

Research article

Maximal and Submaximal Intensity Isometric Knee Extensions Induce an Underestimation of Time Estimates with Both Younger And Older Adults: A Randomized Crossover Trial

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Abstract

Our perception of time plays a critical role in nearly all daily activities and especially in sports. There are no studies that have investigated and compared time perception during exercise in young and older adults. Thus, this study aimed to compare the effects of exercise on time perception between younger and older adult populations. Thirty-three recreationally active participants were recruited and assigned to either the younger (university students, 9 males and 10 females) or older adults (>60 years, 8 males and 6 females). All participants completed four exercise conditions over two sessions on separate days: approximately 30-seconds of knee extensors 100%, 60% and 10% of maximum voluntary isometric contraction (MVIC), and control (no contractions). Prospective time perception was estimated (at 5-, 10-, 20-, and 30-seconds) at the beginning of each session and while performing the exercise. A main effect for condition ($p < 0.001$, $d = 1.06$) with subsequent post-hoc tests indicated participants significantly underestimated (estimated time was shorter than chronological time) time in all three exercise conditions compared to the control. There were no significant age group differences. In conclusion, exercise underestimated time estimates regardless of intensity or age. This questions the postulated intensity-dependent relationship between exercise and time perception. While older adults were expected to be less accurate in their time estimates, they may have been able to adopt alternative strategies for age-related changes in their internal clock, resulting in no significant age group differences.

Key words: Elderly, time perception, exercise, ageing, prospective time.

Introduction

Time is a construct that is considered by many to be a very precise and objective measure. However, while Einstein's theory of special relativity suggested that time is relative in relation to physics (Einstein, 1905), time may also be relative or subjective in relation to physiological effects. 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 and Meck, 2012; Gil and Droit-Volet, 2012; Allman et al., 2014; Cheng et al., 2016; Turgeon et al., 2016; Droit-Volet and Berthon, 2017), which is associated

with different environmental, physiological, and psychological states (Wittmann, 2013; Allman et al., 2014).

While time is measured in our daily lives by devices such as clocks providing precise units (i.e., hours, minutes, seconds, milliseconds), the human subjective perception of time is influenced by the frequency of events occurring over a designated period. For example, we may state: "time flies when you're having fun." When you are involved in an engaging 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, often causing people to underestimate time (estimated time was shorter than chronological time) intervals (Gill and Droit-Volet, 2012). When bored, fewer 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. 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 and Meck, 2012; Gill and Droit-Volet, 2012; Allman et al., 2014; Cheng et al., 2016; Turgeon et al., 2016; Droit-Volet and Berthon, 2017).

Two time perception theories; Pacemaker Accumulator Model (PAM: also known as the Scalar Expectancy Theory)(Gibbon et al. 1984) and the Striatal Beat Frequency Model (SB-FM)(Meck 1983, Meck and Church 1983) both highlight that time perception is influenced by arousal (Allman and Meck, 2012; Allman et al., 2014). PAM proposes that an internal clock judges time by collecting pacemaker pulses comparing the current information from the timing task to stored information from other timing tasks (Allman and Meck, 2012; Gibbon et al., 1984). The SB-FM is suggests that our internal timekeeping mechanism begins with dopamine release inducing groups of cortical neurons to reset, synchronize and begin oscillating (Allman and Meck, 2012, Matell and Meck, 2004). The rate of oscillatory activity determines how time is perceived in the brain. A greater frequency of either efferent (motor) or afferent (sensory) neural events (greater physiological arousal) 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 underestimate time intervals (Gill and Droit-

Volet, 2012). While these theories provide biologically plausible mechanisms, the exact neural basis for subjective time perception is still unknown (Wittmann, 2013).

Exercise is a form of physiological arousal and is thought to influence time perception. With muscular contractions, you can increase efferent motor unit recruitment and firing frequency (Behm 2004). 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 afferent 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. Processing increased frequencies of internal events such as increased heart rate, muscle activation (e.g., measured by electromyography (EMG)), thermoregulation and other physiological or external signals may distort time perception.

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 and Lehnhoff, 2005). According to Coelho et al. (2004), the internal clock speeds up with age, though Turgeon and 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 and 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 and Carter, 2020).

Hence, 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 (estimating the onset of a time interval such as 5-, 10-, 20- and 30-seconds) during exercise will be shorter than pre-trial/non-exercise time estimates in both cohorts (Edwards and McCormick, 2017; Hanson and Lee, 2020). It was also hypothesized that younger adults would be more accurate and less variable in their time estimation compared to older adults (Wittmann and Lehnhoff, 2005).

