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UNIVERSITY OF TARTU
Press
1632

Institute of Sport Sciences and Physiotherapy, Faculty of Medicine, University of Tartu, Tartu, Estonia

The dissertation was accepted for the commencement of the degree of Doctor of Philosophy in Exercise and Sport Sciences on 17th June 2022 by the Institute Council of the Institute of Sport Sciences and Physiotherapy, Faculty of Medicine, University of Tartu, Tartu, Estonia.

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Commencement: White Hall of the University of Tartu Museum, 25 Lossi St., Tartu, 25th August 2022

Publication of this dissertation is granted by the Institute of Sport Sciences and Physiotherapy, University of Tartu, by the Doctoral School of Behavioural, Social and Health Sciences created under the auspices of European Union Social Fund and in collaboration with Estonian Ministry of Education and Research (Institutional Grant No. PRG 1120; PUT1395G).

This research was supported by national scholarship program Kristjan Jaak and DoRa which are funded and managed by Education and Youth Board, a government agency of the Estonian Ministry of Education and Research.

European Union
European Regional
Development Fund

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ISSN 1406-1058
ISBN 978-9949-03-971-5 (print)
ISBN 978-9949-03-972-2 (pdf)



University of Tartu Press
www.tyk.ee

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# LIST OF ORIGINAL PUBLICATIONS

**I** Purge, P., Valiulin, D., Kivil, A., Müller, A., Tschakert, G., Jürimäe, J., Hofmann, P. (2021). The Effect of Lower Body Anaerobic Pre-Loading on Upper Body Ergometer Time Trial Performance. *Sports*, 9(6): 79. https://doi.org/10.3390/sports9060079.

**II** Valiulin, D., Purge, P., Mäestu, J., Jürimäe, J., Hofmann, P. (2022). Effect of Short-Duration High-Intensity Upper-Body Pre-Load Component on Performance among High-Level Cyclists. *Sports*, 10(3): 32. https://doi.org/10.3390/sports10030032.

**III** Valiulin, D., Purge, P., Hofmann, P., Mäestu, J., Jürimäe, J. (2021). Can We Improve the Functional Threshold Power Test by Adding High-Intensity Priming Arm-Crank? *Journal of Functional Morphology and Kinesiology*, 6(4): 88. https://doi.org/10.3390/jfmk6040088.

**Paper I**, Dmitri Valiulin had primary responsibility for data analysis, investigation, and editing the final version of manuscript.

**Paper II and III**, Dmitri Valiulin had primary responsibility for study protocol development, enrollment of the participants, performing measurements, data analysis, and writing the manuscripts.

# ABBREVIATIONS

| | |
|---|---|
| 10% Δ | 10% of the difference between the work rate at the $VT_2$ and $\dot{V}O_{2max}$ above $VT_2$ |
| BMI | body mass index |
| $CI_{95\%}$ | confidence interval at a 95% level |
| FTP20 | 20-minute Functional Threshold Power Test |
| HIE | high-intensity exercise |
| HR | heart rate |
| La | lactate |
| [La] | lactate concentration |
| mLSS | maximal lactate steady state |
| $MPT_{high}$ | maximal performance test with common warm-up added by high-intensity priming load |
| $MPT_{low}$ | maximal performance test with common warm-up |
| $P_{max}$ | maximal power |
| PPO | peak power output |
| RER | respiratory-exchange-ratio |
| RPE | rating of perceived exertion |
| $\dot{V}CO_2$ | carbon dioxide output |
| $\dot{V}O_{2max}$ | maximal oxygen consumption |
| $VT_1$ | first ventilatory threshold |
| $VT_2$ | second ventilatory threshold |

# 1. INTRODUCTION

An adequate warm-up is a key aspect of a successful and sustainable performance with better perception and lower risk of traumas (McGowan et al., 2015). Finding a balance between warm-up-induced activation and physiological benefits remains crucial for every pre-competitive preparation. In this context, maintaining the muscles in an optimal pre-start condition plays an important role before each competition (McGowan et al., 2015).

A traditional warm-up process, consists of light endurance activity and stretching, is the basic requirement for a successful performance (Burkett et al., 2005; Hajoglou et al., 2005; Richendollar et al., 2006). Active warm-up is responsible for physiological changes, the combined effect of which is capable of improving competitive performance (Bishop et al., 2001). The main effects are increased muscle temperature, nerve conduction rate, speeded metabolism kinetics, oxygen uptake kinetics ($\dot{V}O_2$), muscle post-activation potentiation, and psychological preparedness (Bishop et al., 2001; McGowan et al., 2015). Since athletic skills and physiological properties have increased rapidly in the recent years, the focus has moved to better physiological preparation (Burnley et al., 2011; Wilkerson et al., 2004), that could speed up $\dot{V}O_2$ kinetics and increase peak power output (PPO) values without spending crucial energy and time.

High-intensity warm-ups are found to have a greater effect on $\dot{V}O_2$ kinetics, increase time to exhaustion and enable a greater aerobic contribution (Burnley et al., 2011, 2005; Jones et al., 2003). In addition, high-intensity warm-ups significantly elevate blood lactate concentration [La] which per se could accelerate $\dot{V}O_2$ at the start of exercise by forcing the organism to stimulate mitochondrial respiration (Burnley et al., 2001). This effect is suggested from an inhibition of lactate production due to an inverse gradient for lactate due to already elevated blood [La] from non-dominant muscles (Parolin et al., 1999). An interaction between lactate (La) producing and La consuming muscle cells and their interaction with the body system can be explained by the lactate shuttle theory (Brooks, 2018, 2009). The latter broadens the knowledge regarding La as glyconeogenetic precursor, energy substrate and key regulator, and explains the distribution of glucose and lactate to well-oxygenated fast-twitch glycolytic and slow-twitch oxidative muscle fibres (Brooks, 2018, 2009).

It is suggested that short-term performance, which is dependent on the ability to break down high-energy phosphate stores, will be negatively affected by an intense warm-up that decreases the availability of high-energy phosphates (Bishop et al., 2001). On the other hand, exercise longer than 2–3 min is primarily limited by aerobic energy contribution which may be enhanced by intense warm-up procedures (Fujii et al., 2019). It has previously been substantiated that blood [La] is related to carbon dioxide output ($\dot{V}CO_2$) (Iaia et al., 2010) and thus to anaerobic effort (Bishop et al., 2001; Gray and Nimmo, 2001; Robergs et al., 1991). A major problem with high-intensity, long-duration exercise is tolerating the side effects of the highly anaerobic first 40–60 s of exercise, which causes rapid increase in heart rate and ventilation. Therefore, it was suggested that an early accelerated increase in $\dot{V}O_2$ (Martin et al., 1975) and a lower net La production within the working muscle improves performance (Tschakert and Hofmann, 2013).

Commonly used warm-up techniques are based on isolated preparation of performance-related muscles added to a general warm-up. In contrast, more general warm-up approaches can impact muscles systemically without raising local muscle acidosis or using glycogen depot (Purge et al., 2017). This thesis intends to research the extent to which high-intensity warm-up could influence a subsequent endurance performance.

# 2. LITERATURE REVIEW

Maximal athletic performance requires an overall systemic preparation, which is reinforced by a preceding warm-up session. The scientific community has agreed on the positive effects of warm-up and absence of warm-up is considered to have a detrimental effect. Although warm-ups can be different, the aim is to prepare musculoskeletal, neural, metabolic, and psychological mechanisms to stimulate performance of muscle contraction (McGowan et al., 2015).

Metabolic conditioning is an emerging trend intended to improve the basic warm-up effects. Competition puts the greatest strain on all the body's functioning mechanisms, while requiring the biggest effort from both local and systemic levels. ATP turnover efficiency rises with tissue oxygenation rates, and higher oxygen ($O_2$) concentration allows the possibility to use slow but high-energy density substrates such as fat or intracellular lactate to provide ATP (Gladden, 2004). Exploiting metabolic mechanisms such as priming can provide higher $O_2$ levels, speed up $\dot{V}O_2$ kinetics, and increase power output and submaximal activation of aerobic mechanisms (Bohnert et al., 1998; Chorley and Lamb, 2019).

High-intensity performance requires a high $\dot{V}O_{2max}$ for endurance athletes, but the true challenge is to sustain a high fraction of $\dot{V}O_{2max}$ for a prolonged time (Ghosh, 2004). $\dot{V}O_{2max}$ alone was not shown to be a good predictor of endurance performance when athletes of similar endurance ability are compared (Morgan et al., 1989). In fact, economy at first ($VT_1$) and second ($VT_2$) ventilatory thresholds plays a crucial role, since athletes with nearly identical $\dot{V}O_{2max}$ values can perform at different levels (Ghosh, 2004). Aerobic training often improves submaximal thresholds such as $VT_1$ and the $VT_2$ as well as other physiological variables without a concomitant increase in $\dot{V}O_{2max}$ (Allen et al., 1985). The $VT_2$ representative of the maximal lactate steady state (mLSS), has a superior relationship to endurance performance compared to $\dot{V}O_{2max}$ and is suggested to be a better indicator of aerobic endurance (Beneke, 1995; Billat et al., 2003). $VT_2$ and mLSS describe a maximal metabolic steady state in which lactate production and utilization are in a fine systemic balance (Billat et al., 2003; Tschakert and Hofmann, 2013) and improvements of $VT_2$ were shown to enhance endurance performance (Bacon et al., 2013). Studies have shown that athletes are capable of maintaining $VT_2$ intensity for an impressive amount of time. Some research limited the capacity to 60 min (Gavin et al., 2012; Morgan et al., 2018) but others have raised discussions about the accuracy of this statement, questioning its physiological basis (Jones et al., 2019). Considering athletes' individuality and the different research methods, work duration at mLSS intensity is suggested to be about ~20–60 min (Tschakert et al., 2022) but may be dependent on exercise mode and muscle mass involved (Gavin et al., 2012; Morgan et al., 2018). However, as the power increases above $VT_2$ intensity, the duration dramatically decreases. Identifying the critical point of maximal metabolic steady state and predicting performance capability is a main concern for many athletes, coaches, and sports scientists. Therefore, $VT_2$ and $\dot{V}O_{2max}$ are both used to select a tailored exercise workload (Bailey et al., 2009; Burnley et al., 2011; Tschakert and Hofmann, 2013).

High-intensity warm-ups are found to have a greater effect on physiological condition (Burnley et al., 2011, 2005; Jones et al., 2003); however, the selected intensity should not induce fatigue or it should be eliminated during the recovery phase before the sports performance. Stronger athletes have shown a faster recovery and greater effect from high-intensity warm-up (Seitz et al., 2014), thus efficient recovery time after warm-up may still vary depending on the individual athlete, affecting subsequent performance and physiological parameters (Hodgson et al., 2005; Seitz and Haff, 2016). Competitive experience and age of the athlete influence the rating of perceived exertion (Barroso et al., 2014), that can vary from day to day despite the same training duration and same intensity due to the specificity of individual characteristics (physical and psycho-social) that might affect the internal load of each individual athlete (Haddad et al., 2017). Therefore, optimizing performance depends on the warm-up intensity, individual factors and recovery time between the warm-up activity and maximal performance (Hodgson et al., 2005; Seitz and Haff, 2016). This is the reason why well-trained athletes tend to use an individualized warm-up, based on athletic experience and current well-being (Palmer et al., 2009).

High-intensity warm-up component, i.e. priming, can induce a significantly elevated [La] in a short period of time – thus affecting metabolic function and creating a negative [La] gradient such as La uptake rather than La efflux on a systemic level. For performances that require (sub)maximal aerobic metabolism, metabolic conditioning can be achieved both by moderate and heavy-intensity exercises equally (Burnley et al., 2005). Overall metabolic status achieved by priming inhibits La production during subsequent time trial (Birnbaumer et al., 2018; Purge et al., 2017). Lower $\dot{V}CO_2$ values from spirometry measurements relate to lower La production per each watt (Iaia et al., 2010), and consequently lower anaerobic effort (Bishop et al., 2001; Gray and Nimmo, 2001; Robergs et al., 1991). Decreased net La production during performance inhibits anaerobic metabolism and expected to enhance aerobic metabolism (Müller et al., 2013; Parolin et al., 1999).

According to previous studies, systemic changes can be generated by any muscle group, regardless of muscle mass or localization (Bogdanis et al., 1994; Bohnert et al., 1998; Spendier et al., 2020). Additionally, systemic changes provoked by non-sport specific muscles give an opportunity to improve subsequent maximal performance efficiency while keeping sport-specific muscles unaffected, and without raising local muscle acidosis or using glycogen depot (Müller et al., 2013; Purge et al., 2017). Previous studies have reported that preloaded high-intensity exercise conducted by the upper body affected glycogenolysis and significantly reduced $\dot{V}CO_2$ during subsequent maximal performance test (Purge et al., 2017). Previously, a variety of studies have investigated such priming effects by non-dominant muscles, e.g. leg exercise priming for subsequent arm and upper-body exercise (Birnbaumer et al., 2018; Bogdanis et al., 1994; Müller et al., 2013; Purge et al., 2017).

Studies have shown that pre-loading by the arms can be compared to prior leg sprint exercise (Bogdanis et al., 1994; Bohnert et al., 1998) and induce similar $\dot{V}O_2$ levels up to 45 min after high-intensity exercise (Burnley et al., 2006). Purge et al. (2017) found that pre-loaded high-intensity exercise conducted by the upper body affected glycogenolysis and significantly reduced $\dot{V}CO_2$ during 7–8 min of all-out performance in rowers. Despite clear evidence of physiological changes, there have also been contradictory findings stating that non-target muscle priming does not have a beneficial effect on subsequent performance (Purge et al., 2017). Possible reasons were inhibited anaerobic energy contribution, overly intensive warm-up, and insufficient recovery after warm-up, as well as modified pacing strategies (Purge et al., 2017). However, physiologically beneficial performance enhancement could only be detected in small-muscle-group exercise (Birnbaumer et al., 2018). Birnbaumer et al. (2018) showed that anaerobic metabolic pre-conditioning significantly improved pull-up exercise compared to a standard warm-up program performed by legs. Bohnert et al. (1998) investigated upper-body pre-loading, which is qualitatively comparable to lower-body pre-loading, although lower in magnitude. According to this approach, Müller et al. (2013) found that arm crank exercise before leg exercise significantly inhibited anaerobic energy contribution during the leg workout. Less anaerobic energy in the same amount of total work means more aerobic energy was produced and consumed. Priming induced by non-sport specific limbs may be a new preparation method, prescribed as metabolic conditioning for endurance sports where aerobic metabolism could be more useful (Birnbaumer et al., 2018; Purge et al., 2017). Although excessively intense exercise before a high-intensity bout may reduce performance level through decreased muscle glycogenolysis and La production (Bangsbo et al., 1993; Gaitanos et al., 1993), and lower levels of muscle glycogen and pH, the effects of anaerobic pre-load with non-dominant muscles remain unclear.

In 1972, Klausen and colleagues investigated positive effects that could be induced by earlier activation of aerobic mechanisms and provide a benefit to cycling performance. Physiological changes such as speeded $\dot{V}O_2$ kinetics and lower net [La] increase are confirmed by numerous studies (Bishop et al., 2001; Gerbino et al., 1996; Müller et al., 2013; Wilkerson et al., 2004). From an athletic perspective physiological changes may act as favorable conditions, although not guaranteeing improved competitiveness (Carter et al., 2005; Ferguson et al., 2007; Sousa et al., 2014). Although half a century has passed since the primary investigation, only marginal performance related effects have been discovered (Bishop et al., 2001; Gerbino et al., 1996; Müller et al., 2013; Wilkerson et al., 2004), there is still some need regarding the optimal dosage of such a conditioning protocol before integrating such priming activities into competitive sports. The most detailed suggestions according implementation of priming have been concluded by Caritá and colleagues (2015). Heavy priming exercise with a duration of 6–10 minutes can improve tolerance to severe exercise of maximum and supramaximal intensity (> 100% $\dot{V}O_{2max}$; duration between 2–5 minutes), but no priming is suggested before completing severe exercise of submaximal intensity (< 100% $\dot{V}O_{2max}$; duration between 9–12 minutes). Severe priming exercise of lower intensities (duration between 15–18 minutes) with sufficient recovery time of 9–20 minutes can be beneficial for subsequent submaximal performance (< 100% $\dot{V}O_{2max}$) and improve exercise tolerance (Caritá et al., 2015). Additionally, priming could serve as a re-warm-up as Yanaoka and colleagues (2020) have shown a positive effect from 1-minute cycling exercise at 90% of $\dot{V}O_{2max}$ at completing a subsequent >10 minute time trial.

