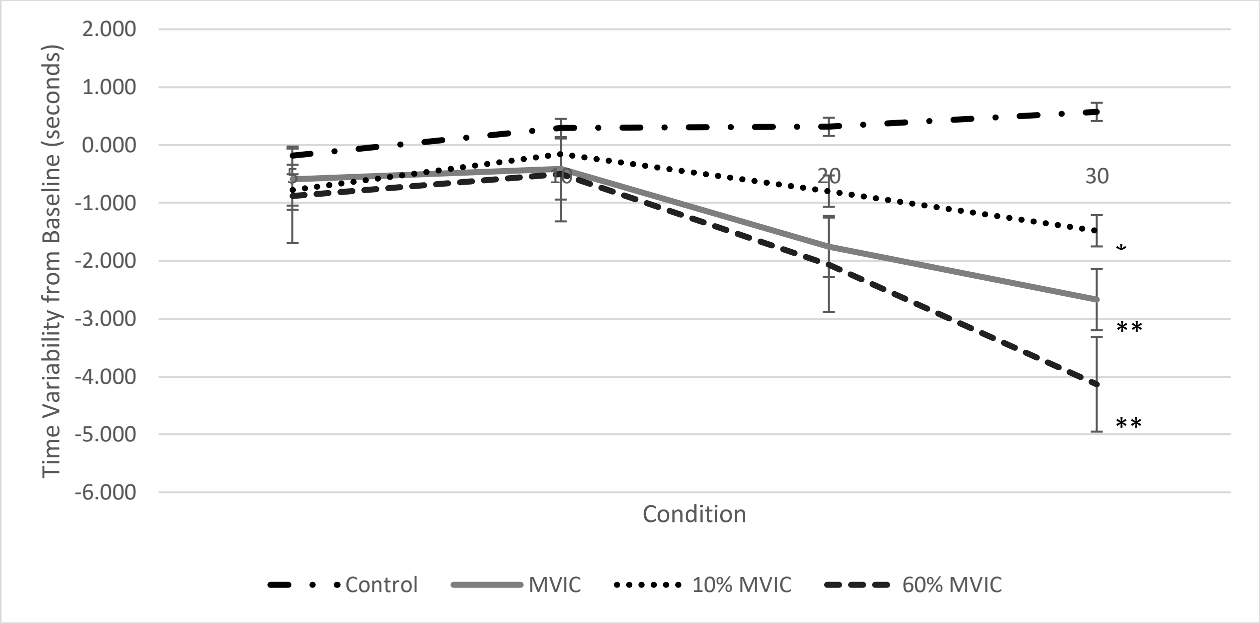
Statistical Analyses

Statistical analyses were calculated using SPSS software (Version 28.0, SPSS, Inc, Chicago, IL). This study employed a repeated measure, within-subjects, crossover design. Kolmogorov–Smirnov tests of normality were conducted for all dependent variables. Significance was defined as $p < .05$. If the assumption of sphericity was violated, the Greenhouse−Geiser correction was employed. A three-way repeated measures ANOVA was utilized to compare time variability in the condition (control, MVIC, 10% MVIC, and 60% MVIC), time estimation (at points 5, 10, 20, and 30 seconds), and age (young, and old). Modified Bonferroni post-hoc tests were conducted to detect significant main effect differences whereas, for significant interactions, post-hoc t-tests corrected for multiple comparisons were conducted to determine differences between values. In cases where the data was not normally distributed, the Kruskal-Wallis H test was utilized. Mann-Whitney U tests were used as post-hoc tests and corrected with the Bonferroni adjustment to control for type-1 error. Partial Eta-squared (η_p^2) values are reported for main effects and overall interactions representing small ($0.01 \leq \eta_p^2 < 0.06$), medium ($0.06 \leq \eta_p^2 < 0.14$) and large ($\eta_p^2 \geq 0.14$) magnitudes of change (from SPSS-tutorials, 2022). Cohen's d effect sizes are reported for the specific post-hoc interactions with $d > 0.2$: trivial, 0.2 - <0.5: small, 0.5 - <0.8: moderate, ≥0.8: large magnitude difference (Cohen 1988).

