

UNIVERSITY OF CALGARY

An Unexpected Monetary Reward Enhances Endurance Exercise Performance but Results in  
Similar Isometric Neuromuscular Performance Fatigability Compared to a Non-Reward Session.

by

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A THESIS

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## Abstract

Extrinsic motivation via monetary reward incentivizes behavior. Data on how an incentivization encourages participants to push beyond their perceived limit are equivocal. This study aimed to determine if physically active, healthy, young adults could be influenced by an unexpected monetary reward to extend their time-to-task failure (TTF) cycling performance. Participants completed a control and reward TTF session in the heavy intensity domain of exercise (HVY<sub>TTF</sub>), and 1 min after, a TTF in the extreme domain (EXT<sub>TTF</sub>). The reward session involved an unexpected incentive offered 1 min before expected task failure during the HVY<sub>TTF</sub>. Neuromuscular (NM) assessments before and after the TTFs and the EXT<sub>TTF</sub> performance itself were used to evaluate performance fatigability. The unexpected incentive significantly increased the HVY<sub>TTF</sub> (46±16 min, 53±22 min;  $p = 0.01$ ) and reduced the EXT<sub>TTF</sub> (68±17 s, 57±17 s;  $p = 0.03$ ). Isometric NM assessments showed no condition effect or interactions. Significant time effects from baseline compared to post-HVY<sub>TTF</sub> and post-EXT<sub>TTF</sub> existed, respectively, for: *i*) IMVC: control, 601N, 414N, 413N ( $p < 0.001$ ); reward, 616N, 418N, 415N ( $p < 0.001$ ); *ii*) Db<sub>10:100</sub>: control, 0.99, 0.73, 0.70 ( $p < 0.001$ ); reward, 1.00, 0.74, 0.72 ( $p < 0.001$ ); and *iii*) Qtw<sub>pot</sub>: control, 177N, 109N, 110N ( $p < 0.001$ ); reward, 174N, 110N, 99N ( $p < 0.001$ ). VA showed no time effect from baseline to post-HVY<sub>TTF</sub> and post-EXT<sub>TTF</sub>: control, 90%, 90%, 87%; reward, 89%, 86%, 84%, respectively. These findings indicate that a monetary reward that increased the HVY<sub>TTF</sub> resulted in a reduced EXT<sub>TTF</sub>. The reduced performance during the dynamic task was not captured by isometric NM assessments.

## **Preface**

This thesis is original, unpublished, independent work by Mackenzie Trpcic, Pablo Fleitas-Paniagua, Rafael de Almeida Azevedo, Danilo Iannetta, Jalal Aboodarda, and Juan Murias. The research conducted, presented, and discussed in Chapters III-V was approved by Ethics Certification REB21-1855 issued by the University of Calgary Conjoint Health Ethics Board for the project “An unexpected monetary reward enhances endurance exercise performance but results in similar isometric neuromuscular performance fatigability compared to a non-reward session”.

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## List of Symbols, Abbreviations, & Nomenclature

<b>Abbreviation</b>	<b>Definition</b>
TT	Time trial
TTF	Time-to-task failure
HVY <sub>TTF</sub>	Time-to-task failure in the heavy intensity domain of exercise
EXT <sub>TTF</sub>	Time-to-task failure in the extreme intensity domain of exercise
NM	Neuromuscular
NMF	Neuromuscular fatigue
ITT	Interpolated twitch technique
MVC	Maximal voluntary contraction
IMVC	Isometric maximal voluntary contraction
PNS	Peripheral nerve stimulation
SIT	Superimposed twitch
VA	Voluntary activation
Db <sub>10</sub>	Low-frequency doublet
Db <sub>100</sub>	High-frequency doublet
Db <sub>10:100</sub>	Low-to-high frequency doublets ratio
Qtw <sub>pot</sub>	Single potentiated twitch
M-wave	Muscle compound action potential
M <sub>max</sub>	Muscle compound action potential amplitude
EMG	Electromyographical signal
rms	Root mean square
rmsEMG	Root mean square of the electromyographical signal
rmsEMG · M <sub>max</sub> <sup>-1</sup>	Root mean square of the electromyographical signal normalized to the corresponding muscle compound action potential amplitude
LFF	Low frequency fatigue
ECC	Excitation-contraction coupling
SR	Sarcoplasmic reticulum
NM <sub>BSL</sub>	Isometric NM assessments at baseline
NM <sub>HVY</sub>	Isometric NM assessments 30 s post-HVY <sub>TTF</sub>
NM <sub>EXT</sub>	Isometric NM assessments 30 s post-EXT <sub>TTF</sub>
VL	Vastus lateralis
RF	Rectus femoris
BF	Biceps femoris
Fatigue	Global fatigue
Pain	Exercising leg pain
RPE	Rating of perceived effort
RPE <sub>max</sub>	Maximal rating of perceived effort
Dyspnea	Intensity of breathlessness
RI	Ramp-incremental
SI	Step-incremental
SRS	Step-ramp-step
LT	Lactate threshold
GET	Gas exchange threshold
RCP	Respiratory compensation point

MMSS	Maximal metabolic steady state
MLSS	Maximal lactate steady state
CP	Critical power
LT2	Lactate turn point
MRT	Mean response time
MOD	Moderate intensity step-transition
HVY	Heavy intensity step-transition
PO	Power output
PO <sub>peak</sub>	Peak power output
$\dot{V}O_2$	Oxygen consumption
$\dot{V}O_{2SC}$	Slow component of oxygen uptake
$\dot{V}O_{2max}$	Maximal oxygen consumption
[La <sup>-</sup> ] <sub>b</sub>	Blood lactate concentration
[La <sup>-</sup> ] <sub>bmax</sub>	Maximal blood lactate concentration
HR	Heart rate
RER	Respiratory exchange ratio
$\dot{V}_E$	Ventilation
$\dot{V}CO_2$	Carbon dioxide output
P <sub>et</sub> O <sub>2</sub>	End tidal pressure of oxygen
P <sub>et</sub> CO <sub>2</sub>	End tidal pressure of carbon dioxide
$\dot{V}_E/\dot{V}O_2$	Ventilatory equivalent ratio of oxygen
$\dot{V}_E/\dot{V}CO_2$	Ventilatory equivalent ratio of carbon dioxide
O <sub>2</sub>	Oxygen
CO <sub>2</sub>	Carbon dioxide
N <sub>2</sub>	Nitrogen
ATP	Adenosine triphosphate
[ATP]	Concentration of adenosine triphosphate
[PCr]	Concentration of phosphocreatine
[Pi]	Concentration of inorganic phosphate
[H <sup>+</sup> ]	Concentration of hydrogen ions
[K <sup>+</sup> ]	Concentration of potassium ions
Ca <sup>2+</sup>	Calcium ion
HVY <sub>SIGNAL</sub>	During the HVY <sub>TTF</sub> , the time from conclusion of baseline to the 1 min signal
HVY <sub>FINAL</sub>	During the HVY <sub>TTF</sub> , the time from conclusion of baseline to task failure
EXT <sub>FINAL</sub>	During the EXT <sub>TTF</sub> , the time from conclusion of baseline to task failure
Δ	Change in
HVY <sub>signal</sub>	During the HVY <sub>TTF</sub> , averaged values in the 30 s prior to giving the 1 min signal
HVY <sub>end</sub>	During the HVY <sub>TTF</sub> , averaged values in the final 30 s prior to task failure
EXT <sub>peak</sub>	During the EXT <sub>TTF</sub> , averaged values in the final 20 s prior to task failure
ANOVA	Analysis of variance
η <sup>2</sup>	Partial eta squared
SD	Standard deviation
B-H	Benjamini-Hochberg

## Chapter I: Introduction

Any type of exercise that is prolonged and/or intense enough will eventually result in the development of fatigue (Ament & Verkerke, 2009; Iannetta, Zhang, et al., 2022). Whereas performing activities of daily living or typical exercise training sessions will not result in an amount of accrued fatigue high enough to induce task disengagement, during activities performed to task failure, the ability to tolerate the symptoms of fatigue will be a key determinant of exercise performance (Poole et al., 2016; Thomas et al., 2018). In addition to using exercise training interventions to increase one's ability to prolong exercise performance, different interventions can be used to manipulate exercise tolerance. For example, factors such as mental fatigue, self-talk, music, carbohydrate mouth-rinsing, amongst others, have presented variable effects on acute exercise performance (Atkinson et al., 2004; Barwood et al., 2015; Bavaresco Gambassi et al., 2019; Blanchfield et al., 2013; Brownsberger et al., 2013; Cabral et al., 2023; Filipas et al., 2019; Hagen et al., 2013; Hardy et al., 2019; Marcora et al., 2009; Nakamura et al., 2010; Van Cutsem et al., 2017). Furthermore, deceitful techniques (e.g., blinding participants regarding an exercise endpoint) have been shown to improve exercise performance, demonstrating that an exercise reserve may exist (Ansdell et al., 2019; Faulkner et al., 2011; Halperin et al., 2014; Jones et al., 2013; Marcora et al., 2009).

The use of a monetary reward as an ergogenic aid to prolong cycling endurance exercise has not been shown to have a statistically significant influence on overall exercise performance (Hulleman et al., 2007; Skorski et al., 2017). These somewhat counterintuitive results might be explained by the fact that the exercise task used was a time trial (TT) (Hulleman et al., 2007; Skorski et al., 2017) and, therefore, pacing might have acted as a confounding variable that affected performance outcomes. Further, when a TT is performed and, simultaneously, a reward

is not blindly administered, it is difficult to determine how pacing acts in conjunction with the motivation to influence exercise behavior. Thus, further research is necessary to assess whether a monetary incentive can improve exercise performance allowing participants to continue exercising beyond a previously perceived limit tolerance.

The factors that control why an individual withdraws from a task are a topic of constant debate (Weavil & Amann, 2019), with components of performance and perceived fatigability interacting to determine task disengagement (Enoka & Duchateau, 2016). From a performance fatigability perspective, neuromuscular (NM) fatigue (NMF) can be measured objectively by examining reductions in isometric maximal voluntary contraction (IMVC) and assessing whether such reductions are due to mechanisms located above (central fatigue) or below (peripheral fatigue) the NM junction (Millet et al., 2011) by delivering brief electrical stimulations during and after the IMVC, respectively (Millet et al., 2011). Another way of measuring performance fatigability relies on the completion of a performance trial (e.g., a time-to-task failure (TTF)) that can be compared under different experimental conditions. Interestingly, measures of performance fatigability quantified isometrically or dynamically often do not elicit similar fatigability outcomes (Krüger et al., 2019), highlighting the task specificity of the physiological mechanisms underpinning task failure (Thomas et al., 2018). From a perceived fatigability perspective, subjective outcomes are commonly measured by rating of perceived effort (RPE) responses during exercise (Hureau et al., 2016; Thomas et al., 2018). It is believed that the combined effects of exercise-induced performance and perceived fatigability contribute to the achievement of a sensory tolerance limit that eventually results in task failure (Hureau et al., 2016; Thomas et al., 2018).

An important aspect to consider when evaluating performance and perceived fatigability is the combined effects of exercise intensity and duration on the evaluated responses (Fullerton et al., 2021; Iannetta, Zhang, et al., 2022). For instance, although it is accepted that any intensity of exercise will result in task failure if sufficient time is allowed, different lines of evidence demonstrate that central and peripheral factors of performance and perceived fatigability fluctuate depending on exercise intensity domain-specific metabolic responses that affect the intracellular metabolic milieu and determine whether homeostasis is attainable (Azevedo et al., 2021; Black et al., 2017; Fullerton et al., 2021; Iannetta, Inglis, et al., 2018; Jones et al., 2008; Vanhatalo et al., 2016; Whipp & Wasserman, 1972). Specifically, during activities to task failure, it has been shown that whereas peripheral aspects of fatigue were progressively increasing during exercise going from moderate- to heavy- to severe- and extreme- intensity domains, central components of fatigue were not distinctively affected by the exercise intensity domain (Iannetta, Zhang, et al., 2022). Furthermore, perceived fatigability was differently affected by the metabolic disruption (i.e., exercise intensity domain) of the activity (Iannetta, Zhang, et al., 2022). Thus, understanding the metabolic disruptions generated by the exercise is essential to appropriately standardize the evaluations of fatigue.

The main objective of this thesis was to determine if physically active, healthy, young adults could be influenced by an unexpected monetary reward to increase their exercise performance by prolonging their time-to-task failure (TTF) in the heavy intensity domain of exercise (HVY<sub>TTF</sub>). Simultaneously, this thesis assessed the effects of an unexpected monetary incentive on: *i*) performance fatigability using an isometric NM assessment after the HVY<sub>TTF</sub>; *ii*) performance fatigability using both a dynamic assessment following the HVY<sub>TTF</sub> by evaluating a TTF in the extreme domain (EXT<sub>TTF</sub>) and an isometric NM assessment following the EXT<sub>TTF</sub>;

*iii)* perceived fatigability during the HVY<sub>TTF</sub> and immediately following the EXT<sub>TTF</sub>. It was hypothesized that an unexpected monetary incentive would allow participants to significantly extend their HVY<sub>TTF</sub> performance, which would result in: *i)* similar significant decreases in isometric evaluations of NM function after the HVY<sub>TTF</sub>; *ii)* significant reductions in the duration of the EXT<sub>TTF</sub> performance with no changes in the subsequent isometric evaluations of NM function; *iii)* similar progressive increments in perceived fatigability up until the point of the 1 min signal (i.e., the announcement of the reward) and following the EXT<sub>TTF</sub>.

Following Chapter I, Chapter II entails a review of literature to scrutinize our current understanding of topics related to the effect(s) of a monetary reward on cycling endurance exercise performance. Chapter III contains the methodology utilized in the investigation of how an unexpected monetary reward enhances endurance exercise performance but results in similar isometric NM performance fatigability compared to a non-reward session. Chapter IV demonstrates the results while Chapter V discusses them. Chapter VI offers conclusions, limitations and methodological considerations, and future directions.

## Chapter II: Literature Review

When performing an exercise bout, no matter the exercise intensity domain, reaching a point at which people stop exercising (i.e., task failure) is inevitable. The reasons for this occurrence are not well understood but are generally attributed to the development of a level of fatigue that ultimately restricts further exercise (Ament & Verkerke, 2009; Iannetta, Zhang, et al., 2022). The mechanisms eliciting fatigue originate at the central level (i.e., above the NM junction) and peripheral level (i.e., below the NM junction) and can be further divided into either performance or perceived fatigability (Enoka & Duchateau, 2016; Iannetta, Zhang, et al., 2022; Micklewright et al., 2017). Importantly, how central and peripheral performance and perceived fatigability interact vary according to the metabolic perturbations generated by the specific bout of exercise, which are dependent on duration and intensity (Iannetta, Zhang, et al., 2022; Thomas et al., 2016). As such, understanding and standardizing the metabolic load elicited by the exercise intervention is important for a proper evaluation of fatigue.

Although several factors have been shown to affect exercise performance (e.g., mental fatigue, self-talk, music, carbohydrate mouth-rinsing, amongst others) (Atkinson et al., 2004; Barwood et al., 2015; Bavaresco Gambassi et al., 2019; Blanchfield et al., 2013; Brownsberger et al., 2013; Cabral et al., 2023; Filipas et al., 2019; Hagen et al., 2013; Hardy et al., 2019; Marcora et al., 2009; Nakamura et al., 2010; Van Cutsem et al., 2017), data on the factors that determine task failure are equivocal. Notably, extrinsic motivation via monetary reward has been investigated to determine its effectiveness as a means of enhancing endurance exercise performance, however, the exercise task was a TT which allowed for pacing and the reward was not offered blindly so, as a result, it is difficult to ascertain how exercise outcomes were impacted (Hulleman et al., 2007; Skorski et al., 2017). Nevertheless, different methods of

deception (e.g., blinding participants regarding an exercise endpoint) have demonstrated the capacity of altering exercise performance (Ansdell et al., 2018; Ducrocq et al., 2017; Faulkner et al., 2011; Halperin et al., 2014; Konings et al., 2018; Marcora et al., 2009), highlighting the likely existence of an exercise reserve when it comes to exercise tolerance and the way in which a bout of exercise can be prolonged.

## **2.1. An Evaluation of Fatigue and Related Concepts**

### ***2.1.1. Definition of fatigue***

Fatigue is defined as a disabling symptom in which physical and cognitive function is limited by interactions between its attributes: *i*) performance fatigability and *ii*) perceived fatigability (Azevedo et al., 2021; Enoka & Duchateau, 2016). Fatigability is understood as the capacity to accumulate exercise-induced fatigue. Performance fatigability is quantified by objective measures of performance (e.g., an decline in maximal voluntary force, power, or endurance for a given task) (Enoka & Duchateau, 2016; Kluger et al., 2013) while perceived fatigability is represented by changes in the sensations that regulate the intensity of the performer (Azevedo et al., 2021; Enoka & Duchateau, 2016). Performance fatigue and perceived fatigue, in combination, determine task failure which is accompanied by the achievement of a sensory tolerance limit (Hureau et al., 2016; Thomas et al., 2018). The development of exercise-induced fatigue depends on population characteristics, as well as the specific exercise task being performed in the investigation (Ansdell et al., 2019, 2020; Thomas et al., 2018) and immediately upon exercise termination, it begins a gradual recovery process (Doyle-Baker et al., 2018; Kluger et al., 2013).

### ***2.1.2. Neuromuscular attributes of performance fatigability***

NMF is determined by central and peripheral components, occurring above and below the NM junction, respectively (Azevedo et al., 2021; Millet et al., 2011; Weavil & Amann, 2019). The interpolated twitch technique (ITT) is commonly used to evaluate NMF as it is considered the gold-standard for identifying central and peripheral fatigue (Enoka & Duchateau, 2016; Kluger et al., 2013). The ITT involves an isometric maximal voluntary contraction (IMVC) that lasts 5 s, accompanied by a peripheral nerve stimulation (PNS) delivered both during the voluntary contraction (i.e., superimposed twitch (SIT)) and after.

A semi-quantitative measure of the level of voluntary activation (VA) during an IMVC enables an estimation of central fatigue (Taylor, 2009). Specifically, if the IMVC demonstrates a SIT that elicits additional force, the VA is labelled incomplete and may indicate either submaximal muscle recruitment (i.e., at baseline) or the presence of central fatigue. A further increase in force production during the SIT indicates that some motor units were either not recruited or not firing at a rate quick enough to allow for fused contractions (Taylor & Gandevia, 2008). Nonetheless, there remains debate regarding the exact mechanisms underpinning VA limitations (Dotan et al., 2021).