Resource distribution throughout the distance, i.e. pacing, plays an important role in ensuring the best possible performance outcome (Abbiss and Laursen, 2008). Bailey et al. (2011) reported that utilizing a fast-start pacing strategy improved both the overall $\dot{V}O_2$ uptake and cycling exercise performance. It is a topic for discussion whether priming can alter a traditional pacing effect, and if it should cover all the distance with moderate intensity changes or just a part with high-intensity spurt. Two studies have attempted to investigate the effects of combining priming with pacing strategies in detail (Brock et al., 2018; Caritá et al., 2014). In both studies primed fast-start conditions performed the fastest, although insignificantly in the Caritá et al. (2014) study, since all primed pacing strategies showed the same beneficial effect. However, it was reported that the presence of priming exercise is principally compared to fast-start pacing (Caritá et al., 2014). Consequently, the fast-start can improve and not by any means decrease performance. These findings give an idea of the positive effects of pacing, although the magnitude and distribution over the distance need to be discussed.

## 2.1 Previous research for methodological set up

Overview articles were selected from the PubMed Central and EBSCO Discovery databases using a close search with further manual filtering (date: 26.03.2022). The search was conducted to put specific topic-descriptive words into abstract or title such as – prior exercise; high intensity; priming; preload; performance; effect. General words to describe physiological and measurable component were added for "all-fields" selection – warm up; lactate; aerobic/anaerobic; maximal; split/trial/sprint. PubMed Central (1) and EBSCO Discovery (2) advanced searches were carried out using following formulas:

((((prior exercise[Abstract] OR high intensity[Abstract] OR "priming"[Abstract] OR preload*[Abstract] OR pre-load*[Abstract]) AND (performance[Abstract] OR effect*[Abstract]))) OR ((prior exercise[Title] OR high intensity[Title] OR "priming"[Title] OR preload*[Title] OR pre-load*[Title]) AND (performance[Title] OR effect*[Title]))) AND (("warm up" OR "warm-up") AND lactate AND ("aerobic" OR "anaerobic") AND ("maximal" OR "all out" OR "all-out" OR "peak") AND ("split" OR "trial" OR "sprint")) (1)

TI (prior exercise OR high intensity OR "priming" OR preload* OR pre-load* ) AND TI ( performance OR effect* ) AND TX ( "warm up" OR "warm-up" ) AND TX lactate AND TX ( "aerobic" OR "anaerobic" ) AND TX ( "maximal" OR "all out" OR "all-out" OR "peak" ) AND TX ( "split" OR "trial" OR "sprint" ) Full Text (2)

Research articles describing physiological changes such as performance alterations were manually filtered out from articles with a measurable competitive component such as time, distance, or number of repetitions.

### 2.1.1 Inclusion and exclusion criteria

The main criterion was the presence of two warm-up protocols, with common warm-up and priming component added, which were completed with a counter-balanced crossover design using a test-retest method. The results of subsequent performance meant giving an adequate measure to both warm-up efficiencies among healthy male participants.

Cyclic sports and exercises until exhaustion were included. Team games are usually multi-variable, and an improved effect can be caused by different factors. The search was focused on endurance sports lasting $\geq 3$ minutes in order to be able to relate maximal performance to aerobic capacity (Viru, 1990), excluding sprint distances with a relatively low aerobic contribution. Pre-loading before shorter efforts < 2 minutes is usually situated to post-activation-potentiation effect, which should be considered as a neurological improvement (McGowan et al., 2015).

Studies which had no relation to human physiology were excluded. As metabolic preconditioning is seeking acute effects on endurance sports, training programs and motor learning specific studies were omitted. Studies including additional performance enhancement such as supplement use or physiological variables as blood flow restriction, ischemic preconditioning, and hypoxia modelling, were also excluded, although these methods could also offer an interesting and comparable effect.

### 2.1.2 Search results

As a result of the search PubMed Central showed 506 articles and EBSCO Discovery databases 341 full-text articles. After title and abstract revision studies which respond to all inclusion criteria were selected and analyzed, their references also filtered and matching studies added to the list. Detailed and systematic processing of methods and performance left in only a minor part of the total studies (13), which can be seen in Table 1.

Thirteen articles fulfilled all criteria. The main cyclic endurance sports were cycling (9), rowing (2), running (1) and modified pull-up exercise (1). Performance distance of targeted sports was not specified in 7 cases, instead they asked subjects to continue until exhaustion with specified intensity. In 7 articles a statistically significant performance improvement ($p < 0.05$) was achieved.

### 2.1.3 Summary from previous research

Former studies on metabolic pre-conditioning investigated the effects of different intensity warm-up protocols on physiological aspects. Being productive in finding effective methods to increase $V˙O_2$ kinetics or PPO (Gerbino et al., 1996; Müller et al., 2013; Tomaras and MacIntosh, 2011), researchers still remain cautious as competitive performance contains more factors than just physiological parameters. Even though objective measures prove athletes' preparedness, individual responses and perception need to be taken into consideration. As speeded up $V˙O_2$ kinetics, increased body and muscle temperature, increased PPO are prerequisites for successful performance, they truly serve the purpose of enhancing athletes' perception before subsequent effort. Feeling energized, fast, and powerful is the subjective part of the warm-up that should not be forgotten.

Studies which did not show performance improvements (Table 1) after high-intensity priming exercise (HIE) stated that the possible causes were reduced depletable energy resource or prolonged fatigue-metabolite levels (Ferguson et al., 2007). Moreover, fatigue and insufficient time to recover could have detrimental effects (Purge et al., 2017). These conditions could easily be prevented, and athletes' perception enhanced. In (2006), Burnley and colleagues found that priming effect of prior heavy exercise on the $V˙O_2$ uptake response persists up to 30–45 min. Knowing this extensive period of time, further research could give athletes some extra recovery time after an HIE priming session or use athletes' self-selected duration based on their readiness without losing any priming effect. Then the results of both Ferguson et al.'s (2007) and Purge et al.'s (2017) studies found to have no improving effect on performance, could have different outcomes.

Although many studies have been conducted on metabolic pre-conditioning research, no conclusive formula has been developed. The results are affected by multiple variables, i.e. pre-conditioning intensity and duration, recovery time and targeted sports intensity and duration. Still no common agreement has been reached (Ferguson et al., 2007). Some study results can show high variability between individuals in the context of the same protocol, and no relation between performance and $V˙O_2$ kinetics (Carter et al., 2005; Ferguson et al., 2007; Sousa et al., 2014). In the light of further research more individual intrinsic factors should be investigated. For example, self-selected recovery duration prior to performance trial along with [La] and RPE Borg scale measurements could show a correlation between enhanced performance and efficient [La] level.

In conclusion, cyclic sports with the possibility to use ergometer or repetitive movement should be considered in further investigations of metabolic pre-conditioning. We suggested using a counterbalanced crossover design with a test-retest method, in which one test would contain high-intensity pre-load with non-sport-specific muscle groups. Subsequent self-selected recovery duration with [La] and RPE Borg scale measurements and using sport-specific performance distance or all-out trial until exhaustion, based on previous research.

**Table 1**. Selected studies for metabolic pre-conditioning topic analysis.

| Research | Pre-conditioning activity | Pre-conditioning duration | Pre-conditioning intensity | [La] before the start | Recovery before MPT | Targeted sports | Targeted sports duration | Statistical significance |
|---|---|---|---|---|---|---|---|---|
| Jones et al., 2003; *n* = 7 | cycling | 6 minutes | 50% Δ (half-way between the gas exchange threshold and $\dot{V}O_{2peak}$) | 2.4 ± 0.3 mmol·L$^{-1}$ | 7 min passive + 3 min active | cycling | Until exhaustion with abrupt intensity increase to 100% $\dot{V}O_{2peak}$ | **Significant increase** in time to exhaustion ($p < 0.05$) |
| Carter et al., 2005; *n* = 11 | cycling | 3 × 73 sec | 90% $\dot{V}O_{2max}$ | 1.7 ± 0.2 mmol·L$^{-1}$ | 6 min active | cycling | Until exhaustion at critical power | **Significant increase** in time to exhaustion ($p < 0.05$) |
| Ferguson et al., 2007; *n* = 6 | cycling | 6 minutes | 275 ± 34 W | 8.6 ± 1.4 mmol·L$^{-1}$ | 2 min active | cycling | Until exhaustion with ramp increment to maximal power | **Not significant decrease** in time to exhaustion ($p > 0.05$) |
| Bailey et al., 2009; *n* = 8 | cycling | 6 minutes | 70% $\dot{V}O_{2max}$ | 9.3 ± 1.8 mmol·L$^{-1}$ and 8.0 ± 1.6 mmol·L$^{-1}$ | 9 and 20 ( ≥ 9 min). | cycling | Until exhaustion with abrupt intensity increase to 80% $\dot{V}O_{2peak}$ | **Significantly improved** exercise tolerance at 80%Δ in the 70-9-80 and 70-20-80 conditions ($p < 0.05$) |
| Palmer et al., 2009; *n* = 8 | cycling | 5 min + 5 min | 100 W and 50% Δ (half-way between the gas exchange threshold and $\dot{V}O_{2peak}$) respectively | 4.8 mmol·L$^{-1}$ | 1 min active + 12 min passive | cycling | 4000 m at performance intensity | **Not significantly** faster performance ($p > 0.05$) |

| Research | Pre-conditioning activity | Pre-conditioning duration | Pre-conditioning intensity | [La] before the start | Recovery before MPT | Targeted sports | Targeted sports duration | Statistical significance |
|---|---|---|---|---|---|---|---|---|
| Burnley et al., 2011; $n = 10$ | cycling | 6 minutes | 50% Δ (half-way between the gas exchange threshold and critical power) | $1.8 \pm 0.5$ mmol·L$^{-1}$ | 7 min passive + 3 min active | cycling | Until exhaustion at 70% Δ (between the gas exchange threshold and peak work rate) with abrupt intensity increase | **Significant increase** in time to exhaustion ($p < 0.05$) |
| Sousa et al., 2014; $n = 6$ | rowing | 6 minutes | 50% Δ (half-way between the gas exchange threshold and critical power) | $5.9 \pm 1.2$ mmol·L$^{-1}$ | 7 minutes | rowing | Until exhaustion with abrupt intensity increase to 100% $\dot{V}O_{2peak}$ | **Significant decrease** in time to exhaustion ($p < 0.05$) |
| Christensen and Bangsbo, 2015; $n = 12$ | cycling | 5 splits of different duration and recovery | all splits of different intensity | $5.1 \pm 1.7$ mmol·L$^{-1}$ | 20 minutes | cycling | 4-minute maximal performance | **Not significantly** decreased mean power ($p > 0.05$) |
| Purge et al., 2017; $n = 9$ | arm crank pre-load | 25 seconds | 30g·kg$^{-1}$ body weight / nearly max | $8.4 \pm 2.3$ mmol·L$^{-1}$ | 9 minutes | rowing | 2000 m at performance intensity | **Significant decrease** of performance ($p < 0.05$) |
| Birnbaumer et al., 2018; $n = 9$ | running | 25 second shuttle run | maximal peak power | $9.28 \pm 1.98$ mmol·L$^{-1}$ | 8 minutes | pull-up exercise | All-out performance | **Significant increase** of performance ($p < 0.05$) |
| Brock et al., 2018; $n = 9$ | cycling | 3 minutes | 70% Δ (70% between the gas exchange threshold and $\dot{V}O_{2peak}$) | $2.7 \pm 0.5$ mmol·L$^{-1}$ | 20 minutes | cycling | 4000 m at performance intensity with 12 sec all-out start | **Significant increase** of performance ($p < 0.05$) |

| Research | Pre-conditioning activity | Pre-conditioning duration | Pre-conditioning intensity | [La] before the start | Recovery before MPT | Targeted sports | Targeted sports duration | Statistical significance |
|---|---|---|---|---|---|---|---|---|
| González-Mohíno et al., 2018; $n = 11$ | running | 6 × 6 second hill strides (60 sec recovery between) | 105% $\dot{V}O_{2max}$ | 1.11 ± 0.66 $mmol \cdot L^{-1}$ | 10 min passive + 5 min active + 3 min passive | running | Until exhaustion with constant speed at 105% $\dot{V}O_{2max}$ | **Significant increase** in time to exhaustion ($p < 0.05$) |
| Chorley and Lamb, 2019; $n = 10$ | cycling | 3 × 10 seconds (30 sec recovery between) | 70% of peak power | 4.9 ± 1.4 $mmol \cdot L^{-1}$ | 5 minutes | cycling | 4000 m at performance intensity | **Not significantly** improved time ($p > 0.05$) |

References listed in the sequence of publication; level of significance $p < 0.05$

# 3. AIMS

The purpose of this study was to determine whether high-intensity priming exercise (HIE) executed by non-sport specific muscles improves outcomes of subsequent sport-specific performance test in male highly trained endurance athletes.

Specific objectives of the study are listed as below:

1. to assess the metabolic response to high-intensity priming exercise and estimate the magnitude of the anaerobic energy contribution to the total energy supply during subsequent maximal performance test.
2. to measure differences in time or mean power in maximal performance test in primed and non-primed conditions.
3. to determine an optimal recovery time before maximal performance test after HIE.
4. to control whether standardized pacing during maximal performance test can compensate the deficit of anaerobic energy contribution induced by prior HIE.

# 4. METHODS

## 4.1 Experimental overview

Participants attended the laboratory on three occasions in all studies within a 3-week period, with each visit being separated by at least 3 recovery days. On the first visit participants' body composition was measured and they were introduced to the testing equipment. To exclude any health risks associated with the maximum stress, all subjects had to perform a specialist-supervised incremental cycle ergometer test as the first exertion. Two gas exchange thresholds ($VT_1$, $VT_2$) were determined by an experienced researcher considering a disproportionate increase in $\dot{V}CO_2$ relative to $\dot{V}O_2$, ventilation breakpoints (V-slope), visual inspection of individual plots and respiratory-exchange-ratio (RER) value. The highest mean measured $O_2$ during 30 s period was considered $\dot{V}O_{2max}$. On two subsequent occasions maximal performance tests (MPTs) were performed. One with traditional warm-up and a second one with additional preload done by non-sport specific musculature.

All participants volunteered to participate in this study and were required to give their written informed consent at the first laboratory visit. Participants were instructed to arrive at the laboratory in a rested and fully hydrated state at least 2 h postprandial. They were asked to avoid ingesting alcohol and caffeine 24 h before each laboratory visit. In addition, maximal efforts no less than 3 days before the laboratory visit were allowed.

Inclusion criteria were that all participants were experienced national level male athletes (skiers in *Paper I* and cyclists in *Paper II, III*), being familiar with indoor competition procedures on particular equipment and have been training for at least 5 years. Exclusion criteria were illness or injury. Current studies were approved by the local University ethics committee (257/T-16 and 290/T-17) in accordance with the Declaration of Helsinki (Hellmann et al., 2014).

In order to objectively compare performance in two maximal performance tests under primed ($MPT_{high}$) and unprimed ($MPT_{low}$) condition. Participants performed both protocols in a randomized order. Participants were instructed to complete both maximal tests as quick as possible. Characteristics of participants are described in Table 2.

