Muscle Oxygenation and Performance Adaptations in Trained Cyclists Following a Polarized and Threshold Training Intervention

by
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Thesis presented in fulfilment of the requirements for the degree of Master of Science (in Sport Science) in the Faculty of Medicine and Health Sciences at Stellenbosch University

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December 2023

Declaration

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Abstract

Training intensity, and its distribution within a training program, is a key variable in positively or negatively influencing athletic performance, through varying physiological adaptations stemming from different training intensities. However, experimental research investigating physiological adaptations to various training intensity distributions is scarce. As such, the purpose of this study was to examine the performance and peripheral adaptations to a polarized (POL) and a threshold (THR) training intervention in trained cyclists.

Seventeen trained road and mountain bike cyclists, including men (n = 13) and women (n = 4), aged between 19 and 49 years, participated in this study. This study followed a pre-post design, with a random assignment of participants into two experimental groups: a POL or a THR training group. The pre- and post-tests included a ramp incremental test to exhaustion and a 30-s Wingate test, with concurrent cardiorespiratory, muscle oxygenation, power, heart rate, and blood lactate data collection. The intervention consisted of six weeks of polarized (80/0/20% in zone 1/2/3) or threshold (45/55/0% in zone 1/2/3) training.

The findings of the present study indicate that both POL and THR training stimulate improvements in power output over a 6-week training period. There were no significant group*time interactions observed for any measured variable ($p > 0.05$), however, effect sizes were calculated to investigate the magnitude of differences after the training intervention. Both THR and POL displayed improvements in power output at LT2, and PPO, however the effect size was numerically greater after THR than POL training (ES = 0.54, 0.29). It was also found that the effect size of muscle oxygen utilization was greater after POL than THR at LT1, LT2, PPO, and after the 30-s Wingate (ES = 0.72, 0.91, 0.74, 1.76). The magnitude of change in VO_2max was larger for POL than THR (5.9% vs. 1.1% improvement, respectively; ES = 0.40). The THR group showed a greater numerical increase in effect size, compared to POL in anaerobic capacity and explosive power (ES = 0.34, 0.40). A moderate and a small numerical increase was observed in effect size in exercise economy at LT2 and PPO in THR, but not in POL ($p > 0.05$, ES = 1.11, 0.45).

It is suggested that the observed improvement in power output at LT2 and PPO in the POL group may be attributed to peripheral aerobic adaptations, as indicated by an increase in O_2 utilization and VO_2max. Secondly, it is suggested that glycolytic adaptations may contribute to the improvement in power output at LT2 and PPO in the THR group, as reflected by a decrease in VO_2/W, along with increases in anaerobic capacity and explosive power. Over a 6-week period, neither POL nor THR appeared to be superior for improving endurance performance, but they may induce different adaptations.

Opsomming

Oefenintensiteit, en die verspreiding daarvan binne 'n oefenprogram, is 'n sleutelveranderlike wat atletiese prestasie positief of negatief beïnvloe. Die uitkoms word bewerkstellig deur wisselende fisiologiese aanpassings in respons op verskillende oefenintensiteite. Nietemin is eksperimentele navorsing, wat die fisiologiese aanpassings in respons op verskillende oefenintensiteitsverspreidings ondersoek, skaars. Dus was die doel van hierdie studie om die prestasie en perifere fisiologiese aanpassings, in respons op 'n gepolariseerde (POL) en 'n drempel (THR) oefenintervensie, in geoefende fietsryers te ondersoek.

Sewentien geoefende pad- en bergfietsryers, insluitend mans (n = 13) en vroue (n = 4), tussen die ouderdom van 19 en 49 jaar, het aan die studie deelgeneem. Hierdie studie het 'n voor-en-na-intervensie ontwerp gevolg, met 'n lukrake toewysing van deelnemers aan twee eksperimentele groepe: 'n POL- of 'n THR-oefengroep. Die voor- en na-toetse het 'n geggradeerde oefentoets tot uitputting en 'n 30-s Wingate-toets ingesluit, met gelyktydige kardiorespiratoriese-, spieroksigenasie-, kraguitset-, hartspoed- en bloedlaktaat data-insameling. Die intervensie het ses weke geduur en het bestaan uit gepolariseerde (80/0/20% in sone 1/2/3) of drempel (45/55/0% in sone 1/2/3) inoefening.