Methods

Participants

An “a priori” statistical analysis (G*power version 3.1.9.2,

Dusseldorf Germany) and the mean group differences and standard deviations from a pilot project (11 participants) was implemented to determine the appropriate number of subjects. Based on the mean difference between two dependent means (matched pairs) (t-test: test family) it was determined that approximately 15 participants were needed to achieve an alpha of 0.05, effect size of 0.5 (moderate magnitude) and a power of 0.8. Two cohorts of participants were recruited for this study. A sample of 14 healthy recreationally active (at least 150 minutes of moderate physical activity per week for at least the last year) older adults were recruited as participants for this study between April to September 2022. In addition, 19 healthy and recreationally active (as defined above) young adults (aged 18-30) were also recruited (Table 1). Exclusion criteria included an absence of knee and hip pain for the past six months when verbally queried by the researchers.

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 and consent form was emailed initially and then verbally explained to all participants upon arrival to the first session. Participants then completed the Physical Activity Readiness Questionnaire (Tremblay et al. 2011) and read and signed the informed consent form. All data was anonymized such that the researcher could not identify individuals when conducting the analyses. 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 (between 10 AM and 4 PM), with a minimum of two days between sessions to allow for muscle recovery (American College of Sports Medicine, 2014).

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. Upon arrival for both sessions, participants were first fitted with a heart rate monitor with heart rates 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 verbally provided to the participants. After the sixth trial, the learning phase was complete, and the participant’s heart rate and temper-

ature were recorded for the second time.

The EMG electrode skin 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 (68 Watts). When five minutes of cycling was completed, heart rate and temperature were taken for the third time.

One session consisted of the control and maximal voluntary isometric contractions (MVIC) (CON+MAX) conditions, and the other consisted of the 10% and 60% MVIC submaximal (SUBMAX) contractions (Figure 1). The two sessions were completed in a randomized order for all participants. An approximately 30-second, low intensity contraction (CON or 10% MVIC) was always combined and performed prior to a high intensity contraction (MAX or 60% MVIC) to ensure there were no fatigue effects upon the subsequent contraction. Height and mass were recorded at the beginning of the first session.

Participants were then instructed to sit in a chair (seat position horizontal to the floor and seatback perpendicular to seat) 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 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 (full knee extension = 180°, lower leg flexed perpendicular to upper leg = 90° knee flexion).

In order to calculate the maximal and submaximal (10% and 60%) contraction intensities to be used during the approximate 30-second time interval, participants initially performed 5-second 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 test-

ing 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 five 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 approximately (based on the participant's perception of 30-seconds) 30-second MVIC and 60% MVIC were the last components to be completed for each session in order to avoid fatigue effects upon the control and 10% MVIC respectively. The two sessions (SUBMAX and CON+MAX) were completed in random order. The protocol was similar to the learning phase completed at the beginning of each session. Participants were verbally informed that the timer had started. They would then prospectively estimate 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 approximately 30-second 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

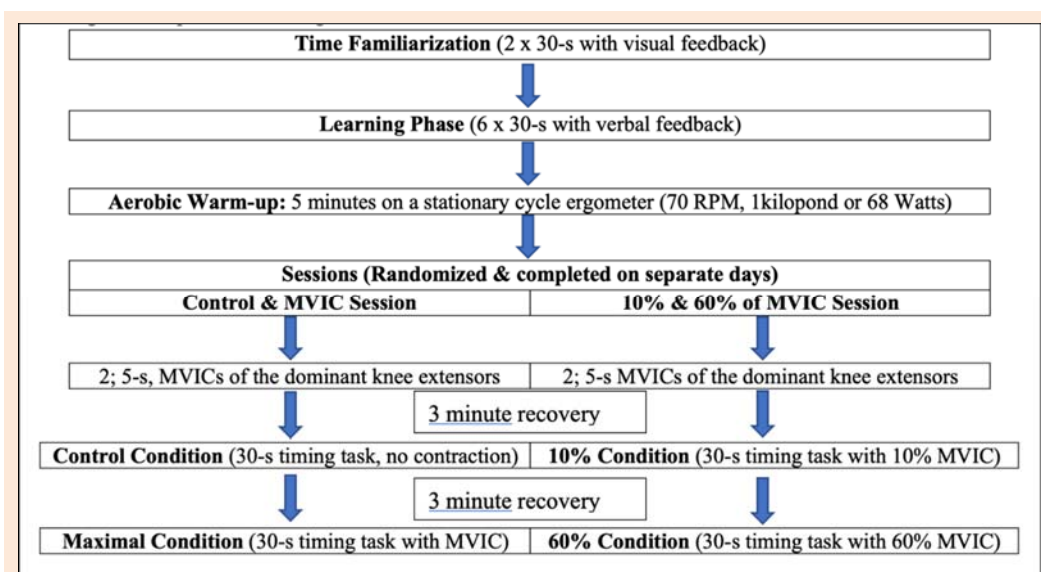


Figure 1. Experimental design. MVIC: Maximal Voluntary Isometric Contraction.

stopped and repeated again after two-minutes of rest. Once the timing protocols were completed, heart rate and temperature were taken one last time (Figure 1).