**Table 2.** Participants' characteristics.

| Characteristic | Mean ± SD | | |
|---|---|---|---|
| | **Paper I** | **Paper II** | **Paper III** |
| Participants (*n*) | 13 | 15 | 11 |
| Age (years) | 18.3 ± 2.9 | 23.3 ± 3.6 | 18.8 ± 0.9 |
| Height (m) | 1.81 ± 0.05 | 1.81 ± 0.07 | 1.82 ± 0.05 |
| Body mass (kg) | 70.8 ± 7.3 | 76.2 ± 10.0 | 73.0 ± 6.6 |
| BMI ($kg \cdot m^{-2}$) | 21.7 ± 1.8 | 23.2 ± 2.0 | 22.0 ± 1.9 |
| Total lean mass (kg) | 55.7 ± 5.9 | 58.6 ± 6.8 | 57.5 ± 4.9 |
| Incremental protocol | (40W + 20 W/min) | (60W + 20 W/min) | (100W + 30 W/3min) |
| $\dot{V}O_{2max}$ ($mL \cdot kg^{-1} \cdot min^{-1}$) | 57.3 ± 5.3 | 65.4 ± 6.7 | 67.9 ± 5.1 |
| $\dot{V}O_{2max}$ ($L \cdot min^{-1}$) | 4.1 ± 0.6 | 4.9 ± 0.5 | 5.0 ± 0.6 |
| $P_{max}$ (W) | 270.1 ± 42.1 | 404.2 ± 42.8 | 369.0 ± 47.9 |
| Ventilatory threshold $VT_1$ (W) | 127.0 ± 25.5 | 218.7 ± 33.9 | 181.4 ± 43.3 |
| Ventilatory threshold $VT_2$ (W) | 186.2 ± 28.2 | 310.8 ± 39.3 | 295.6 ± 39.9 |

BMI – body mass index, maximal oxygen uptake ($\dot{V}O_{2max}$), maximal power ($P_{max}$), first ventilatory threshold ($VT_1$), second ventilatory threshold ($VT_2$).

### 4.1.1 Experimental Tests in Paper I

The test started with an initial work rate of 40 W with increments of 20 W after every min until volitional exhaustion (Purge et al., 2017). Experimental all-out tests in an indoor environment were maximally converged to competitive situations using a wind-resistance-braked skiing ergometer. This mode of exercise is conducted by repeatedly pulling down the handles from above the shoulders that are connected to a pulley system. It is characterized by the work of mainly the upper body (Fukuda et al., 2013).

A 1000 m of double poling was completed in the shortest time possible. Athletes were allowed to choose ergometer resistance level between 4 and 6 but were not allowed to check for stroke rate and pace during the trial. Power and stroke frequency were recorded continuously to analyze pace strategy and speed for different parts of distance. Two protocols were performed to measure the effect of a high-intensity anaerobic warm-up phase on all-out cross-country ski endurance performance. Both protocols were aiming to measure parameters of MPT which in one case was following a low-intensity warm-up ($MPT_{low}$) with a 14 min duration of recovery between warm-up and workout. In the second protocol ($MPT_{high}$), an additional 25 s high-intensity anaerobic cycling pre-load protocol was performed 5 min after the end of warm up, leaving approximately 9 min for recovery before the 1000 m all-out skiing ergometer MPT (Fig. 1). The order of tests was randomized for each participant to minimize learning effects and exclude a possible advantage of one or other protocol sequence. The warm-up in $MPT_{low}$ consisted of a 20 min workload at 50% $\dot{V}O_{2max}$ from the incremental exercise test. In the experimental setting a 25 s high-intensity anaerobic lower body cycling pre-load HIE was added to cause a significant increase in blood [La].

Blood [La] was determined for both conditions at rest (baseline), after the warm-up (immediately after, + 3', + 5'), after the anaerobic priming load (immediately after, + 1', + 2', + 3', + 4', + 5', +7', + 9'), and during recovery (immediately after MPT, + 1', + 3', + 6', + 9', + 12', + 15') (total of 19 samples in $MPT_{high}$ and 12 in $MPT_{low}$ protocol). Heart rate (HR) and gas-exchange were measured continuously as showed in Measurements chapter.

### 4.1.2 Experimental Tests in Paper II

Two maximal 4000 m cycling tests with upper-body pre-load ($MPT_{high}$) or common warm-up conditions ($MPT_{low}$) were compared (Fig. 1). $MPT_{low}$ and $MPT_{high}$ protocols started with a 20-min warm-up at 40% of $\dot{V}O_{2max}$. A 25 s high-intensity all-out arm crank effort on an upper-body hand-crank ergometer was added in the $MPT_{high}$ condition. The 25 s was suggested to induce a lactate increase to a level 8–10 $mmol \cdot L^{-1}$ to induce a sufficient subsequent inhibition without negative side-effects of the induced acidosis (Purge et al., 2017). In both testing conditions, subjects were allowed to recover from the warm-up until they reported readiness for the subsequent maximal performance. Maximal performance bouts started with a 12 s all-out start. Ten seconds before beginning each MPT, subjects were instructed to take a standing position and adjust the crank angle to their preferred position, as it was documented during the first laboratory visit. Subjects were provided with a 3 s count-down before the 12 s all-out start. Following the initial 12 s all-out upright cycling, subjects were instructed to take a seated position for the remaining test duration. Strong verbal encouragement was provided during both maximal tests. Remaining distance was the only landmark that cyclists were provided, and subjects were unaware of the elapsed time or implemented power (W), the power display and time were covered to exclude any numerical comparison.

Blood [La] was determined for both conditions at rest (baseline), after the warm-up (immediately after, + 3', + 5'), after the anaerobic priming load (immediately after, + 3', + 4', + 5', + 7', + 9', immediately before MPT), and during recovery (immediately after MPT, + 3', + 4', + 5', + 7', + 9', + 11', + 13', + 15') (total of 20 samples in $MPT_{high}$ and 14 in $MPT_{low}$ protocol). Heart rate (HR) and gas-exchange were measured continuously as showed in Measurements chapter.

### 4.1.3 Experimental Tests in Paper III

Functional threshold power (FTP) is a frequently used additionally important performance quality indicator for cyclists which is highly correlated to mLSS (Denham et al., 2020) and relative power exertion during a mass-start bike race (Sørensen et al., 2019). It is the maximum mean power, which can be sustained for an approximately 1 h period and is a good predictor of overall performance capacity (Denham et al., 2020). FTP can be evaluated by a time efficient 20 min FTP test (FTP20), which predominantly relies on aerobic metabolism (Denham et al., 2020). So, more cycling specific 20 min FTP test with longer distance and fixed pace was performed as MPT in order to explore the effects of priming while excluding any additive pacing effect. The protocol was created considering correlation findings from *Paper II* regarding recovery time and consistent with prior research (Burnley et al., 2005; Jones et al., 2003). Since the main interest of this thesis was priming effect on the performance, an all-out spurt in the end of MPT was added as the measurable variable.

$MPT_{low}$ and $MPT_{high}$ (Fig. 1) protocols started with a similar 20 min warm-up at 40% of $\dot{V}O_{2max}$. A 25 s high-intensity all-out arm crank effort on an upper-body hand crank ergometer was added for the $MPT_{high}$ protocol. In both testing conditions, participants were required to recover from the warm-up for a minimum of 10 min plus self-determined duration, until they reported readiness for the subsequent maximal performance test.

The 20 min maximal performance bouts started with 17 min of constant work at a controlled pace of 10% Δ [$VT_2$ plus 10% of the difference between the work rate at the $VT_2$ and $\dot{V}O_{2max}$] to cover the possible standard error from determining $VT_2$ and ensure a gradual increase in blood [La] (Jones et al., 2003). During the final 3 min of the FTP20 performance, athletes were required to perform their self-paced maximal final spurt. They were provided with a 3 s countdown before the start and instructed to increase the pace to achieve the maximal exertion by the end of the 20 min. Strong verbal encouragement was provided during both maximal tests. Remaining time was the only information that cyclists were provided, and participants were made unaware of implemented power (W); the power display was covered to exclude any numerical comparison.

Blood [La] was determined for both conditions at rest (baseline), after the warm-up (immediately after, + 3', + 5'), after the anaerobic priming load (immediately after, + 3', + 4', + 5', + 7'), during the test (immediately before, + 5', + 10', + 15'), and during recovery (immediately after MPT, + 3', + 4', + 5', + 7', + 9', + 11', + 13', + 15') (total of 21 samples in $MPT_{high}$ and 16 in $MPT_{low}$ protocol). Heart rate (HR) and gas-exchange were measured continuously as showed in Measurements chapter.

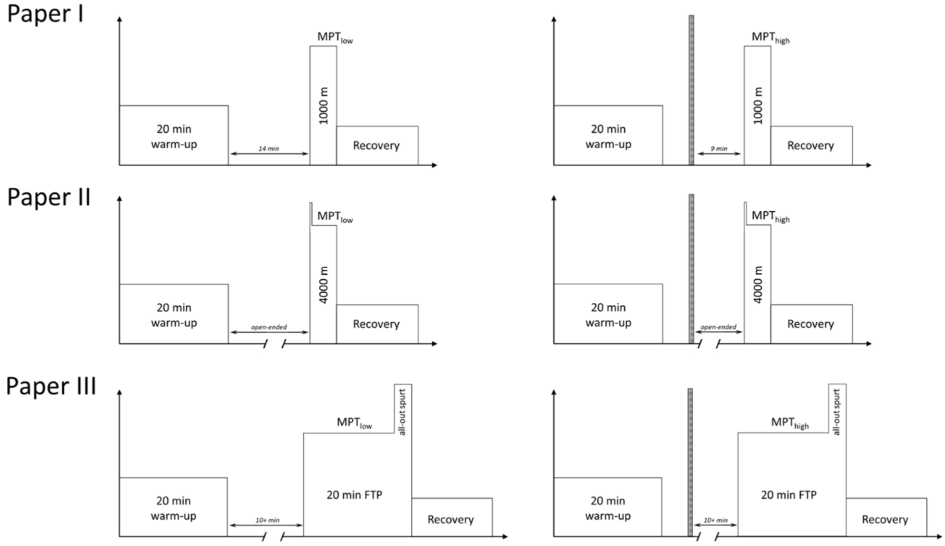


**Figure 1.** Schematic difference between maximal performance test with common warm-up ($MPT_{low}$ – left side column) and a protocol with added by a 25 s high-intensity all-out arm crank exercise ($MPT_{high}$ – right side column).

## 4.2 Measurements

On the first visit participants' anthropometric parameters with precision of 0.1 cm of height (Martin metal anthropometer) and 0.05 kg of body mass (A&D Instruments, Abingdon, UK), and body composition using dual-energy X-ray absorptiometry (DEXA) (Hologic Discovery DXA; Massachusetts, USA) were measured.

Heart rate (Polar Electro Oy; Espoo, Finland) and spirometric breath-by-breath functions (Cortex Metamax 3B, Cortex Biophysik; Leipzig, Germany) were measured and analyzed. The analyzer was calibrated before the test with barometric pressure, ambient air, humidity readings and gases of known concentrations. Incremental and experimental tests were performed: in *Paper I* on a C2 ski ergometer (SkiErg, Concept2, Inc., Morrisville, VT, USA, 2009®); in *Paper II* Cyclus2 ergometer (RBM Elektronik-Automation GmbH, Germany) and Wattbike Pro (Wattbike Limited; Nottingham, UK), respectively; in *Paper III* both tests were performed on Cyclus2 ergometer. Pre-loading exercise either by lower-body (*Paper I*: break weight 70 $g \cdot kg^{-1}$ body weight) or upper-body (*Paper II* and *III*: break weight 35 $g \cdot kg^{-1}$ body weight) was performed on a Monark Ergomedic 849E (Vansbro, Sweden).

Blood [La] (EKF-Diagnostic; Barleben, Germany) was determined for both conditions at rest, after the warm-up, after the anaerobic priming load, during the test (in *Paper III*), and during recovery. Arterialized blood samples (20 µL) were taken from a pre-warmed fingertip (from a hyperemised earlobe in *Paper I*). The finger (earlobe in *Paper I*) was always cleansed with alcohol, and the first drop of blood was removed to prevent contamination of the sample. At the same time as the [La] measurements, participants were asked to evaluate their overall- and muscle fatigue using the Borg rating of perceived exertion (0 to 10-point in *Paper I* and 6 to 20-point in *Paper II*, *III*) scale (Borg, 1978).

All data were analyzed by means of computer support using standard software (MetaMax-Analysis 3.21, Cortex, Leipzig, Germany).

## 4.3 Statistical analysis

All data variables were checked for normal distribution using the Shapiro-Wilk test, visual inspection of descriptive statistics, and z-score. Parametric methods such as paired samples t-test for comparison of means and 2-way repeated measures ANOVA test for comparison of time course with $p < 0.05$ as the level of significance were applied for parametric data. Wilcoxon signed-rank test and Kruskal-Wallis test were applied in the case of nonparametric data.

Data are expressed as mean ± standard deviation (SD), presented with effect size ($\eta^2$) and confidence intervals (CI). Effect size based on Cohen's classification $0.01 < d < 0.2$ was considered as 'very small', $0.2 < d < 0.5$ 'small', $0.5 < d < 0.8$ 'medium', $0.8 < d < 1.2$ 'large', $1.2 < d < 2.0$ 'very large' and $d > 2.0$ 'huge' (Cohen, 1988). Partial Eta squared for two variables in repeated measures $\eta^2 < 0.04$ was considered 'small', $\eta^2 = 0.25$ 'moderate', and $\eta^2 > 0.64$ 'strong' (Ferguson, 2009). Correlations were determined using Pearson's correlation coefficient ($r$). The magnitudes of the correlation coefficients were stratified into groups comprising negligible ($r < 0.30$), low ($0.30 < r < 0.50$), moderate ($0.50 < r < 0.70$), high ($r > 0.7$) (Hopkins et al., 2009; Mukaka, 2012).

A prior power analysis was performed using G*Power© software (version 3.1.9.2, 2017) for comparison between two independent means. Data management and analysis were executed using Statistics for Windows, version 23.0 (IBM Corp., Armonk, NY, USA).

# 5. RESULTS

## 5.1 Priming effect on 1000m Ski-ergometer test (Paper I)

Ski ergometer maximal performance during $MPT_{low}$ was not faster compared to the $MPT_{high}$ condition (225.1 ± 17.6 s vs. 226.1 ± 15.7 s; $p > 0.05$). $MPT_{low}$ was slower in the first 400m ($p > 0.05$) but tended to be faster in the last 600m. However, correlation analysis showed that slower start during first 200m was more beneficial for $MPT_{high}$ and resulted in a shorter total time ($r = -0.410$, $p < 0.05$) and vice versa (Fig. 2), indicating some pacing effects.

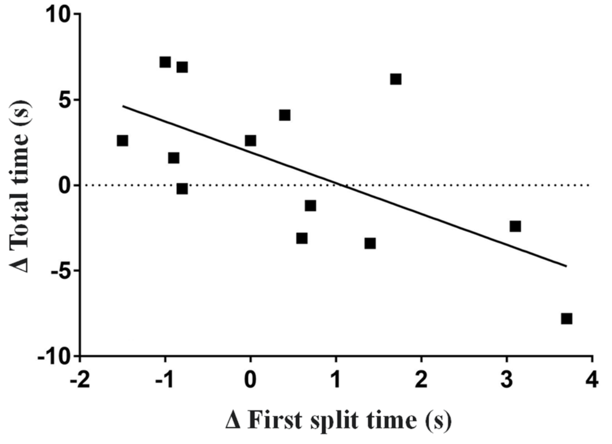


**Figure 2.** The relationship between first 200m split time (difference between $MPT_{low}$ and $MPT_{high}$) and final difference in overall time in a maximal 1000-m all-out Ski-ergometer time trial performance test with low intensity ($MPT_{low}$) and with 25 s all-out cycling pre-load exercise ($MPT_{high}$) ($r = -0.410$; $p < 0.05$).

The 25 s lower-body high-intensity priming exercise significantly increased [La] before the start 8.2 ± 2.2 $mmol \cdot L^{-1}$ and 1.4 ± 0.3 $mmol \cdot L^{-1}$, in $MPT_{high}$ and $MPT_{low}$ respectively. Although, maximal [La] after MPT was 14.7 ± 4.6 $mmol \cdot L^{-1}$ in $MPT_{high}$ and 11.8 ± 2.4 $mmol \cdot L^{-1}$ in $MPT_{low}$, the net [La] increase was reduced by approximately 50% in $MPT_{high}$ ($p < 0.05$). Net [La] changes during recovery were similar for both protocols; however, remaining 13.5% higher in $MPT_{high}$ trial even 15 min after the maximal test. Thus, considering [La] data in relation to power ($W^{-1}$) during MPT, less total anaerobic energy was produced in $MPT_{high}$ ($p < 0.001$) although split by split analysis considering net $\dot{V}CO_2$ increase in relation to $W^{-1}$ no significant differences occurred ($p > 0.05$; $d_{200} = 0.04$; $d_{400} = 0.5$; $d_{600} = 0.5$; $d_{800} = 0.4$; $d_{1000} = 0.2$). $\dot{V}O_2$ uptake value was significantly higher in the first 400m of $MPT_{high}$ ($p < 0.05$), while $\dot{V}CO_2$ value was significantly lower in the first 200m ($p < 0.05$) and in the fourth and fifth 200m split.