Die bevindinge van hierdie studie dui daarop dat beide POL- en THR-inoefening verbeterings in kraguitset oor 'n 6-weke oefenperiode stimuleer. Daar was geen beduidende groep*tyd-interaksies vir enige gemete veranderlike waargeneem nie ($p > 0.05$) nie, maar effekgroottes is bereken om die grootte van verskille na die oefen intervensie te ondersoek. Beide THR- en POL-groepe het verbeterings in kraguitset by LT2 en PPO getoon, maar die effekgrootte was numeries groter na THR as na POL-inoefening (EG = 0.54, 0.29). Daar is ook gevind dat die effekgrootte van spieroksigenasie na POL groter was as na THR by LT1, LT2, PPO en na die 30-s Wingate (EG = 0.72, 0.91, 0.74, 1.76). Die grootte van verandering in VO2maks was groter vir POL as vir THR (5.9% vs. 1.1% verbetering, onderskeidelik; EG = 0.40). Die THR-groep het 'n groter numeriese toename in effekgrootte getoon in anaërobiese kapasiteit en eksplosiewe krag in vergelyking met POL (EG = 0.34, 0.40). 'n Matige en 'n klein toename, onderskeidelik, is waargeneem in oefenekonomie by LT2 en PPO in THR, maar nie in POL nie ($p > 0.05$, EG = 1.11, 0.45).

Dit word voorgestel dat die waargenome verbetering in kraguitset by LT2 en PPO in die POL-groep toegeskryf kan word aan perifere aërobiese aanpassings, soos aangedui deur 'n toename in O2-benutting en VO2maks. Tweedens word gesuggereer dat glikolitiese aanpassings moontlik bydra tot die verbetering in kraguitset by LT2 en PPO in die THR-groep, soos weerspieël deur 'n afname in VO2/W, tesame met toenames in anaërobiese kapasiteit en eksplosiewe krag. Oor 'n 6-weke tydperk blyk dit dat nie POL óf THR meer voordelig is vir die verbetering van uithouvermoë prestasie nie, maar hulle mag verskillende aanpassings induseer.

Acknowledgements

Prof Elmarie Terblanche – Thank you for your guidance, support, encouragement, and feedback during the past two years.

Ms Louise Engelbrecht – Thank you for helping me get comfortable with all the laboratory equipment, and help make the laboratory a space that I truly feel comfortable working in.

My friends in the Sport Physiology Laboratory – Thank you for always being there to bounce ideas, have a laugh, and be supportive throughout this process.

My parents – Thank you for the opportunity to complete my master's degree, and for your continuous support and belief.

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Glossary

(a-v) O_2difference	-	arteriovenous oxygen difference
ATP	-	adenosine triphosphate
CMJ	-	countermovement jump
EMG	-	electromyographic amplitude
ES	-	effect size
Fat_{max}	-	maximal fat oxidation rate
h	-	hour
HHb	-	deoxygenated hemoglobin
HR	-	heart rate
HVLIT	-	high-volume low-intensity training
kg	-	kilogram
L	-	litre
LT1	-	lactate threshold 1 / aerobic threshold
LT2	-	lactate threshold 2 / anaerobic threshold
MCT1	-	monocarboxylate transporter 1
MCT4	-	monocarboxylate transporter 4
min	-	minute
mL	-	millilitre
MLSS	-	maximal lactate steady state
mmol	-	millimole
MVC	-	maximal voluntary contraction
NIRS	-	near-infrared spectroscopy
O_2	-	oxygen
O_2Hb	-	oxygenated hemoglobin