An indirect estimation of peripheral fatigue is achieved by means of electrically evoked contractions of various frequencies, specifically by the measuring amplitudes (Jones, 1996; Millet et al., 2011; Verges et al., 2009). Variables of peripheral fatigue utilize electrically evoked forces from potentiated (i.e., after IMVC) high- and low-frequency doublets (i.e., 100 Hz ( $Db_{100}$ ) and 10 Hz ( $Db_{10}$ ), respectively), along with single potentiated twitch ( $Q_{tw_{pot}}$ ) (Doyle-Baker et al., 2018; Hureau et al., 2016; Millet et al., 2012; Twomey et al., 2017; Verges et al., 2009). The low-to-high frequency doublets ratio (i.e.,  $Db_{10:100}$ ) and  $Q_{tw_{pot}}$  likely represent the excitation-

contraction coupling (ECC) failure (Millet et al., 2012). The muscle compound action potential (M-wave) amplitude ( $M_{\max}$ ) is quantified as the peak-to-peak amplitude and/or area of the electromyographical signal (EMG) of the  $Q_{tw_{pot}}$  (Krüger et al., 2020; Rodriguez-Falces & Place, 2018). It offers insight pertaining to the neuromuscular transmission/action potential propagation (Twomey et al., 2017) and helps determine any changes in sarcolemma excitability during a contraction (Rodriguez-Falces & Place, 2021). In addition, the maximal root mean square (rms) of the EMG (rmsEMG) measured in the initial 500-ms of force plateau during the IMVC can be normalized to the corresponding  $M_{\max}$  ( $\text{rmsEMG} \cdot M_{\max}^{-1}$ ) for assessing maximal central motor drive (i.e., corollary discharges) (Hureau et al., 2016). Importantly, regarding the above peripheral fatigue variables, there is sensitivity to changes in exercise duration and intensity (Azevedo et al., 2019, 2021; Brownstein et al., 2021; Thomas et al., 2015, 2016).

### ***2.1.3. Perceived fatigability***

An evaluation of perceived fatigability is achieved by way of an initial perceptual response provided by an individual, combined with the rate of change of this response based on their psychological state (Renfree et al., 2014; Smits et al., 2014). It is during a bout of exercise that perceptual scales can be used to record responses indicating the fluctuations of internal signals (i.e., global fatigue (Fatigue), exercising leg pain (Pain), RPE, and intensity of breathlessness (Dyspnea)) (Kluger et al., 2013). These scales are indicative of discrete psychological constructs that are generated by the integration of feedback, feedforward, and emotional mechanisms and/or the brain processing (Iannetta, Zhang, et al., 2022). Fatigue ratings are reflective of context-independent integrations of physiological, neurobiological, and motivational alterations (Micklewright et al., 2017). Pain ratings offer a reflection of type III/IV nociceptive feedback activity resulting from exercise-induced muscle metabolic perturbations

(Pollak et al., 2014). RPE ratings have been a reliable indicator of perceived fatigability (Kluger et al., 2013) with peak values linked to task failure (Faulkner et al., 2008) and therefore, an achievement of a sensory tolerance limit (Hureau et al., 2016; Thomas et al., 2018). More specifically, RPE ratings reflect the activity of premotor/motor brain regions that drive motoneurons which innervate exercising muscles (i.e., corollary discharge) (Marcora, 2019). Dyspnea ratings quantify the integration of stimuli from respiratory centers located in the brainstem, corollary discharge (reflective of central motor drive to respiratory muscles), and afferent feedback from respiratory muscles (Laviolette & Laveneziana, 2014).

## **2.2. The Exercise Intensity Domains and Corresponding Thresholds: Metabolic Responses and Fatigue Development**

Whipp and colleagues (Whipp & Wasserman, 1972) were the first to propose the domains schema to describe domain-specific metabolic responses. Subsequently, several authors have described how exercising within these domains affect exercise tolerance (Black et al., 2017; Fullerton et al., 2021; Iannetta, Inglis, et al., 2018; Jones et al., 2008; Vanhatalo et al., 2016). The identification of two distinct thresholds (i.e., gas exchange threshold (GET) and respiratory compensation point (RCP)) during a ramp-incremental (RI) cycling test enables the categorization of exercise into exercise intensity domains (i.e., moderate, heavy, and severe) (Gaesser & Poole, 1996; Whipp, 1996; Whipp et al., 2002). The GET separates the moderate intensity domain of exercise from the heavy intensity domain (Whipp et al., 1982). The RCP is used to identify the metabolic rate that separates the heavy intensity domain of exercise from the severe domain (Keir, Pogliaghi, et al., 2018). Each of the above exercise intensity domains elicits predictable physiological responses (Black et al., 2017; Boone & Bourgois, 2012; Fullerton et al., 2021; Gaesser & Poole, 1996; Keir et al., 2022; Poole & Jones, 2012).

### ***2.2.1. The moderate intensity domain of exercise***

Within the moderate intensity domain of exercise, constant-load exercise can be sustained for very long periods of time, often in the vicinity of 4 hrs (Black et al., 2017). Within this domain, the oxygen uptake ( $\dot{V}O_2$ ) increases monoexponentially and quickly reaches steady state within 2 to 3 min (Barstow et al., 1993). The rapid achievement of  $\dot{V}O_2$  steady state and limited metabolic disturbance results in minimal disruption of the biochemical equilibrium within the exercising muscle cells, which almost exclusively rely on oxidative phosphorylation to support adenosine triphosphate (ATP) resynthesis (Ament & Verkerke, 2009; Black et al., 2017; Carter et al., 2002; Fullerton et al., 2021; Iannetta, Inglis, Mattu, et al., 2020; Jones et al., 2011; Özyener et al., 2001). Consequently, the blood lactate concentration ( $[La^-]_b$ ) slightly rises but quickly returns to its baseline concentrations as the body balances its rate of appearance and disappearance mainly through oxidation (Fullerton et al., 2021; Ghosh, 2004; Özyener et al., 2001). The development of NMF in this domain in comparison to other domains is characterized by minor changes in peripheral fatigue in relation to baseline, and if task duration is extensively prolonged (i.e.,  $\geq 2$  hrs), there is a progressive increase in central fatigue and perceived fatigability (Millet, 2011; Burnley et al. 2012).

### ***2.2.2. The lactate threshold and gas exchange threshold***

Although different terms can be used to define the threshold that separates the moderate from the heavy intensity domain of exercise, the most widely used are the lactate threshold (LT) and the GET. Although once this threshold is surpassed a slow component of oxygen uptake ( $\dot{V}O_{2sc}$ ) begins to develop,  $[La^-]_b$  starts to elevate beyond baseline values, and metabolite perturbations increase to affect the mechanical machinery of the muscle cell, all these responses

can eventually stabilize provided that the next exercise intensity boundary is not transcended (Ament & Verkerke, 2009; Keir et al., 2016).

While both the LT and GET are synonymous, they are independently measured. To estimate the LT, a step-incremental (SI) cycling test typically comprised of 3-5 min long stages is performed, with  $[La^-]_b$  assessments completed at the end of each stage and prior to an increase of the power output (PO). Using this approach, the LT is identified as the initial systematic rise in  $[La^-]_b$  above baseline values (Faude et al., 2009). The  $\dot{V}O_2$  at the GET is best estimated by way of RI or short (i.e., 1 min) SI cycling tests whereby the  $\dot{V}O_2$  is plotted against the raw profiles of the carbon dioxide output ( $\dot{V}CO_2$ ), respiratory exchange ratio (RER), ventilation ( $\dot{V}_E$ ), ventilatory equivalent ratio of oxygen ( $\dot{V}_E/\dot{V}O_2$ ), end tidal pressure of carbon dioxide ( $P_{et}CO_2$ ), ventilatory equivalent ratio of carbon dioxide ( $\dot{V}_E/\dot{V}CO_2$ ), and end tidal pressure of oxygen ( $P_{et}O_2$ ) (Keir et al., 2022). The  $\dot{V}O_2$  at GET can be identified as the point at which the  $\dot{V}CO_2$  starts to rise disproportionately with respect to the  $\dot{V}O_2$  (V-slope method) concomitantly with a first breakpoint in the  $\dot{V}_E/\dot{V}O_2$  and  $P_{et}O_2$ , whereas  $P_{et}CO_2$  and  $\dot{V}_E/\dot{V}CO_2$  remain stable (Keir et al., 2022) (see Figure 2.2.4.).

### ***2.2.3. The heavy intensity domain of exercise***

In the heavy intensity domain of exercise, the exercise performed in the upper boundary can be maintained for approximately 60 min and task failure is associated with intermediate (i.e., greater than the moderate intensity domain of exercise but less than the severe domain) changes in muscle metabolic perturbation (Black et al., 2017). Specifically, the initiation of exercise within this domain triggers an increase in  $[La^-]_b$ , and the development of the so-called  $\dot{V}O_{2sc}$  (Jones et al., 2011; Whipp, 1994). The  $\dot{V}O_{2sc}$  is crucial in the investigation of endurance exercise tolerance (Jones et al., 2011). Above the GET or LT, the  $\dot{V}O_{2sc}$  affects the  $\dot{V}O_2$  amplitude,

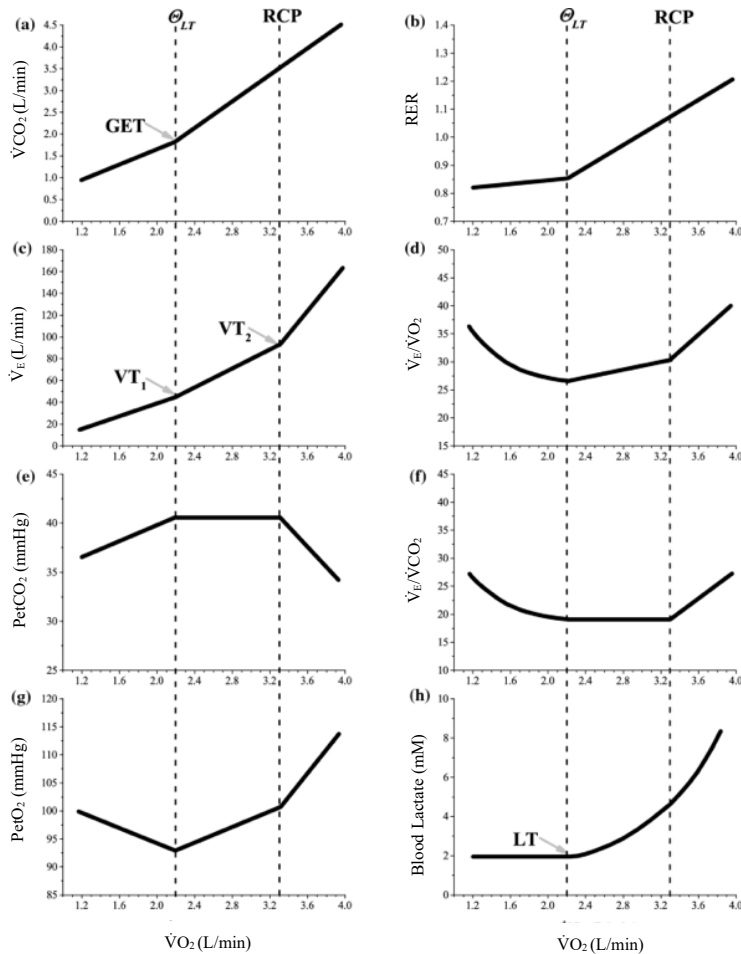
causing a delay in the achievement of steady state, which can take as long as approximately 10-15 min to occur (Barstow & Mole, 1991; Keir et al., 2016; Paterson & Whipp, 1991). Therefore, during a constant-PO bout of exercise within the heavy intensity domain, the  $\dot{V}O_{2sc}$  must be considered to accurately estimate the  $\dot{V}O_2$  steady state (Keir et al., 2016; Paterson & Whipp, 1991). In terms of its mechanistic basis, the  $\dot{V}O_{2sc}$  is thought to be localized within the exercising limbs and arises predominantly due to a: *i*) reduced efficiency of skeletal muscle contraction and/or mitochondrial energy production; *ii*) delayed but evolving and progressive recruitment of the less efficient fast-twitch (type II) muscle fibers (Jones et al., 2011; Keir et al., 2016; Krstrup et al., 2004; Poole et al., 1991; Poole & Jones, 2017; Shinohara & Moritani, 1992). Furthermore, compared to muscle metabolic perturbations in the moderate intensity domain of exercise, in the heavy domain there exists a continuous decline in the concentration of high-energy phosphates (i.e., [ATP] and phosphocreatine ([PCr])) along with an increase in the concentration of fatigue-related metabolites (i.e., inorganic phosphate ([Pi]), hydrogen ions ([H<sup>+</sup>]), and potassium ions ([K<sup>+</sup>])) (Black et al., 2017; Fullerton et al., 2021; Iannetta, Zhang, et al., 2022). Following some delays, a new steady state is achieved (Jones et al., 2011; Whipp, 1994) but the process of this metabolic homeostasis is still likely associated with the development of peripheral fatigue. In particular, [Pi] affects skeletal muscle force production by altering calcium ion (Ca<sup>2+</sup>) handling (Hureau et al., 2022); also, a diminishing store of glycogen localized within the myofibrils causes a reduction in sarcoplasmic reticulum (SR) Ca<sup>2+</sup> release (Ørtenblad et al., 2013). In comparison to the development of NMF during exercise performed within the moderate intensity domain of exercise, exercise within the heavy domain is often characterized by a greater development of peripheral fatigue and perceived fatigability (Burnley et al., 2012; Iannetta, Zhang, et al., 2022; Thomas et al., 2016).

#### ***2.2.4. The maximal metabolic steady state***

The maximal metabolic steady state (MMSS) represents the highest metabolic rate at which exercise can be maintained almost exclusively by oxidative metabolism (Iannetta, Inglis, Pogliaghi, et al., 2020; Keir, Pogliaghi, et al., 2018). There are several different approaches that can be used to evaluate the MMSS, including the maximal lactate steady state (MLSS) (Heck et al., 1985; Iannetta, Fontana, et al., 2018; Inglis et al., 2019; Keir, Pogliaghi, et al., 2018), critical power (CP) (Keir, Pogliaghi, et al., 2018; Mattioni Maturana et al., 2018), lactate turn point (LT2) (Caen et al., 2021; Keir et al., 2022), and the respiratory compensation point (RCP) (Iannetta, Inglis, Pogliaghi, et al., 2020; Keir, Paterson, et al., 2018; Keir, Pogliaghi, et al., 2018). Although the MLSS and CP are likely the most precise approaches to evaluate the work rate associated with MMSS, they require several visits to the lab and, in the case of CP, maximal efforts (Heck et al., 1985; Iannetta, Fontana, et al., 2018; Iannetta, Ingram, et al., 2022; Mattioni Maturana et al., 2018; Poole et al., 1988). Then, the MMSS can be estimated from incremental tests. Using step increments of relatively long durations (i.e., 3-4 min), the LT2 can be derived, which relies on measurements of  $[La^-]_b$  (Caen et al., 2021; Keir et al., 2022). Nevertheless, given that RI cycling tests are commonly used, the RCP can be used as a demarcation point of the  $\dot{V}O_2$  associated with the MMSS, thus representing the metabolic rate that separates the heavy from the severe intensity domain of exercise (Iannetta, Inglis, Pogliaghi, et al., 2020; Keir, Paterson, et al., 2018; Keir, Pogliaghi, et al., 2018).

The RCP reflects the metabolic rate at which compensation of ventilatory mechanisms can maintain elevated but stable metabolic acidosis (Whipp et al., 1989), and can be used as a proxy for the metabolic rate at the MMSS. Comparable to the identification of the GET, an estimation of the RCP is possible when the  $\dot{V}O_2$  is plotted against the raw profiles of  $\dot{V}CO_2$ ,

RER,  $\dot{V}_E$ ,  $\dot{V}_E/\dot{V}O_2$ ,  $P_{et}CO_2$ ,  $\dot{V}_E/\dot{V}CO_2$ ,  $P_{et}O_2$ . The RCP represents the end of the isocapnic buffering phase visible in the steep decline of  $P_{et}CO_2$  alongside the onset of a hyperventilatory response observed as a second and first breakpoint in the  $\dot{V}_E/\dot{V}O_2$  and  $\dot{V}_E/\dot{V}CO_2$ , respectively (see Figure 2.2.4.; Keir et al., 2022).



**Figure 2.2.4.** Schematic representation of the gas exchange and ventilatory variables, and blood lactate concentration ( $[La^-]_b$ ) that are used in the identification of the gas exchange threshold (GET), and/or lactate threshold (LT), and respiratory compensation point (RCP) upon collection during a ramp-incremental (RI) cycling test. Top-to-bottom, left-to-right: Carbon dioxide output ( $\dot{V}CO_2$ ), respiratory exchange ratio (RER), ventilation ( $\dot{V}_E$ ), ventilatory equivalent ratio of oxygen ( $\dot{V}_E/\dot{V}O_2$ ), end tidal pressure of carbon dioxide ( $P_{et}CO_2$ ), ventilatory equivalent ratio of carbon dioxide ( $\dot{V}_E/\dot{V}CO_2$ ), end tidal pressure of oxygen ( $P_{et}O_2$ ), and blood lactate concentration ( $[La^-]_b$ ) are plotted in relation to the oxygen uptake ( $\dot{V}O_2$ ).  $\dot{V}O_2$  associated with the GET/LT and RCP is indicated by vertical lines intersecting the abscissa (Keir et al., 2022).

Although the  $\dot{V}O_2$  at the RCP coincides with the  $\dot{V}O_2$  at MMSS, the PO at the RCP derived from a RI cycling test typically overestimates the PO at the MMSS. This has been used

as an argument against the correspondence between the RCP and the MMSS. However, this lack of agreement in terms of PO simply reflects that the  $\dot{V}O_{2sc}$  that can be fully expressed during constant work rate exercise, cannot be completely developed during a fast-adjusting RI cycling test. This leads to an estimation of the PO associated with the  $\dot{V}O_2$  at the RCP that exceeds the PO associated with that same  $\dot{V}O_2$  during constant work rate exercise. To correct for this issue, a step-ramp-step (SRS) cycling protocol has recently been developed, allowing for an estimation of the PO at the RCP that corrects for the lack of expression of the  $\dot{V}O_{2sc}$  during the RI cycling test in a single session (Iannetta, Inglis, Pogliaghi, et al., 2020). The SRS cycling protocol utilizes a: *i*) moderate intensity step-transition (MOD) to quantify and account for the  $\dot{V}O_2$  mean response time (MRT), which reflects the body's transit time for deoxygenated blood leaving the working muscles arriving to be expressed at the level of the lung (Whipp & Wasserman, 1972); *ii*) RI cycling test; *iii*) heavy intensity step-transition (HVY) to adjust the RI cycling tests'  $\dot{V}O_2$ -PO relationship, thus allowing for the  $\dot{V}O_{2sc}$  observed during constant load exercise to be accounted for (Iannetta et al., 2019).