Results

Time Estimates

A significant interaction was found for Condition * Time ($F_{(9, 108.975)} = 7.601$, $p < 0.001$, $\eta_p^2 = 0.197$). At the 5-second mark (Table 3), the participants underestimated time significantly more in the MVIC (Mean Difference (MD) = 0.437, $p < 0.05$), 10% of MVIC (MD = 0.610, $p < 0.001$), and 60% of MVIC (MD = 0.763, $p < 0.001$) compared to the control condition. No significant interactions were identified between the conditions at the 10-second mark. However, at the 20 and 30-second periods (Table 3), the participants also underestimated time significantly more with the MVIC (20-s: MD = 2.117, $p < 0.001$, 30-s: MD = 3.255, $p < 0.001$) and 60% of MVIC conditions (20-s: MD = 2.463, $p < 0.01$, 30-s: MD = 4.790, $p < 0.001$) compared to the control condition. Also, at 30-seconds, participants underestimated time significantly more in the 60% MVIC condition compared to the 10% condition (MD = 2.733, $p < 0.01$) (Figure 1).



** $p < 0.05$ compared to control*

*** $p < 0.001$ compared to control*

Figure 1: Mean Time Variability by Condition

Table 3: Time Estimates (in seconds). Significance symbols illustrate Condition x Time interactions. There were no significant age effects. Mean ± standard deviation; Cohen's d effect size: d

		Deviation from 5-Seconds			
		Control	MVIC*	10% MVIC***	60% MVIC***
Younger Adults	**Mean** **d**	-0.154±0.445	-0.376±0.901 0.33	-0.651±0.494 1.06	-0.472±0.794 0.51

Older Adults	**Mean**	-0.220±0.804	-0.874±0.822	-0.944±0.889	-1.42±0.808
	d		0.80	0.86	1.49
		Deviation from 10-Seconds			
		Control	MVIC	10% MVIC	60% MVIC
Younger Adults	**Mean**	0.116±0.739	-0.188±1.77	-0.0469±1.89	-0.289±1.33
	d		0.06	0.05	0.17
Older Adults	**Mean**	0.536±1.40	-0.716±1.93	-0.305±1.57	-0.787±2.48
	d		0.11	0.16	0.13
		Deviation from 20-Seconds			
		Control	MVIC***	10% MVIC	60% MVIC**
Younger Adults	**Mean**	0.101±1.60	-1.68±2.75	-0.753±3.23	-1.84±2.61
	d		0.73	0.27	0.83
Older Adults	**Mean**	0.603±2.57	-1.84±3.25	-0.853±2.65	-2.37±4.42
	d		0.43	0.10	0.51
		Deviation from 30-Seconds			
		Control	MVIC***	10% MVIC ^{X}	60% MVIC$^{***, X}$
Younger Adults	**Mean**	0.265±2.58	-2.91±4.41	-1.77±3.90	-3.97±3.82
	d		0.76	0.46	1.15
Older Adults	**Mean**	0.989±3.13	-2.34±5.91	-1.08±5.68	-4.35±7.50
	d		0.30	0.02	0.63

** indicates $p < 0.05$ compared to the control*
*** indicates $p < 0.01$ compared to the control*
**** indicates $p < 0.001$ compared to the control*
^{X} indicates $p < 0.01$ between the two conditions

Within the control condition (Table 4), participants significantly underestimated time at the 5-second mark compared to the 10-second mark (MD = 0.514, $p < 0.01$). No other significant differences in time estimation were found for the control condition. For the MVIC condition (Table 4), participants significantly underestimated time more at the 20-second (MD = 1.312, $p < 0.001$) and 30-second mark (MD = 2.175, $p < 0.05$) compared to the 10-second mark. No other significant differences in time estimates were found for the MVIC condition or the entirety of the

10% MVIC condition. In the 60% MVIC condition (Table 4), participants underestimated time significantly more at 30-seconds compared to 5-seconds (MD = 3.212, p < 0.01), at 20-seconds (MD = 1.571, p < 0.01) and 30-seconds (MD = 3.623, p < 0.001) compared to 10-seconds, and at 30-seconds compared to 20-seconds (MD = 2.052, p < 0.05). No significant effects were found between Condition * Age, Time * Age, or Condition * Time * Age.