p	-	p-value
PO	-	power output
POL	-	polarized
PPO	-	peak power output
PYR	-	pyramidal
R	-	Pearson correlation coefficient
R^2	-	coefficient of determination
RFD	-	rate of force development
RMR	-	resting metabolic rate
RQ	-	respiratory quotient
SD	-	standard deviation
SJ	-	squat jump
SmO_2	-	muscle oxygen saturation
THR	-	threshold
TID	-	training intensity distribution
TTE	-	time to exhaustion
vLT1	-	velocity at lactate threshold 1
VO_2max	-	maximal oxygen uptake
VT1	-	ventilatory threshold 1
VT2	-	ventilatory threshold 2
W	-	watt
Z2/Z2/Z3	-	zone 1 / zone 2 / zone 3
1RM	-	1 repetition maximum
µL	-	microlitre

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Content of Thesis

Chapter 1 – Introduction. This chapter contains the background information and problem statement, as well as the aims and hypotheses of the study.

Chapter 2 – Literature review. Article one: *"Physiological and Endurance Sport Performance Adaptations to Polarized and Threshold Training: A Review"*. The purpose of this chapter was to collect and summarize the existing literature relating to training intensity distributions and their physiological and performance outcomes. A second purpose was to provide a rationale why investigating muscle oxygenation adaptations to various training intensity distributions will contribute to our understanding of the spectrum of peripheral muscle adaptations to exercise training.

Chapter 3 – Methodology. This chapter explains the study design, participant information, methods for data collection, information about the training intervention, ethics, and statistical analysis.

Chapter 4 – Results and Discussion. Article two: *"Performance and Physiological Adaptations to a Six-Week Polarized and Threshold Training Intervention in Trained Cyclists"*. The focus of this article was to describe the physiological and performance adaptations to a six-week polarized or training intervention in trained cyclists.

Chapter 5 – Conclusion. This chapter includes a summary of the main findings of the study, a review of the hypotheses, the practical applications of the findings, limitations of the study, and suggestions for future research.

Chapter 1 Problem Statement

Background

A comprehensive understanding of the optimal training intensity distribution (TID) can be of paramount importance for athletes and coaches striving to optimize athletic performance. TIDs refer to three distinct training zones: zone 1, below the aerobic threshold (< LT1); zone 2, between the aerobic and anaerobic thresholds (between LT1 and LT2); and zone 3, above the anaerobic threshold (> LT2) (Seiler and Kjerland, 2006). The aerobic threshold can be defined as the threshold above which the body predominantly relies on carbohydrate as a substrate for ATP production; this threshold is also commonly referred to as LT1, or VT1. The anaerobic threshold can be defined as the threshold above which the lactate production is in excess of the lactate clearance rate. Above this intensity the oxygen independent pathways are becoming more active in the total ATP production. As such, the term 'anaerobic threshold' is slightly misleading as the muscle is not deficient in oxygen, but rather more reliant on oxygen independent pathways. This threshold is also commonly referred to as maximum lactate steady state, onset of blood lactate accumulation, LT2, VT2, or oxygen independent threshold. Though it should be noted that these thresholds may fall at marginally different intensities, due to different measurement methods. In the present thesis the aerobic and anaerobic thresholds will be referred to as LT1 and LT2.

Among endurance athletes, two distinct TID models have been identified (Esteve-Lanao et al., 2005). Firstly, a polarized training model (POL) (Foster et al., 2007; Muñoz et al., 2014) which is characterized by a large proportion of training time in zone 1 (~ 80% of training time), supplemented with zone 3 training (~ 20% of training time). Notably, this model allocates limited- or no time to the intermediate (zone 2) intensity paradigm. The second TID model commonly used is a threshold training model (THR) (Enoksen et al., 2011; Tjelta and Enoksen, 2010). This training model comprises a large proportion of volume in the intermediate zone 2 intensity (~ 55%), with most- to all other training performed in the low intensity zone 2 (~ 45%).