### ***2.2.5. The severe (and extreme) intensity domain of exercise***

Within the severe intensity domain, both  $[La^-]_b$  and  $\dot{V}O_2$  continuously rise with the  $\dot{V}O_{2sc}$  further developing as a steady state is unattainable due to metabolic acidosis progressively worsening and exercise intolerance and/or task failure ensuing (Filho et al., 2012; Fullerton et al., 2021; Poole & Jones, 2012). The eventual failure to maintain a given PO is associated with the attainment of a consistent critical muscle metabolic milieu, involving low concentrations of substrates and high levels of metabolites (Black et al., 2017). Compared to both the moderate and heavy intensity domain of exercise, NMF within this domain is characterized by greater peripheral fatigue development and near-maximal or maximal values in perceived fatigability by

way of RPE (Burnley et al., 2012; Iannetta, Zhang, et al., 2022; Thomas et al., 2016).

Furthermore, there exists a supra-severe exercise intensity domain called the extreme domain whereby task failure is reached in less than ~2 min and occurs before the  $\dot{V}O_{2max}$  can be elicited (Alexander et al., 2019; Hill & Stevens, 2005).

### **2.3. Motivational Strategies Affecting Exercise Performance**

The psychobiological model of endurance exercise performance postulates that people will consciously decide to terminate a bout of exercise when: *i*) the effort required by the constant-PO exercise test exceeds the maximum effort they are willing to exert in order to succeed (i.e., the so-called potential motivation); *ii*) it is believed that a true maximal effort has been given and continuation is perceived as impossible. Therefore, an increase in the potential motivation may improve exercise tolerance (Marcora, 2008; Staiano et al., 2018) and different types of interventions that, on some level, act as a source of motivation may fuel this. Thus far, the manipulation of interventional strategies has demonstrated variable effects, dependent on the method, participant characteristics, as well as exercise type, duration, and intensity.

One approach that has been used to affect performance has been related to mental state manipulations. The induction of mental fatigue prior to cycling endurance exercise has been shown to hinder exercise performance (Brownsberger et al., 2013; Filipas et al., 2019; Marcora et al., 2009; Van Cutsem et al., 2017). Conversely, motivational self-talk during cycling endurance exercise has been indicated to result in an enhancement of exercise performance (Barwood et al., 2015; Blanchfield et al., 2013; Cabral et al., 2023; Hardy et al., 2019).

Another motivational strategy used to evaluate changes in performance has involved listening to music. It has been shown that listening to music during cycling endurance exercise at high intensities fluctuates in its effect on exercise performance. For example, Atkinson et al.

(2004) found that listening to “trance” dance music during a cycling TT significantly shortened completion time, and Nakamura et al. (2010) found that listening to preferred music during highly intense cycling exercise increased the distance of exercise completed. On the other hand, Hagen et al. (2013) demonstrated that during a 10 km cycling TT, listening to self-selected motivational music did not meaningfully motivate well-trained, task-habituated cyclists to enhance their exercise performance.

A different strategy has involved the use of mouth rinses. It has been demonstrated that the use of carbohydrate mouth-rinsing in physically active participants was effective in increasing cycling TTF performance at MLSS, however, additional research is necessary to confirm the benefits (Bavaresco Gambassi et al., 2019).

### ***2.3.1. Monetary reward used as a tool to modify exercise performance***

Financial incentives involve an array of enticements, all of which have economic value to the receiver (Barte & Wendel-Vos, 2017). A direct gift means that an individual receives the yield immediately (i.e., cash payments and coupons) whereas a lottery means that the individual has a lower than 100% chance to receive the yield (Barte & Wendel-Vos, 2017). When a reward is involved in the context of financial incentivization, achieving such reward depends on the success of an individual reaching goals related to exercise (Barte & Wendel-Vos, 2017).

Therefore, for the individual to win the conditional reward, they must act and perform according to whatever the standard has been set at (i.e., if the reward is \$50 for the fastest time during a TT at a fixed intensity, the individual will only receive the prize if they are indeed the fastest).

It is known that exercise has an important role in health and performance outcomes (Marcora & Staiano, 2010; Myers et al., 2002; Newman et al., 2006). Using a financial incentive to enhance exercise performance may bring us one step closer to better understanding the

mechanisms related to task failure, which remain contentious. The use of a financial incentive has the potential to allow researchers to get closer to the true limit of sustainable exercise. Therefore, by using such a financial incentive in a specific way to fuel exercise beyond its perceived limit of sustainability (i.e., a monetary reward offered unexpectedly during exercise just before the point of perceived task failure), an investigation can occur to gain a better understanding of the development of exercise-induced fatigue.

Literature using extrinsic motivation in the form of monetary reward for the purpose of analyzing its effect on cycling endurance exercise performance have not shown positive effects as an ergogenic aid. A study by Hulleman et al. (2007) evaluated whether extrinsic motivation applied immediately before exercise would influence either the pacing strategy or the overall performance during cycling TTs. Seven well-trained male cyclists ( $32 \pm 11$  yrs) completed a total of four 1500 m non-randomized TTs, including a practice TT, two self-paced TTs, and an incentivized TT. Participants were offered a \$100 reward if they could outperform their best time by more than 1 s in the incentivized TT (i.e., terminal TT). The results revealed that only two participants improved by more than 1 s in the terminal TT and there were no significant differences between the TTs for time (s), average total PO (i.e., average mechanical PO attributable to both aerobic and anaerobic sources ( $P_{\text{tot}}$ , in W)), average mechanical PO attributable to aerobic sources ( $P_{\text{aer}}$ , in W), average mechanical PO attributable to anaerobic energy sources ( $P_{\text{anaer}}$ , in W), or average  $\dot{V}O_2$  ( $L \cdot \text{min}^{-1}$ ) in intermediate fractions of the TT or the total TT. In another study, Skorski et al. (2017) analysed the influence of a monetary reward on pacing and performance during short and long cycling TTs. Twenty-three participants (6 males and 17 females) were randomized into either a “reward” or “non-reward” group. The “rewarded” group was informed that a monetary reward would be distributed to all participants and that the

amount depended upon their highest average PO ( $W \cdot kg^{-1}$ ) produced over all TTs. In both groups, participants completed five sessions consisting of an incremental cycling TTF, followed by four randomized, self-paced TTs of varied duration and distance (2 long = 30 min and 20 km; 2 short = 6 min and 4 km). Results demonstrated no significant differences between groups in time (min) and distance covered (km) during either of the TTs; however, upon commencement of both TTs, pacing was altered. In the “reward” group, participants started all TTs more conservatively whereas participants in the “non-reward” group adopted a parabolic shaped pattern. In these studies, an examination of the influence of a monetary reward on exercise outcomes was impeded by pacing strategies since the exercise task was a TT and, therefore, participants could change the PO in an attempt to maximize exercise performance and minimize the development of a catastrophic internal milieu (Hettinga et al., 2006; Hulleman et al., 2007). In addition to the uncertainty involving pacing, the reward was not blindly offered and, therefore, it is difficult to understand how exercise behavior was affected.

Therefore, to bridge gaps in research that have thus far been discrepant, it may be useful to examine the effect of an unexpected monetary reward offered just before the point of perceived task failure during a constant-PO TTF to see if exercise can be enhanced.

### ***2.3.2. The use of deception to modulate exercise performance***

A comprehensive search of literature suggests that the use of deception to modulate exercise has not been performed by using an unexpected monetary reward to influence prolonged exercise. Nevertheless, other forms of psychological interventions have been employed.

It has been discovered that the knowledge of an exercise endpoint has an important role in pacing strategies. Withholding information from participants about the exercise endpoint has been shown to reduce their ability to formulate a pacing strategy, causing them to underperform

possibly due to a decreased motivation and psychological strain (Faulkner et al., 2011; Halperin et al., 2014; Marcora et al., 2009). In addition, maximal forces have been suppressed until the expectation of a final repetition and/or bout of exercise (Halperin et al., 2014; Jones et al., 2013). Halperin et al. (2014) had participants complete fatiguing protocols (i.e., 12 elbow flexion MVCs with a work-to-rest ratio of 5/10 s) in a control, unknown, and deception condition. In the control condition participants were informed they would perform 12 MVCs, and then completed all 12; after the 11<sup>th</sup> MVC, they were told the next would be the last. In the unknown condition, participants were not told how many MVCs they would perform but were stopped after 12; again, after the 11<sup>th</sup> MVC, they were told the next would be the last. In the deception condition, participants were told they would perform only 6 MVCs, but after the 6 were completed, they were asked to perform a few more repetitions and were stopped after 12. After the 5<sup>th</sup> and 11<sup>th</sup> MVC, respectively, participants were told that the next would be the last. It was found that average MVC forces were significantly greater in the deception condition compared to the unknown condition thus highlighting that an unknown duration of exercise leads to an ‘underperformance’. Also, in the deception condition, participants produced greater MVC force in contraction #6 compared to both the control and unknown conditions and in all conditions, participants produced greater MVC force in contraction #12 versus contraction #11. Therefore, not only did participants ‘underperform’ but they also suppressed their maximum efforts until they were informed that the end of exercise was near. Faulkner et al. (2011) found that during 6 km treadmill TTs, providing no distance feedback during exercise resulted in a significantly slower completion time with lower  $\dot{V}O_2$  and HR compared to when both accurate and inaccurate distance feedback was provided. Considering a TTF does not define an exercise endpoint, the findings discussed above should be further investigated when the exercise task being performed

is a cycling TTF whereby participants are blinded to time and, ideally, task failure can be attributed to maximal performance outcomes. Then, when a TTF is performed and incentivized at perceived task failure, not only does it eliminate the possibility of pacing, but it also may allow for any ‘underperformance’ or suppression of maximum effort to become discernible by way of a significant extension of exercise.

Another concept related to exercise performance is that the ‘critical threshold of peripheral fatigue’ is correlated with exercise tolerance since participants either cannot or will not exceed the limit (Ansdell et al., 2018). It has been hypothesized that deceptive feedback may motivate recreationally active participants (i.e., not well-trained participants) to improve exercise performance by tolerating a greater than usual magnitude of NMF, thereby accessing a theoretical contractile reserve (Ansdell et al., 2018; Ducrocq et al., 2017; Konings et al., 2018). Specifically, Ducrocq et al. (2017) aimed to investigate the effect of different magnitudes of deception on performance and exercise-induced fatigue during a 5 km cycling TT. Findings demonstrated that during a 5 km cycling TT, a moderate level of deception (i.e., 2% greater speed compared to a control condition) improved exercise performance and was associated with a greater reduction in post-exercise MVC force and VA, along with a significant alteration of the  $Q_{tw_{pot}}$  recovery. Interestingly, a large level of deception (i.e., 5% greater speed compared to a control condition) demonstrated no difference in exercise performance or fatigue indices.

Based on the information presented above, deceptive feedback can also be utilized by way of offering an unexpected monetary reward just before the point of perceived task failure to see if there is a performance enhancement, and pre- and post-exercise isometric NM assessments can help identify the existence of a contractile reserve.

## 2.4. Research Objectives

The primary objective of this thesis was to determine if physically active, healthy, young adults could be influenced by an unexpected monetary reward to increase their exercise performance by prolonging their HVY<sub>TTF</sub>. Simultaneously, this study assessed the effects of an unexpected monetary incentive on: *i*) performance fatigability using an isometric NM assessment following the HVY<sub>TTF</sub>; *ii*) performance fatigability using both a dynamic assessment following the HVY<sub>TTF</sub> by evaluating a EXT<sub>TTF</sub> and an isometric NM assessment following the EXT<sub>TTF</sub>; *iii*) perceived fatigability during the HVY<sub>TTF</sub> and immediately following the EXT<sub>TTF</sub>.

## 2.5. Hypotheses

It was hypothesized that an unexpected monetary reward would allow participants to significantly extend their HVY<sub>TTF</sub> performance, which would result in: *i*) similar significant decreases in isometric evaluations of NM function after the HVY<sub>TTF</sub>; *ii*) significant reductions in the duration of the EXT<sub>TTF</sub> performance with no changes in the subsequent isometric evaluations of NM function; *iii*) similar progressive increases in perceived fatigability up until the point of the 1 min signal (i.e., the announcement of the reward) and following the EXT<sub>TTF</sub>.

## Chapter III: Methods

### 3.1. Participants

An a priori power analysis using G\*Power version 3.1 indicated the required sample size to achieve statistical power of 0.80 for detecting an effect size of Cohen's  $d = 0.66$ , at a significance criterion of  $\alpha = 0.05$ , accounting for an attrition rate of 20%, was  $n = 23$ .

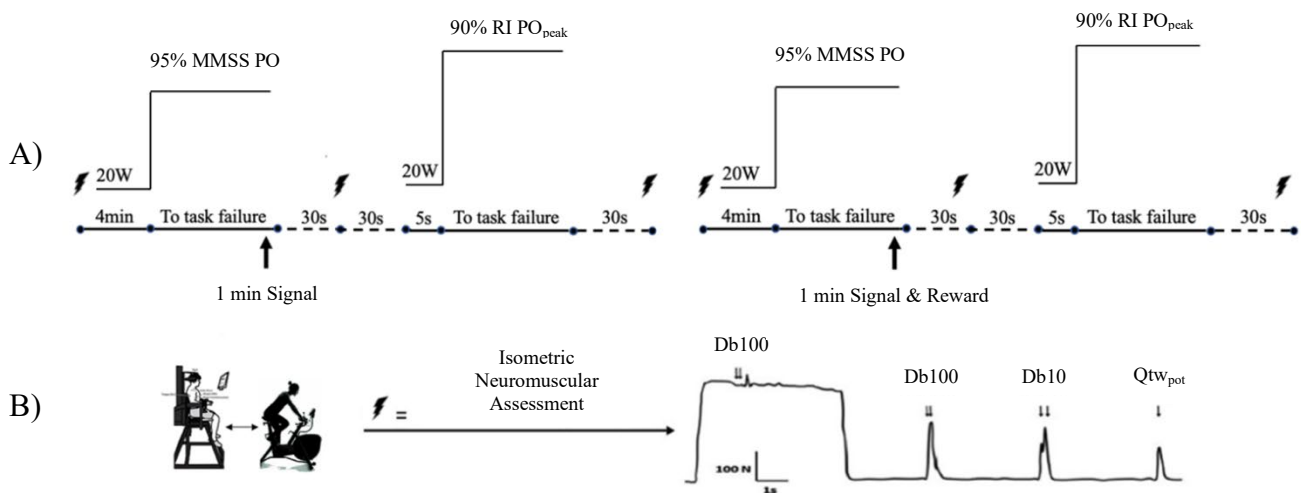
Eighteen young volunteers (9 males and 9 females;  $23 \pm 3$  yr,  $73.2 \pm 11.0$  kg,  $174.8 \pm 7.8$  cm) completed this study. Participants were eligible after they passed the CSEP Physical Activity Readiness Questionnaire-Plus (PAR-Q+), confirmed being physically active (1-4 hours of regular exercise per week) (Cramer et al., 2012), and were between 18-30 yrs of age. Exclusion criteria included: if participants had an injury, were obese ( $BMI \geq 30$  kg/m<sup>2</sup>), smoked or used tobacco products, excessively consumed alcohol (males  $\geq 15$  drinks/week; females  $\geq 7$  drinks/week), or had cardiovascular or metabolic diseases. Approval was obtained from the Conjoint Health Research Ethics Board at the University of Calgary to complete all components of this study (REB21-1855). Prior to all exercise, participants signed a written informed consent form (see Appendix B).

### 3.2. Experimental Design

Figure 3.2. depicts the basic experimental design. Three visits to the laboratory were required from each participant. This included a: *i*) SRS cycling protocol to establish the  $\dot{V}O_{2max}$ ,  $PO_{peak}$ , and the PO estimated to represent the MMSS; *ii*) TTF at a PO corresponding to 95% of the estimated MMSS ( $HVY_{TTF}$ ) followed, 1 min later, by a dynamic performance fatigability assessment performed at a PO corresponding to 90% of the  $PO_{peak}$  ( $EXT_{TTF}$ ). Lastly, *iii*) the testing sequence from the previous session was repeated, differing only in the occurrence of an unexpected monetary reward offered near task failure during the  $HVY_{TTF}$ . Sessions #2 and #3

were not randomized due to a prioritization of participants being blinded to the reward until the exact point it was revealed. In addition to the metabolic measurements that took place in all visits, Sessions #2 and #3 included isometric NM assessments that occurred at baseline ( $NM_{BSL}$ ), as well as 30 s post-HVY<sub>TTF</sub> ( $NM_{HVY}$ ), and 30 s post-EXT<sub>TTF</sub> ( $NM_{EXT}$ ), as described below.

Testing sessions were performed on an electromagnetically braked cycle ergometer (Velotron: RacerMate, Seattle, WA), in an environmentally controlled room (temperature: 19-20°C; humidity: 50-60 %), with at least 48 hrs between each session, at a similar time of the day ( $\pm 1$  hr). Prior to each session, participants were instructed to avoid the consumption of food and caffeinated and/or alcoholic beverages for at least 2 and 12 hrs, respectively, and to abstain from strenuous physical activity for at least 24 hrs. Furthermore, participants were asked to self-record what they ate in the 48 hrs prior to each session. In the initial visit to the laboratory, participants self-selected their cadence (70-90 revolutions/min (rpm)) and maintained it throughout the entirety of the study. Participants were blinded to PO and elapsed time. The definition of task failure included: *i*) volitional exhaustion due to the inability to continue cycling within 10 rpm of the requested cadence for greater than 5 s despite strong verbal encouragement; *ii*) task disengagement.