Table 4: Time Deviation from Baseline (mean ± SD; (Cohen's d effect size, compared to control)) in seconds for each time interval.

Control

5*	**10***	**20**	**30**
-0.183 ± 0.613	0.294 ± 1.07	0.135 ± 2.05	0.573 ± 2.81

** indicates p <0.01*

MVIC**

5	**$10^{*,X}$**	**20***	**30^{X}**
-0.587 ± 0.891 (0.54)	-0.412 ± 1.83 (0.08)	-1.75 ± 2.93 (0.65)	-2.67 ± 5.03 (0.53)

** indicates p < 0.001*
^{X} indicates p < 0.05

10% MVIC^{Y}

5	**10**	**20**	**30**
-0.776 ± 0.693 (0.53)	-0.156 ± 1.74 (0.10)	-0.796 ± 2.96 (0.26)	-1.48 ± 4.67 (0.24)

60% MVIC**

5*	**$10^{X, Z}$**	**$20^{Z, Y}$**	**$30^{*, X, Y}$**
-0.878 ± 0.922 (0.90)	-0.501 ± 1.89 (0.14)	-2.07 ± 3.45 (0.70)	-4.13 ± 5.58 (0.84)

** indicates p < 0.01*
^{X} indicates p < 0.001
^{Z} indicates p < 0.01
^{Y} indicates p < 0.05
*** indicates p < 0.001 compared to the control condition*

A significant main effect for Condition ($F_{(3, 71.241)} = 8.721$, p < 0.001, $\eta_p^2 = 0.22$) indicated that compared to the control condition, participants significantly underestimated time in the MVIC (MD = 1.647, p < 0.001), 10% MVIC (MD = 1.081, p < 0.05), and 60% MVIC conditions (MD

= 2.220, $p < 0.001$). No significant interactions were found between the conditions involving isometric knee extension contractions (Table 3)

A significant main effect for Time ($F_{(3, 36)} = 7.151$, $p < 0.01$, $\eta_p^2 = 0.187$) showed that participants underestimated time more at the 5-second mark compared to the 10-second mark (MD = 0.430, $p < 0.05$). Lastly, participants underestimated time more at 20-seconds (MD = 0.871, $p < 0.01$), and 30-seconds (MD = 1.688, $p < 0.05$) compared to the 10-second time estimate (Table 5). No significant differences in time estimation were found between the two age groups.

Table 5: Time Deviation from Baseline Main Effect (mean ± SD,) in seconds

5*	**$10^{*, X, Y}$**	**20^{Y}**	**30^{X}**
-0.606 ± 0.826	-0.194 ± 1.68	-1.08 ± 3.01	-1.93 ± 4.90

*; $d = 0.32$
^{X}: $d = 0.52$
^{Y}; $d = 0.37$

$^{*, X}$ *indicates* $p < 0.05$ *between corresponding conditions*
^{Y} *indicates* $p < 0.01$ *between corresponding conditions*

EMG Integral

A significant difference in EMG integral was found across age in the MVIC condition in the first and last 5 seconds ($X^2_{(1)} = 10.28$, $p < 0.001$, $\eta_p^2 = 0.33$ and $X^2_{(1)} = 8.94$, $p < 0.005$, $\eta_p^2 = 0.28$, respectively), such that the younger cohort (YC) had greater EMG activity (first and last 5 seconds: m = 2.52 ± 1.19 mV and m = 2.81 ± 1.44 mV, respectively) compared to the older cohort (OC) (first and last 5 seconds: m = 1.12 ± 0.836 mV and m = 1.34 ± 0.949 mV, respectively). Significantly lower EMG integral values were found for the 60% MVIC condition with the first ($X^2_{(1)} = 4.11$, $p < 0.05$, $\eta_p^2 = 0.11$, YC: m = 1.94 ± 1.21 mV; OC: m = 1.15 ± 0.640 mV) versus the last five-seconds ($X^2_{(1)} = 5.92$, $p < 0.05$, $\eta_p^2 = 0.17$; YC: m = 1.99 ± 1.11 mV;

OC: m = 1.16 ± 0.646 mV) (Table 6). No significant age differences in EMG integral were evident for the 10% or 60% MVIC conditions.