Previous research has shown that adopting a POL training model for endurance athletes may be optimal due to the large volume of lower intensity work, while maintaining a sufficient stimulus of high-intensity work. The lower intensity zone 1 training has been found to affect mostly aerobic adaptations, such as a decrease in carbohydrate oxidation and plasma lactate concentration at the same absolute work rate, and enhanced ability of the working muscle to generate ATP aerobically (Laursen, 2010; Westgarth-Taylor et al., 1997). Typically, high intensity zone 3 training facilitates improvements in maximal aerobic capacity (VO_2max) by increasing cellular stress, as found by Weston et al. (2014) (Weston et al., 2014).

THR training is very specific to most endurance race events. Due to the aerobic nature of endurance events, athletes spend most competition time in the intermediate zone 2 (Muñoz et al., 2013). Training according to a THR distribution has been observed to improve an athlete's velocity at the anaerobic threshold (LT2), and as such improve endurance performance through improved average pace during the race (Evertsen et al., 2001; Kenneally et al., 2018). A THR training program has also been found to induce adaptations in the oxidative metabolism of muscle cells (Faude et al., 2009).

Different training intensities have been found to elicit distinct physiological responses (MacInnis and Gibala, 2017). From prior research this seems to extend to both POL and THR training approaches. Among practitioners and researchers alike there is a debate as to which TID model may be superior in maximizing physiological adaptations, as well as performance.

Adaptations to exercise training can be broadly categorized as either central or peripheral, based on where the adaptation occurs in the body (Gibala and MacInnis, 2022). Central adaptations refer to cardiovascular and circulatory changes, whereas peripheral adaptations refer to muscular changes (Hellsten and Nyberg, 2011). Central adaptations are the physiological adaptations associated with oxygen delivery to the working muscles, while peripheral adaptations are concerned with oxygen utilization in the working muscles. Different exercise programs can cause varying physiological adaptations, despite similar performance outcomes (Daussin et al., 2007). To boost performance, athletes could therefore adapt their training throughout their season or career, to maintain performance, but keep applying a novel stimulus.

One way to assess peripheral adaptations is through near-infrared spectroscopy (NIRS). NIRS measures tissue oxygenation status non-invasively by near-infrared light being absorbed and reflected differently by oxygenated and deoxygenated hemoglobin and myoglobin (O_2Hb and HHb). O_2Hb and HHb can be used to determine muscle oxygen saturation (SmO_2) using the following equation (Feldmann and Erlacher, 2021; Myers C, 2020):

$$SmO_2 = \frac{O_2Hb}{O_2Hb + HHb} \times 100.$$

Conversion of O_2Hb to HHb, in other words a decrease in SmO_2, is indicative of oxygen utilization of the muscle. Changes in the O_2 utilization of the muscle have been found to be largely due to adaptations in muscle capillary networks, and mitochondrial respiratory capacity (Ryan et al., 2013). Strong correlations have been found between a decrease in SmO_2 during incremental exercise at exhaustion, and VO_2max (Shibuya and Tanaka, 2003). Utilizing NIRS to assess peripheral adaptations after different TIDs may aid in quantifying changes that can boost endurance performance.

Problem Statement

To date, only a few studies have reported on the performance and physiological adaptations in response to the two training models and the findings from these studies are not conclusive. Notably, there has been no investigation on how muscle oxygenation is affected by polarized or threshold exercise training.

The purpose of this study was to broaden our understanding of the underlying physiological adaptations and changes in performance markers associated with POL and THR training in cycling. The findings of this study can be used as a guideline for competitive athletes and coaches on how they should train to optimally enhance their performance. Understanding how an individuals' body adapts to specific types of training can help prevent athletes from doing ineffective training which may hamper training progress, or from over-training which will negatively affect performance. The findings of this study will also help exercise physiologists understand how different training strategies impact physiological adaptations.