Measures

Measures of EMG, tympanic temperature and heart rate were used to monitor possible changes in physiological activity that might impact time estimates as proposed with PAM and SB-FM. EMG was used to measure muscle activity and the Borg Scale as a psychophysical measure of perceived exertion. The Mini-Mental State Exam (MMSE) (Folstein, 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 (tympanic) 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 EMG (s-EMG) was used in this study to record muscle activity of the dominant rectus femoris. Self-adhesive Cl/AgCl bipolar electrodes (Meditrace™ 130 ECG conductive adhesive electrodes, Syracuse, USA) were used in parallel with the muscle fibres and systematically placed according to “Surface Electromyography for the Non-Invasive Assessment of Muscles” (SENIAM) (Hermens et al., 1999) 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 (Hermens et al., 1999). 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 k Ω). 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.

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 and control condition. This value was recorded at the end of each 5-, 10-, 20-, and 30-second time estimates during all four 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 measures, 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 mixed three-way repeated measures ANOVA with a power of 0.8 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). Bonferroni post-hoc tests were conducted to detect significant main effect differences whereas, for significant interactions, Bonferroni post-hoc t-tests corrected for multiple comparisons (α -value divided by the number of analyses on the dependent variable) 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 2), the participants underestimated time significantly more in the MVIC (Mean Difference (MD) = -0.437-s, $p < 0.05$), 10% of MVIC (MD = -0.610-s, $p < 0.001$), and 60% of MVIC (MD = -0.763-s, $p < 0.001$) 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 2), the participants also underestimated time significantly more with the MVIC (20-s: MD = -2.117-s, $p < 0.001$, 30-s: MD = -3.255-s, $p < 0.001$) and 60% of MVIC conditions (20-s: MD = -2.463-s, $p < 0.01$, 30-s: MD = -4.790-s, $p < 0.001$) 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-s, $p < 0.01$) (Figure 2).

Within the control condition (Table 3), participants significantly underestimated time at the 5-second mark compared to the 10-second mark (MD = -0.514-s, $p < 0.01$). No other significant differences in time estimation were found for the control condition. For the MVIC condition (Table 3), participants significantly underestimated time more at the 20-second (MD = -1.312-s, $p < 0.001$) and 30-second mark (MD = -2.175-s, $p < 0.05$) 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 3), participants underestimated time significantly more at 30-seconds compared to 5-seconds (MD = -3.212-s, $p < 0.01$), at 20-seconds (MD = -1.571-s, $p < 0.01$) and 30-seconds (MD = -3.623-s, $p < 0.001$) compared to

10-seconds, and at 30-seconds compared to 20-seconds (MD = -2.052-s, $p < 0.05$). No significant effects were

found between Condition * Age, Time * Age, or Condition * Time * Age.

Table 2. Time estimates (in seconds).

Deviation from 5-Seconds		Control	MVIC*	10% MVIC***	60% MVIC***
Younger Adults	Mean	-0.154 ± 0.445	-0.376 ± 0.901	-0.651 ± 0.494	-0.472 ± 0.794
	d		0.33	1.06	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 ± .91	-1.08 ± 5.68	-4.35 ± 7.50
	d		0.30	0.02	0.63

Significance symbols illustrate Condition x Time interactions. There were no significant age effects. Mean ± standard deviation; Cohen's d effect size: d. * 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.

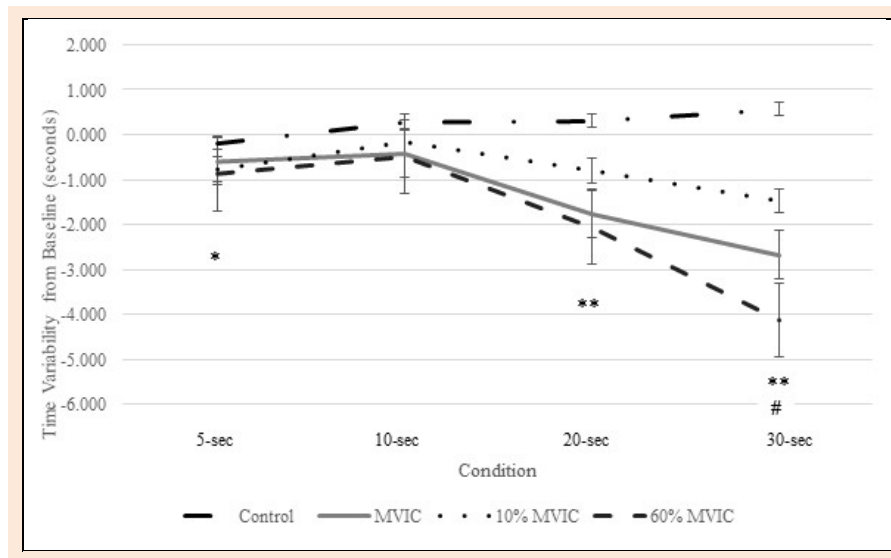


Figure 2. Mean time variability by condition.