**Figure 3.2.** Schematic representation of the basic design of Session #2 and #3 (left to right) and the isometric NM assessment. A, The  $NM_{BSL}$  prior to the  $HVY_{TTF}$  until task failure with a 4 min cycling warm-up and a 30 s break for  $NM_{HVY}$ , followed by the dynamic performance fatigability assessment via  $EXT_{TTF}$  until task failure with 5 s cycling warm-up and a 30 s break for the  $NM_{EXT}$ . Prior to task failure in the  $HVY_{TTF}$  is the 1 min signal in Session #2 and the 1 min signal with reward offering in Session #3. B, Isometric chair and cycle ergometer set-up along with the isometric NM assessment protocol.

### 3.3. Procedures

#### 3.3.1. Session #1: SRS Protocol

There was a thorough explanation of all physiological and perceptual measures (i.e., isometric NM function, EMG,  $\dot{V}O_2$ , heart rate (HR),  $[La^-]_b$ , Fatigue, Pain, RPE, and Dyspnea). Then, participants were familiarized with the isometric NM assessments and set-up for the continuous recording of EMG,  $\dot{V}O_2$ , and HR. The SRS cycling protocol included: *i*) a moderate intensity step-transition (MOD) to estimate the  $\dot{V}O_2$  MRT (Iannetta et al., 2019) which involved cycling 4 min at 20 W, followed by 6 min at 60-100 W (the PO was selected based on predicted fitness level of the participant to maximize increases in the  $\dot{V}O_2$  signal while ensuring MOD responses); *ii*) a RI cycling test that included a 4-min baseline at 20 W followed by the PO being increased in a ramp-like manner by  $30 \text{ W} \cdot \text{min}^{-1}$  (i.e., 1 W every 2 s) until task failure; *iii*) a 30-min rest period followed by participants transitioning from a 2-min 20 W baseline to a steady state exercise for 12 min corresponding to a PO of 50-65%  $PO_{peak}$  (HVY). The HVY bout allowed for an estimation of the dissociation between the RI cycling test and constant load  $\dot{V}O_2$  to PO relationship so that the estimated PO at MMSS could be retrieved (Iannetta et al., 2021). At baseline and conclusion of the RI cycling test, and at the end of the HVY bout,  $[La^-]_b$  was measured and Fatigue, Pain, RPE, and Dyspnea were all recorded.

#### 3.3.2. Session #2: Control TTFs

Prior to beginning exercise, participants were set-up for the physiological measurements that were evaluated in the session and the testing sequence for the specific session was explained

in detail. Next, participants were situated in an isometric chair positioned slightly above and behind the cycle ergometer to undergo the  $NM_{BSL}$ . Subsequently, once set-up for  $\dot{V}O_2$  evaluation and situated on the cycle ergometer, a 4-min 20 W baseline was followed by the  $HVY_{TTF}$ . Instruction was given to, during exercise, signal researcher(s) upon nearing task failure (i.e., approximately 1 min of exercise left in the tank (see Figure 3.2.)). To communicate this 1 min signal, participants raised a hand at eye-level and displayed their index finger. Upon task failure, participants moved from the cycle ergometer to the isometric chair so that 30 s after,  $NM_{HVY}$  took place. Then, participants moved from the isometric chair to the cycle ergometer and, at the 1 min mark, resumed cycling and began the  $EXT_{TTF}$ . Again, immediately following task failure, participants moved from the cycle ergometer to the isometric chair so that 30 s after,  $NM_{EXT}$  occurred. For  $NM_{HVY}$  and  $NM_{EXT}$ , the delay from exercise to stimulation was standardized to 30 s.  $[La^-]_b$  was evaluated at baseline and during the  $HVY_{TTF}$ , every 5 min for the first 15 min, at 30 min, and thereafter every 10 min until task failure. In addition, Fatigue, Pain, RPE, and Dyspnea were assessed at baseline and during the  $HVY_{TTF}$ , every 10 min of exercise, and at the point of the 1 min signal. Furthermore, during the  $EXT_{TTF}$ ,  $[La^-]_b$  and Fatigue, Pain, RPE, and Dyspnea were evaluated immediately at the end of the test.

### ***3.3.3. Session #3: Reward TTFs***

The procedure for the second session was repeated for the third session; however, an unexpected monetary reward was used to incentivize prolonged exercise. Therefore, once the 1 min signal indicating that the participant was near finishing the exercise was given during the  $HVY_{TTF}$ , participants were informed that they would win a reward if they continued the exercise task. The design of the reward was purposeful and thus was offered two-fold: *i*) 1 raffle ticket won for every additional 1 min interval of exercise; *ii*) a \$10 pre-paid credit card earned for

every additional 5 min interval of exercise (for perspective, this value would be equivalent to buying 3 regular coffees in a coffee shop in Canada). Each raffle ticket was added to a draw to win a \$250 pre-paid credit card while the \$10 pre-paid credit cards were immediately distributed. After participation was completed, researchers discussed with each participant the importance of the use of deception in this study, and requested maintenance of confidentiality pertaining to the unexpected reward offering until data collection was completed.

### **3.4. Measurements**

#### ***3.4.1. Isometric neuromuscular assessment***

The IMVC of knee extensors from the dominant leg, which was determined based on the preferred leg used to kick a ball, and isometric NM function responses were evaluated on an isometric chair secured by chest and hip straps with hips and knees flexed at 90°. The ankle was attached perpendicularly to a force transducer (LC101-2K, Omegadyne, Sunbury, OH). Force was obtained from a strain gauge attached to the isometric chair with a non-extensible strap, sampled at 2000 Hz and digitally converted using the PowerLab acquisition hardware and LabChart software (ADInstruments, Bella Vista, Australia), and monitored on a computer. Recommendations related to instructions, practice, visual feedback of performance, and standardized verbal encouragement were adopted to ensure maximum effort. PNS was performed by delivering percutaneous electrical stimuli using a constant-current stimulator (DS7A, Digitimer, Welwyn Garden City, Hertfordshire, UK) to the femoral nerve via cathode electrode (10 mm stimulating diameter; Meditrace 100, Covidien) in the inguinal triangle and 50 x 90 mm rectangular anode electrode (Durastick Plus, DJO Global, Vista, CA) placed between the greater trochanter and the suprailiac projections. The electrical stimuli intensity was adjusted in each session and prior to any exercise by delivering 1 ms rectangular single stimulus incrementally

until reaching plateau in twitch torque and maximal M-wave amplitudes on the vastus lateralis (VL) and rectus femoris (RF) muscles. The stimulation intensities were adjusted to 130% to ensure maximal twitch torque and M-wave amplitudes. Thereafter, participants performed a standardized warm-up consisting of three 5 s voluntary contractions at subjective intensities of 10, 30, 50, and 75% of the estimated IMVC torque. Each 5 s contraction was interspersed by 30 s of rest. Next, two 5 s IMVCs were performed. The performance fatigability assessment consisted of a 5 s IMVC, electrical nerve stimulations of high-frequency (100 Hz:  $Db_{100}$ ) and low-frequency (10 Hz:  $Db_{10}$ ) doublets, and a single potentiated twitch ( $Q_{tw_{pot}}$ ). During the 5 s IMVC plateau, a superimposed  $Db_{100}$  was applied and then, upon muscle relaxation,  $Db_{100}$ ,  $Db_{10}$ , and  $Q_{tw_{pot}}$  were elicited every 2 s. The highest measurements were used for subsequent analyses.

### ***3.4.2. Electromyography***

EMG activity of the dominant leg knee extensor VL, RF, and biceps femoris (BF) muscles were recorded via self-adhesive surface electrodes (10 mm recording diameter) (Meditrace 100, Covidien, Mansfield, MA) in a bipolar configuration with a 30 mm interelectrode distance and the reference electrode placed on the patella. The skin was shaved, gently abraded, and cleansed with isopropyl alcohol 70% to obtain a low impedance ( $< 10 \text{ k}\Omega$ ) between electrodes. To prevent movement artifact, electrodes and connected wires were taped to the skin using adhesive tape. Signals were analog-to-digital converted at a sampling rate of 2000 Hz by PowerLab system (16/35; ADInstruments) and octal bio-amplifier (ML138, ADInstruments; common mode rejection ratio = 85 dB, gain = 500) with bandpass filter (5–500 Hz).

### ***3.4.3. Ventilatory and gas exchange data***

All ventilatory and gas exchange variables were measured breath-by-breath with a metabolic cart (Quark, CPET; COSMED, Rome, Italy). The system consisted of a low dead space turbine as well as oxygen (O<sub>2</sub>) and carbon dioxide (CO<sub>2</sub>) gas analyzers; these were calibrated with a syringe of known volume (3 L) and a gas-mixture of known concentration (16% O<sub>2</sub>; 5% CO<sub>2</sub>; balance nitrogen (N<sub>2</sub>), respectively). A face mask was used to collect inspired and expired volumes and gas concentrations; HR was recorded using radiotelemetry (H10 Polar Transmitter; Polar Electro, Inc., Kempele, Finland).

### ***3.4.4. Blood lactate concentration***

[La<sup>-</sup>]<sub>b</sub> measurements were initiated by wiping a finger with an alcohol swab. This was followed by a finger-prick and the collection of a 20 µL blood sample with a capillary tube which was mixed in an EKF prefilled safe lock plastic tube for analysis using a laboratory device (Biosen C-Line Clinic, EKF Industrie, Elektronik GmbH, Barleben, Germany).

### ***3.4.5. Perceived fatigability assessment***

A multicomponent assessment of perceptual responses was performed based on Fatigue (0-10 bottom-to-top Rating of Fatigue scale (Micklewright et al., 2017), Pain (0-10 left-to-right Visual Analog Scale (McCormack et al., 1988), RPE (6-20 top-to-bottom Borg's scale (Borg, 1982)), and Dyspnea (0-10 top-to-bottom Dyspnea scale (Borg et al., 2010)). These scales were chosen because they are reflective of discrete psychological constructs generated by the brain processing and/or integration of distinct feedback, feedforward, and emotional mechanisms. When responding to the Fatigue scale, participants were asked to rate how fatigued they felt either in the moment or at the end of exercise (whereby 0 indicated no fatigue whatsoever and 10 indicated extreme fatigue) (Micklewright et al., 2017). For the Pain scale, participants were

asked to rate the pain experienced within the exercising leg as related to the sensation of aching and burning of the muscles (whereby 0 indicated no pain at all and 10 indicated extremely unpleasant pain) (McCormack et al., 1988). During an assessment using the RPE scale, participants were asked to rate their perceived effort in relation to how hard and strenuous the exercise was (whereby 6 indicated no effort whatsoever and 20 indicated maximal effort) (Borg, 1982). For the Dyspnea scale, participants were asked to rate how breathless they felt (whereby 0 indicated not being breathless whatsoever and 10 indicated an extreme need to breathe) (Borg et al., 2010). At the beginning of the study, participants were familiarized with each of the scales and before each subsequent session, they were reminded of their meaning.

### **3.5. Data Analyses**

#### ***3.5.1. Time data, involving the $HVY_{TTF}$ and the dynamic performance fatigability assessment via the $EXT_{TTF}$***

The duration for the  $HVY_{TTF}$  for the control and reward sessions involved the time from the conclusion of the baseline to the 1 min signal ( $HVY_{SIGNAL}$ ), as well as to task failure ( $HVY_{FINAL}$ ). The duration for the  $EXT_{TTF}$  for the control and reward sessions involved the time from the conclusion of the baseline to task failure ( $EXT_{FINAL}$ ). The change in ( $\Delta$ )  $HVY_{TTF}$  duration and  $EXT_{TTF}$  duration between the control and reward sessions ( $\Delta HVY_{FINAL}$ ;  $\Delta EXT_{FINAL}$ ) was calculated.

#### ***3.5.2. Isometric neuromuscular assessment***

For the baseline analysis, only the highest amplitudes were accepted. Therefore, maximal voluntary torque was calculated as the highest IMVC prior to exercise, and electrically evoked torque from the doublets and single pulse was determined as the peak torque of each stimulation on the relaxed muscle.  $Db_{10}$  amplitude was only considered for assessing the low-frequency

fatigue (LFF), which was measured by  $Db_{10}$  normalized to  $Db_{100}$  at rest ( $Db_{10:100}$ ) (Verges et al., 2009). VA was assessed by a superimposed paired-pulse technique, as previously described (Strojnik & Komi, 1998):

$$VA (\%) = 100 - D \times (IMVC_{Db_{100}} / IMVC_{peak}) / Db_{100} \times 100.$$

Where  $IMVC_{Db_{100}}$  is the voluntary torque when superimposed  $Db_{100}$  was delivered,  $IMVC_{peak}$  is the highest torque during the IMVC before the superimposed  $Db_{100}$ ,  $D$  is the difference between the torque level at the time of  $IMVC_{Db_{100}}$  and the maximum torque during superimposed  $Db_{100}$ , and  $Db_{100}$  is the electrically evoked torque on the relaxed muscle after IMVC. This modified formula was used to account for the possibility of human-error in the manual delivery of the superimposed  $Db_{100}$  along with the chance that participants were unable to achieve a true plateau in their IMVC.

The  $M_{max}$  was quantified as the peak-to-peak amplitude of the EMG of the  $Q_{tw_{pot}}$  in the VL and RF muscles, respectively ( $M_{maxVL}$ ;  $M_{maxRF}$ ) (Krüger et al., 2020). In addition, obtained during all IMVCs, the maximal root mean square (rms) of the EMG of the VL and RF muscles, respectively ( $rmsEMG_{VL}$ ;  $rmsEMG_{RF}$ ), was measured during the first 500-ms of force plateau (i.e., the 500-ms prior to the SIT) using the following equation:

$$rmsEMG_{VL/RF} = \sqrt{\frac{1}{n} \sum_i x_i^2}.$$

Where  $n$  is the number of values and  $x_i$  is each value. Then, the  $rmsEMG_{VL/RF}$  was normalized to the corresponding  $M_{max}$  ( $rmsEMG_{VL/RF} \cdot M_{max}^{-1}$ ) in the given formula:

$$rmsEMG_{VL/RF} \cdot M_{max}^{-1} = \frac{rmsEMG_{VL/RF}}{M_{max}}$$

### 3.5.3. Ventilatory and gas exchange data

During the RI cycling test, the raw profiles of  $\dot{V}_E$ ,  $\dot{V}CO_2$ , RER,  $PetO_2$  and  $PetCO_2$ ,  $\dot{V}_E/\dot{V}O_2$  and  $\dot{V}_E/\dot{V}CO_2$ , were plotted against  $\dot{V}O_2$  for the estimation of the GET and the RCP (Keir et al., 2022). The GET was identified as the point at which  $\dot{V}CO_2$  began to increase disproportionately with respect to  $\dot{V}O_2$  (V-slope method) concomitantly with a first breakpoint in the  $\dot{V}_E/\dot{V}O_2$  and  $PetO_2$ , whereas  $PetCO_2$  and  $\dot{V}_E/\dot{V}CO_2$  were stable. The RCP corresponded to the point at which  $PetCO_2$  began a precipitous fall after a period of isocapnia concomitantly with a second and first breakpoint in the  $\dot{V}_E/\dot{V}O_2$  and  $\dot{V}_E/\dot{V}CO_2$ , respectively. Subsequently, breath-by-breath respiratory data was cleaned on an individual basis and interpolated to 1 s intervals. The PO at GET was identified through linear interpolation of the  $\dot{V}O_2$ -to-PO relationship after accounting for the individual MRT (Iannetta et al., 2019). The PO at RCP was identified after aligning the  $\dot{V}O_2$  at the RCP with its steady state equivalent (Iannetta, Inglis, Pogliaghi, et al., 2020). Briefly, the  $\dot{V}O_2$  and PO coordinates corresponding to GET and to the HVY bout were used to establish the  $\dot{V}O_2$ -PO relationship in the heavy intensity domain. Thereafter, projection of this relationship to the estimated  $\dot{V}O_2$  at RCP allowed identification of the corresponding PO.

During all testing sessions, breath-by-breath respiratory data was cleaned by removing data points lying  $\pm 3$  standard deviation (SD) from the local mean, followed by a linear interpolation to 1 s intervals (Origin, Origin Lab, Northampton, MA). Interpolated data from the RI cycling test was converted into a 20 s rolling average and the highest values were considered maximal values (i.e.,  $\dot{V}O_{2max}$ ,  $\dot{V}CO_{2max}$ ,  $HR_{max}$ ,  $RER_{max}$ ,  $\dot{V}_{Emax}$ , and breathing frequency (fB;  $fB_{max}$ )). Likewise, for the  $HVY_{TTF}$  and  $EXT_{TTF}$ , respectively, the interpolated data was converted into a 20 s rolling average. During the  $HVY_{TTF}$  in the control and reward sessions, the values in the 30 s prior to giving the 1 min signal were averaged (i.e.,  $HVY_{signal}$ ) (e.g.,  $\dot{V}O_{2signal}$ ) and the

values in the final 30 s prior to task failure were averaged (i.e.,  $HVY_{end}$ ) (e.g.,  $\dot{V}O_{2end}$ ). During the  $EXT_{TTF}$  in the control and reward sessions, the values in the final 20 s prior to task failure were averaged (i.e.,  $EXT_{peak}$ ) (e.g.,  $\dot{V}O_{2peak}$ ).

### 3.6. Statistical Analyses

Data are presented as mean  $\pm$  SD. A Shapiro–Wilk’s test and visual analysis using histograms, q-q plots, and box plots confirmed normal data distribution. To assess sphericity for the two-way repeated measures ANOVA analysis, Mauchly tests were performed. When assumptions of sphericity were violated, Greenhouse–Geisser correction factor was applied. When F values were significant for ANOVA comparisons, a Bonferroni post hoc analysis was used to determine where differences existed. Partial eta squared ( $\eta^2$ ) comparisons were computed, and effect sizes were evaluated as small ( $< 0.02$ ), medium (0.02-0.26), or large ( $> 0.26$ ) (Bakeman, 2005). Furthermore, correlations were assessed using Spearman’s correlations coefficient when assumptions of linearity were violated and/or outliers were present (Schober et al., 2018).