Table 6: EMG integral between age cohort in millivolts (mv) (mean ± SD)

	First Five-Seconds	Last Five-Seconds
	MVIC	
Younger cohort	2.52 ± 1.19*	2.81 ± 1.44^{Z}
Older cohort	1.12 ± 0.836*	1.34 ± 0.949^{Z}
	10% MVIC	
Younger cohort	0.257 ± 0.154	0.273 ± 0.166
Older cohort	0.228 ± 0.0914	0.261 ± 0.0913
	$60\%\ \text{MVIC}^{Y}$	
Younger cohort	1.94 ± 1.21	1.99 ± 1.11
Older cohort	1.15 ± 0.640	1.16 ± 0.646

**; d = 1.38*
^{Z}; d = 1.23

** indicates $p < 0.001$*
^{Z} indicated $p < 0.005$
^{Y} indicates $p < 0.05$ for both the first and last-five seconds.

Fatigue Index

No significant differences in Fatigue Index were found between the younger and older cohorts.

Power Spectral Density (PSD)

No significant differences in median or maximum PSD were identified between the older and younger cohort.

Discussion

This was the first study to investigate whether time perception is altered when performing an isolated isometric exercise. It was determined that the MVIC, 60% MVIC and 10% MVIC conditions had deleterious effects on the subjects' perception of time. More specifically, participants tended to underestimate the time intervals across the different conditions compared to their baseline values (Figure 1). The higher intensity contraction conditions (MVIC and 60% MVIC) had more disturbance on time perception compared to the lower intensity 10% MVIC condition at the 30-second estimate. Lastly, the time estimates at 10-seconds were the most accurate when compared to estimates at 5, 20, and 30-seconds. There were no significant differences in time perception between the younger and older participants, even with the greater maximal and 60% submaximal contraction EMG activity of the younger cohort.

The finding that the MVIC and 60% MVIC conditions yielded significant time underestimations compared to the control were in line with the hypothesis. This time estimate disruption has been attributed to an intensity-dependent relationship between time perception and exercise, which has been found in other studies. Edwards & McCormick (2017) utilized cycling and had subjects estimate when 25%, 50%, 75%, and 100% of the trial was complete in different RPE conditions. They found that at the 75% and 100% intervals, time estimates for the RPE 20 condition (maximal exertion) was shortest when compared to RPE 11 (light intensity) and RPE 15 (moderate intensity). Subjects also completed a rowing task, where they found similar intensity-dependent results. Hanson & Lee (2020) investigated exercise intensity in individuals who self-selected their running pace. Results showed that participants significantly underestimated time when running at RPE 17 condition compared to RPE 11. Together with the results of the present study, these findings suggest that time is perceived to pass by more slowly when exercise intensity increases.

This study also showed that the low-intensity, 10% MVIC contraction condition affected the participants' time perception, a finding that contradicts the intensity-dependent results found by Edwards & McCormick (2017) and Hanson & Lee (2020). This may be attributed to the dual-task nature of this study. Participants were viewing a monitor, which displayed the force from their isometric contraction in real-time and asked to maintain a certain level of force. Maintaining the prescribed force while estimating the 5, 10, 20, and 30-second time intervals may have impacted the participant's ability to perceive time accurately. However, the distraction of viewing the monitor cannot be the primary factor underlying the underestimation of time, as the MVIC condition did not necessitate screen monitoring. Although the 60% MVIC condition was also a multi-task event with the distraction of viewing the monitor, maintaining a moderately intense contraction, and estimating time, time underestimation was not significantly different from the MVIC condition. Hence, while distractions (i.e., dual or multi-tasking) can affect time estimates, there was no additive adverse effect on the performance of moderate or high-intensity isometric contractions.