* $p < 0.05$: 100% MVIC, 60% MVIC and 10% MVIC significantly different compared to control

** $p < 0.001$: 100% MVIC and 60% MVIC significantly different compared to control

$p=0.01$: 60% MVIC significantly different than 10% MVIC

Table 3. Time deviation from chronological time: Mean ± SD; (Cohen's d effect sizes compared to control) in seconds for each time interval.

	5*	10*	20	30
Control	-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-s, $p < 0.001$), 10% MVIC (MD = -1.081-s, $p < 0.05$), and 60% MVIC conditions (MD = -2.220-s, $p < 0.001$). No other significant interactions (condition x time estimation x age) were found (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-s, $p < 0.05$). Lastly, participants underestimated time more at 20-seconds (MD = -0.871-s, $p < 0.01$), and 30-seconds (MD = -1.688-s, $p < 0.05$) compared to the 10-second time estimate (Table 4). No significant differences in time estimation were found between the two age groups.

Table 4. Time deviation from chronological time: 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

*. ^X indicates $p < 0.05$ between corresponding conditions. ^Y indicates $p < 0.01$ between corresponding conditions. *: $d = 0.32$. ^X: $d = 0.52$. ^Y: $d = 0.37$

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: $m = 2.52 \pm 1.19$ mV and $m = 2.81 \pm 1.44$ mV, respectively) compared to the older cohort (OC) (first and last 5 seconds: $m = 1.12 \pm 0.836$ mV and $m = 1.34 \pm 0.949$ 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: $m = 1.94 \pm 1.21$ mV; OC: $m = 1.15 \pm 0.640$ mV) versus the last five-seconds ($X^2_{(1)} = 5.92$, $p < 0.05$, $\eta_p^2 = 0.17$; YC: $m = 1.99 \pm 1.11$ mV; OC: $m = 1.16 \pm 0.646$ mV) (Table 5). No significant age differences in EMG integral were evident for the 10% or 60% MVIC conditions (Table 5).

Fatigue index

No significant differences in Fatigue Index were found

Table 5. 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 ± 1.44Z
	Older cohort	1.12 ± 0.836*	1.34 ± 0.949Z
10% MVIC	Younger cohort	0.257 ± 0.154	0.273 ± 0.166
	Older cohort	0.228 ± 0.0914	0.261 ± 0.0913
60% MVIC ^Y	Younger cohort	1.94 ± 1.21	1.99 ± 1.11
	Older cohort	1.15 ± 0.640	1.16 ± 0.646

* indicates $p < 0.001$, ^Z indicated $p < 0.005$ ^Y indicates $p < 0.05$ for both the first and last-five seconds with data from both younger and older cohort combined. *: $d = 1.38$ ^Z: $d = 1.23$

Discussion

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 (estimated time was

between the younger and older cohorts.

Heart rate

A significant main effect for condition showed that the control condition exhibited lower heart rate (beats per min) (74.6 ± 10.6) than the maximal (91.6 ± 12.4), 60% MVIC (92.5 ± 13.8) or 10% MVIC (90.7 ± 13.5) conditions.

Tympanic temperature

There were no significant main effects or interactions revealed for tympanic temperature.

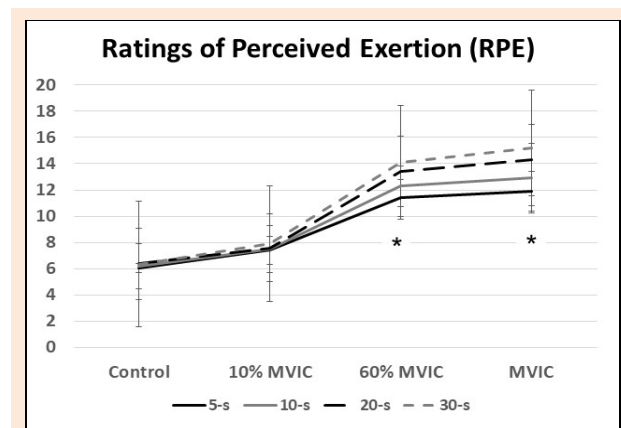


Figure 3. Ratings of Perceived Exertion (RPE). Asterisks indicate significant differences between each time point for the MVIC and 60% MVIC conditions.