Paired t-tests were effective in analyzing all time data, including the  $HVY_{TTF}$  and the dynamic performance fatigability assessment via the  $EXT_{TTF}$ . Isometric NM assessment profiles were compared as absolute values between sessions (i.e., control and reward) and across time points (i.e.,  $NM_{BSL}$ ,  $NM_{HVY}$ , and  $NM_{EXT}$ ) by a two-way repeated measures ANOVA. A two-way repeated measures ANOVA was used two-fold to compare the perceived fatigability via perceptual responses as means of Fatigue, Pain, Dyspnea, and RPE, respectively, between sessions (i.e., control and reward) and across time points: *i*) during the  $HVY_{TTF}$  (i.e., baseline, 10 min, 20 min, and 30 min); *ii*) during the  $HVY_{TTF}$  and  $EXT_{TTF}$  (i.e., at the point of the 1 min signal during the  $HVY_{TTF}$  and at the end of the  $EXT_{TTF}$ ).  $\dot{V}O_2$  stability was evaluated using a

paired t-test by comparing the responses between 20 min and 30 min during the constant-PO bout of exercise (Azevedo et al., 2021; Iannetta, Ingram, et al., 2022). A two-way repeated measures ANOVA was used to evaluate the trend in  $\dot{V}O_2$  by comparing  $\dot{V}O_{2\text{signal}}$ ,  $\dot{V}O_{2\text{end}}$ , and  $\dot{V}O_{2\text{peak}}$  between sessions (i.e., control and reward) and across time points (i.e., at  $HVY_{\text{signal}}$ ,  $HVY_{\text{end}}$ , and  $EXT_{\text{peak}}$ ). Via the same method, the same analysis was performed to evaluate the trend in  $\dot{V}CO_2$ , HR, and  $\dot{V}_E$ , independently.  $[La^-]_b$  stability was evaluated using a paired t-test between the last time points available during the constant-PO bout, 15 min and 30 min (Iannetta, Ingram, et al., 2022). The absolute and relative  $\dot{V}O_{2\text{max}}$ , independently, were plotted against the  $\Delta HVY_{\text{FINAL}}$  and the  $\Delta EXT_{\text{FINAL}}$  for correlations using Pearson's correlations coefficient (Schober et al., 2018). In addition, the  $\Delta$  cardiorespiratory variables between the control and reward sessions at  $HVY_{\text{end}}$  (i.e.,  $\Delta \dot{V}O_{2\text{end}}$ ,  $\Delta \dot{V}CO_{2\text{end}}$ ,  $\Delta HR_{\text{end}}$ ,  $\Delta RER_{\text{end}}$ ,  $\Delta \dot{V}_{E\text{end}}$ ,  $\Delta fB_{\text{end}}$ ) were plotted against the  $\Delta HVY_{\text{FINAL}}$  for correlations using Pearson's correlations coefficient (Schober et al., 2018). Statistical significance was set at  $p < 0.05$ . For all correlations, the p-values were corrected using the Benjamini-Hochberg (B-H) procedure (Benjamini & Hochberg, 1995). All statistical analyses were performed using SPSS version 25 (SPSS, IBM, Chicago, IL).

## Chapter IV: Results

Table 4 depicts the participants characteristics and the outcomes from the RI cycling test at task failure.

### 4.1. Time Duration of the HVY<sub>TTF</sub> and Dynamic Performance Fatigability Assessment via the EXT<sub>TTF</sub> in the Control Session and Reward Session

Figure 4.1 summarizes the time duration of the distinct conditions (i.e., HVY<sub>SIGNAL</sub>, HVY<sub>FINAL</sub>, and EXT<sub>FINAL</sub>). The time at which participants provided the 1 min signal indicating that they expected to have 1 min left to exercise (i.e., HVY<sub>SIGNAL</sub>) was not different in the control session (44±16 min) compared to the reward session (44±19 min) ( $t(17) = 0.04, p = 0.97$ ). Contrastingly, whereas HVY<sub>FINAL</sub> in the control session (46±16 min) was significantly shorter than the reward session (53±22 min) ( $t(17) = -2.86, p = 0.01$ ), the EXT<sub>FINAL</sub> in the reward session was shorter (57±17 s) in comparison to the control session (68±17 s) ( $t(17) = 2.31, p = 0.03$ ).

### 4.2. Isometric Performance Fatigability Assessments in the Control Session and Reward Session

Variables of isometric NM function during each session (i.e., control and reward), at different time points (i.e., NM<sub>BSL</sub>, NM<sub>HVY</sub>, and NM<sub>EXT</sub>), are reported in Table 4.2 and summarized in Figure 4.2. The two-way repeated measures ANOVA did not reveal any main condition effects or condition x time interaction effects. The main time effects are reported below. For IMVC, there was a main effect of time ( $F = 26.55, p < 0.001, \eta^2 = 0.61$ ) whereby there was a significant reduction from NM<sub>BSL</sub> to NM<sub>HVY</sub> and NM<sub>EXT</sub> ( $p < 0.001$ ). For VA, there was no main effect of time ( $F = 1.73, p = 0.23, \eta^2 = 0.09$ ). There was a main effect of time for Db<sub>10:100</sub> ( $F = 135.06, p < 0.001, \eta^2 = 0.89$ ) whereby reductions from NM<sub>BSL</sub> were significant compared to NM<sub>HVY</sub> and NM<sub>EXT</sub> ( $p < 0.001$ ). For Qtw<sub>pot</sub>, there was a main effect of time ( $F =$

58.49,  $p < 0.001$ ,  $\eta^2 = 0.775$ ) as  $NM_{BSL}$  was significantly greater than  $NM_{HVY}$  and  $NM_{EXT}$  ( $p < 0.001$ ) and  $NM_{HVY}$  was significantly greater than  $NM_{EXT}$  ( $p < 0.001$ ). Furthermore, there was a main effect of time for both  $M_{maxVL}$  and  $M_{maxRF}$  ( $F = 5.10$ ,  $p = 0.02$ ,  $\eta^2 = 0.23$ ;  $F = 8.72$ ,  $p = 0.004$ ,  $\eta^2 = 0.34$ ). From  $NM_{BSL}$ ,  $M_{maxRF}$  was significantly different compared to  $NM_{HVY}$  and  $NM_{EXT}$  ( $p = 0.01$ ;  $p = 0.02$ , respectively); however, from  $NM_{BSL}$ ,  $M_{maxVL}$  was not significantly different compared to  $NM_{HVY}$  and  $NM_{EXT}$  ( $p = 0.13$ ,  $p = 0.06$ , respectively). Lastly, for  $rmsEMG_{VL} \cdot M_{max}^{-1}$  and  $rmsEMG_{RF} \cdot M_{max}^{-1}$ , respectively, no main effect of time was detected ( $F = 0.79$ ,  $p = 0.42$ ,  $\eta^2 = 0.04$ ;  $F = 0.38$ ,  $p = 0.58$ ,  $\eta^2 = 0.02$ ).

### **4.3. Perceptual Responses During the HVY<sub>TTF</sub> and EXT<sub>TTF</sub> in the Control Session and Reward Session**

Perceptual response variables (i.e., Fatigue, Pain, RPE, and Dyspnea) during each session (i.e., control and reward), at different time points (i.e., in the HVY<sub>TTF</sub> at baseline, 10 min, 20 min, 30 min, at the 1 min signal, and at the end of the EXT<sub>TTF</sub>) are presented in Figure 4.3. The two-way repeated measures ANOVAs did not reveal any main condition effects or condition x time interaction effects.

#### ***4.3.1. Fatigue, Pain, RPE, and Dyspnea in the HVY<sub>TTF</sub> at baseline, 10 min, 20 min, 30 min, at the 1 min signal, and at the end of the EXT<sub>TTF</sub>***

For Fatigue, a main effect of time ( $F = 279.70$ ,  $p < 0.001$ ,  $\eta^2 = 0.94$ ) was detected so that Fatigue was progressively greater from baseline to 10 min ( $p < 0.001$ ), 10 to 20 min ( $p < 0.001$ ), and 20 to 30 min ( $p < 0.001$ ). Fatigue also had a main effect of time ( $F = 28.00$ ,  $p < 0.001$ ,  $\eta^2 = 0.62$ ) so that Fatigue was greater from the point of the 1 min signal during the HVY<sub>TTF</sub> to the end of the EXT<sub>TTF</sub> ( $p < 0.001$ ). For Pain, there was a main effect of time ( $F = 103.38$ ,  $p < 0.001$ ,  $\eta^2 = 0.86$ ) so that Pain was progressively greater from baseline to 10 min ( $p < 0.001$ ), 10 to 20 min ( $p$

< 0.001), and 20 to 30 min ( $p < 0.001$ ). Pain also had a main effect of time ( $F = 19.51, p < 0.001, \eta^2 = 0.53$ ) so that Pain was greater from the point of the 1 min signal during the HVY<sub>TTF</sub> to the end of the EXT<sub>TTF</sub> ( $p < 0.001$ ). For RPE, there was a main effect of time ( $F = 154.14, p < 0.001, \eta^2 = 0.90$ ) so that RPE was progressively greater from baseline to 10 min ( $p < 0.001$ ), 10 to 20 min ( $p < 0.001$ ), and 20 to 30 min ( $p < 0.001$ ). RPE also had a main effect of time ( $F = 14.17, p = 0.002, \eta^2 = 0.46$ ) so that RPE was greater from the point of the 1 min signal during the HVY<sub>TTF</sub> to the end of the EXT<sub>TTF</sub> ( $p < 0.002$ ). For Dyspnea, there was a main effect of time ( $F = 86.65, p < 0.001, \eta^2 = 0.84$ ) as Dyspnea was progressively greater from baseline to 10 min ( $p < 0.001$ ), 10 to 20 min ( $p < 0.001$ ), and 20 to 30 min ( $p < 0.001$ ). Dyspnea also had a main effect of time ( $F = 21.47, p < 0.001, \eta^2 = 0.56$ ) so that Dyspnea was greater from the point of the 1 min signal during the HVY<sub>TTF</sub> to the end of the EXT<sub>TTF</sub> ( $p < 0.001$ ). In the control session, there were two participants who did not maintain exercise for at least 30 min so that perceptual responses could be recorded. In the reward session, a different participant did not maintain exercise for at least 30 min. Therefore, for these participants, the 30 min perceptual responses were deemed representative of the point of the 1 min signal, so the same responses were used at 30 min and the point of their 1 min signal. Statistical analysis with and without these participants was performed. The results showed similar statistical outcomes (values not reported for simplicity).

#### 4.4. $\dot{V}O_2$ , $\dot{V}CO_2$ , HR, $\dot{V}E$ , and $[La^-]_b$ Responses During the $HVY_{TTF}$ and $EXT_{TTF}$ in the Control Session and Reward Session

##### 4.4.1. $\dot{V}O_2$ , $\dot{V}CO_2$ , HR, and $\dot{V}E$ responses during the initial 30 min of the $HVY_{TTF}$ , as well as at $HVY_{signal}$ , $HVY_{end}$ , and $EXT_{peak}$ in each session

The  $\dot{V}O_2$ ,  $\dot{V}CO_2$ , HR, and  $\dot{V}E$  responses during the initial 30 min of the  $HVY_{TTF}$ , as well as at  $HVY_{signal}$ ,  $HVY_{end}$ , and  $EXT_{peak}$  in the control and reward session are presented in Figure 4.4.1.

In the control session and reward session, independently, the  $\dot{V}O_2$  responses elicited between 20 min ( $2.35 \pm 0.50 \text{ L} \cdot \text{min}^{-1}$ ;  $2.33 \pm 0.47 \text{ L} \cdot \text{min}^{-1}$ ) and 30 min ( $2.33 \pm 0.47 \text{ L} \cdot \text{min}^{-1}$ ;  $2.35 \pm 0.48 \text{ L} \cdot \text{min}^{-1}$ ) were not statistically different ( $t(17) = -1.57, p = 0.13$ );  $t(17) = -0.75, p = 0.46$ ). In the control session, 2 participants lasted only 27 and 28 min, and in the reward session, 1 participant only lasted 22 min. Therefore, for these participants, their  $\dot{V}O_2$  response at 30 min was computed as the 20 s average prior to task failure. A statistical analysis comparing 20 to 30 min was run with and without these participants and the results demonstrated similar outcomes (values not reported for simplicity).

The two-way repeated measures ANOVAs did not reveal any main condition effects pertaining to the cardiorespiratory variables (i.e.,  $\dot{V}O_2$ ,  $\dot{V}CO_2$ , HR, and  $\dot{V}E$ ) during each session (i.e., control and reward), at different time points (i.e., at  $HVY_{signal}$ ,  $HVY_{end}$ , and  $EXT_{peak}$ ). For  $\dot{V}O_2$ , no main effects were revealed. For  $\dot{V}CO_2$ , a main effect of time ( $F = 8.68, p = 0.01, \eta^2 = 0.34$ ) was detected whereby  $\dot{V}CO_2$  was greater from  $HVY_{signal}$  to  $EXT_{peak}$  ( $p = 0.03$ ) and  $HVY_{end}$  to  $EXT_{peak}$  ( $p = 0.02$ ). For HR, a main effect of time ( $F = 17.87, p < 0.001, \eta^2 = 0.51$ ) and condition x time interaction effect ( $F = 5.12, p < 0.01, \eta^2 = 0.23$ ) was revealed whereby HR was greater in the control session from  $HVY_{signal}$  to  $EXT_{peak}$  ( $p < 0.001$ ) and from  $HVY_{end}$  to  $EXT_{peak}$

( $p < 0.001$ ) and in the reward session from HVY<sub>signal</sub> to HVY<sub>end</sub> ( $p = 0.04$ ) and HVY<sub>end</sub> to EXT<sub>peak</sub> ( $p = 0.01$ ). For  $\dot{V}_E$ , a main effect of time ( $F = 11.38$ ,  $p = 0.003$ ,  $\eta^2 = 0.40$ ) was detected whereby  $\dot{V}_E$  was greater from HVY<sub>signal</sub> to HVY<sub>end</sub> ( $p = 0.01$ ) and HVY<sub>signal</sub> to EXT<sub>peak</sub> ( $p = 0.01$ ).

#### **4.4.2. $[La^-]_b$ between 15 min and 30 min of each session**

Figure 4.4.2. displays the  $[La^-]_b$  responses in the control and reward session. The  $[La^-]_b$  responses elicited between the control session and reward session were not statistically different. In the control session,  $[La^-]_b$  was stable and not statistically significant between 15 min ( $4.85 \pm 1.80 \text{ mmol} \cdot \text{L}^{-1}$ ) and 30 min ( $5.13 \pm 2.30 \text{ mmol} \cdot \text{L}^{-1}$ ) ( $t(17) = -1.77$ ,  $p = 0.10$ ). Similarly,  $[La^-]_b$  from 15 min ( $4.67 \pm 1.57 \text{ mmol} \cdot \text{L}^{-1}$ ) to 30 min ( $4.88 \pm 2.03 \text{ mmol} \cdot \text{L}^{-1}$ ) in the reward session was stable and not significantly different ( $t(17) = -1.30$ ,  $p = 0.21$ ). In the control session, two participants did not last until 30 min for a blood sample to be taken. In the reward session, a different participant did not last until 30 min for a blood sample to be taken. Statistical analysis comparing 15 min to 30 min with and without these participants was performed. The results showed similar statistical outcomes (values not reported for simplicity).

#### **4.5. The Relationship Between $\dot{V}O_{2\max}$ and the Change in HVY<sub>TTF</sub> and EXT<sub>TTF</sub> Duration, Independently, Between the Control and Reward Session**

The absolute  $\dot{V}O_{2\max}$  and the  $\Delta HVY_{\text{FINAL}}$  between sessions were not significantly correlated,  $r(18) = 0.12$ ,  $p = 0.65$ . There was also no significant correlation between the relative  $\dot{V}O_{2\max}$  and the  $\Delta HVY_{\text{FINAL}}$ ,  $r(18) = -0.11$ ,  $p = 0.67$ . Similarly, the absolute  $\dot{V}O_{2\max}$  and the  $\Delta EXT_{\text{FINAL}}$  between sessions were not significantly correlated,  $r(18) = -0.11$ ,  $p = 0.67$ ; in addition, the relative  $\dot{V}O_{2\max}$  and the  $\Delta EXT_{\text{FINAL}}$  between sessions were not significantly correlated,  $r(18) = -0.04$ ,  $p = 0.87$ .

#### 4.6. The Relationship Between the Change in Cardiorespiratory Variable(s) and the Change in HVY<sub>TTF</sub> Duration Between the Control and Reward Session

The correlation between the absolute  $\Delta\dot{V}O_{2\text{end}}$  and the  $\Delta\text{HVY}_{\text{FINAL}}$  was not significant,  $r(18) = 0.40, p = 0.10$ , and there was also no significant correlation between the relative  $\Delta\dot{V}O_{2\text{end}}$  and the  $\Delta\text{HVY}_{\text{FINAL}}$ ,  $r(18) = 0.37, p = 0.14$ . The correlation between the absolute  $\Delta\dot{V}CO_{2\text{end}}$  and the  $\Delta\text{HVY}_{\text{FINAL}}$  was not significant,  $r(18) = 0.17, p = 0.49$ , and there was also no significant correlation between the relative  $\Delta\dot{V}CO_{2\text{end}}$  and the  $\Delta\text{HVY}_{\text{FINAL}}$ ,  $r(18) = 0.16, p = 0.52$ . Furthermore, there was no significant correlation between: *i*)  $\Delta\text{HR}_{\text{end}}$  vs.  $\Delta\text{HVY}_{\text{FINAL}}$ ,  $r(18) = -0.05, p = 0.85$ , *ii*)  $\Delta\text{RER}_{\text{end}}$  vs.  $\Delta\text{HVY}_{\text{FINAL}}$ ,  $r(18) = -0.06, p = 0.82$ , *iii*)  $\Delta\dot{V}_{\text{Eend}}$  vs.  $\Delta\text{HVY}_{\text{FINAL}}$ ,  $r(18) = -0.08, p = 0.74$ , and *iv*)  $\Delta\text{fB}_{\text{end}}$  vs.  $\Delta\text{HVY}_{\text{FINAL}}$ ,  $r(18) = 0.02, p = 0.95$ .