The finding that exercise can lengthen an individual's experience of time can be understood through the lens of the Pacemaker Accumulator Model (PAM) (Grondin, 2010; Allman & Meck, 2012). With the MVC and 60%MVC conditions, as participants isometrically contracted their knee extensors; muscle fatigue and discomfort may have been experienced due to the tension, partial blood occlusion, metabolite accumulation, and other factors. This negative sensation acts as a form of physiological arousal (Edwards & Polman, 2013). Furthermore, the neuromuscular system will experience and contribute to heightened neural activity with increased motor unit recruitment and rate coding (firing frequency) (Behm 2004). Distractions (watching the computer monitor with 10% and 60% MVIC), increase sensory activity, and this overall increase in arousal may have an impact on their timing system. In the case of the PAM, arousal affects the mode switch in the clock stage. The mode switch is responsible for the storage of timing information, which is stored in an accumulator in a linear fashion. This timing information then passes through working and reference memory before a decision is made. Heightened arousal is thought to increase the rate at which the pacemaker processes information, resulting in extended perceptions of time intervals. Differences in attention, pacemaker speed, memory, and decision-making skills result in time perception differences (Allman & Meck, 2012). According to Dormal et al. (2017), exercise-induced arousal can produce this effect and generate distortion in time perception during exercise.

Furthermore, attention was directed towards the monitor displaying their force production in the 10% and 60% MVIC conditions. It has been hypothesized that distraction away from the concept of time can cause the collection of pulses in the accumulator to begin at a later time (Droit-Volet & Gil, 2009, Hanson & Lee, 2020), according to the PAM. With the distraction, the Striatal Beat Frequency model suggests that oscillating neurons may synchronize and fire at a faster rate (Merchant et al., 2013). These physiological phenomena may affect the clock speed of the timing system, which is regulated by dopamine activity in the medial prefrontal cortex (Matell & Meck, 2004). Both models suggest this state would cause the individual to estimate intervals of time to be longer than chronological time (retrospective timing) and to produce intervals of time that are shorter than chronological time (prospective timing). The greater time impairments with the higher intensity contractions (MVIC and 60% MVIC) suggest that heightened neuromuscular activity was more disruptive than the sensory distraction of watching the monitor during a low-intensity contraction (10% MVIC).

Another difference is that distortions in time were found at all time point estimates in the present study. In contrast, Edwards & McCormick (2017) only found distortions in the last two time estimates. In the present study, participants were instructed to squeeze a hand trigger to estimate 5, 10, 20, and 30 seconds. The Edwards & McCormick (2017) protocol had participants verbally identify when they believed 25%, 50%, 75%, and 100% of the 30-second Wingate and 1200-second rowing tasks. It is possible that having the participants engage in an additional motor task to squeeze the trigger interacted with the isometric knee extension contraction, causing an underestimation of time early in the time trial.

It was anticipated that time variability would steadily increase as participants estimated the four consecutive times. As time progresses, you would naturally expect a greater variability as small errors made early may amplify the longer the trial progresses. Therefore, it is interesting that subjects underestimated time more at 5, 20, and 30-seconds compared to 10-seconds (Figure 1). No other significant interactions between times were found in the analysis. Edwards & McCormick (2017) found no deficits at 50% of total time (which corresponds to the 10-second estimate). However, this study utilized another method to quantify time perception. Instead of measuring the variability for each time point (i.e., referring to a pre-test value), they compared their time estimates to chronological time and had no control group to compare estimates. Hanson & Lee (2020) utilized a similar protocol and found no differences between any of the time estimates. Mechanistically, there does not appear to be any logical reason as to why time estimates at 10-seconds were more accurate compared to 5, 20, and 30-seconds. Rather, this finding may be attributed to lifelong learning. Countdowns from 10-seconds are commonly used in our society, from rocket take-offs to space, the countdown to the New Year and the end of many time-restricted sports. Many films from the mid-twentieth century included 10-second countdowns before the movie began. As the subjects in this study were recreationally active, they may also be accustomed to 10-second intervals from sports and exercise, where it is common for a trainer to push athletes by saying, “only 10-seconds remaining”. It is speculated that this additional lifelong exposure of 10-second time intervals led subjects to estimate the 10-second time point most accurately.