Ratings of Perceived Exertion (RPE)

There were significant main effects for conditions ($F_{(3,84)} = 56.92$, $p < 0.0001$, $\eta_p^2 = 0.670$), time ($F_{(3,84)} = 51.05$, $p < 0.0001$, $\eta_p^2 = 0.646$), as well as significant condition x time interactions ($F_{(9,252)} = 11.56$, $p < 0.0001$, $\eta_p^2 = 0.292$). All conditions significantly ($p < 0.0001$) differed except for the MVIC (13.66 ± 4.67) and 60% MVIC (12.8 ± 2.8) conditions. The main effect for time revealed that overall, the RPE was perceived to be significantly greater with each time point ($p < 0.0001$). There were no significant RPE differences over time for the Control and 10% MVIC. However, each subsequent time point showed significantly ($p = 0.001$ to $p < 0.0001$) higher RPE scores with the MVIC and 60% MVIC conditions (Figure 3).

shorter than chronological time) across the different conditions compared to their chronological times (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 accord 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 and McCormick (2017) utilized cycling and had subjects estimate when 25%, 50%, 75%, and 100% of the trial was completed 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 and 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 and McCormick (2017) and Hanson and 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 PAM (Gibbon et al. 1984, Grondin, 2010; Allman and Meck, 2012). With the MVIC 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. RPE values were higher with the MVIC and 60% MVIC illustrating the increased exertion at higher contraction intensities. This negative sensation acts as a form of physiological arousal (Edwards and 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 and 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. According to the PAM, it is 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 and Gil, 2009, Hanson and Lee, 2020). With the distraction, the SB-FM 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 and Meck, 2004). Dopamine is directly involved with movement control as it modulates higher-order motor centers such as the basal ganglia with dopamine cells synapsing onto motoneurons' dopamine receptors (Schwarz and Peever 2011). 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 and McCormick (2017) only found distortions when they had to estimate when 75% and 100% of the exercise bout time had elapsed (30-s of Wingate and 1200-s on a rowing ergometer). In the present study, participants were instructed to squeeze a hand trigger to estimate 5-, 10-, 20-, and 30-seconds. 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 be amplified as the duration of the trial progresses. This effect was observed with 20-s and 30-s intervals demonstrating

greater underestimations than 10-s. However, it is interesting that subjects also underestimated time more at 5-seconds compared to 10-seconds (Figure 1). No other significant differences between times were found in the analysis. Edwards and McCormick (2017) found no deficits at 50% of total time (which corresponds to the 10-second estimate). However, their 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 and Lee (2020) utilized a similar protocol and found no differences between any of the time estimates. The finding that time estimates at 10-seconds were more accurate compared to 5-, 20-, and 30-seconds 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 and Lehnhoff, 2005). Coelho et al. (2004) suggested that with age, internal clock speeds up, such that older adults tend to underestimate time compared to younger adults. Nevertheless, their study was not exercise-related and the findings lost statistical significance when controlled for literacy. 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 underestimate 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). The SB-FM theory suggests that our internal timekeeping mechanism begins with a phasic release of dopamine from dopaminergic midbrain projections to the cortex and dorsal striatum at the onset of the “to-be-timed” interval (Matell and Meck, 2004). This causes groups of cortical neurons to reset, synchronize their firing, and begin oscillating at their respective periods in the dorsal striatum (Allman and Meck, 2012). These dopamine-reliant oscillating neurons are essentially the clock mechanism, and thus age-related declines could adversely affect senior’s time perception.

Interestingly, a review by Turgeon et al. (2016) concluded that alternative neural strategies 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 seniors rely more on the cortico-cerebellar and hippocampal regions which are recruited to the timing system and are less affected by aging (Meck, 2005; Merchant et al., 2013; Lusk et al., 2016). Furthermore, 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 and Wing, 2012). Such a threshold appears not to be reached in this study, meaning that the older adults were able to compensate for their potentially 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.

Furthermore, the older adults recruited for this study were quite educated (50% of participants had university-level education) and were physically active across the lifespan. Being physically (Hillman et al., 2008) and mentally (Coelho et al. 2004, Valenzuela and 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 familiarization session may not have been performing true MVICs and were contracting at a lower intensity during the protocols. There was no significant difference in RPE between the MVIC and 60% MVIC suggesting the participants experienced similar exertion levels with both conditions. With a prolonged MVIC, EMG would be expected to decrease over time due to derecruitment of motor neurons and attenuated rate coding (Behm 2004). However, EMG activity increased by 11.5% and 19.6% in the young and elderly participants respectively during the 30-second MVIC protocol (Table 5). This increase in muscle activity rather than decrease suggests that the participants may have subconsciously paced themselves in preparation for a 30-second MVIC and the older group paced (contracted at a lower relative contraction intensity) to a greater extent than the younger group. 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.