**Table 4.** Participant characteristics and RI cycling test results at task failure. Data presented as mean±SD.

Variable	Total (n=18)
Age (yrs)	23±3
Height (cm)	174.8±7.8
Body Mass (kg)	73.2±11.0
PO <sub>peak</sub> (W)	285±44
PO <sub>peak</sub> (W·kg <sup>-1</sup> )	3.9±0.7
[La <sup>-</sup> ] <sub>bmax</sub> (mmol·L <sup>-1</sup> )	10.4±1.3
RPE <sub>max</sub> (Borg 6-20)	18.2±1.2
VO <sub>2max</sub> (L·min <sup>-1</sup> )	3.04±0.55
VO <sub>2max</sub> (mL·kg <sup>-1</sup> ·min <sup>-1</sup> )	41.9±7.5

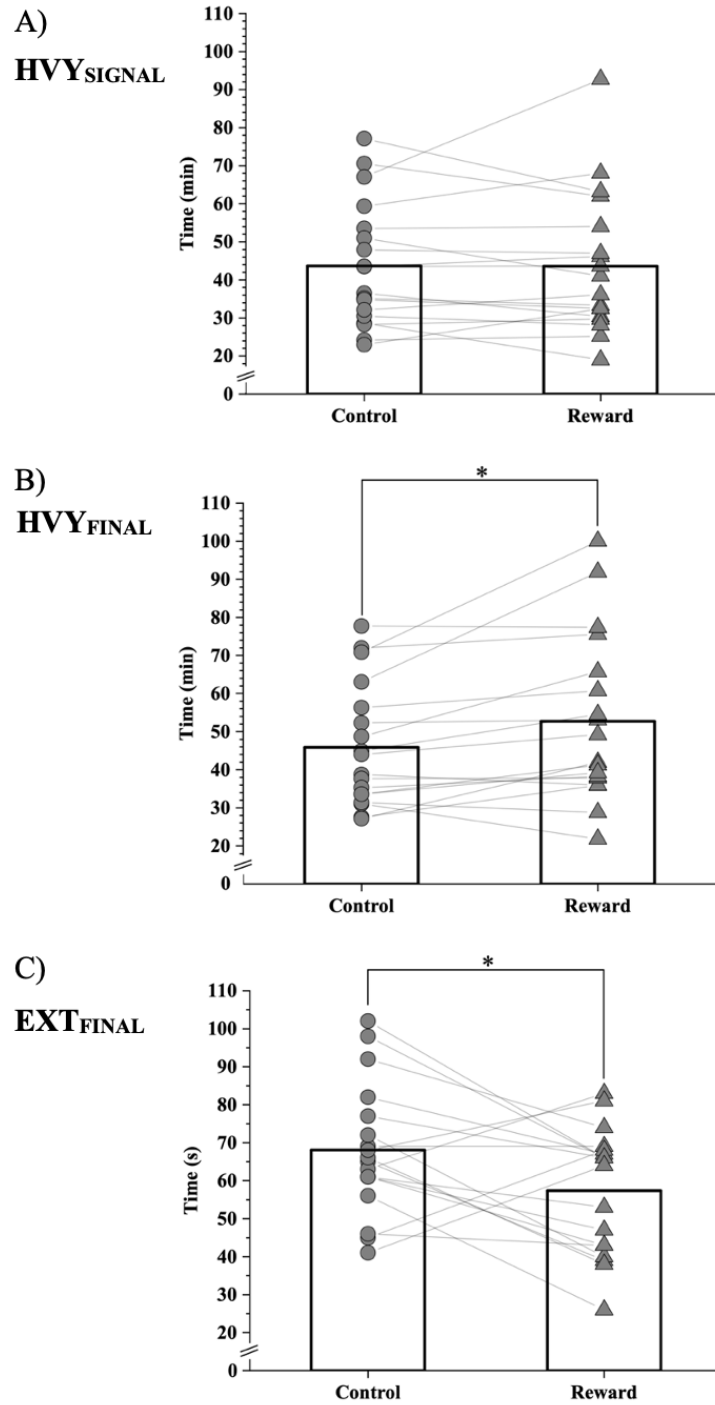
**Table 4.2.** Isometric performance fatigability assessments in each session (i.e., control, reward), assessed pre- ( $NM_{BSL}$ ) and post-exercise ( $NM_{HVY}$ ,  $NM_{EXT}$ ). Data are presented as means $\pm$ SD.

Variable	$NM_{BSL}$	$NM_{HVY}$	$NM_{EXT}$
$\&IMVC, N$			
Control	601 $\pm$ 201	414 $\pm$ 109*	413 $\pm$ 116*
Reward	616 $\pm$ 231	418 $\pm$ 120*	415 $\pm$ 128*
VA, %			
Control	90 $\pm$ 6	90 $\pm$ 9	87 $\pm$ 10
Reward	89 $\pm$ 8	86 $\pm$ 11	84 $\pm$ 15
$\&Db_{10:100}$			
Control	0.99 $\pm$ 0.11	0.73 $\pm$ 0.09*	0.70 $\pm$ 0.09*
Reward	1.00 $\pm$ 0.11	0.74 $\pm$ 0.09*	0.72 $\pm$ 0.11*
$\&Qtw_{pot}, N$			
Control	177 $\pm$ 54	109 $\pm$ 29*	100 $\pm$ 29* <sup>^</sup>
Reward	174 $\pm$ 56	110 $\pm$ 24*	99 $\pm$ 24* <sup>^</sup>
$\&M_{maxVL}, mV$			
Control	10.26 $\pm$ 4.81	8.54 $\pm$ 3.91	8.10 $\pm$ 4.23
Reward	10.15 $\pm$ 5.21	9.04 $\pm$ 2.63	8.87 $\pm$ 2.90
$\&M_{maxRF}, mV$			
Control	6.49 $\pm$ 1.65	5.57 $\pm$ 1.23*	5.47 $\pm$ 1.88*
Reward	6.90 $\pm$ 2.50	6.14 $\pm$ 2.11*	6.12 $\pm$ 2.14*
$rmsEMG_{VL} \cdot M_{max}^{-1}$			
Control	0.06 $\pm$ 0.05	0.04 $\pm$ 0.02	0.07 $\pm$ 0.09
Reward	0.06 $\pm$ 0.03	0.05 $\pm$ 0.02	0.05 $\pm$ 0.02
$rmsEMG_{RF} \cdot M_{max}^{-1}$			
Control	0.07 $\pm$ 0.02	0.07 $\pm$ 0.02	0.08 $\pm$ 0.11
Reward	0.06 $\pm$ 0.03	0.06 $\pm$ 0.03	0.06 $\pm$ 0.03

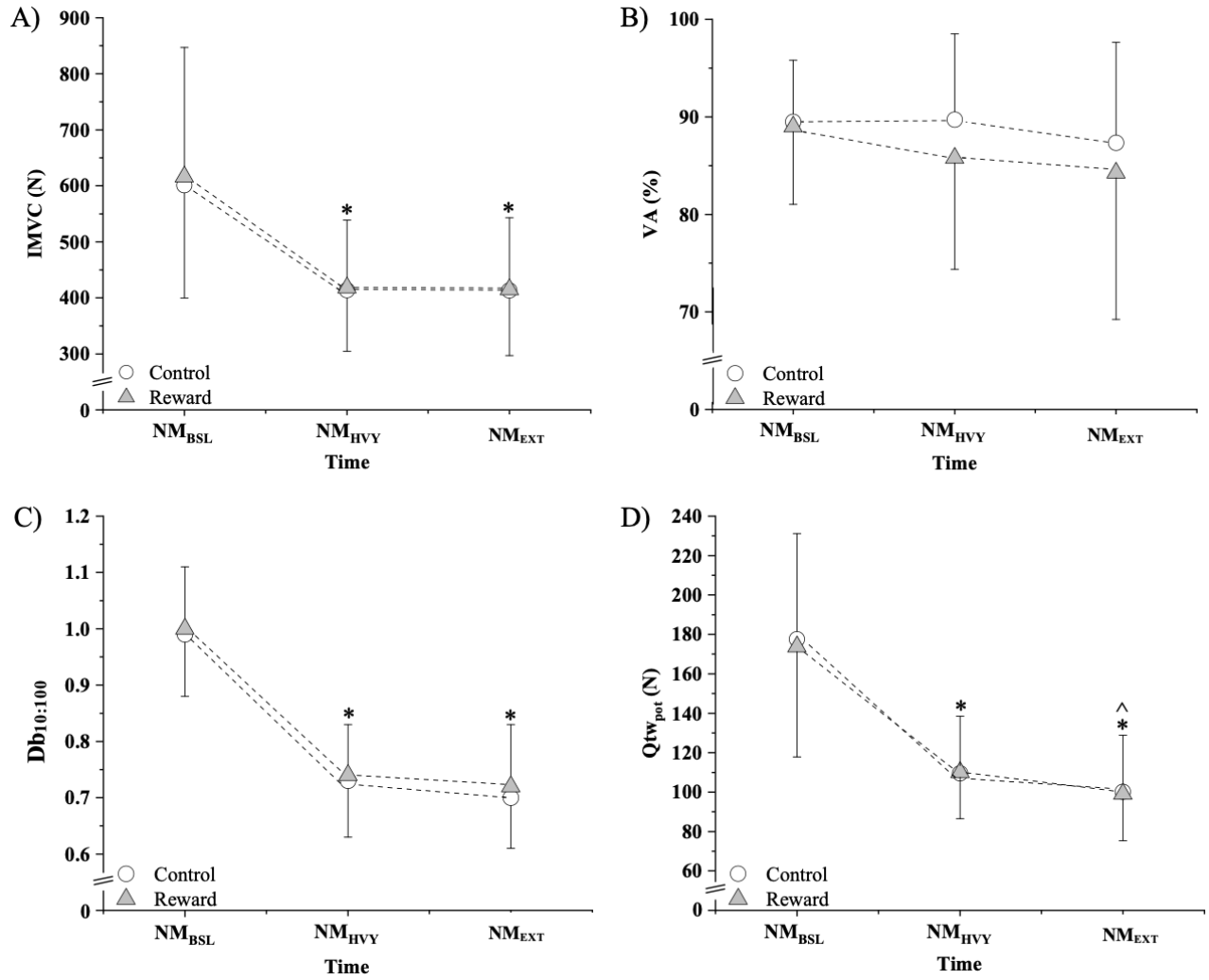
$\&$ Main effect of time.

\*Significant difference from  $NM_{BSL}$ .

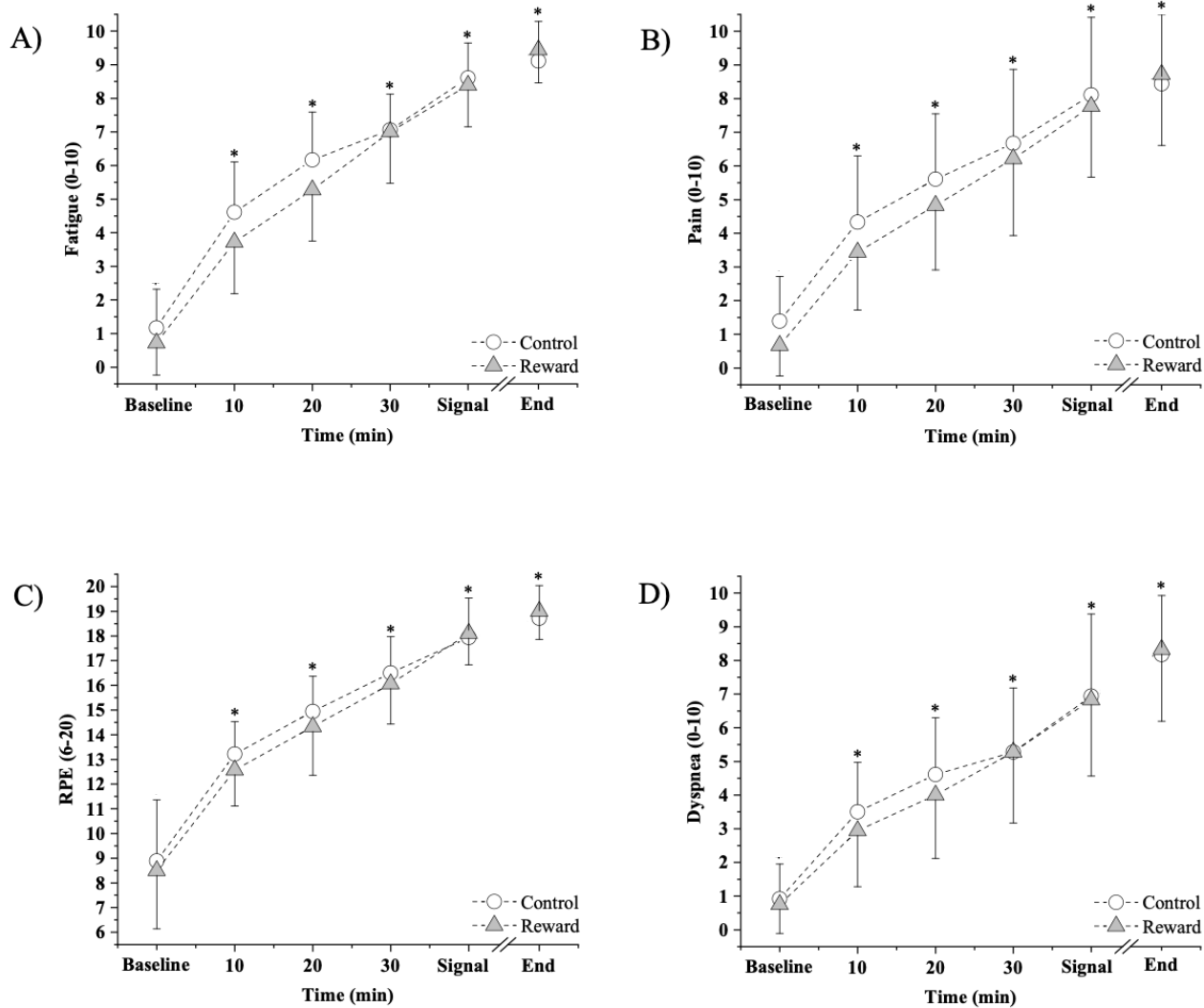
<sup>^</sup>Significant difference from  $NM_{HVY}$ .



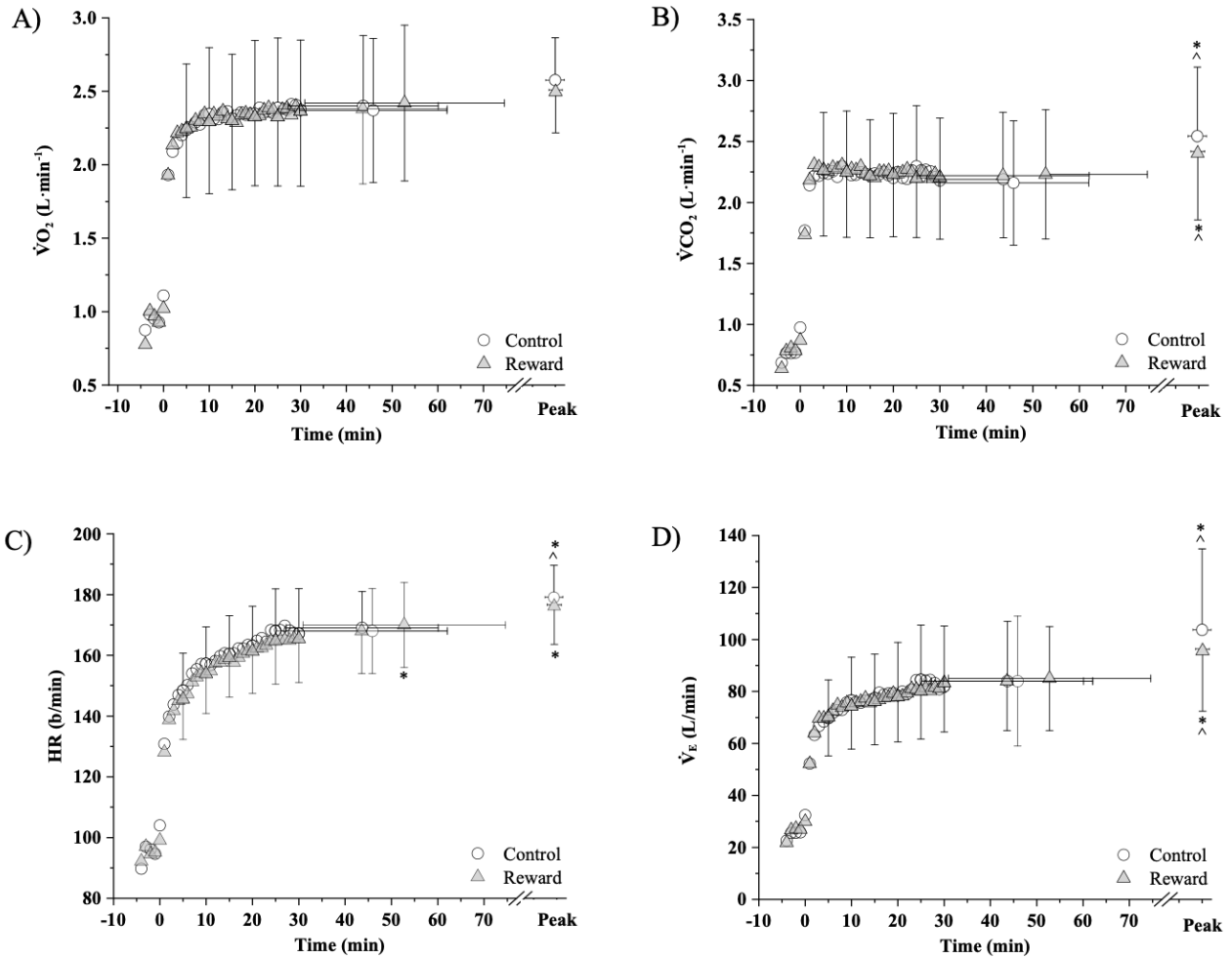
**Figure 4.1.** Group mean total with individual variability tests (n=18) between sessions for time durations of the HVY<sub>TTF</sub> and dynamic performance fatigability assessment via the EXT<sub>TTF</sub> (Panels – A: HVY<sub>SIGNAL</sub>, Panel B: HVY<sub>FINAL</sub>; Panel C: EXT<sub>FINAL</sub>). \*Significant difference between sessions.