Research aims

1. To determine the magnitude of changes in power output, aerobic capacity, anaerobic capacity, and muscle oxygenation following a 6-week POL and THR training intervention in trained cyclists.
2. To determine the relationship between the changes in muscle oxygenation markers, and changes in performance indicators following a 6-week POL and THR training intervention in trained cyclists.

Hypotheses

H_1: A THR training intervention will lead to a higher workload at a sub-maximal exercise intensity, compared to a POL training model. Ghosh (2004) found decreases in O_2 cost, lactate accumulation and depletion of glycogen at a given exercise intensity, after THR training (Ghosh, 2004). This was hypothesized to result in an improvement in submaximal exercise intensity.

H_2: There will be no difference in change in aerobic capacity between the training interventions. Treff et al. (2017) compared a POL and a pyramidal (PYR) training intensity distribution over an 11-week training period and found no significant change in VO_2max between training models (Treff et al., 2017).

H_3: A THR training model will lead to greater improvements in anaerobic capacity, compared to a POL training model. Pérez et al. (2020) found that runners could better maintain maximum force development following 12-weeks of THR training, compared to POL training (Pérez et al., 2020).

H_4: A POL training intervention will elicit greater muscle oxygenation adaptations than a threshold training model. Egan & Zierath (2013) observed that cellular stress occurs in proportion to exercise intensity, and that there is evidence that higher intensity exercise elicits a greater metabolic signal in the active muscles compared to moderate intensity exercise(Egan and Zierath, 2013).

H_5: A THR training model will improve exercise economy (VO_2/W) more than a POL training model. Stöggl & Sperlich (2014) found an improvement in work economy at a sub-maximal intensity favoring THR training over POL training (Stöggl and Sperlich, 2014).

H_6: There will be positive correlations between changes in muscle oxygenation and changes in markers of endurance performance. Shibuya & Tanaka (2003) observed a significant relationship between SmO_2 at aerobic exhaustion and VO_2max (Shibuya and Tanaka, 2003).

Variables

The variables of the study are presented in Table 1.1.

Table 1.1 - Variables of the study.

Independent	Training intensity distribution, namely: • Polarized training (80 / 0 / 20 % in zone 1 / 2 / 3) • Threshold training (45 / 55 / 0 % in zone 1 / 2 / 3)
Dependent	• Markers of aerobic endurance performance: ○ Power output at LT1 ○ Power output at LT2 ○ PPO ○ Absolute and relative VO_2max ○ HR_{max} ○ VO_2 at LT1 ○ VO_2 at LT2 ○ VO_2 at PPO • Anaerobic performance: ○ 30-s Wingate PPO ○ 30-s Wingate mean PO ○ 30-s Wingate minimum PO ○ Explosive power (time to reach PPO) ○ Anaerobic capacity (total power produced as a function of time and body weight) ○ Fatigue index (percentage decline in power output over 30-s) • Muscle oxygenation: ○ Relative O_2Hb and HHb, absolute SmO_2 at LT1 ○ Relative O_2Hb and HHb, absolute SmO_2 at LT2 ○ Relative O_2Hb and HHb, absolute SmO_2 at PPO ○ Relative O_2Hb and HHb, absolute SmO_2 after 30-s Wingate
Control	None

Assumptions

It was assumed that participants were motivated to take part in the study, and that they would perform the tests and the prescribed training to the best of their ability.

Participants were asked to follow certain rules before the testing session: no exercise for 24-h, no caffeine for 12-h, and no food for 2-h preceding the testing session. It was assumed that the participants followed these guidelines as there are no reliable objective way their compliance could be assessed.

Regarding the training intervention and the data collection, it was assumed that six weeks of training for approximately 9.5-h per week according to a POL or a THR training model will be enough to elicit a statistically significant change in performance and muscle oxygenation variables.

The NIRS device only measures the muscle oxygenation of a small portion of the *Vastus Lateralis* muscle below the probe. It was assumed that this would be an accurate representation of the active muscles.