Additionally, rating of perceived exertion before tests ($RPE_{before}$) was significantly ($p < 0.05$) lower in $MPT_{low}$ compared to $MPT_{high}$ and also after all-out exercise (Table 3).

**Table 3.** The results of maximal 1,000-m all-out Ski ergometer time trial performance test (MPT) per 200m splits with low intensity warm up ($MPT_{low}$) and additional high 25 s all-out cycling pre-load ($MPT_{high}$).

| **Participants ($n$ = 13)** | **$Time_{200m}$ (s)** | **$Time_{400m}$ (s)** | **$Time_{600m}$ (s)** | **$Time_{800m}$ (s)** | **$Time_{1000m}$ (s)** | **Time (s)** | **$RPE_{before}$** | **$RPE_{after}$** |
|---|---|---|---|---|---|---|---|---|
| $MPT_{low}$ | 44.8 ± 4.2 | 44.9 ± 4.4 | 45.6 ± 4.0 | 45.7 ± 3.1 | 44.1 ± 2.6 | 225.1 ± 17.6 | 0.6 ± 0.8 | 8.9 ± 0.9 |
| $MPT_{high}$ | 44.3 ± 3.7 | 44.4 ± 3.5 | 45.8 ± 3.4 | 46.6 ± 3.2 | 45.2 ± 3.5 | 226.1 ± 15.7 | 1.4 ± 1.2 | 9.5 ± 0.7 |
| Dif | 0.5 ± 1.6 | 0.6 ± 1.6 | −0.2 ± 1.4 | −0.8 ± 1.5 | −1.1 ± 1.9 | −0.9 ± 4.6 | −0.8 ± 1.2 | −0.7 ± 1.1 |
| $p$ | 0.28 | 0.21 | 0.05* | 0.07 | 0.07 | 0.47 | 0.04* | 0.05* |
| Effect size | 0.12 | 0.11 | 0.05 | 0.29 | 0.42 | 0.06 | 1.0 | 0.67 |

*Significantly different from $MPT_{low}$ ($p < 0.05$); Effect size $0.01 < d < 0.2$ was considered as 'very small', $0.2 < d < 0.5$ 'small', $0.5 < d < 0.8$ 'medium', $0.8 < d < 1.2$ 'large', $1.2 < d < 2.0$ 'very large' and $d > 2.0$ 'huge' (Cohen, 1988).

The RPE immediately after MPT, was significantly higher in $MPT_{high}$ (9.5 ± 0.7) compared to $MPT_{low}$ (8.9 ± 0.9), which means a significantly greater internal load was experienced by $MPT_{high}$ ($p < 0.05$). Even though the internal load was greater, participants were able to perform with a minimal total time difference compared to $MPT_{low}$ (1 ± 4.6 s; $p > 0.05$).

## 5.2 Priming effect on 4000m cycling sprint (Paper II)

A 4000 m MPT was completed in 328.9 ± 17.4 s by $MPT_{high}$ condition which was significantly slower compared to 323.6 ± 16.2 s in $MPT_{low}$ ($p < 0.05$; $d = 0.7$) with a mean performance alteration of 5.3 ± 7.7 s (1.6%, $p < 0.05$; $CI_{95\%}$ = [0.1, 9.5]). Moreover, $MPT_{high}$ condition performed slower in all 500m splits, although insignificantly (except 1500m–2000m split; $p = 0.026$; $d = 0.6$). No significant difference was measured between MPT all-out start power in both conditions, 10.5 ± 2.1 $W{\cdot}kg^{-1}$ and 9.7 ± 2.5 $W{\cdot}kg^{-1}$ in $MPT_{low}$ and $MPT_{high}$, respectively ($p > 0.05$, $d = 0.5$, $CI_{95\%}$ = [−1.6, 0.2]) (Table 4).

Self-selected recovery lasted 522.0 ± 122.7 s in the $MPT_{low}$ condition, compared to 792.6 ± 237.2 s in $MPT_{high}$. Data analysis showed that longer self-selected recovery time before the maximal performance tests was significantly related to a better maximal performance time in $MPT_{high}$ ($r = -0.550$; $p < 0.05$), contrary shorter recovery in $MPT_{low}$ condition related to faster time trial ($r = 0.619$; $p < 0.05$) (Fig. 3).

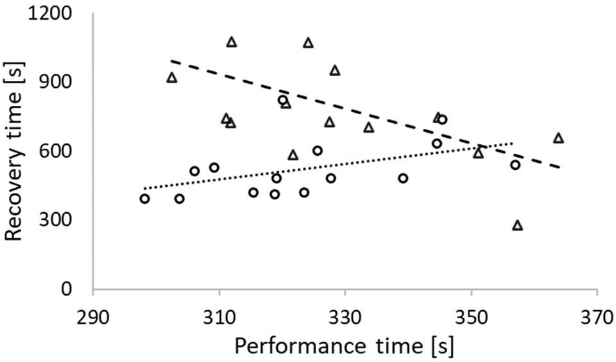


**Figure 3**. Correlation between recovery time (s) and performance time (s). Dashed line together with triangle-shaped data points indicate $MPT_{high}$ trial ($r = -0.550$; $p < 0.05$) and dotted line together with circle-shaped data points $MPT_{low}$ trial ($r = 0.619$; $p < 0.05$).

$MPT_{high}$ condition spirometric values before the all-out start indicate speeded $\dot{V}O_2$ kinetics ($p < 0.05$, $d = 0.4$), accompanied with significantly higher $\dot{V}CO_2$ values ($p < 0.05$, $d = 0.5$), indicating that some buffering of acidosis from the priming was still ongoing. Although during the initial 500 m both parameters net increases were constantly and significantly lower in $MPT_{high}$ compared to $MPT_{low}$ condition ($p < 0.006$); and also lower, however insignificantly, in mean values in relation to absolute power (W) ($p > 0.05$). Thus, no differences in aerobic economy ($5.04 \pm 0.85$ mL·min$^{-1}$·W$^{-1}$ in $MPT_{low}$ and $4.96 \pm 0.65$ mL·min$^{-1}$·W$^{-1}$ in $MPT_{high}$) and anaerobic power production could be found during initial 500 m split. Significantly lower anaerobic power exertion, according to net $\dot{V}CO_2$ and mean absolute power, was found during 500–1000 m ($d = 1.1$), 2000–2500 m ($d = 0.6$) and 2500–3000 m ($d = 0.8$) splits and insignificantly lower during other splits ($p > 0.05$). Despite the differences in net $\dot{V}O_2$ and net $\dot{V}CO_2$, the total $\dot{V}O_2$ consumption per W$^{-1}$ did not show any significant differences between trials ($p = 0.765$). However, RER data show $MPT_{low}$ as being more anaerobic whereas $MPT_{high}$ RER values remained lower ($p < 0.05$) during the entire race.

[La] achieved by priming action, was significantly higher in $MPT_{high}$ right before the start ($6.9 \pm 2.1$ mmol·L$^{-1}$) compared to $MPT_{low}$ ($1.4 \pm 0.5$ mmol·L$^{-1}$), $p < 0.001$; $d = 2.5$; $CI_{95\%}$ = [4.3, 6.7]. Although, $MPT_{high}$ [La] remained higher until the end, the total net increase was significantly lower ($11.1 \pm 2.7$ mmol·L$^{-1}$) compared to $14.9 \pm 2.2$ mmol·L$^{-1}$ in $MPT_{low}$ ($p < 0.001$; $d = 1.2$; $CI_{95\%}$ = [−5.5, −2.1]. According to [La] and mean power data, calculations showed that $MPT_{low}$ produced more $La_{net}$ per each W$^{-1}$, meaning more total anaerobic work was performed ($p < 0.05$, $d = 0.9$) (Table 4).

An overall RPE before the start ($8.3 \pm 3.0$ in $MPT_{low}$ and $8.2 \pm 1.9$ in $MPT_{high}$) and immediately after MPT ($18.5 \pm 2.2$ in $MPT_{low}$ and $19.5 \pm 0.9$ in $MPT_{high}$) did not show significant difference ($p > 0.05$). A muscle type RPE before the start ($8.3 \pm 3.0$ in $MPT_{low}$ and $8.1 \pm 1.8$ in $MPT_{high}$) and immediately after MPT ($18.7 \pm 2.3$ in $MPT_{low}$ and $19.5 \pm 0.9$ in $MPT_{high}$) did not show significant difference ($p > 0.05$).

**Table 4.** Effect of prior high-intensity warm-up on MPT ($n = 15$).

| Parameter | $MPT_{low}$ | $MPT_{high}$ | *p*-value | Effect size (95% CI) |
|---|---|---|---|---|
| Initial 12 s | | | | |
| Distance (m) | 198 ± 14 | 192 ± 17 | 0.133 | 0.4 (−15.3 to 2.2) |
| Average power (W·kg$^{-1}$) | 10.5 ± 2.1 | 9.7 ± 2.5 | 0.104 | 0.5 (−1.6 to 0.2) |
| Peak power (W·kg$^{-1}$) | 1014 ± 219 | 974 ± 221 | 0.391 | 0.2 (−139.3 to 58.0) |
| Performance | | | | |
| Time (s) | 323.6 ± 16.2 | 328.9 ± 17.4 | 0.019 | 0.7 (1.0 to 9.5) |
| Average power (W·kg$^{-1}$) | 5.6 ± 0.7 | 5.3 ± 0.7 | 0.018 | 0.7 (−0.6 to −0.1) |
| $La_{before}$ (mmol·L$^{-1}$) | 1.4 ± 0.5 | 6.9 ± 2.1 | <0.001 | 2.5 (4.3 to 6.7) |
| $La_{net}$ (mmol·L$^{-1}$) | 14.9 ± 2.2 | 11.1 ± 2.7 | <0.001 | 1.2 (−5.5 to −2.1) |
| $La_{max}$ (mmol·L$^{-1}$) | 16.3 ± 2.2 | 17.9 ± 2.4 | 0.017 | 0.7 (0.3 to 2.9) |
| $\dot{V}O_{2before}$ (L·min$^{-1}$) | 0.5 (0.47 –0.66) | 0.64 (0.51–0.78) | 0.023 | 0.4 (0.03 to 0.16) |
| $\dot{V}O_{2max}$ (L·min$^{-1}$) | 4.9 (4.8–5.2) | 4.6 (4.3–5.2) | 0.013 | 0.4 (−0.4 to −0.1) |
| Recovery time (s) | 522 ± 123 | 792 ± 237 | 0.003 | 0.9 (110.2 to 431.0) |

$MPT_{low}$ – maximal performance test without prior loading; $MPT_{high}$ – maximal performance test with prior loading; CI – Confidence Interval for the Difference.

## 5.3 Priming effect on FTP20 cycling test (Paper III)

Mean constant power for initial 17 min, i.e 10% Δ, of MPT was 4.2 ± 0.5 W·kg$^{-1}$ and for final 3-minute all-out spurt 4.94 ± 0.27 W·kg$^{-1}$ in $MPT_{low}$ and 4.85 ± 0.39 W·kg$^{-1}$ in $MPT_{high}$, which was not statistically different ($p$ = 0.116; $d$ = 0.5; $CI_{95\%}$ = [−0.0, 0.3]) (Fig. 4).

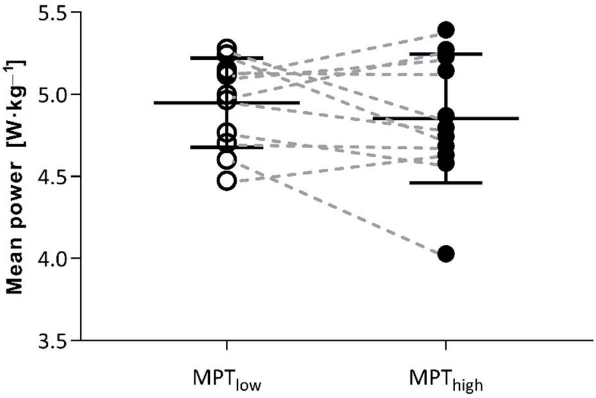


**Figure 4.** MPT performance mean power output during final spurt of $MPT_{low}$ and $MPT_{high}$.

Strong correlations occurred between $MPT_{low}$ self-paced finish power and incremental test values of $V˙O_{2max}$ (mL·kg$^{-1}$·min$^{-1}$) ($p$ = 0.005; $r$ = 0.78), maximal relative power (W·kg$^{-1}$) ($p$ = 0.011; $r$ = 0.73), and 10% Δ $VT_2$ ($p$ = 0.016; $r$ = 0.70). Self-paced finish power was not correlated with self-selected recovery time after warm-up, even though recovery time after warm-up was significantly longer in the $MPT_{high}$ condition as the strenuous priming exercise significantly delayed the feeling of readiness from 813 ± 138 s in $MPT_{low}$ to 958 ± 226 s in $MPT_{high}$ ($p$ = 0.011; $d$ = 0.9; $CI_{95\%}$ = [42, 249]).

Despite of significantly longer self-selected recovery after warm-up in $MPT_{high}$ the [La] before the start were still significantly higher in $MPT_{high}$ (5.7 ± 0.5 mmol·L$^{-1}$ versus 1.1 ± 0.1 mmol·L$^{-1}$; $p$ < 0.001; $d$ = 2.6; $CI_{95\%}$ = [3.4, 5.7]). However, recovery was long enough to remove the elevated $V˙O_2$ level up to the start. The values at the start did not differ between $MPT_{high}$ with 0.59 ± 0.12 L·min$^{-1}$ compared to 0.56 ± 0.13 L·min$^{-1}$ in $MPT_{low}$ ($p$ = 0.640; $d$ = 0.1; $CI_{95\%}$ = [−0.11, 0.17]). Between-group effects were also insignificant ($p$ = 0.57; $\eta^2$ = 0.73) throughout the tests. Calculation of metabolic economy was conducted by relating $V˙O_2$ to mean power for each split but showed no significant difference between conditions throughout the tests ($p$ > 0.05) (Fig. 5).

Similarly, $V˙CO_2$ values were not different at the start between $MPT_{high}$ with 0.53 ± 0.11 L·min$^{-1}$ compared to 0.53 ± 0.13 L·min$^{-1}$ in $MPT_{low}$ ($p$ = 0.96; $d$ = 0.02) nor net increase throughout the race had any significant difference among two variables between $MPT_{high}$ and $MPT_{low}$ conditions. Although visual inspection of last 3 min of $V˙O_2$ and $V˙CO_2$ graphs in Figure 5 can seem to have a tendency for larger net increase in $MPT_{high}$, the differences were not significant ($0.195 < p < 0.299$; $0.3 < d < 0.4$). The between-group effect was insignificant ($p = 0.15$; $\eta^2 = 0.15$) throughout the test. RER values demonstrated a steady-state (Fig. 5) from minutes 10 to 17 of the maximal performance up to the final spurt and reached its peak by the end of performance with no significant between-group effect ($p = 0.39$; $\eta^2 = 0.10$).

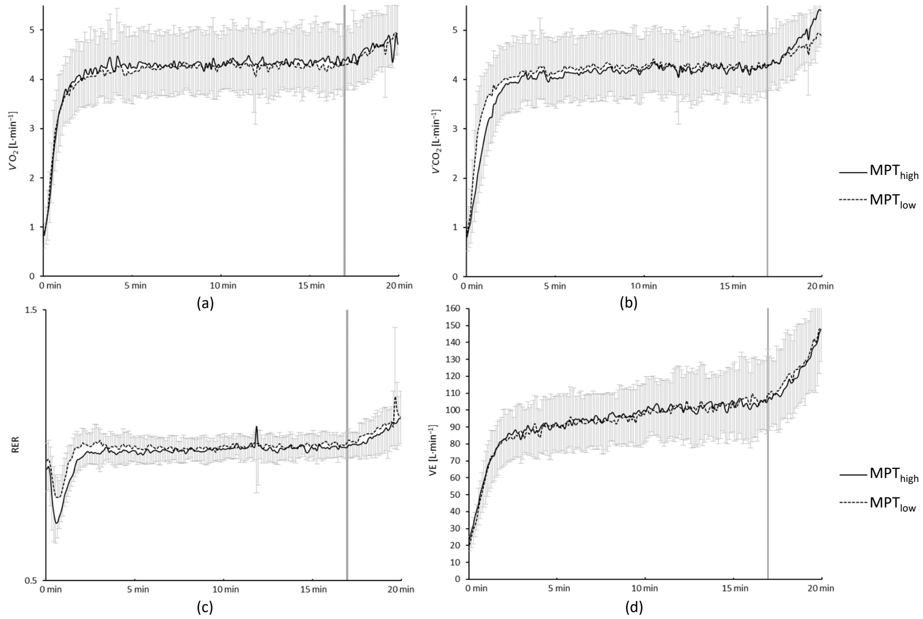


**Figure 5.** (**a**) Oxygen uptake ($V^{\cdot}O_2$); (**b**) carbon dioxide output ($V^{\cdot}CO_2$); (**c**) ventilation ($V^{\cdot}E$); (**d**) respiratory exchange ratio (RER), after a usual low intensity warm up ($MPT_{low}$) and an additional 25 s all-out arm crank priming pre-load ($MPT_{high}$).