The results did not show any differences in time perception between the younger and older cohorts. It was expected that older adults would be less accurate and more variable in their timing compared to their younger counterparts (Wittmann & Lehnhoff, 2005). Coelho et al. (2004) suggested that as one ages, their internal clock speeds up, such that older adults tend to underestimate time compared to younger adults. However, the more plausible explanation is that the internal clock becomes slower with age (Block et al., 1999; Bherer et al., 2007). This means people of advanced age tend to understimate and over-produce intervals relative to chronological time (i.e., a person with a slow internal clock may perceive a 5-second stimulus as lasting only 3 seconds, and when asked to produce a 3-second interval, instead produce a 5-second one). Furthermore, cognitive aging of the ventral tegmental area (VTA) has been shown to decrease dopamine levels, which could also explain why older adults seem to have a slower internal clock (Peterson et al., 2017).

Interestingly, a review by Turgeon et al. (2016) concluded that partial compensation can mask age-related declines in time perception, allowing older adults to perform nearly or as well as younger adults until cognitive or physical demands push them past the threshold for compensation. It was proposed that the cortico-cerebellar and hippocampal regions (which are less affected by aging) are recruited to the timing system (Meck, 2005; Merchant et al., 2013; Lusk et al., 2016). Such a threshold appears not to be reached in this study, meaning that the older adults were able to compensate for their slower internal clock using the above circuitry. As the subjects were physically active individuals, they may have relatively well-developed and active cortico-cerebellar regions, allowing for efficient compensation of their proposed slower internal clock.

More possibilities may explain the lack of differences in time perception between the two age groups. The older adults recruited for this study were quite educated (50% of participants had university-level education) and were physically active across the lifespan. Having engaged in such study and career and activity choice, the subjects may have experienced a neuroprotective effect, such that they did not experience as much cognitive (i.e., internal clocks) aging as expected. Being physically (Hillman et al., 2008) and mentally (Valenzuela & Sachdev, 2006) active throughout the lifetime may have offered similar neuroprotective effects.

It was expected for participants to experience significant deficits in timing during the MVIC and 60% MVIC contractions. In theory, these exercise intensities should be high enough to break the threshold of compensation for older adults. However, this was not observed in this study. Though the old adults were physically active, most were not accustomed to high-intensity anaerobic work. This would suggest that some participants, even following the familarization session may not have been performing true MVICs and were contracting at a lower intensity during the protocols. As such, it might be possible that the older adults were unknowingly contracting just until they reached the threshold for compensation, allowing them to estimate the time intervals as accurately as their younger counterparts.

Limitations

As with any investigation, this study was not without limitations. The participants consisted of two recreationally-active cohorts: university-aged students and older adults aged 60 years and above. Therefore, the results of this study may not accurately reflect that of the entire population across all ages and physical activity levels. Another limitation in this study is the large standard deviations relative to the mean, which is a result of large heterogeneity across the different individual outcomes.

Conclusions

The perception of time is an important concept that impacts nearly everything we do. This study found that, regardless of age, participants underestimated time when performing isometric knee extension contractions in their dominant leg compared to the control condition. It was noted that participants underestimated time more at 30-seconds in the 60% MVIC condition compared to 10% MVIC. These results add to a growing body of literature investigating time perception and exercise. It partially supports the notion of an intensity-dependent threshold where time begins to be impaired, but perhaps this relationship is not as clearly defined as previous studies have articulated. In addition, subjects underestimated time at 5, 20, and 30-seconds, while they did not at 10-seconds. Together, these findings suggest that there may be ideal exercise intensities and times to optimize one's perception of time. If someone has an accurate perception of time and does not feel like time is lagging by, they may be more inclined to engage and enjoy exercise. While this study did not find age-related effects, future research should investigate different ages, durations, and types of contractions, and inactive populations to better gauge how different people experience time in different situations.