Increases in body temperature have been suggested to distort temporal perception (Pieron (1923; 1945), with small circadian increases (i.e., afternoon) inducing time overestimation (Hoagland 1933) or warm water immersion (38°C) leading to underestimation of time (van Maanen et al., 2019). Time underestimation was reported when core

temperature increased with running in a warm, humid environment (Tamm et al. 2015). However, there was no significant increase in body temperature in the present study. There was also no significant differences in heart rate between the experimental conditions with only the control condition experiencing lower heart rates. Thus, neither heart rate nor tympanic temperature were sensitive indicators of changes in arousal.

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. Furthermore, with between-subject comparisons (mixed ANOVA), it is possible that the analysis was not sufficiently powered to detect large effects between young and older adults. Finally, while the purpose of inquiring about RPE provided additional subjective exercise intensity information and additionally disrupt the participants' ability to estimate time by counting, it also constituted an additional task. However, as all conditions including the control condition had this task, it was a common independent variable.

Conclusion

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.

Acknowledgements

There is no conflict of interest. The present study complies with the current laws of the country in which it was performed. The datasets generated and analyzed during the current study are not publicly available but are available from the corresponding author, who was an organizer of the study.

References

Allman, M.J. and Meck, W.H. (2012) Pathophysiological distortions in time perception and timed performance. *Brain (London, England: 1878)* **135(3)**, 656-677.

- <https://doi.org/10.1093/brain/awr210>
- Allman, M.J., Teki, S., Griffiths, T.D. and Meck, W.H. (2014) Properties of the Internal Clock: First- and Second-Order Principles of Subjective Time. *Annual Review of Psychology* **65(1)**, 743-771. <https://doi.org/10.1146/annurev-psych-010213-115117>
- American College of Sports Medicine. (2014) *ACSM's guidelines for exercise testing and prescription*. Philadelphia, PA.: Lippincott, Williams and Wilkins, 26-73.
- Behm, D.G., and Carter, T.B. (2020) Effect of exercise-related factors on the perception of time. *Frontiers of Physiology*. **11**, 770. <https://doi.org/10.3389/fphys.2020.00770>
- Behm, D.G. (2004) Force maintenance with submaximal fatiguing contractions. *Canadian Journal of Applied Physiology* **29(3)**, 274-293. <https://doi.org/10.1139/h04-019>
- Bherer, L., Desjardins, S. and Fortin, C. (2007) Age-Related Differences in Timing With Breaks. *Psychology and Aging* **22(2)**, 398-403. <https://doi.org/10.1037/0882-7974.22.2.398>
- Block, R.A., Zakay, D. and Hancock P.A. (1999) Developmental Changes in Human Duration Judgments: A Meta-Analytic Review. *Developmental Review* **19(1)**, 183-211. <https://doi.org/10.1006/drev.1998.0475>
- Borg, G. Borg's (1998) perceived exertion and pain scales. *Human Kinetics Publishers*. pp. 12-18.
- Cheng, R.K., Tipples, J., Narayanan, N.S. and Meck, W.H. (2016) Clock speed as a window into dopaminergic control of emotion and time perception. *Timing Time and Perception*. **4(1)**, 254-261. <https://doi.org/10.1163/22134468-00002064>
- Coelho, M., Ferreira, J.J., Dias, B., Sampaio, C., Martins, I.P. and Castro-Caldas, A. (2004) Assessment of time perception: The effect of aging. *Journal of International Neuropsychology Society* **10(3)**, 332-341. <https://doi.org/10.1017/S1355617704103019>
- Cohen, J. (1988) *Statistical power analysis for the behavioral sciences*. Hillsdale, NJ: Erlbaum Publishers. pp. 24-36.
- Dormal, V., Heeren, A., Pesenti, M., and Maurage, P. (2017) Time perception is not for the faint-hearted? Physiological arousal does not influence duration categorisation. *Cognitive Processing* **19(3)**, 399-409. <https://doi.org/10.1007/s10339-017-0852-3>
- Droit-Volet, S. and Berthon, M. (2017) Emotion and implicit timing: The arousal effect. *Frontiers of Psychology* **8**, 176-176. <https://doi.org/10.3389/fpsyg.2017.00176>
- Droit-Volet, S. and Gil, S. (2009) The time-emotion paradox. *Philosophical Transactions of the Royal Society B: Biological Sciences* **364(1525)**: 1943-1953. <https://doi.org/10.1098/rstb.2009.0013>
- Edwards, A.M. and McCormick, A. (2017) Time perception, pacing and exercise intensity: maximal exercise distorts the perception of time. *Physiology and Behavior* **180**, 98-102. <https://doi.org/10.1016/j.physbeh.2017.08.009>
- Edwards, A.M. and Polman, R.C.J. (2013) Pacing and awareness: brain regulation of physical activity. *Sports Medicine* **43(11)**, 1057-1064. <https://doi.org/10.1007/s40279-013-0091-4>
- Effect size - a quick guide. (2022) SPSS tutorials Effect Size A Quick Guide Comments. (n.d.). Retrieved August 10, 2022, from [https://www.spss-tutorials.com/effect-size/#:~:text=ANOVA%20%2D%20\(Partial\)%20Eta%20Squared&text=%CE%B7%20%3D%200.01%20indicates%20a,0.14%20indicates%20a%20large%20effect](https://www.spss-tutorials.com/effect-size/#:~:text=ANOVA%20%2D%20(Partial)%20Eta%20Squared&text=%CE%B7%20%3D%200.01%20indicates%20a,0.14%20indicates%20a%20large%20effect).
- Einstein, A. (1905) Zur Elektrodynamik bewegter Körper. *Annalen der Physik* **17**, 891-893. <https://doi.org/10.1002/andp.19053221004>
- Folstein, M.F. (1975) "Mini-mental state." A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research* **12(3)**, 189-198. [https://doi.org/10.1016/0022-3956\(75\)90026-6](https://doi.org/10.1016/0022-3956(75)90026-6)
- Gibbon, J., Church, R.M. and Meck, W.H. (1984) Scalar Timing in Memory. *Annals of New York Academy of Science* **423**, 52-77. <https://doi.org/10.1111/j.1749-6632.1984.tb23417.x>
- Gil, S. and Droit-Volet, S. (2012) Emotional time distortions: The fundamental role of arousal. *Cognition and Emotion* **26(5)**, 847-862. <https://doi.org/10.1080/02699931.2011.625401>
- Grondin, S. (2010) Timing and time perception: A review of recent behavioral and neuroscience findings and theoretical directions. *Attention, Perception, Psychophysics* **72(3)**, 561-582. <https://doi.org/10.3758/APP.72.3.561>
- Hanson, N.J. and Lee, T.L. (2020) Time Flies When You're at RPE13: How Exercise Intensity Influences Perception of Time. *Journal of Strength and Conditioning Research* **34(12)**, 3546-3553.