However, net [La] increase in $MPT_{high}$ was $5.4 \pm 2.6$ mmol·$L^{-1}$ and $10.8 \pm 2.9$ mmol·$L^{-1}$ in $MPT_{low}$ ($p < 0.001$; $d = 2.16$; $CI_{95\%} = [3.7, 7.1]$). Considering [La] data in relation to $W^{-1}$, less total anaerobic energy was produced in $MPT_{high}$ ($p < 0.001$). Also split-by-split net [La] increase per $W^{-1}$ showed that anaerobic energy production in $MPT_{low}$ was not significantly different only from 10' to 15', other 5' splits showed significant shift towards anaerobic contribution compared to $MPT_{high}$ ($p < 0.019$; $0.9 < d < 1.6$) (Table 5).

**Table 5.** Physiological changes throughout MPT's ($n$ = 11).

| Stage | Parameter | $MPT_{low}$ | $MPT_{high}$ | $p$-value | Effect size (95% CI) |
|---|---|---|---|---|---|
| Warm-up | Mean power ($W \cdot kg^{-1}$) | 147.6 ± 19.1 | 147.6 ± 19.1 | | |
| | Recovery time (s) | 813 ± 138 | 958 ± 226 | 0.011 | 0.94 (41.7 to 249.2) |
| Before start | $\dot{V}O_2$ ($L \cdot min^{-1}$) | 0.6 ± 0.1 | 0.6 ± 0.1 | 0.640 | 0.14 (–0.1 to 0.2) |
| | $\dot{V}CO_2$ ($L \cdot min^{-1}$) | 0.5 ± 0.1 | 0.5 ± 0.1 | 0.955 | 0.02 (–0.1 to 0.1) |
| | [La] ($mmol \cdot L^{-1}$) | 1.1 ± 0.4 | 5.6 ± 1.7 | < 0.001 | 2.67 (3.4 to 5.7) |
| MPT 5' | $\dot{V}O_2$ ($L \cdot min^{-1}$) | 3.7 ± 0.6 | 3.7 ± 0.5 | 0.434 | 0.25 (–0.1 to 0.3) |
| | $\dot{V}CO_2$ ($L \cdot min^{-1}$) | 3.9 ± 0.8 | 3.4 ± 0.5 | 0.098 | 0.55 (–0.1 to 1.1) |
| | [La] ($mmol \cdot L^{-1}$) | 5.2 ± 0.8 | 6.8 ± 1.1 | < 0.001 | 1.55 (0.9 to 2.4) |
| | Net [La] increase ($mmol \cdot L^{-1}$) | 4.0 ± 0.8 | 1.2 ± 0.7 | < 0.001 | 1.72 (1.7 to 4.0) |
| MPT 10' | $\dot{V}O_2$ ($L \cdot min^{-1}$) | 4.3 ± 0.6 | 4.2 ± 0.5 | 0.580 | 0.17 (–0.1 to 0.2) |
| | $\dot{V}CO_2$ ($L \cdot min^{-1}$) | 4.2 ± 0.6 | 4.2 ± 0.5 | 0.413 | 0.26 (–0.1 to 0.3) |
| | [La] ($mmol \cdot L^{-1}$) | 6.2 ± 1.1 | 6.6 ± 1.8 | 0.191 | 0.42 (–0.3 to 1.2) |
| | Net [La] increase ($mmol \cdot L^{-1}$) | 1.2 ± 0.2 | −0.2 ± 1.6 | 0.011 | 0.93 (0.4 to 2.4) |
| MPT 15' | $\dot{V}O_2$ ($L \cdot min^{-1}$) | 4.3 ± 0.7 | 4.3 ± 0.5 | 0.451 | 0.23 (–0.1 to 0.3) |
| | $\dot{V}CO_2$ ($L \cdot min^{-1}$) | 4.3 ± 0.7 | 4.2 ± 0.5 | 0.331 | 0.31 (–0.1 to 0.3) |
| | [La] ($mmol \cdot L^{-1}$) | 6.6 ± 1.5 | 6.9 ± 2.1 | 0.530 | 0.20 (–0.7 to 1.3) |
| | Net [La] increase ($mmol \cdot L^{-1}$) | 0.4 ± 0.8 | 0.2 ± 0.9 | 0.713 | 0.11 (–0.8 to 1.1) |
| MPT 20' | $\dot{V}O_2$ ($L \cdot min^{-1}$) | 4.6 ± 0.6 | 4.6 ± 0.5 | 0.804 | 0.08 (–0.2 to 0.3) |
| | $\dot{V}CO_2$ ($L \cdot min^{-1}$) | 4.9 ± 0.6 | 4.8 ± 0.6 | 0.456 | 0.23 (–0.2 to 0.4) |
| | [La] ($mmol \cdot L^{-1}$) | 11.6 ± 2.7 | 9.8 ± 3.4 | 0.073 | 0.60 (–0.2 to 3.8) |
| | Net [La] increase ($mmol \cdot L^{-1}$) | 5.0 ± 2.1 | 2.9 ± 2.3 | 0.015 | 0.88 (0.5 to 3.7) |
| Perfor-mance | Average $power_{steady}$ ($W \cdot kg^{-1}$) | 4.2 ± 0.5 | 4.2 ± 0.5 | | |
| | Average $power_{all\text{-}out}$ ($W \cdot kg^{-1}$) | 4.94 ± 0.27 | 4.85 ± 0.39 | 0.308 | 0.32 (–0.1 to 0.3) |
| | [$La_{net}$] ($mmol \cdot L^{-1}$) | 10.8 ± 2.9 | 5.4 ± 2.6 | < 0.001 | 2.16 (–7.1 to –3.7) |
| | [$La_{max}$] ($mmol \cdot L^{-1}$) | 11.9 ± 2.8 | 11.1 ± 2.7 | 0.200 | 0.41 (–0.5 to 2.3) |

$MPT_{low}$ – maximal performance test without prior loading; $MPT_{high}$ – maximal performance test with prior loading; CI – Confidence Interval of the Difference.

Reported RPE for overall readiness which felt convenient to start the exertion was indicated by 7.1 ± 1.4 in $MPT_{low}$ compared to 8.0 ± 1.5 points in $MPT_{high}$ ($p = 0.126$) according to the Borg rating of perceived exertion (6 to 20-point) scale. Reported muscle type readiness was found significantly ($p = 0.031$) higher at 8.1 ± 1.7 points in $MPT_{high}$ compared to 7.1 ± 1.4 points in $MPT_{low}$ at the start. The overall RPE immediately after MPT was not significantly different ($p > 0.05$) in $MPT_{low}$ (19.6 ± 0.9) compared to $MPT_{high}$ (19.2 ± 1.5), similarly the muscle type RPE did not report any significant difference (19.6 ± 0.5 in $MPT_{low}$ and 19.1 ± 1.2 in $MPT_{high}$) ($p > 0.05$). Between-group effects during 15 min of recovery after the maximal performance were insignificant for overall fatigue ($p = 0.80$; $\eta^2 = 0.02$) and muscle fatigue ($p = 0.12$; $\eta^2 = 0.01$), meaning no subjectively determined benefit related to recovery could be pointed to in either case.

## 5.4 Priming effect on economy and anaerobic contribution (Paper I, II, III)

Consistent calculations were used among all studies in order to compare the effect of priming on economy and anaerobic energy production. Spirometric values of $\dot{V}O_2$ and $\dot{V}CO_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$) were related to relative power ($W \cdot kg^{-1}$); similarly total net [La] values were related to absolute power ($W^{-1}$). Difference between calculated economy and anaerobic energy production could be considered as the anaerobic component. The exact values of total MPT and split-by-split calculations are given in Table 6. Considering the effect size above 'large' ($d > 0.8$) (Cohen, 1988) and significance level of $p < 0.05$, the data could be summed up as follows.

Total economy was significantly higher in $MPT_{low}$ in *Paper I* ($p < 0.05$; $d = 1.4$) and in $MPT_{high}$ in *Paper III* ($p < 0.05$; $d = 1.5$). Total anaerobic contribution calculated from $\dot{V}CO_2$ data was significantly higher in $MPT_{low}$ in *Paper I* ($p < 0.05$; $d = 2.0$) and *Paper II* ($p < 0.05$; $d = 1.7$), no significant difference occurred in *Paper III* ($p > 0.05$; $d = 0.8$). Although, an anaerobic contribution calculated from [La] data had a larger effect size and significance, showing inhibited anaerobic energy production in $MPT_{high}$ trial in all three studies ($p < 0.001$ and $d = 2.2$ in *Paper I*; $p < 0.01$ and $d = 1.7$ in *Paper II*; $p < 0.001$ and $d = 2.2$ in *Paper III*).

Split-by-split data is not applicable while 'small' and 'medium' effect size indicate limited practical significance.

**Table 6.** Economy and anaerobic contribution of each MPT

| | Paper I | | | Paper II | | | Paper III | | |
|---|---|---|---|---|---|---|---|---|---|
| | $MPT_{low}$ | $MPT_{high}$ | *p*-value; effect size (*d*) | $MPT_{low}$ | $MPT_{high}$ | *p*-value; effect size (*d*) | $MPT_{low}$ | $MPT_{high}$ | *p*-value; effect size (*d*) |
| Total work economy ($mL \cdot min^{-1} \cdot W^{-1}$) | 14.7 ± 3.3 | 14.9 ± 3.2 | < 0.05; 1.4 | 13.6 ± 3.6 | 13.7 ± 3.7 | > 0.05; 0.3 | 14.1 ± 1.1 | 13.9 ± 1.1 | < 0.05; 1.5 |
| Work economy by splits ($mL \cdot min^{-1} \cdot W^{-1}$) | Min. 9.1 ± 3.3; Max. 17.3 ± 2.4 | Min. 9.4 ± 2.5; Max. 17.6 ± 2.7 | > 0.05; 0.03 < *d* < 0.2 | Min. 5.0 ± 0.8; Max. 15.7 ± 1.5 | Min. 5.0 ± 0.6; Max. 15.6 ± 1.3 | > 0.05; 0.06 < *d* < 0.3 | Min. 11.4 ± 3.3; Max. 14.2 ± 4.1 | Min. 11.3 ± 3.2; Max. 14.1 ± 4.1 | > 0.05; 0.02 < *d* < 0.3 |
| Total anaerobic contribution ($mL \cdot min^{-1} \cdot W^{-1}$) | 17.1 ± 4.6 | 14.7 ± 3.4 | < 0.05; 2.0 | 15.4 ± 4.2 | 14.7 ± 4.2 | < 0.05; 1.7 | 14.4 ± 1.1 | 13.8 ± 1.6 | > 0.05; 0.8 |
| Anaerobic contribution by splits ($mL \cdot min^{-1} \cdot W^{-1}$) | Min. 9.5 ± 3.7; Max. 21.0 ± 3.4 | Min. 9.4 ± 1.9; Max. 20.0 ± 3.3 | > 0.05; 0.04 < *d* < 0.5 | Min. 9.1 ± 3.3; Max. 17.3 ± 2.6 | Min. 9.4 ± 2.5; Max. 17.6 ± 2.9 | II, V, VI < 0.05; 0.6 < *d* < 1.1 I, III, IV, VII, VIII > 0.05; 0.1 < *d* < 0.6 | Min. 12.4 ± 4.3; Max. 15.0 ± 4.3 | Min. 10.5 ± 3.0; Max. 14.8 ± 4.3 | > 0.05; 0.1 < *d* < 0.6 |
| Total anaerobic contribution ($mmol \cdot L^{-1} \cdot W^{-1}$) | 0.05 ± 0.01 | 0.03 ± 0.01 | < 0.001; 2.2 | 0.04 ± 0.01 | 0.03 ± 0.01 | < 0.01; 1.7 | 0.03 ± 0.01 | 0.02 ± 0.01 | < 0.001; 2.2 |
| Net [La] increase by splits ($mmol \cdot L^{-1}$) | N/A | N/A | | N/A | N/A | | I 4.0 ± 0.8 II 1.2 ± 0.2 III 0.4 ± 0.8 IV 5.0 ± 2.1 | I 1.2 ± 0.7 II −0.2 ± 1.6 III 0.2 ± 0.9 IV 2.9 ± 2.3 | I, II, IV < 0.05; 0.9 < *d* < 1.7 III > 0.05; 0.1 |

1000m Ski-ergometer test (*Paper I*) was divided into 5 splits (200 m each); 4000m cycling sprint (*Paper II*) was divided into 8 splits (500 m each); FTP20 cycling test (*Paper III*) was divided into 4 splits (5 minutes each); level of significance $p < 0.05$

# 6. DISCUSSION

## 6.1 General findings

The main finding of present thesis was that priming could not improve performance time or mean power throughout the MPT from the statistical point of view in three of our studies. However, every study contained subjects who improved their $MPT_{high}$, which means that single-subject effect is important. Moreover, priming had a strong effect on [La] before the start, lowering net [La] increase during the performance and respectively the total anaerobic contribution.

The four-minute upper-body maximal exertion performed in *Paper I* is highly related to $\dot{V}O_{2max}$ and locomotion's oxygen cost (Losnegard et al., 2011). The distribution of aerobic versus anaerobic energy supply was described to be ~70%/30% (Losnegard et al., 2011), which is similar to what was found for other sports of the same duration (Gastin, 2001). It is a fact that anaerobic energy contribution is important for successful maximal performance, as it can fulfil fast and explosive energy demands (Secher, 1993) but as the race progresses, aerobic energy production becomes more dominant. Energy system contribution in cross-country skiing was shown to be similar to running, cycling and rowing (Losnegard et al., 2011) at least with the applied duration of maximal exercise in *Paper I*. On the other hand, HIE preload as applied in our *Paper I* and *Paper III* reduced [La] increase, and accordingly anaerobic energy production, while without reducing overall performance. The findings of the current study are consistent with those of Baker and colleagues (2010), who found that aerobic metabolism and energy production are able to support extremely high muscle force application and power outputs – meaning that a preceding high-intensity bout or a preliminary race will not necessarily impair a subsequent time trial. In support of Baker and colleagues (2010), the results from *Paper I* and *Paper III* showed a significant reduction of the increase in net [La] in $MPT_{high}$ (Müller et al., 2013) without significant differences for overall peak and mean power which is consistent with Bogdanis et al. (1994).

Significantly slower time was shown by $MPT_{high}$ in *Paper II* (328.9 ± 17.4 s in versus 323.6 ± 16.2 s; $p < 0.05$; $d = 0.7$), with accompanying changes in participants' spirometric response on performance trials, as their respective $\dot{V}O_2$ and $\dot{V}CO_2$ curves during performance were significantly different. Moreover, during all 500 m splits $\dot{V}O_2$ and $\dot{V}CO_2$ both remained lower in the $MPT_{high}$ condition throughout the execution of the protocol, although $\dot{V}O_2$ was higher just before the start. The results indicate that in $MPT_{high}$, less absolute $O_2$ was consumed, less carbon dioxide exhaled, and a larger part of work was performed aerobically. However, the total amount was insufficient to produce beneficial effects. Therefore, efficient priming mechanisms for such short-duration maximal effort need to be questioned, which is in line with earlier results for all-out rowing exercise (Purge et al., 2017).