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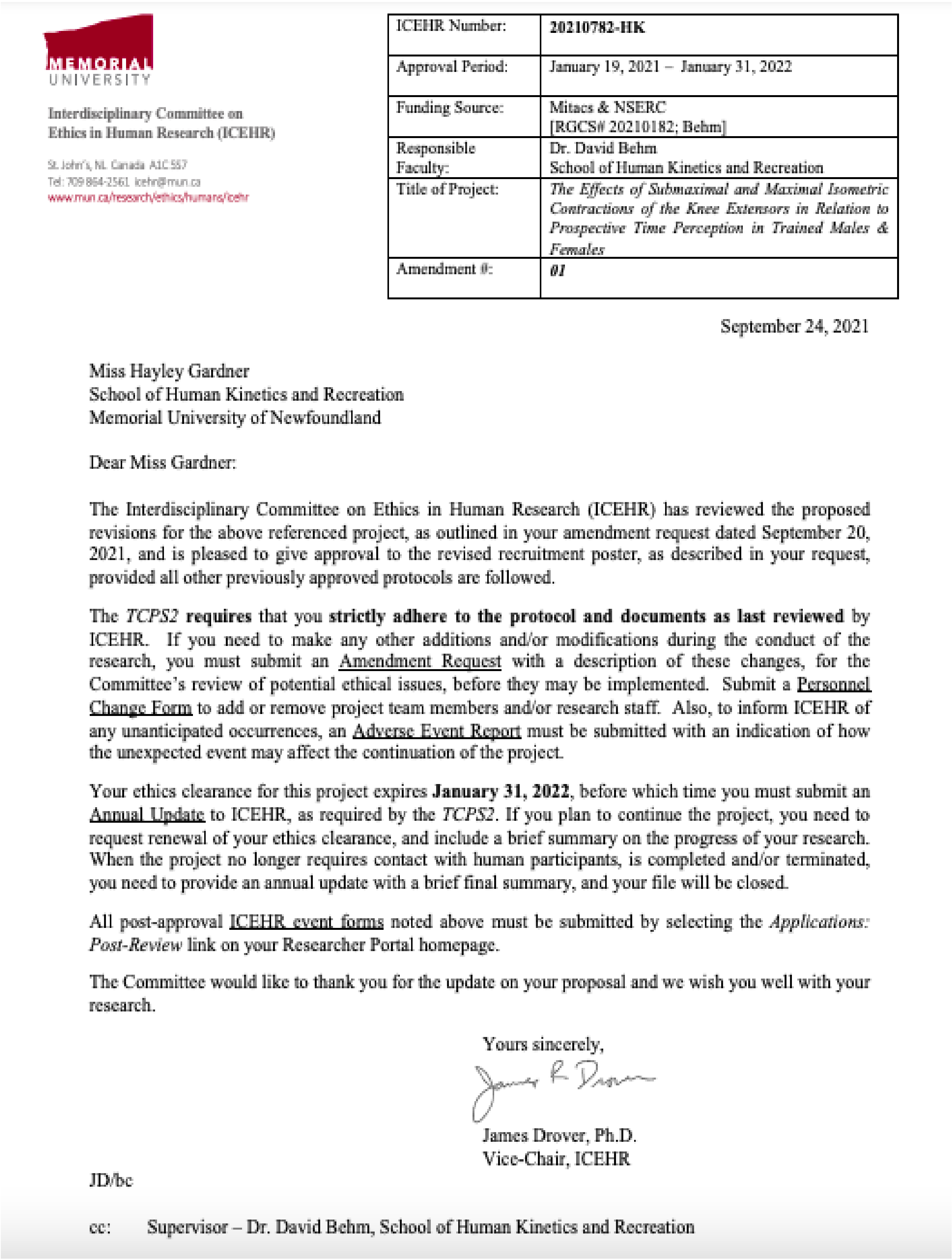
Appendix A



MEMORIAL UNIVERSITY

Interdisciplinary Committee on Ethics in Human Research (ICEHR)

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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