- <https://doi.org/10.1519/JSC.0000000000002221>
- Hermens HJ, Merlatti R, and Freriks B. (1999) European recommendations for surface electromyography results of the SENIAM project. Enschede, Netherlands: Roessingh Research and Development, 24-83.
- Hillman, C., Erickson, K. and Kramer, A. (2008) Be smart, exercise your heart: exercise effects on brain and cognition. *Natural Reviews of Neuroscience* **9**, 58-65. <https://doi.org/10.1038/nrn2298>
- Hoagland, H. (1933) The physiological control of judgments of duration: Evidence of a chemical clock. *Journal of General Psychology* **9**, 267-287. <https://doi.org/10.1080/00221309.1933.9920937>
- Ivry, R.B., Keele, S.W. and Diener, H.C. (1988) Dissociation of the lateral and medial cerebellum in movement timing and movement execution. *Experimental Brain Research* **73**(1), 167-180. <https://doi.org/10.1007/BF00279670>
- Jual, E. and Barron, J. (2017) Age-Related Diseases and Clinical and Public Health Implications for the 85 Years Old and Over Population. *Frontiers of Public Health* **5**, 335-341. <https://doi.org/10.3389/fpubh.2017.00335>
- Lusk, N.A., Petter, E.A., MacDonald, C.J. and Meck, W.H. (2016) Cerebellar, hippocampal and striatal time cells. *Current Opinions in Behavioral Science* **8**, 186-192. <https://doi.org/10.1016/j.cobeha.2016.02.020>
- Matell, M.S. and Meck, W.H. (2000) Neuropsychological mechanisms of interval timing behavior. *Biological Essays* **22**(1), 94-103. [https://doi.org/10.1002/\(SICI\)1521-1878\(200001\)22:1<94::AID-BIES14>3.0.CO;2-E](https://doi.org/10.1002/(SICI)1521-1878(200001)22:1<94::AID-BIES14>3.0.CO;2-E)
- Matell, M.S. and Meck, W.H. (2004) Cortico-striatal circuits and interval timing: coincidence detection of oscillatory processes. *Cognitive Brain Research* **21**(2), 139-170. <https://doi.org/10.1016/j.cogbrainres.2004.06.012>
- Meck, W.H. (1983) Selective adjustment of the speed of internal clock and memory processes. *Journal of Experimental Psychology Animal Behavioral Processes* **9**(2), 171-201. <https://doi.org/10.1037/0097-7403.9.2.171>
- Meck, W.H. and Church, R.M. (1983) A mode control model of counting and timing processes. *Journal of Experimental Psychology Animal Behavioral Processes* **9**(3), 320-334. <https://doi.org/10.1037/0097-7403.9.3.320>
- Meck, W.H. (2005) Neuropsychology of timing and time perception. *Brain and Cognition* **58**(1), 1-8. <https://doi.org/10.1016/j.bandc.2004.09.004>
- Merchant, H., Harrington, D.L. and Meck, W.H. (2013) Neural basis of the perception and estimation of time. *Annual Review of Neuroscience* **36**(1), 313-336. <https://doi.org/10.1146/annurev-neuro-062012-170349>
- Oldfield, R.C. (1971) The assessment and analysis of handedness: Edinburgh Inventory. *Neuropsychologia* **9**, 97-113. [https://doi.org/10.1016/0028-3932\(71\)90067-4](https://doi.org/10.1016/0028-3932(71)90067-4)
- Peterson, A.C., Zhang, S., Hu, S., Chao, H. and Li, C-S.R. (2017) The Effects of Age, from Young to Middle Adulthood, and Gender on Resting State Functional Connectivity of the Dopaminergic Midbrain. *Frontiers of Human Neuroscience* **11**, 52-62. <https://doi.org/10.3389/fnhum.2017.00052>