In *Paper III*, aerobic energy contribution was facilitated at the expense of anaerobic energy. A more economical power production due to a primed aerobic metabolism could be beneficial in the case of an energy deficit during longer distances among comparable athletes and saving more energetic reserves for the competition state. Perceived exertion data, overall fatigue, and spirometric capacity indicated that the FTP20 is too short to induce energy depletion. Furthermore, Borg RPE values showed statistically significant changes in readiness to perform for muscle fatigue levels, but at the same time reported overall fatigue did not show any statistical difference. Certainly, the practical significance of a 1-point difference is not highly relevant, although it can give an idea of altered perception after priming and that athletes are less dependent on muscle fatigue rather than overall fatigue when determining readiness to perform. This can give some confidence for further studies to feel free to use even higher loads for priming effects as muscle alterations cannot be the primary reason to limit readiness to perform.

Andersson et al. (2016) found that cross-country skiers tend to use positive pacing strategies with higher accumulated oxygen deficit during the first half of the time trial, while accumulated $O_2$ deficit was decreased during the final 300 m. Similar results were shown in *Paper I*, athletes reached their $\dot{V}O_{2max}$ at the end of the first 400 m split and it was similar in both $MPT_{high}$ and $MPT_{low}$ tests. In the $MPT_{high}$ test the athletes performed better during the first 400 m, although insignificantly. However, $MPT_{low}$ showed significantly faster time during the last 400 m split. The decrease in overall performance in $MPT_{high}$ compared to $MPT_{low}$ was related to a small number of participants starting too fast. The others were able to perform faster although a reduced anaerobic contribution was indicated by a significant decrease in net [La] and in $\dot{V}CO_2$. Maximal blood [La] in our study were found at 11.8 ± 2.4 mmol·L$^{-1}$ after 1000 m in $MPT_{low}$, and 14.7 ± 4.6 mmol·L$^{-1}$ in $MPT_{high}$ which is comparable to the results of our previous studies in rowers (Purge et al., 2017). The metabolic pre-conditioning elevated both pre and post all-out exercise [La] but was well within tolerable limits.

## 6.2 Self-estimated recovery time outcome

While $O_2$ availability is crucial in maintaining the work level, prior priming has been proven to have a rapidly achievable (Chorley and Lamb, 2019) and relatively long-lasting and up to 45-min effect (Burnley et al., 2006). In earlier studies a 10-min recovery duration after priming was robustly estimated to have a beneficial effect on $\dot{V}O_2$ response and a substantial increase in performance (Burnley et al., 2005; Jones et al., 2003). Sprint exercise before a heavy exercise described in prior studies may be compared to the applied HIE in our study as the physiological influence on $\dot{V}O_2$ response and lasting lactic acidosis was similar (Burnley et al., 2001). This implies that high-intensity anaerobic pre-load exercise without sufficient recovery may limit athletic performance and maximal effort capacity, as long as maximal anaerobic energy contribution is required (Bishop et al., 2001; Iaia et al., 2010; Parolin et al., 1999). Our conducted studies aimed to equalize perceived readiness for maximal performance, to eliminate any psychological feeling of distress or fatigue.

Interestingly, the subjects later described the $MPT_{high}$ performance (in *Paper II*) as a “bad-leg day” and was perceived as uncomfortable laboratory temperature or sleepy feeling, which did not occur under the non-primed condition. This “bad-leg” feeling may be attributed to the obviously decreased anaerobic energy contribution, as shown by other studies (Bogdanis et al., 1994; Müller et al., 2013). As all of them followed the same preparation and regimen before both performance trials, and started from a fully recovered state, we assume the arm-crank loading preceding the time trial to be the main cause. Another cause may be that subjects might have overestimated their readiness or have become additionally sensitive to external factors after having experienced the supramaximal 25 s effort. In a similar study with rowers, Purge et al. (2017) also suggested that athletes who were forced to begin the time trial after 9-min recovery could not achieve their readiness to perform maximally in this study. Despite this limitation and a slower start, rowers were able to perform the second part of the distance at the same speed, thus calling into question the pacing strategy (Purge et al., 2017). Interestingly, our $MPT_{high}$ trial cyclists’ split times never achieved the same speed compared to $MPT_{low}$ respective splits. However, the subjects were given the free will to determine their readiness level; we expected to have them fully prepared and recovered from the previous high-intensity short-duration arm-crank exercise.

Rating of perceived exertion was reported during all three studies at the same time with [La] sampling. Shorter recovery time in $MPT_{high}$ trial in *Paper I* caused a significant difference between two conditions in overall RPE before the start ($0.8 \pm 1.2$; $p < 0.05$), which referred to certain inequality and possible reason for a modest priming effect. Therefore, to equalize the internal load indicated by RPE, self-selected recovery time was adopted in *Paper II* and *III*. As the result, *Paper II*’s overall RPE before the start and immediately after MPT were insignificantly different ($p > 0.05$), although subjective recovery up to 11' was slower in $MPT_{high}$. Similarly, *Paper III* overall RPE before the start and immediately after MPT did not show any significant difference ($p > 0.05$). Therefore, self-selected recovery time did more or less equalize the perceived internal load, since RPE in $MPT_{high}$ was still found to be greater immediately after MPT in *Paper II*, although not significant difference occurred ($p > 0.05$). However, it appears that self-estimated recovery duration cannot guarantee optimal performance.

## 6.3 Implementation of different pacing strategies

Some details from *Paper I* suggest beneficial effects are not realized due to an unfavorable pacing strategy. Starting the first 200 m split faster than in $MPT_{low}$ resulted in a prolonged total time compared to the $MPT_{low}$ condition, which may be explained by the fact that a lower anaerobic contribution suggested participants to underestimate their condition and start faster. At the same time the 5-min split analysis from *Paper III* did not indicate a significant difference between spirometric variable levels, although additional analyses showed significantly elevated $\dot{V}O_2$, RER, and $\dot{V}E$ parameters during the first 2 min of $MPT_{high}$. Moreover, the [La] change during the first 5 min of $MPT_{high}$ was significantly lower, which means that the same performance could be delivered with less anaerobic metabolism. If an increased demand for aerobic energy production could be less strenuous than anaerobic production, then lower overall fatigue during the start phase could be maintained. Apparently, this gives some space for higher intensity at the start and in combination with a suitable choice of intensity a significant improvement may be suggested due to the priming. Therefore, according to *Paper I*'s results, refraining from a faster start is therefore necessary with respect to overall performance time, which could allow athletes to gain the effects of a reduced anaerobic energy contribution during the first minute of high-intensity anaerobic exercise. Contrarily, *Paper III* suggests that a physiologically favorable condition occurs during first 2 minutes of the race. We may argue that forcing an athlete's metabolism towards aerobic metabolism by inhibiting anaerobic glycolysis during the first minute of exercise can preserve the muscles' abilities to perform on a high level for finishing the distance without losing overall performance, although the optimal dosage of pre-load and recovery remains unclear and needs further investigations. Pacing the workload was shown to increase overall performance in the pull-up exercise (Birnbaumer et al., 2018), which indicates that a different pacing strategy needs to be developed by applying such a metabolic pre-conditioning warm-up compared to the usual pacing strategy. However, pacing gives the opportunity to realize the potential from priming. *Paper III*'s findings make it clear that a poor pacing strategy, as suggested by Purge et al., 2017, cannot be the reason for priming a non-beneficial effect as both trials were paced to the same fatigue levels using the same strategy and a fixed pace. During the last 3 min, a cycling competition reaches its culmination where no pacing can be rationalized as an all-out strategy is most common. Pacing should instead be timed at greatest physiological response achieved by priming and should be used as a tool to realize the potential.

According to Caritá et al. (2014), priming is principal compared to fast-start pacing. Therefore, metabolic preparation can have an even more prominent effect than decisions made during maximal performance. In *Paper I* it was decided to exclusively investigate the effects of priming and no pacing was added to MPT. Correlation analysis of completed performance showed contrary/opposite results to previous studies (Bailey et al., 2011; Brock et al., 2018; Caritá et al., 2014), that a slow start was more favorable for the primed condition. Specifically, primed participants' slower first 200m split resulted in a shorter total MPT time. Despite this statistical finding, the slow start for $MPT_{high}$ trial was doubted, since priming-induced spirometric changes were present, particularly in the beginning of the maximal performance, which is in line with Purge and colleagues' (2017) findings. Moreover, it was noted that a high-intensity priming bout could change the perception of subjects and raise a level of caution that did not allow them to start at the same speed. With the intention of avoiding any self-pacing strategies, it was decided to add all-out start to the beginning of the maximal exertion in *Paper II*, during which the altered spirometric conditions were present. *Paper II*'s pacing regime was adopted from Brock and colleagues (2018), using 12 s all-out start. Brock et al. (2018) has shown the combination of priming and all-out start to be the most beneficial when performed before a time trial and showed better results for such a protocol compared to any other condition (all-out unprimed, self-paced-unprimed and self-paced primed). Their research group used a 3-min submaximal 70 Δ gas exchange threshold (GET) leg exercise as a priming activity, and in the current study we tried to achieve the same effect using a low-volume high-intensity arm-crank priming exercise. Additionally, initial 12 s should have been completed mainly by an alactic energy production, which is already suggested to be effectively re-stored 10 min after heavy-intensity priming exercise and not so much dependent on oxygenation status (Burnley et al., 2011). This is in line with the results of mean power and distance travelled during the first 12 s, which did not show any significant difference between two conditions. However, overall performance mean power was lower in $MPT_{high}$ ($p$ = 0.018), thus total performance was significantly slower by 5.3 ± 7.7 s. *Paper III*'s pacing strategy was intended to prepare both conditions to the same exertion rate during the first 17 minutes, with prior calculated intensity from incremental test of 10% Δ [$VT_2$ plus 10% of the difference between the work rate at the $VT_2$ and $\dot{V}O_{2max}$], and all-out spurt during last 3 minutes as the competitive component. Both conditions reached an aimed exertion rate as seen from RER values 1.0 ± 0.04 (Fig. 5) in $MPT_{high}$ and 1.0 ± 0.03 in $MPT_{low}$ ($p$ = 0.129; $d$ = 0.5) right before all-out spurt. Thus, priming did not decrease the ability of $MPT_{high}$ to tolerate a 17-minute exertion slightly above the $VT_2$, although could not perform significantly better during the last 3-minute all-out spurt. However, refraining from all-out start and beginning the distance with equally fixed pace did not spare/reserved anaerobic capability up to the end of MPT in *Paper III*, which was inhibited by priming from the very start. Even though [La] levels after 15 min were not significantly different between both interventions ($p$ = 0.53; $d$ = 0.2) the net [La] increase during the final 5' of MPT was significantly higher in $MPT_{low}$ ($p$ = 0.015). This means that submaximal intensity was too high to potentially restore anaerobic capacity, during the progress of MPT. We suggest that participants were used to a gradual increase of [La] such as in $MPT_{low}$, whereas in $MPT_{high}$, [La] values already plateaued at significant levels and anaerobic energy contribution may have been already depleted/inhibited to some extent by the beginning of the final spurt. Although FTP20 is predominantly aerobic (Denham et al., 2020), potentially the duration was still not long enough to bring out beneficial effects of priming.

Importantly, the effect of a high-intensity anaerobic start needs to be elucidated. High-intensity effort increases muscle and blood [La] and decreases pH already by the first minute of a 3–4 min race if starting [La] is low (Martin et al., 1975). It is well known that anaerobic glycolysis is at its highest after about 40–50 s and starts to decrease thereafter due to inhibitory effects of the high [La], low pH situation (Rivera-Brown and Frontera, 2012). It was shown that pre-elevation of systemic La levels by non-specific muscle exercise inhibited subsequent net La production, an effect which is suggested to be applied in competitive high-intensity exercise to improve performance (Müller et al., 2013). Previous studies have suggested that arterialized blood [La] level <5 $mmol \cdot L^{-1}$ could have a beneficial effect on subsequent performance as values substantially >5 $mmol \cdot L^{-1}$ could lead to a reduction in performance (Burnley et al., 2005; Gerbino et al., 1996). Although [La] could be used as an additional fuel for muscle contraction (Brooks, 1998), it is also a limiting factor as decreased pH inhibits anaerobic glycolysis for subsequent performance (Bangsbo et al., 1993). Within the investigated [La] elevation, pre-exercise blood [La] and MPT performance in $MPT_{high}$ were not significantly related although the optimal limits of [La] increase need to be elucidated. Two main effects may be expected from priorly elevated [La], such as a decrease of anaerobic energy production during the first minute of a race and a resulting increased oxidative energy contribution (Birnbaumer et al., 2018; Bogdanis et al., 1994). Developing this idea opens new doors to understanding the metabolic background of competitions longer than 2–3 min. On the one hand the strategy of metabolic pre-conditioning could be helpful in the prologue but on the other the higher [La] levels during recovery may be disadvantageous for the subsequent exercise bouts. However, this intervention may be beneficial as in some cases even an increased performance was found (Birnbaumer et al., 2018) if [La] elevation ($9.3 \pm 2.0$ $mmol \cdot L^{-1}$ before start) was induced by muscle groups not involved in the main exercise workout. Thus, specific sport should also be re-evaluated as potentially the priming produced by bigger muscle mass can elevate [La] levels to a greater extent without causing significant fatigue. Priming HIE executed by lower-body, as in *Paper I* and such as applied by Birnbaumer et al. (2018), may be more favorable to successfully increase performance.

## 6.4 Priming as a highly individual approach

Correlation analysis in *Paper III* showed that last 3 min relative power in $MPT_{low}$ was correlated with variables from the incremental tests such as $\dot{V}O_{2max}$ ($mL \cdot kg^{-1} \cdot min^{-1}$), maximal relative power ($W \cdot kg^{-1}$), and 10% $\Delta$ $VT_2$ for the first 17 min. Since $MPT_{high}$ did not correlate with any of these initial values, it shows that initial physiological preparation cannot predict a performance capacity in primed condition and can easily diminish previous training. However, many studies (Bailey et al., 2009; Bohnert et al., 1998; Burnley et al., 2011; Gerbino et al., 1996) have shown the physiological advantages of priming, although they cannot guarantee any improved results during an actual race (Carter et al., 2005; Ferguson et al., 2007; Sousa et al., 2014). In this case, we still suggest pre-load to have beneficial effects, which are highly individual and rather empirical methods are needed to distinguish such effects in every single athlete. For example, in *Paper I* six participants (46.2%) from $MPT_{high}$ completed 1000m Ski-ergometer test in a shorter time; in *Paper II* two participants (13.3%) from $MPT_{high}$ completed

4000m cycle ergometer test in a shorter time; in *Paper III* four participants (36.4% **typo in original article*) benefited from the priming and developed higher mean power during last 3 min of the final spurt in our study. A possible explanation for this might be the neuromuscular excitability, which was induced on central level, since priming was performed with non-primary muscle groups. However, previous studies prescribed neuromuscular potentiation mainly to single repetition or sprint exercise, but endurance sport on submaximal level is not common (Seitz and Haff, 2016). However, a clear advantage of this particular low-volume priming method is that it could enable the athletes to have a time-efficient and physiologically beneficial re-warm-up during a competitive event with multiple time trials. A previous study by Yanaoka and colleagues (2020) found that 1-minute cycling at 90% of $\dot{V}O_{2max}$ is superior to 15-minute rest period and may increase a subsequent intermittent cycling sprint performance over 10 minutes.

## 6.5 Limitations and strengths of the dissertation

The main limitation of *Paper II* and *Paper III* is the non-specific recovery time before the MPT. Since the effect of prior heavy exercise can be modified by the duration of recovery, it should thus be treated as the independent variable (Burnley et al., 2006). The main reasons for choosing self-selected recovery time is the aim of providing a comparably full readiness among subjects based on their perceived state, since expected maximal performance should be well pre-conditioned based on athletes' competitive experience and age (Barroso et al., 2014). The previous study shows that effective recovery duration can vary among individuals (Seitz et al., 2014) and we were willing to exclude any insufficient recovery, and provide self-selected conditions that would correspond to those of an ideal competitive preparation, which has also shown to be beneficial (Palmer et al., 2009). Evaluating the pros and cons, it was decided to rely on subjects' self-perception since all of them have been well trained athletes with more than 5 years of competitive experience. The second limitation was found in *Paper I*, when poor performance in some participants could occur because they were not frequently using the skiing ergometer, as many of them prefer to use roller skis as an alternative for the summer season. In the absence of experience of using it for maximal performance, starting and finishing pace strategies were based simply on the first laboratory test. Similarly, some of the participants did not switch power during the final all-out spurt in *Paper III* though preferring to add more watts. Thirdly, statistical power calculations prior to all studies showed a sufficient number of participants, but the total number of 20 participants would allow us to use additional regression analysis, which could show cause and effect relationship.