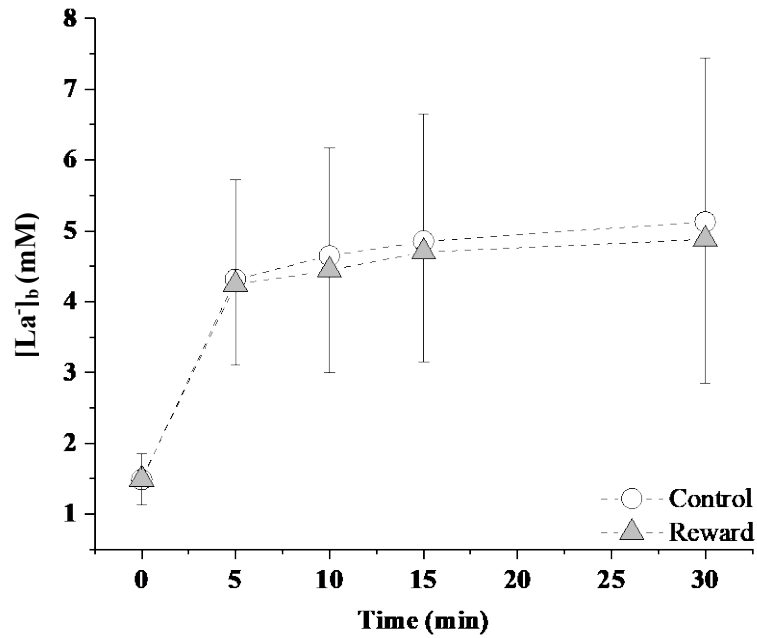
**Figure 4.2.** Group mean total for isometric performance fatigability assessments measured in each session (i.e., control and reward), assessed pre- (NM<sub>BSL</sub>) and post-exercise (NM<sub>HVY</sub>, NM<sub>EXT</sub>) (Top Panels – A: IMVC, B: %VA; Bottom Panels – C: Db<sub>10:100</sub>, D: Qtw<sub>pot</sub>). \*Significant difference from baseline in both sessions. ^Significant difference from NM<sub>HVY</sub>



**Figure 4.3.** Group mean total of perceived fatigability via perceptual responses (Top Panels – A: Fatigue, B: Pain; Bottom Panels – C: RPE, D: Dyspnea) in each session during the HVY<sub>TTF</sub> at baseline, 10 min, 20 min, 30 min, and at the point of the 1 min signal, and in the EXT<sub>TTF</sub> at the end. \*Significant difference from prior data point in both sessions.



**Figure 4.4.1.** Group mean cardiorespiratory responses (Top Panels – A:  $\dot{V}O_2$  (L·min<sup>-1</sup>), B:  $\dot{V}CO_2$  (L·min<sup>-1</sup>); Bottom Panels – C: HR (b/min), D:  $\dot{V}_E$  (L/min)) represented as 1 min averages during each session in the initial 30 min of the HVY<sub>TTF</sub>, as well as at HVY<sub>signal</sub>, HVY<sub>end</sub>, and EXT<sub>peak</sub>. Error bars with the SD are present at 5 min intervals and at task failure for the x- and y-axis, independently. \*Significant difference from HVY<sub>signal</sub> in the same session. ^Significant difference from HVY<sub>end</sub> in the same session.



**Figure 4.4.2.** Group mean  $[La^-]_b$  responses during each session at baseline, 5 min, 10 min, 15 min, and 30 min in the HVY<sub>TF</sub>.

## Chapter V: Discussion

This study evaluated the use of a monetary reward on exercise performance and fatigability outcomes during a HVY<sub>TTF</sub> followed by a EXT<sub>TTF</sub> bout of cycling exercise. The main findings were that: *i*) physically active, healthy, young adults can be influenced by an unexpected monetary reward to increase their HVY<sub>TTF</sub> performance; *ii*) whereas the increase in performance elicited no changes in performance fatigability evaluated through an isometric NM assessment following the HVY<sub>TTF</sub>, there was a reduction in duration during the dynamic performance fatigability assessment via the EXT<sub>TTF</sub> in the reward session compared to control; *iii*) between sessions, there were similar profiles of perceived fatigability up until the point of the 1 min signal (i.e., the announcement of the reward) and following the EXT<sub>TTF</sub>.

### 5.1. The Impact of the Unexpected Incentive on the HVY<sub>TTF</sub> Performance

In agreement with one of the hypotheses, the unexpected monetary reward improved cycling exercise performance during the HVY<sub>TTF</sub>. Although previous studies indicated that the use of a financial incentive had no significant effects on cycling endurance exercise performance outcomes (Hulleman et al., 2007; Skorski et al., 2017), our results demonstrated an underperformance of exercise compared to a control session, indicating the existence of an untapped energy reserve that participants can access when motivated to do so.

A potential reason for the divergent results might be connected to the different methodologies used in the present compared to the previous studies (Hulleman et al., 2007; Skorski et al., 2017) that: *i*) utilized TTs as the exercise task; *ii*) did not blindly incentivize participants. During TTs, prolonging the duration of exercise is not possible and the changes in exercise performance rely on the differences in total work accumulated during the selected period. This model might result in pacing acting as a confounding variable, as it enables the work

rate to be altered to regulate energy expenditure during the trial (Skorski & Abbiss, 2017). Furthermore, fluctuations in work rate associated with pacing may result in participants traversing between exercise intensity domains, which will affect the availability of energy reserves (Fullerton et al., 2021; Thomas et al., 2016) and, potentially, impact performance. Likewise, when a TT is performed and, simultaneously, a reward can be anticipated (i.e., it is not blindly administered), it is difficult to ascertain how pacing and motivation act concurrently to influence exercise behavior. Based on these potential limitations, by using a TTF whereby a consistent cadence and constant-PO was maintained for the entirety of the exercise bout, the uncertainty involving pacing and its effect on exercise outcomes was eliminated. In addition, the use of deception by way of an unexpected monetary reward being offered just before the point of perceived task failure made it possible to directly observe and measure an incentivized extension of exercise.

## **5.2. Connection Between TTF Performance and Performance Fatigability Assessments**

### ***5.2.1. Post-HVY<sub>TTF</sub> isometric performance fatigability assessments***

As expected, exercise in the HVY<sub>TTF</sub> resulted in a significant reduction in the IMVC from NM<sub>BSL</sub> to NM<sub>HVY</sub>, in both sessions. However, the extension of the HVY<sub>TTF</sub> in the reward session did not further attenuate maximal force-generating capacity, which displayed virtually the same profile as in control session. From a peripheral fatigue perspective, both Db<sub>10:100</sub> and Qtw<sub>pot</sub> were reduced from NM<sub>BSL</sub> to NM<sub>HVY</sub> which demonstrates that the HVY<sub>TTF</sub> induced peripheral fatigue and impaired muscle contraction (Calderón et al., 2014; Millet et al., 2012); nevertheless, there was no significant difference in the decline between the reward and the control session. From a central fatigue perspective, VA showed small but not significant differences from NM<sub>BSL</sub> to NM<sub>HVY</sub> in both sessions. This lack of central fatigue contrasts with other investigations that have

shown a significant decline following cycling exercise in the vicinity of the upper boundary of the heavy intensity domain (Azevedo et al., 2022; Iannetta et al., 2022; Thomas et al., 2016) but still might indicate the absence of a decline in the level of “drive” to muscle fibers and motoneurons or central motor command (Hureau et al., 2016). Nevertheless, there are additional possibilities that may help explain the the lack of differences such as: *i*) a large variability in the data; *ii*) a true plateau in the IMVC not being achieved (i.e., at  $NM_{BSL}$ ) and thus implying lower than normal VA values; *iii*) the chance that there was an underestimation of the reported VA results due a recovery of the IMVC and electrically evoked force recovery that begins immediately upon task failure and is affected if a short time delay (i.e., 30 s) exists between the end of exercise and the assessment (Carroll et al., 2017).

The increase in performance in the reward session did not elicit a further decline in isometric performance fatigability. A previous investigation found that, during constant-PO TTFs surrounding MLSS, the first 5 min of exercise is when the vast majority of IMVC, VA, and contractile function decline occurred (i.e., ~75% of baseline) and, afterwards, the rate of decline was much slower (Azevedo et al., 2022). Therefore, even though the reward session in the present study showed a significant increase in the duration of the  $HVY_{TTF}$ , the fact that the decline in isometric performance fatigability occurs at a much slower rate as the bout of exercise progresses beyond 10-15 min, and that nearly all isometric performance fatigability reductions occur at around 30 min (Azevedo et al., 2022) during a heavy intensity trial suggests that the  $HVY_{TTF}$  performance enhancement in the reward session was not long enough to further impact isometric performance fatigability. Then, it likely that the unexpected reward offering was appealing enough to have influenced participants to have “pushed” their sensory tolerance limit, and thus override their initial desire to voluntarily disengage from the task (Hureau et al., 2016).

However, it is possible that a greater reward may have been needed to elicit a longer “push” so to have tapped further into the energy reserve and, consequently, produced a greater decline in isometric performance fatigability that could have been measured during the isometric task. An alternative explanation could be that an upper limit of performance fatigability had been reached for isometric task evaluations and that dynamic tasks that are similar to the evaluated condition are needed to see changes in performance fatigability elicited by the intervention. This idea of needing task-specific evaluations to capture declines in performance fatigability has been discussed elsewhere (Krüger et al., 2019).

### ***5.2.2. EXT<sub>TTF</sub> performance and post-EXT<sub>TTF</sub> isometric performance fatigability assessments***

Unlike the isometric performance fatigability assessments, the dynamic performance fatigability assessment via EXT<sub>TTF</sub> captured differences between the control and reward session as the reward session was shorter than the control session. Previous studies have shown that, when a previous exercise task is performed even at a slightly greater PO, the duration of a subsequent TTF has been shortened (Azevedo et al., 2021; Fullerton et al., 2021; Iannetta, Inglis, et al., 2018). Fullerton et al. (2021) found that manipulating exercise duration had marked effects on subsequent TTF performance whereby, at MLSS, as the duration was increased (from 15, to 30, and to 45 min), subsequent TTF performance was reduced in a seemingly linear pattern (from ~29%, to ~52%, and to ~69%). By analogy, we expected that with the HVY<sub>TTF</sub> performed at the same demanding PO, a significantly longer duration would elicit a decline in the EXT<sub>TTF</sub>. In theory, while there is no depletion of anaerobic sources during exercise in the heavy domain, there is a progressive decline of substrates (i.e., [PCr], [ATP]) (Black et al., 2017) that are still important for subsequent exercise (i.e., the EXT<sub>TTF</sub>) (Fullerton et al., 2021).

Furthermore, IMVC, VA, and  $Db_{10:100}$  did not show further decline from  $NM_{HVY}$  to  $NM_{EXT}$  between sessions thus confirming that the upper limit of the isometric performance fatigability had already been achieved (for these variables) and there was no capacity for further decline. However,  $Q_{tw_{pot}}$  was further reduced from  $NM_{HVY}$  to  $NM_{EXT}$  and, consequently, supports the idea that during whole-body locomotor exercise (i.e., cycling), increases in exercise intensity result in greater reductions in  $Q_{tw_{pot}}$  (Azevedo et al., 2022; Iannetta, Zhang, et al., 2022; Thomas et al., 2015, 2016, 2018). The  $Q_{tw_{pot}}$  as a measure of peripheral fatigue is strongly associated with metabolic disturbance and depletion of [PCr], which is likely associated with severe/extreme exercise intensities (Azevedo et al., 2021; Black et al., 2017).

### **5.3. The Role of Perceived Fatigability Throughout Exercise**

Evaluations of perceived fatigability (i.e., Fatigue, Pain, RPE, Dyspnea) displayed the same profiles (i.e., no significant condition or interaction effects) as the performance fatigability outcomes for each session up until the point of the 1 min signal during the  $HVY_{TTF}$ . Therefore, the possibility that reduced perceived fatigability prior to the unexpected monetary reward being offered played a major role in the significant increase in exercise performance during the  $HVY_{TTF}$  can be ruled out. Similarly, it is unlikely that task failure during the  $EXT_{TTF}$  ride was due to perceived fatigability since the outcomes of performance fatigability were the same between sessions, despite the reduction in exercise duration. Nevertheless, perceived fatigability at the 1 min signal during the  $HVY_{TTF}$  was significantly less than at the end of the  $EXT_{TTF}$ , in both sessions. Accordingly, it cannot be ruled out that perceived fatigability may have been greater at task failure of the  $HVY_{TTF}$  compared to at the 1 min signal during the  $HVY_{TTF}$ , especially in the reward session since participants lasted significantly longer and had more time to further express perceived fatigue.

A prediction postulated at the psychological level of explanation by the psychobiological model of endurance exercise performance likely supports our findings. The  $HVY_{TTF}$  being significantly prolonged suggests that the unexpected incentive increased the level of potential motivation sufficiently enough to justify a greater and/or maximal effort (Marcora, 2019).

#### **5.4. Cardiorespiratory Variables and Their Contribution to TTF Performance**

Although the consistency of  $\dot{V}O_2$  and  $[La^-]_b$  responses between sessions was not essential to our aim since a repeated, within-subjects design was utilized, we aimed to have participants exercising in the upper boundary of the heavy intensity domain of exercise so that exercise would elicit metabolic conditions that were sustainable but intensely stressful (Black et al., 2017).

Unlike  $\dot{V}O_2$ ,  $\dot{V}CO_2$ , and  $\dot{V}_E$ , for which there were no significant increases from  $HVY_{signal}$  to  $HVY_{end}$ , HR in the reward session was significantly increased from  $HVY_{signal}$  to  $HVY_{end}$ . This was likely due to the increased cardiovascular drift with prolonged exercise in the reward session, which is commonly seen during prolonged constant-PO exercise regardless of the intensity (Azevedo et al., 2021; Coyle & González-Alonso, 2001; Souissi et al., 2021). Furthermore, with no significant increase in  $\dot{V}O_2$  from  $HVY_{end}$  to  $EXT_{peak}$ , it is likely that the  $EXT_{TTF}$  was too intense and short to allow for a full expression to maximal values (i.e.,  $\dot{V}O_{2max}$ ) (Azevedo et al., 2021; Iannetta, Zhang, et al., 2022).

There is a common belief that, compared to the less fit individuals, those who are fitter can ‘dig deeper’, work relatively harder, and finish exercise with a lower security reserve (Esteve-Lanao et al., 2008; Millet, 2011). In this study, the lack of significant relationship between the  $\dot{V}O_{2max}$  and the  $\Delta HVY_{FINAL}$  and the  $\Delta EXT_{FINAL}$  between sessions, independently, suggests that fitness did not impact the extension of the  $HVY_{TTF}$  or reduction of the  $EXT_{TTF}$ ,

respectively. This finding is supported by a study that found adept runners to be faster than the non-adept not as a result of more effort but instead due to an underlying physiological capacity (Esteve-Lanao et al., 2008).

Lastly, there were no significant correlations between any of the cardiorespiratory variables (i.e.,  $\dot{V}O_2$ ,  $\dot{V}CO_2$ , HR, RER,  $\dot{V}_E$ , and fB) and the  $\Delta HVY_{FINAL}$ . Therefore, these variables were not integral to the extension of the exercise bout in  $HVY_{TTF}$  in the reward compared to the control condition.

### **5.5. A Summary of the Interpreted Results**

In summary, this thesis used an unexpected monetary reward for the purpose of motivating participants to prolong their  $HVY_{TTF}$ . Then, by way of a comparison from  $NM_{BSL}$  to  $NM_{HVY}$ , it was determined that the incentivized extension of exercise did not exacerbate the declines in isometric performance fatigability outcomes. Further, the significantly shorter duration of the dynamic performance fatigability assessment via the  $EXT_{TTF}$  in the reward session contradicted the  $NM_{EXT}$  whereby no condition effect was found. Lastly, profiles of perceived fatigability were similar between sessions during the  $HVY_{TTF}$  up until the unexpected monetary reward was offered, as well as immediately after task failure of the  $EXT_{TTF}$ .

## Chapter VI: Conclusions

The purpose of this thesis was to investigate the impact of an unexpected monetary reward on exercise performance by determining whether: *i)* physically active, healthy, young adults can be influenced by an unexpected monetary reward to increase their  $HVY_{TTF}$  performance; *ii)* performance fatigability was altered; *iii)* perceived fatigability was significantly different.

The novel findings presented and discussed in Chapters IV and V of this thesis demonstrated that an unexpected monetary reward has ergogenic effects. Interestingly, despite the longer  $HVY_{TTF}$  under the experimental condition (i.e., the reward session), distinct methods of quantifying fatigue presented mixed effects. Whereas isometric performance fatigability assessments demonstrated significant time effects that were similar in each session (i.e., no condition effects), a dynamic performance fatigability assessment via the  $EXT_{TTF}$  showed a significantly shorter duration due to the longer  $HVY_{TTF}$  in the reward session. The profiles of perceived fatigability were similar at all measured time points between sessions. These findings are important when investigating the limit of endurance exercise tolerance as they indicate that this limit can be modified. Furthermore, the findings in this thesis present a possible limitation when trying to evaluate performance fatigability during a dynamic task (i.e., cycling exercise) using a static evaluation (i.e., IMVC). This suggests that optimal performance fatigability assessments may require protocols that take the characteristics of the task into account to produce results that most accurately reflect the decline in performance.

### 6.1. Limitations and Methodological Considerations

The current thesis had some limitations and methodological components that must be considered.

This thesis utilized a SRS cycling protocol to have participants performing the constant-PO during the  $HVY_{TTF}$  near the upper boundary of the heavy intensity domain of exercise. Although the SRS cycling protocol has been shown to be accurate at establishing the PO associated with the heavy-severe boundary (Iannetta, Inglis, Pogliaghi, et al., 2020), it remains an estimation and an appropriate validation would be needed to confidently establish this boundary. Thus, it is possible that some participants might have performed their exercise slightly above the MMSS. Nevertheless, the precision of this estimation was not integral for the purpose of this study. The repeated measures design allowed participants to act as their own method of comparison. An individual's exercise performance in the control session was compared to their exercise performance in the reward session, at the same PO. Therefore, the estimated intensity was accepted as viable if participants were able to maintain the exercise for a duration accepted to be considered within the upper limit of the heavy intensity domain (i.e., ~30 min) but not too long to be in the middle to lower regions of the heavy intensity domain (i.e., ~90 min).

In this thesis, it was essential that the  $HVY_{SIGNAL}$  was similar between the control and reward session so that reliable and accurate comparisons could be made regarding the impact of incentivization on endurance exercise outcomes. When the study was being designed, a concern existed with the reproducibility of a cycling TTF, as some have shown low reliability of TTFs at the MLSS (Faude et al., 2017), or decreased performance in the first TTF in a series of two cycling TTFs (Laursen et al., 2003). As reported in the results section, there was no statistically significant difference between the  $HVY_{SIGNAL}$  in the control session versus the reward session ( $p = 0.97$ ), which alleviated pre-conceived concerns in this regard.