- Pieron, H. (1945) The sensations: Their functions, processes and mechanisms. London: Muller Publishers. 126-148.
- Pieron, H. (1923) Les problemes psychophysiologiques de la perception du temps. *Annee Psychologie*. **24**, 1-25. <https://doi.org/10.3406/psy.1923.4475>
- Schwarz, P.B. and Peever, J.H. (2011) Dopamine triggers skeletal muscle tone by activating D1-like receptors on somatic motoneurons. *Journal of Neurophysiology* **106**, 1299-1309. <https://doi.org/10.1152/jn.00230.2011>.
- Tamm, M., Jakobson, A., Havik, M., Timpmann, S., Burk, A., Oopik, V., Allik, J. and Kreegipuu, K. (2015) Effects of heat acclimation on time perception. *International Journal of Psychophysiology* **95**, 261-269. <https://doi.org/10.1016/j.ijpsycho.2014.11.004>
- Tremblay M.S., Warburton D.E.R., Janssen I., Paterson D.H., Latimer A.E., Rhodes R., Kho M.E., Hicks A., LeBlanc A.G., Zehr L., Murumets K., and Duggan M. (2011) New Canadian Physical Activity Guidelines. *Applied Physiology, Nutrition and Metabolism* **36**, 36-46. <https://doi.org/10.1139/H11-009>
- Turgeon, M., Lustig, C. and Meck, W.H. (2016) Cognitive aging and time perception: roles of Bayesian optimization and degeneracy. *Frontiers of Aging Neuroscience* **8**, 102-112. <https://doi.org/10.3389/fnagi.2016.00102>
- Turgeon, M. and Wing, A.M. (2012) Late onset of age-related difference in unpaced tapping with no age-related difference in phase-shift error detection and correction. *Psychology and Aging* **27**(4), 115-120. <https://doi.org/10.1037/a0029925>
- Valenzuela, M.J. and Sachdev, P. (2006) Brain reserve and dementia: a systematic review. *Psychology and Medicine* **36**(4), 441-454. <https://doi.org/10.1017/S0033291705006264>
- van Maanen, L., van der Mij, R., van Beurden, M., Roijendijk, L., Kingma, B., Miletić, S. and van Rijn, H. (2019) Core body temperature speeds up temporal processing and choice behavior under deadlines. *Scientific Reports* **9**(1), 10053. <https://doi.org/10.1038/s41598-019-46073-3>
- Wittmann, M. (2013) The inner sense of time: how the brain creates a representation of duration. *Nature Reviews and Neuroscience* **14**(3), 217-223. <https://doi.org/10.1038/nrn3452>
- Wittmann, M. and Lehnhoff, S. (2005) Age effects in perception of time. *Psychology Reports* **97**(3), 921-935.

Key points

- Participants underestimated time when performing unilateral (dominant leg) isometric knee extension contractions compared to the control condition.
- Participants underestimated time more at 30-seconds in the 60% MVIC condition compared to 10% MVIC, which partially supports an intensity-dependent threshold where time begins to be impaired,
- Time was also underestimated time at 5-, 20-, and 30-seconds, but not at 10-seconds, which may be related to the familiarity with the ubiquitous 10-second countdowns that occur in society (e.g., New Year's eve, sports)
- These findings were independent of age.

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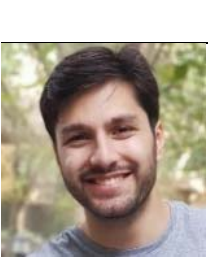

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