The current study's incremental test protocol was different in all three studies (Table 2); however, it did not affect the results. Standard 1-minute incremental step is suggested for further studies. Additionally, our experiment is limited to the influence of high-intensity anaerobic metabolic preconditioning exercise on just a single subsequent bout of either cross-country specific ergometer 1000m exercise or cycling specific 4000m sprint and FTP20 but did not focus on several repeated exercise bouts such as in a real-life competition (Hébert-Losier et al., 2017).

The main strength of this thesis is the consistent methods of priming with greatly homogenous well-trained athletes that allowed to gather data in a short period. Two protocols were prepared in a way that priming was left as the only variable between two conditions. Calculated intensities for priming, warm-up, and pacing (*Paper III*) guaranteed the expected physiological response (Fig. 5). All protocols contained a competitive component that served as a quantitative measure. In case of individual compatibility with any of the protocols, the methods are cheap and easy to apply without any additional expenses.

# 7. CONCLUSIONS

Based on the results of the current dissertation, the following conclusions were made:

1. Priming lowers net [La] increase and respectively the total anaerobic energy contribution during subsequent maximal performance test. (*Paper I*, *II*, *III*)
2. Warm-up added by HIE may not improve performance during subsequent maximal performance test; however, positive responses observed at the individual level suggest that some subjects may benefit from this method. (*Paper I, II, III*)
3. Self-selected recovery time after HIE should be longer because of additional load to ensure an optimal performance and equal perceived exertion during subsequent maximal performance test. (*Paper II*, *III*)
4. Steady pace after warm-up added by HIE improves exercise tolerance and enhances second ventilation threshold due to increased economy during not less than 17 minutes of anaerobic exercise. (*Paper III*)

# 8. PRACTICAL APPLICATIONS

Metabolic conditioning is an emerging trend improving basic warm-up effects. Based on our study results, anaerobic HIE performed with non-dominant muscles with respect to the main task has the potential to inhibit the net La increase at the start of exercise and the total net La of the performance, while remaining insignificantly different mean power. Consequently, 25 second all-out arm crank exercise or lower-body HIE cycling is sufficient to inhibit anaerobic and facilitate aerobic metabolism. Although it did not improve the performance, it could be used to enhance aerobic efficiency during training process, as pre-loading with opposite muscle groups cannot be recommended prior to time trials.

This research extends our knowledge of systemic metabolism and possibilities to alter anaerobic mechanisms. Exercise therapy is safe intervention and in selected cases is just as effective as medical treatment. High-intensity low-volume priming could serve as an additional treatment effect in the cases of chronic diseases, where exogenous additional lactate could inhibit the particular disease and add an effect to medication, chemo- or radiotherapy.

Our findings could encourage the health systems to create the necessary infrastructure to provide a supervised exercise, while it is important that society supports the active lifestyle. However, there is still a need to define the most optimal type and dose of exercise, but avoiding physical activity poses a greater risk than engaging in physical exercise. The author hope that current thesis could promote the debate and bring something valuable in todays' research.

# 9. REFERENCES


Abbiss, C.R., Laursen, P.B. (2008). Describing and understanding pacing strategies during athletic competition. *Sports Medicine*, 38(3), 239–252. https://doi.org/10.2165/00007256-200838030-00004

Allen, W.K., Seals, D.R., Hurley, B.F., Ehsani, A.A., Hagberg, J.M. (1985). Lactate threshold and distance-running performance in young and older endurance athletes. *Journal of Applied Physiology,* 58(4), 1281–1284. https://doi.org/10.1152/jappl.1985.58.4.1281

Andersson, E., Holmberg, H.-C., Ørtenblad, N., Björklund, G. (2016). Metabolic responses and pacing strategies during successive sprint skiing time trials. *Medicine & Science in Sports & Exercise*, 48(12), 2544–2554. https://doi.org/10.1249/MSS.0000000000001037

Bacon, A.P., Carter, R.E., Ogle, E.A., Joyner, M.J. (2013). $VO_{2max}$ trainability and high intensity interval training in humans: A meta-analysis. *PLoS One,* 8(9), e73182. https://doi.org/10.1371/journal.pone.0073182

Bailey, S.J., Vanhatalo, A., Dimenna, F.J., Wilkerson, D.P., Jones, A.M. (2011). Fast-start strategy improves $\dot{V}O_2$ kinetics and high-intensity exercise performance. *Medicine & Science in Sports & Exercise*, 43(3), 457–467. https://doi.org/10.1249/MSS.0b013e3181ef3dce

Bailey, S.J., Vanhatalo, A., Wilkerson, D.P., Dimenna, F.J., Jones, A.M. (2009). Optimizing the "priming" effect: influence of prior exercise intensity and recovery duration on $O_2$ uptake kinetics and severe-intensity exercise tolerance. *Journal of Applied Physiology*, 107(6), 1743–1756. https://doi.org/10.1152/japplphysiol.00810.2009

Baker, J.S., McCormick, M.C., Robergs, R.A. (2010). Interaction among skeletal muscle metabolic energy systems during intense exercise. *Journal of Nutrition and Metabolism*, 2010, 905612, 1–13. https://doi.org/10.1155/2010/905612

Bangsbo, J., Michalsik, L., Petersen, A. (1993). Accumulated $O_2$ deficit during intense exercise and muscle characteristics of elite athletes. *International Journal of Sports Medicine*, 14(4), 207–213. https://doi.org/10.1055/s-2007-1021165

Barroso, R., Cardoso, R.K., Carmo, E.C., Tricoli, V. (2014). Perceived exertion in coaches and young swimmers with different training experience. *International Journal of Sports Physiology and Performance*, 9(2), 212–216. https://doi.org/10.1123/ijspp.2012-0356

Beneke, R. (1995). Anaerobic threshold, individual anaerobic threshold, and maximal lactate steady state in rowing. *Medicine & Science in Sports & Exercise*, 27(6), 863–867. PMID: 7658947

Billat, V.L., Sirvent, P., Py, G., Koralsztein, J.-P., Mercier, J. (2003). The concept of maximal lactate steady state: a bridge between biochemistry, physiology and sport science. *Sports Medicine*, 33, 407–426. https://doi.org/10.2165/00007256-200333060-00003

Birnbaumer, P., Müller, A., Tschakert, G., Sattler, M.C., Hofmann, P. (2018). Performance enhancing effect of metabolic pre-conditioning on upper-body strength-endurance exercise. *Frontiers in Physiology*, 9, 963. https://doi.org/10.3389/fphys.2018.00963

Bishop, D., Bonetti, D., Dawson, B. (2001). The effect of three different warm-up intensities on kayak ergometer performance. *Medicine & Science in Sports & Exercise*, 33(6), 1026–1032. https://doi.org/10.1097/00005768-200106000-00023

Bogdanis, G.C., Nevill, M.E., Lakomy, H.K. (1994). Effects of previous dynamic arm exercise on power output during repeated maximal sprint cycling. *Journal of Sports Science*, 12(4), 363–370. https://doi.org/10.1080/02640419408732182

Bohnert, B., Ward, S.A., Whipp, B.J. (1998). Effects of prior arm exercise on pulmonary gas exchange kinetics during high-intensity leg exercise in humans. *Experimental Physiology*, 83(4), 557–570. https://doi.org/10.1113/expphysiol.1998.sp004138

Borg, G. (1978). Subjective aspects of physical and mental load. *Ergonomics*, 21(3), 215–220. https://doi.org/10.1080/00140137808931715

Brock, K., Antonellis, P., Black, M.I., DiMenna, F.J., Vanhatalo, A., Jones, A.M., Bailey, S.J. (2018). Improvement of oxygen-uptake kinetics and cycling performance with combined prior exercise and fast start. *International Journal of Sports Physiology and Performance*, 13(3), 305–312. https://doi.org/10.1123/ijspp.2016-0557

Brooks, G.A. (2018). The science and translation of lactate shuttle theory. *Cell Metabolism*, 27(4), 757–785. https://doi.org/10.1016/j.cmet.2018.03.008

Brooks, G.A. (1998). Intra- and extra-cellular lactate shuttles. *Medicine & Science in Sports & Exercise*, 32(4), 790–799. https://doi.org/10.1097/00005768-200004000-00011

Brooks, G.A. (1986). Lactate production under fully aerobic conditions: the lactate shuttle during rest and exercise. *Federation Proceedings*, 45(13), 2924–2929. PMID: 3536591

Burkett, L.N., Phillips, W.T., Ziuraitis, J. (2005). The best warm-up for the vertical jump in college-age athletic men. *The Journal of Strength & Conditioning Research*, 19(3), 673–676. https://doi.org/10.1519/15204.1

Burnley, M., Davison, G., Baker, J.R. (2011). Effects of priming exercise on $VO_2$ kinetics and the power-duration relationship. *Medicine & Science in Sports & Exercise*, 43(11), 2171–2179. https://doi.org/10.1249/MSS.0b013e31821ff26d

Burnley, M., Doust, J.H., Carter, H., Jones, A.M. (2001). Effects of prior exercise and recovery duration on oxygen uptake kinetics during heavy exercise in humans. *Experimental Physiology*, 86(3), 417–425. https://doi.org/10.1113/eph8602122

Burnley, M., Doust, J.H., Jones, A.M. (2006). Time required for the restoration of normal heavy exercise $VO_2$ kinetics following prior heavy exercise. *Journal of Applied Physiology*, 101(5), 1320–1327. https://doi.org/10.1152/japplphysiol.00475.2006

Burnley, M., Doust, J.H., Jones, A.M. (2005). Effects of prior warm-up regime on severe-intensity cycling performance. *Medicine & Science in Sports & Exercise*, 37(5), 838–845. https://doi.org/10.1249/01.MSS.0000162617.18250.77

Caritá, R.A.C., Greco, C.C., Denadai, B.S. (2014). The positive effects of priming exercise on oxygen uptake kinetics and high-intensity exercise performance are not magnified by a fast-start pacing strategy in trained cyclists. *PLoS One*, 9(4), e95202. https://doi.org/10.1371/journal.pone.0095202

Caritá, R.A.C., Denadai, B.S., Greco, C.C. (2015). Efeito da intensidade do exercício prévio na resposta fisiológica e na performance aeróbia de curta duração. *Revista Brasileira de Cineantropometria e Desempenho Humano*, 17(1), 112. https://doi.org/10.5007/1980-0037.2015v17n1p112

Carter, H., Grice, Y., Dekerle, J., Brickley, G., Hammond, A.J.P., Pringle, J.S.M. (2005). Effect of prior exercise above and below critical power on exercise to exhaustion. *Medicine & Science in Sports & Exercise*, 37(5), 775–781. https://doi.org/10.1249/01.MSS.0000162631.07404.7C

Chorley, A., Lamb, K.L. (2019). The effects of a cycling warm-up including high-intensity heavy-resistance conditioning contractions on subsequent 4-km time trial performance. *Journal of Strength and Conditioning Research*, 33(1), 57–65. https://doi.org/10.1519/JSC.0000000000001908

Christensen, P.M., Bangsbo, J. (2015). Warm-up strategy and high-intensity endurance performance in trained cyclists. *International Journal of Sports Physiology and Performance*, 10(3), 353–360. https://doi.org/10.1123/ijspp.2014-0228

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences, 2nd ed*. Lawrence Erlbaum Associates: New York, NY, USA. pp 20–27.

Denham, J., Scott-Hamilton, J., Hagstrom, A.D., Gray, A.J. (2020). Cycling power outputs predict functional threshold power and maximum oxygen uptake. *Journal of Strength and Conditioning Researc*h, 34(12), 3489–3497 https://doi.org/10.1519/JSC.0000000000002253

Ferguson, C., Whipp, B.J., Cathcart, A.J., Rossiter, H.B., Turner, A.P., Ward, S.A. (2007). Effects of prior very-heavy intensity exercise on indices of aerobic function and high-intensity exercise tolerance. *Journal of Applied Physiology*, 103(3), 812–822. https://doi.org/10.1152/japplphysiol.01410.2006

Ferguson, C.J. (2009). An effect size primer: A guide for clinicians and researchers. *Professional Psychology: Research and Practice*, 40(5), 532–538. https://doi.org/10.1037/a0015808

Fujii, N., Hara, H., Enomoto, Y., Tanigawa, S., Nishiyasu, T. (2019). Effects of work-matched supramaximal intermittent vs. submaximal constant-workload warm-up on all-out effort power output at the end of 2 minutes of maximal cycling. *European Journal of Sport Science* 19(3), 336–344. https://doi.org/10.1080/17461391.2018.1503335

Fukuda, D.H., Hetrick, R.P., Kendall, K.L., Smith-Ryan, A.E., Jackson, M.E., Stout, J.R. (2013). Characterization of the work–time relationship during cross-country ski ergometry. *Physiological Measurement*, 35(1), 31–43. https://doi.org/10.1088/0967-3334/35/1/31

Gaitanos, G.C., Williams, C., Boobis, L.H., Brooks, S. (1993). Human muscle metabolism during intermittent maximal exercise. *Journal of Applied Physiology*, 75(2), 712–719. https://doi.org/10.1152/jappl.1993.75.2.712

Gastin, P.B. (2001). Energy system interaction and relative contribution during maximal exercise. *Sports Medicine*, 31, 725–741. https://doi.org/10.2165/00007256-200131100-00003

Gavin, T.P., Van Meter, J.B., Brophy, P.M., Dubis, G.S., Potts, K.N., Hickner, R.C. (2012). Comparison of a field-based test to estimate functional threshold power and power output at lactate threshold. *The Journal of Strength & Conditioning Research*, 26(2), 416–421. https://doi.org/10.1519/JSC.0b013e318220b4eb

Gerbino, A., Ward, S.A., Whipp, B.J. (1996). Effects of prior exercise on pulmonary gas-exchange kinetics during high-intensity exercise in humans. *Journal of Applied Physiology*, 80(1), 99–107. https://doi.org/10.1152/jappl.1996.80.1.99

Ghosh, A.K. (2004). Anaerobic threshold: its concept and role in endurance sport. *Malaysian Journal of Medical Sciences*, 11(1), 24–36. PMID: 22977357

Gladden, L.B. (2004). Lactate metabolism: a new paradigm for the third millennium. *The Journal of Physiology*, 558(1), 5–30. https://doi.org/10.1113/jphysiol.2003.058701

González-Mohíno, F., Martín, R., Santos-García, D., Fidel, P., de Asis Fernandez, F., Yustres, I., González-Ravé, J. (2018). Effects of high-intensity warm-ups on running performance. *International Journal of Sports Medicine*, 39(6), 426–432. https://doi.org/10.1055/s-0044-102132

Gray, S., Nimmo, M. (2001). Effects of active, passive or no warm-up on metabolism and performance during high-intensity exercise. *Journal of Sports Sciences*, 19(9), 693–700. https://doi.org/10.1080/02640410152475829

Haddad, M., Stylianides, G., Djaoui, L., Dellal, A., Chamari, K. (2017). Session-RPE method for training load monitoring: validity, ecological usefulness, and influencing factors. *Frontiers in Neuroscience* 11, 612. https://doi.org/10.3389/fnins.2017.00612

Hajoglou, A., Foster, C., De Koning, J.J., Lucia, A., Kernozek, T.W., Porcari, J.P. (2005). Effect of warm-up on cycle time trial performance. *Medicine & Science in Sports & Exercise*, 37(9), 1608–1614. https://doi.org/10.1249/01.mss.0000177589.02381.0a

Hébert-Losier, K., Zinner, C., Platt, S., Stöggl, T., Holmberg, H.-C. (2017). factors that influence the performance of elite sprint cross-country skiers. *Sports Medicine*, 47, 319–342. https://doi.org/10.1007/s40279-016-0573-2

Hellmann, F., Verdi, M., Schlemper Junior, B.R., Caponi, S. (2014). 50th anniversary of the Declaration of Helsinki: The double standard was introduced. *Archives of Medical Research*, 45(7), 600–601. https://doi.org/10.1016/j.arcmed.2014.10.005

Hodgson, M., Docherty, D., Robbins, D. (2005). Post-activation potentiation: underlying physiology and implications for motor performance. *Sports Medicine*, 35, 585–595. https://doi.org/10.2165/00007256-200535070-00004