An unavoidable limitation was that the testing sessions were not randomized, as introducing the reward in the second constant-PO exercise session was the only way to keep it

unexpected. Although learning and/or training effects could be considered as a potential source of error, this was minimized as: *i*) participants were experienced with endurance performance activities/testing, which virtually eliminated a learning effect; *ii*) the duration of the study (i.e., three sessions with at least 48 hrs of recovery in between) was too short to result in any meaningful training effect. Regardless, the results indicate that a training and/or learning effect was not a concern since the HVY<sub>SIGNAL</sub> was provided at the same time in the control and the reward session, as previously stated.

Since this thesis involved the use of deception to ensure that the monetary reward offering remained unexpected, it was crucial to eliminate the potential of subject bias. Therefore, confidentiality was a key element to success regarding maintaining the integrity of the study and its design. If participants were to find out or anticipate that a monetary reward existed prior to it being offered during the HVY<sub>TTF</sub>, the data would then have been unusable. As such, participants were aware of the exercise to be performed and measurements recorded; however, they were blinded to the true purpose of the study. At the conclusion of the data collection process, a questionnaire was distributed to confirm that each participant had no prior knowledge of the incentivization aspect of the study. Importantly, all participants self-reported to have been unaware.

During the HVY<sub>TTF</sub>, perceptual responses were recorded and used as a tool to assess perceived fatigability during exercise and at the point of the 1 min signal. This way, perceptual responses were analyzed to determine if the level of perceived fatigability was similar prior to the incentivized extension of exercise. Nevertheless, at task failure during the HVY<sub>TTF</sub>, there were no perceptual responses recorded. This was due to a prioritization of the isometric performance fatigability assessments which had to occur very quickly after task failure. Also,

with such a tight window between the  $HVY_{TTF}$  and  $EXT_{TTF}$  (i.e., 1 min), along with an isometric performance fatigability assessment in between, there was not enough time to concurrently assess perceptual responses. Furthermore, recording the perceptual responses retrospectively would not have been effective since valid responses may have been confounded by the stimulation sensation felt during the isometric performance fatigability assessment. It would have been interesting to have measured if participants were able to access their perceptual reserve as they significantly increased the  $HVY_{TTF}$  in the reward session. Nevertheless, perceived fatigability at the end of the  $EXT_{TTF}$  was similar between sessions even with a reduction of the  $EXT_{TTF}$ .

## **6.2. Future Directions**

Future investigations are suggested to examine the effectiveness of an incentivization in establishing truly maximal exercise outcomes, as well as further assessing the mechanistic basis for the extension of exercise. Specifically, physiological variables were assessed up until the point of task failure in both sessions but, unfortunately, perceived fatigability could not be measured at task failure in both sessions due to methodological limitations. Therefore, in future investigations it would be interesting to consider identifying the difference in perceived fatigability at the point of the 1 min signal (i.e., task failure prior to incentivization) to the ‘true’ point of task failure (i.e., task failure after incentivization). By doing so, perceived fatigability in the control session may be compared to the reward session and its contribution to task failure, and ultimately achieving maximal exercise outcomes, could be assessed.

In addition, this thesis examined the correlation between the  $\dot{V}O_{2max}$  and the  $\Delta HVY_{FINAL}$  and  $\Delta EXT_{FINAL}$ , independently, to assess if participant fitness levels were connected to the potential changes in exercise performance outcomes. Moving forward, investigations should

include participants with a broader range of fitness levels to allow for a more comprehensive assessment.

### **6.3. Final Remarks**

In conclusion, this thesis demonstrated that an unexpected monetary reward is an effective strategy that can be used to increase endurance exercise performance. Between sessions, isometric performance fatigability assessments were not statistically different, only presenting time effects within each session and with similar response between sessions whereas, in the reward session, there was a significant reduction in the dynamic performance fatigability assessment by way of the  $EXT_{TTF}$ . In addition, there was no significant difference in perceived fatigability between sessions during the  $HVY_{TTF}$  and at the end of the  $EXT_{TTF}$ . Therefore, the distinct performance fatigability assessments provided opposing results in their evaluation of fatigue, highlighting the potential need to evaluate performance fatigability using a methodology that captures the characteristics of the task being evaluated. Importantly, an interesting factor to consider is to measure perceptual responses at task failure to assess perceived fatigability and its contribution to task failure. Lastly, a more widespread population of fitness levels might help to better assess the correlations between participant fitness (i.e.,  $\dot{V}O_{2max}$ ) and the  $\Delta HVY_{FINAL}$  and  $\Delta EXT_{FINAL}$ , independently.

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## Appendices

### *Appendix A: Supplementary Table*

**Supplementary Table 1.** Using a paired t-test, the ramp-incremental (RI) cycling test  $\dot{V}O_{2max}$  was compared to the post-exercise time-to-task failure (TTF) in the extreme intensity domain of exercise ( $EXT_{TTF} \dot{V}O_{2peak}$  in each session (i.e., control and reward), independently. Compared to the RI cycling test  $\dot{V}O_{2max}$  ( $3.04 \pm 0.55 \text{ L} \cdot \text{min}^{-1}$ ), both the control  $EXT_{TTF} \dot{V}O_{2peak}$  ( $2.58 \pm 0.50 \text{ L} \cdot \text{min}^{-1}$ ) and reward  $EXT_{TTF} \dot{V}O_{2peak}$  ( $2.50 \pm 0.47 \text{ L} \cdot \text{min}^{-1}$ ) were significantly less ( $t(17) = 7.92, p < 0.001$ ;  $t(17) = 4.43, p < 0.001$ ).

Variable	RI $\dot{V}O_{2max}$	Control $EXT_{TTF} \dot{V}O_{2peak}$	Reward $EXT_{TTF} \dot{V}O_{2peak}$
$\dot{V}O_2 (\text{L} \cdot \text{min}^{-1})$	$3.04 \pm 0.55$	$2.58 \pm 0.50^*$	$2.50 \pm 0.47^*$

\*Significant difference from RI  $\dot{V}O_{2max}$

*Appendix B: Letter of Informed Consent*

**INFORMED CONSENT FORM**

**Title:** Examining the limit of sustainable endurance exercise tolerance in in physically active, healthy, young adults.

**Sponsor:** The University of Calgary

**Funder:** NSERC

**Primary Investigator:** [REDACTED]

[REDACTED]

**Introduction:**

[REDACTED] and associates from the Human Performance Laboratory (HPL) at the University of Calgary are conducting a research study in the HPL.

This consent form is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, please ask. Take the time to read this and to understand any accompanying information. You will receive a copy of this form for your records.

You are a possible participant in this study because you showed an interest in our project. Your participation in this research study is voluntary.

**What is the purpose of this study?**

The purpose of this study is to investigate sustainable endurance exercise tolerance. We aim to determine if the limit of endurance exercise tolerance is fixed or flexible.

**How many people will take part in this study?**

Twenty-three (23) participants will take part in this study through the University of Calgary.

**What will happen if I take part in this study?**

Throughout the entirety of the study, you will self-select your cadence (70-90 revolutions/min (rpm)) and maintain it. You will be blinded to time. Exhaustion will be operationally defined as an inability to continue cycling within 10 rpm of the requested cadence for greater than 5 s despite strong verbal encouragement, and/or task disengagement.

***Session #1: The Step-Ramp-Step (SRS) Cycling Test.***

Time Commitment: ~1.5 hrs

In Session #1, you will fill out the *PAR-Q+* form to ensure this experiment is safe for you to do. You will have the entire experimental procedure explained to you in detail. This includes a thorough explanation of all physiological measures (i.e., neuromuscular (NM) assessments, electromyography (EMG), oxygen consumption ( $\dot{V}O_2$ ), heart rate (HR), and blood lactate concentration ( $[La^-]_b$ ), and perceptual responses (i.e., global fatigue (Fatigue), exercising leg pain (Pain), rating of perceived exertion (RPE), and intensity of breathlessness (Dyspnea). You will have the opportunity to ask questions before consenting.

Next, we will set-up and familiarize you with the NM measurements. This will involve non-invasive electrical stimulations of the femoral nerve in your groin area. These stimulations will cause twitching of your thigh muscles and only mild discomfort. The sensation will be very brief (< 1 s) and will in no way result in any pain or harm. If you deem the sensation felt from the stimulation to be exceedingly uncomfortable (i.e., exceeding a 5/10 on a scale measuring the level of discomfort experienced), the study will not proceed.

Prior to beginning exercise, we will set-up for the continuous recording of several physiological measures. This includes EMG,  $\dot{V}O_2$ , and HR. EMG will measure muscle electrical activity. Electrodes will be placed on the skin of the muscles on the thigh of your dominant leg (vastus lateralis (VL) and rectus femoris (RF)). To measure  $\dot{V}O_2$ , you will wear a mask that covers your nose and mouth. HR will be measured via chest strap, and recordings will be made at baseline and every 10 min.

You will then perform the SRS cycling protocol. Specifically, you will perform a moderate intensity step transition (MOD), a ramp-incremental (RI) test, followed by a recovery period before a heavy intensity step transition (HVY). MOD will consist of cycling for 4 min at 20W (very easy cycling), followed by 6 min at 60-100W (moderate intensity cycling). Immediately after, the RI test will be initiated. This involves a baseline lasting 4 min at 20W, followed by a ramp that will increase by 30W each minute (30W/min), concluding when you feel like you can no longer sustain the exercise. After 30 min of rest, you will perform HVY. This consists of cycling for 4 min at 20W, followed by 12 min at 50-65% of the RI peak power output ( $PO_{peak}$ ) determined from the RI test. This intensity will feel vigorous yet manageable. For perceptual responses, Fatigue, Pain, RPE, and dyspnea will be recorded at baseline and termination of the RI test, as well as at baseline and termination of the latter HVY bout. At baseline and conclusion of the RI test, as well as at baseline and conclusion of the latter HVY bout, we will measure your  $[La^-]_b$ . By drawing a small blood sample through a finger prick puncture using a lancet, each sample will be immediately collected into a capillary tube and placed into a portable lactate analyzer (Lactate Plus). Therefore, there will be a total of 4  $[La^-]_b$  tests in this session.

### ***Session #2: Time to Task Failure (TTF) - Control Condition.***

Time Commitment: ~2 hrs

In Session #2, you will receive a brief overview of the testing sequence whereby a control condition will be established. You will begin the session with a NM assessment. This involves an IMVC – a leg muscle contraction at your greatest effort. You will maintain your IMVC for 3 s

and during such, a nerve stimulus will be applied to the femoral nerve in your groin region. Upon relaxation and during this rest period, there will be 3 more stimuli applied once every 2 s.

Before starting exercise testing, we will set-up the necessary physiological measurements. This includes EMG,  $\dot{V}O_2$ , and HR. To measure perceptual responses during the first TTF, Fatigue, Pain, RPE, and Dyspnea will be assessed at baseline and every 10 min until exercise termination; furthermore, during the second TTF, Fatigue, Pain, RPE, and Dyspnea will be assessed at the beginning and end.

Then, you will complete a warm-up consisting of a 4-min cycle at 20W. Immediately after, you will perform a TTF at 95% of your maximal metabolic steady state (MMSS) power output (PO). This is an intensity that you should feel is moderately hard but sustainable for a long time. Upon reaching the point at which you feel like you can no longer tolerate the exercise, a NM assessment will take place within 30 s. Afterwards, you will resume cycling at 20W until the 1-min mark, whereby you will perform another TTF at a PO that is 90% of the RI  $PO_{peak}$  (very hard exercise), aimed to last approximately 1-2 min. Again, once you stop the exercise, you will undergo a NM assessment. It is important to ensure you are performing within the heavy intensity domain of exercise. Thus, a small blood sample through a finger prick will be taken and analyzed at baseline and during the first TTF, every 5 min for the first 30 min, and every 10 min until exercise termination. Therefore, the total number of  $[La^-]_b$  tests in this session will vary depending on exercise duration. On average, we predict the voluntary exercise to last for approximately 60 min, indicating an approximate total of 10  $[La^-]_b$  tests.

### ***Session #3: TTF Series B - Test Condition.***

Time Commitment: ~2 hrs

During session #3, the exact same testing sequence that you performed in session #2 will be repeated. The only difference is, at the beginning of the session, you will be instructed to, during exercise, communicate to researchers when you are nearing your point of exercise termination. You will do this by raising your hand at eye-level and displaying your index finger for just a moment to signal researchers that you are nearing the end of your ability to maintain exercise (i.e., you have approximately 1 min of exercise left in the tank).

### **(!) Prior to arriving at the laboratory for testing, please adhere to the following guidelines:**

- *Be consistent in your morning routine on the testing days.*
- *Refrain from consuming food and caffeinated and/or alcoholic beverages for at least 2 and 12 hrs, respectively, prior to testing sessions.*
- *Refrain from participating in unusually strenuous exercise the day prior to testing sessions.*
- *Wear comfortable clothes.*

### **How long will I take part in this study?**

- Participation in this study will occur over approximately 2 weeks.
- Once included in this study, you will be required to visit the laboratory 3 times for a total time commitment of approximately 5-5.5 hrs.

- The first visit will last approximately 1.5 hrs, and subsequent visits will be about 2 hrs long.
- The visits will occur at similar times of the day, either in the morning or afternoon/evening, depending on your preference.

**Are there any potential risks or discomforts that I can expect from taking part in this study?**

Any exercise may be uncomfortable or carries a slight risk if you are not used to doing exercise or unfit. The risk of a cardiac event (i.e., heart attack, dysrhythmias, etc.) in a mixed subject population (healthy low-risk and unhealthy high-risk patients together) is approximately 6:10,000. However, the risk decreases in a previously healthy (i.e., young, physically active) population.

During exercise testing, you might experience some minor discomforts. They will become less noticeable with familiarization. You will experience responses inherent to high intensity exercise. Including increased breathing and sweating, general nausea, and muscle pain and fatigue. Furthermore, the NM assessment process is often intense and finger pricks to draw blood might cause mild discomfort. Also, the face mask worn during the RI test might be uncomfortable.

**Are there any additional risks related to Covid-19?**

By participating in this research study, you may have an increased risk of exposure to Covid-19. This is because you will have increased human interactions and spend some time within the facility. We are mitigating this risk by adopting the following measures:

- You will be screened upon each visit for the presence of any symptoms related to Covid-19.
- You will be asked upon each visit if you were in contact with any person who tested positive for Covid-19.
- All testers in the research laboratory will be wearing personal protection equipment (this includes gloves, masks, face shields, lab coats).
- You will be asked to wash your hands upon arrival to the laboratory, as well as to wear a mask at all times while not being tested.
- All the surfaces and multi-use equipment will be carefully disinfected before and after each use.

More information related to the risks and the risk mitigation strategies are detailed in a specific consent form attached to this document.

**If I take part in this study, will I benefit?**

As a result of participating in this study, you will benefit by way of knowledge learning and accumulation, not only to do with exercise but also how it works since you will be offered your individual results from your testing sessions. You will have the opportunity to learn about your

physiological and/or perceptual responses(s) to exercise. You can ask questions about the purpose of the study, specific measures, and overall findings.

### **What other choices do I have if I choose to not participate?**

Your participation in this research project is entirely voluntary. The consent to participate in this study will be asked at the beginning of the study and will remain valid for the rest of the study.

### **Can I stop being in this study?**

You can withdraw anytime just by sending an email to [REDACTED] or by simply expressing this desire verbally to a researcher.

You might be withdrawn from this study for the following reasons:

- Changes in your status so that you do not fit within the admission criteria for this study.
- You cannot complete all testing sessions within the proposed period of the study.
- You are not able to comply with the instructions prior to each testing session.

However, once the data is published, you will not be able to withdraw from the study. If new information becomes available that might affect your willingness to participate in the study, you will be informed as soon as possible.

### **Do I have to pay for anything, or will I be paid for participating?**

If you are driving your car to attend any session (i.e., you are coming to the University of Calgary only to participate in the study), we will cover parking expenses. We will give you a parking permit before each session. You will be expected to relinquish the permit when you have finished your session. If you use public transit to attend any session, please provide us with your transit ticket/receipt. You will be reimbursed for the amount required to come to and from the session.

### **If I suffer a research-related injury, will I be compensated?**

If you suffer an injury because of participating in this research, no compensation will be provided to you by the researchers, or by the University of Calgary. You still have your legal rights. Nothing said in this consent form alters your right to seek damages.

### **Will information about me and my participation be kept confidential?**

Information obtained during this research project is confidential. Nobody, except the researchers, will have access to your personal information. Your records are listed according to an identification number rather than by your name. Published reports resulting from this study will not identify you by name. Thus, your right to privacy will be retained. If you require it, you will be given a summary of your results and the averages for all participants in the study. Should you withdraw from the study at any time, information collected up to that point might be used for scientific purposes unless you request otherwise. In that case, the information collected will be discarded. Additionally, the

data collected from this study may be combined and reported in aggregate with data from past and future studies conducted by this research team.

**How long will information from the study be kept?**

The research data analyzed in this study might be used only for future research and kept in a de-identifiable state.

- The researchers intend to keep the research data for approximately 10 yrs.

Any future use of this research data is required to undergo review by a Research Ethics Board.

**Do any of the researchers have a conflict of interest?**

No conflicts of interest, financial or otherwise, are present for this research study.

**Contact for future research?**

University of Calgary researchers may contact me in the future to ask me to take part in other research studies.

YES

NO

**How can I find out about the study results?**

Your study result will be made available to you individually through a detailed fitness report at the end of your study period.

**Whom may I contact if I have questions about this study?**

**The Research Team:**

You may contact [REDACTED] with any questions or concerns about the research or your participation in this study.

**Conjoint Health Research and Ethics Board (CHREB):**

If you have any questions concerning your rights as a possible participant in this research, please contact the Chair, Conjoint Health Research Ethics Board, University of Calgary at 403-220-7990.

**How do I indicate my agreement to participate?**

Your signature on this form indicates that you have understood the information regarding your participation in the research project. You agree to participate. In no way does this waive your legal rights nor release the investigators or involved institutions from their legal and professional responsibilities.

**Signature of Study Participant**

\_\_\_\_\_  
Name of Participant

\_\_\_\_\_  
Signature and Date

**Signature of Person Obtaining Consent**

\_\_\_\_\_  
Investigator/Delegate's Name

\_\_\_\_\_  
Signature and Date

**Signature of Witness**

\_\_\_\_\_  
Name of Witness

\_\_\_\_\_  
Signature and Date

A signed copy of this consent form has been given to you to keep for your records and reference.