Hopkins, W.G., Marshall, S.W., Batterham, A.M., Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine & Science in Sports & Exercise*, 41(1), 3–12. https://doi.org/10.1249/MSS.0b013e31818cb278

Iaia, F.M., Perez-Gomez, J., Nordsborg, N., Bangsbo, J. (2010). Effect of previous exhaustive exercise on metabolism and fatigue development during intense exercise in humans. *Scandinavian Journal of Medicine & Science in Sports*, 20(4), 619–629. https://doi.org/10.1111/j.1600-0838.2009.00942.x

Jones, A.M., Burnley, M., Black, M.I., Poole, D.C., Vanhatalo, A. (2019). The maximal metabolic steady state: redefining the 'gold standard'. *Physiology Reports*, 7(10), e14098. https://doi.org/10.14814/phy2.14098

Jones, A.M., Wilkerson, D.P., Burnley, M., Koppo, K. (2003). Prior heavy exercise enhances performance during subsequent perimaximal exercise. *Medicine & Science in Sports & Exercise*, 35(12), 2085–2092. https://doi.org/10.1249/01.MSS.0000099108.55944.C4

Klausen, K., Knuttgen, H.G., Forster, H.V. (1972). Effect of pre-existing high blood lactate concentration on maximal exercise performance. *Scandinavian Journal of Clinical and Laboratory Investigation*, 30(4), 415–419. https://doi.org/10.3109/00365517209080279

Losnegard, T., Mikkelsen, K., Rønnestad, B.R., Hallén, J., Rud, B., Raastad, T. (2011). The effect of heavy strength training on muscle mass and physical performance in elite cross-country skiers. *Scandinavian Journal of Medicine & Science in Sports*, 21(3), 389–401. https://doi.org/10.1111/j.1600-0838.2009.01074.x

Martin, B.J., Robinson, S., Wiegman, D.L., Aulick, L.H. (1975). Effect of warm-up on metabolic responses to strenuous exercise. *Medicine & Science in Sports & Exercise*, 7(2), 146–149. https://doi.org/10.1249/00005768-197500720-00026

McGowan, C.J., Pyne, D.B., Thompson, K.G., Rattray, B. (2015). Warm-up strategies for sport and exercise: Mechanisms and applications. *Sports Medicine*, 45, 1523–1546. https://doi.org/10.1007/s40279-015-0376-x

Morgan, D.W., Baldini, F.D., Martin, P.E., Kohrt, W.M. (1989). Ten-kilometer performance and predicted velocity at $VO_{2max}$ among well-trained male runners. *Medicine & Science in Sports & Exercise*, 21(1), 78–83. https://doi.org/10.1249/00005768-198902000-00014

Morgan, P.T., Black, M.I., Bailey, S.J., Jones, A.M., Vanhatalo, A. (2018). Road cycle TT performance: Relationship to the power-duration model and association with FTP. *Journal of Sports Sciences*, 37(8), 902–910. https://doi.org/10.1080/02640414.2018.1535772

Mukaka, M. (2012). A guide to appropriate use of correlation coefficient in medical research. *Malawi Medical Journal*, 24(3), 69–71. PMID: 23638278

Müller, A., Tschakert, G., Moser, O., Gröschl, W., Hofmann, P. (2013). High-intensity exercise warm-up, inhibition of glycolysis, and its practical consequences. In Proceedings of the 6th International Congress on Science and Skiing, St. Christoph am Arlberg, Austria, 14–19 December 2013. pp 224–230.

Palmer, C.D., Jones, A.M., Kennedy, G.J., Cotter, J.D. (2009). Effects of prior heavy exercise on energy supply and 4000-m cycling performance. *Medicine & Science in Sports & Exercise*, 41(1), 221–229. https://doi.org/10.1249/MSS.0b013e31818313b6

Parolin, M.L., Chesley, A., Matsos, M.P., Spriet, L.L., Jones, N.L., Heigenhauser, G.J.F. (1999). Regulation of skeletal muscle glycogen phosphorylase and PDH during maximal intermittent exercise. *American Journal of Physiology-Endocrinology and Metabolism*, 277(5), E890–E900. https://doi.org/10.1152/ajpendo.1999.277.5.E890

Purge, P., Hofmann, P., Merisaar, R., Mueller, A., Tschakert, G., Mäestu, J., Jürimäe, J. (2017). The effect of upper body anaerobic pre-loading on 2000-m ergometer-rowing performance in college level male rowers. *Journal of Sports Science and Medicine*, 16(2), 264–271. PMID: 28630580

Richendollar, M.L., Darby, L.A., Brown, T.M. (2006). Ice bag application, active warm-up, and 3 measures of maximal functional performance. *Journal of Athletic Training*, 41(4), 364–370. PMID: 17273459

Rivera-Brown, A.M., Frontera, W.R. (2012). Principles of exercise physiology: responses to acute exercise and long-term adaptations to training. *PM&R*, 4(11), 797–804. https://doi.org/10.1016/j.pmrj.2012.10.007

Robergs, R.A., Pascoe, D.D., Costill, D.L., Fink, W.J., Chwalbinska-Moneta, J., Davis, J.A., Hickner, R. (1991). Effects of warm-up on muscle glycogenolysis during intense exercise. *Medicine & Science in Sports & Exercise*, 23(1), 37–43. https://doi.org/10.1249/00005768-199101000-00007

Secher, N.H. (1993). Physiological and biomechanical aspects of rowing. Implications for training. *Sports Medicine*, 15(1), 24–42. https://doi.org/10.2165/00007256-199315010-00004

Seitz, L.B., de Villarreal, E.S., Haff, G.G. (2014). The temporal profile of postactivation potentiation is related to strength level. *Journal of Strength and Conditioning Research*, 28(3), 706–715. https://doi.org/10.1519/JSC.0b013e3182a73ea3

Seitz, L.B., Haff, G.G. (2016). Factors modulating post-activation potentiation of jump, sprint, throw, and upper-body ballistic performances: A systematic review with meta-analysis. *Sports Medicine*, 46, 231–240. https://doi.org/10.1007/s40279-015-0415-7

Sørensen, A., Aune, T.K., Rangul, V., Dalen, T. (2019). The validity of functional threshold power and maximal oxygen uptake for cycling performance in moderately trained cyclists. *Sports,* 7(10), 217. https://doi.org/10.3390/sports7100217

Sousa, A., Ribeiro, J., Sousa, M., Vilas-Boas, J.P., Fernandes, R.J. (2014). Influence of prior exercise on $vo_2$ kinetics subsequent exhaustive rowing performance. *PLoS One*, 9(1), e84208. https://doi.org/10.1371/journal.pone.0084208

Spendier, F., Müller, A., Korinek, M., Hofmann, P. (2020). intensity thresholds and maximal lactate steady state in small muscle group exercise. *Sports*, 8(6), 77. https://doi.org/10.3390/sports8060077

Tomaras, E.K., MacIntosh, B.R. (2011). Less is more: standard warm-up causes fatigue and less warm-up permits greater cycling power output. *Journal of Applied Physiology*, 111(1), 228–235. https://doi.org/10.1152/japplphysiol.00253.2011

Tschakert, G., Handl, T., Weiner, L., Birnbaumer, P., Müller, A., Groeschl, W., Hofmann, P. (2022). Exercise duration: Independent effects on acute physiologic responses and the need for an individualized prescription. *Physiological Reports*, 10(3), e15168. https://doi.org/10.14814/phy2.15168

Tschakert, G., Hofmann, P. (2013). High-intensity intermittent exercise: methodological and physiological aspects. *International Journal of Sports Physiology and Performance*, 8(6), 600–610. https://doi.org/10.1123/ijspp.8.6.600

Thompson, W.R., Gordon N.F., Pescatello L.S. (2009). *ACSM's Guidelines for exercise training and prescription 8^th^ ed*. Wolters Kluwer, Lippincott Williams & Wilkins, Philadelphia, USA.

Viru, A. (1990). *Sportlik saavutusvõime*. Tartu Ülikooli Spordifüsioloogia kateeder, Tartu, Estonia. pp 64,67.

Wilkerson, D.P., Koppo, K., Barstow, T.J., Jones, A.M. (2004). Effect of prior multiple-sprint exercise on pulmonary $O_2$ uptake kinetics following the onset of perimaximal exercise. *Journal of Applied Physiology*, 97(4), 1227–1236. https://doi.org/10.1152/japplphysiol.01325.2003

Yanaoka, T., Hamada, Y., Fujihira, K., Yamamoto, R., Iwata, R., Miyashita, M., Hirose, N. (2020). High-intensity cycling re-warm up within a very short time-frame increases the subsequent intermittent sprint performance. *European Journal of Sport Sciences*, 20(10), 1307–1317. https://doi.org/10.1080/17461391.2020.1713901

# SUMMARY IN ESTONIAN

## Lühiajalise maksimaalse eelpingutuse mõju maksimaalsele pingutusele vastupidavusalade sportlastel

Klassikaliselt tuntud eelsoojenduse ülesehitus ühendab endas madala intensiivsusega aeroobset harjutust ($MPT_{low}$), millele järgneb venitus ning spordiala spetsiifiline soojendus (Burkett et al., 2005; Hajoglou et al., 2005; Richendollar et al., 2006). Mõlema eesmärk on lihaste ja keha temperatuuri tõstmine, närvijuhtivuse parandamine, kiirendatud metabolism ning hapnikutarbimise ja füsioloogilise valmisoleku parandamine. Sportlikust soojendusest tingitud aktivatsioon ja tekitatud väsimus peaksid olema omavahel hästi reguleeritud tasakaalus ning viima sportliku saavutusvõime paranemiseni (McGowan et al., 2015).

Viimasel ajal on hakatud uurima kehalises pingutuses mitteosalevate lihasgruppide tugevat, kuid lühiaegset (*high-intensity exercise* − HIE) eelpingutust (Birnbaumer et al., 2018; Purge et al., 2017), väsitamata spordiala-spetsiifilisi lihasgruppe. Lisades HIE eelpingutust aeroobsele harjutusele ($MPT_{high}$), võib see aidata häälestada keha süsteemsed mehhanismid eelseisvaks pingutuseks. Mõju avaldub ka väiksemate lihasgruppidega sooritatud HIE eelpingutusest (Bogdanis et al., 1994; Bohnert et al., 1998; Spendier et al., 2020), mis suudab tõsta maksimaalse hapniku omastamist ($\dot{V}O_2$) suurte lihasgruppidega teostatud HIE eelpingutusega võrreldavale tasemele (Bogdanis et al., 1994; Bohnert et al., 1998). Eelpingutusest tingitud kõrgenenud [La] pärsib anaeroobse energia produktsiooni, mida sportlikul sooritusel kompenseerivad vastavalt aeroobsed mehhanismid. Seejuures summaarne energia tootmine ei tarvitse olla vähenenud (Müller et al., 2013). Kuigi HIE eelpingutus võib aktiveerida füsioloogilisi näitajaid, ei garanteeri füsioloogiline valmisolek paremat sportlikku sooritust (Carter et al., 2005; Ferguson et al., 2007; Sousa et al., 2014). Samas kiire starditempo valik koos eelpingutusega on näidanud positiivset mõju tulemusele (Brock et al., 2018; Caritá et al., 2014).

Anaeroobse töö energia tootmine põhineb enamjaolt glükoosi lagundamisel ehk glükolüüsil, mille esmasel lagunemisel koguneb lihasesse püruvaat, mis lihase hapnikuvaeguse korral muundatakse laktaadi dehüdrogenaasi toimel laktaadiks. Algselt suureneb [La] lihaste tasandil, mis madalal intensiivsusel edukalt hapniku abil lagundatakse, ning edaspidi vereringes, kui lihase hüpoksiline seisund pole enam võimeline suurt hulka laktaati elimineerima (Gladden, 2004). Vereringe kannab laktaati kui energiaallikat teistele lihastele ning organitele, mis oma hapnikuvarude abil sellest efektiivselt ATP-d sünteesivad (Brooks, 2018, 2009, 1998; Gladden, 2004). Lisaks on laktaat ka glükoneogeneetiline prekursor ning regulaator (Brooks, 2018, 1986).

**Uurimustöö eesmärgid**

Uurimustöö eesmärk oli kindlaks määrata, kas mitte-spordispetsiifiliste lihaste sooritatud kõrge intensiivsusega eelpingutus (HIE) parandab järgneva spordispetsiifilise maksimaalse jõudluse testi tulemusi kõrgelt treenitud meessoost vastupidavusalade sportlastel.

Uurimustöös püstitati järgmised ülesanded:

1. Hinnata HIE eelpingutuse mõju keha metaboolsetele mehhanismidele ja anaeroobse energia tootmise osakaalule kogu energiavarustusest järgneva maksimaalse jõudluse testi ajal.
2. Mõõta aja ning võimsuse erinevusi maksimaalse jõudluse testis eelpingutusega ning ilma.
3. Määrata optimaalne taastumisaeg enne maksimaalse jõudluse testi pärast HIE eelpingutust.
4. Kontrollida, kas standardiseeritud tempo maksimaalse jõudluse testi ajal suudab kompenseerida eelnevast HIE-st põhjustatud anaeroobse energia puudujääki.

**Uuritavad ja metoodika**

Käesolev doktoritöö koosneb kolmest eraldiseisvast uuringust. Uuringus I osales 13 suusatajat (18.1 ± 2.9 a; 181 ± 5 cm; 70.8 ± 7.6 kg; 57.3 ± 5.3 $mL\cdot kg^{-1}\cdot min^{-1}$), uuringus II 15 jalgratturit (23.3 ± 3.6 a; 181 ± 7 cm; 76.2 ± 10.0 kg; 65.4 ± 6.7 $mL\cdot kg^{-1}\cdot min^{-1}$) ja uuringus III 11 jalgratturit (18.8 ± 0.9 a; 182 ± 5 cm; 73.0 ± 6.6 kg; 67.9 ± 5.1 $mL\cdot kg^{-1}\cdot min^{-1}$).

Uuritavad läbisid võistlusdistantsi kahel korral maksimaalse võimaliku võimsusega, mõlemale eelnes madala intensiivsusega soojendus (20 min), kuid $MPT_{high}$ puhul lisandus ka kõrge intensiivsusega lühiajaline anaeroobne pingutus (25 sek). Uuringute protokollid erinesid taastumisaja, MPT kestvuse ning määratud tempo poolest.

**Järeldused**

1. Eelpingutus vähendab neto [La] kasvu ning vastavalt kogu anaeroobse energiatootmise osakaalu järgneva maksimaalse jõudluse testis. (Uuring I, II, III)
2. Soojendusele lisatud HIE ei pruugi järgneva maksimaalse jõudluse testi ajal jõudlust parandada; siiski, üksikisiku tasandil täheldatud positiivsed mõjud viitavad, et mõned katsealused võivad sellest meetodist kasu saada. (Uuring I, II, III)
3. Sportlaste endi valitud taastumisaeg pärast HIE-d peaks lisakoormuse tõttu olema pikem, et tagada optimaalne jõudlus ja võrdne tajutud pingutus järgneva maksimaalse jõudluse testi ajal. (Uuring II, III)
4. Ühtlane tempo pärast eelpingutusega soojendust parandab soorituse taluvust ning võimekust teisel ventilatsioonilävel tänu suurenenud ökonoomsusele vähemalt 17-minutilise anaeroobse treeningu ajal. (Uuring III)

# ACKNOWLEDGEMENTS

It is a genuine pleasure to express my sincere gratitude and appreciation to people supporting me during my studies.

- Research Fellow Priit Purge for academic supervision and coaching throughout the experimental testing, his comprehensive support and valuable advice on dealing with challenges.
- Professor Peter Hofmann for his positive attitude, enthusiastic faith in science and an individual approach regarding explanations of human physiology and exercise therapy.
- Associate Professor Jarek Mäestu for a valuable advice.
- Professor Jaak Jürimäe for close revision and useful comments on all manuscripts.
- Professor Priit Kaasik for a valuable suggestions and kind support throughout the studies.
- All the athletes, who agreed to participate in our project.
- Colleagues and friends, Dr. Pärt Prommik, Dr. Rasmus Pind, Dr. Evelin Mäestu and Eno Vahtra.

Finally, my most special thanks to my son George for being an immense motivator throughout the studies and lighting up my days with joy and happiness.

# PUBLICATIONS

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