It was assumed that all equipment will produce reliable data during testing after daily calibration according to the manufacturer's specifications.

Chapter 2 Literature Review

Introduction to Article

The literature review of the present study is presented in a review article format.

The article, titled *"Physiological and Endurance Sport Performance Adaptations to Polarized and Threshold Training: A Review,"* aims to summarize the existing literature relating to TIDs and the ensuing physiological and performance adaptations. Second, the aim was to provide a rationale for the investigation of muscle oxygenation adaptations to various TIDs.

The article was written in accordance with the author's guidelines of the Journal of Strength & Conditioning Research (Addendum A). The JSCR referencing style was applied.

[For convenience, the tables are included in the text, and are numbered according to the chapter in this thesis. In the submitted manuscript, these will be placed at the end of the document.]

Physiological and Endurance Sport Performance Adaptations to Polarized and Threshold Training: A Review

Abstract

The objective of this review was to compare the effects of various training intensity distribution models on endurance sport performance and the associated physiological adaptations.

The literature search was conducted on June 30th, 2023. Studies were selected if they comprised endurance-trained athletes, analysis of training intensity distribution, included a polarized (POL) and/or a threshold (THR) training group, and assessed either internal or external measurements of endurance performance. Twenty studies were included in the review: twelve with performance outcome measures and eight with physiological outcome measures. It was found that a larger body of evidence favors a high-volume, low-intensity training (HVLIT) model, or a POL training model, over a THR or pyramidal (PYR) training model for performance outcomes. There is consensus that a high volume of training at a low intensity is key for endurance sports performance. However, there is still uncertainty regarding the optimal distribution of zone 2 and zone 3 training for optimal endurance adaptations. Experimental studies report desirable adaptations resulting from both zone 2 and zone 3 training. Zone 3 training seems optimal for improving VO_2max, and increasing power/speed at a given intensity, while zone 2 training seems beneficial for maintaining muscular strength and enhancing exercise economy. Current research suggests that a high volume of zone 1 training, along with a nuanced approach to higher intensity training that embraces the desired adaptations specific to each individual, may be the best strategy for athletic success.

Keywords: Polarized training; threshold training; pyramidal training; aerobic performance.

Introduction

In endurance sports, exercise training can be defined as purposeful physical activity aimed at improving the structure or function of physiological systems (38). The underlying principle is that the athlete's body responds to a training stimulus, with the goal of maximizing adaptations while minimizing the risk of overload and injury. Endurance training primarily focuses on enhancing cardiovascular fitness, increasing muscle capillarization, improving mitochondrial density, and optimizing fat utilization to improve energy efficiency and enable athletes to sustain higher intensities for longer durations (29). The training stimulus can be manipulated by altering three principal components, namely, exercise intensity, exercise duration, and exercise frequency (3). Appropriate manipulation of these variables is key, as altering each variable has an impact on metabolic, cardiopulmonary and/or neuromuscular responses.

To guide our understanding and prescription of exercise intensity, duration, and frequency, different intensity zones have been described. These zones are based on physiological markers, such as the lactate threshold, ventilatory threshold, percentage of maximum heart rate, or subjective factors, such as a rating of perceived exertion (39). Much of the existing literature on training intensity distribution (TID) refers to a 3-zone model, which utilizes measurable thresholds, such as the aerobic and anaerobic lactate thresholds (LT1 and LT2) or the ventilatory and respiratory compensation thresholds (VT1 and VT2), to define the three intensity zones (26). Various terms are used to refer to the three zones, however, they all represent similar physiological markers that reflect the utilization of different energy systems: zone 1, characterized by exercise intensity at or below the aerobic threshold; zone 2, encompassing intensities between the aerobic and anaerobic thresholds; and zone 3, representing exercise intensities at or above the anaerobic threshold (5). These zones serve as valuable markers for determining appropriate training intensities and targeting specific physiological systems during training sessions. Some coaches or practitioners prefer to use a five-zone training model. This distinguishes intensities within the three-zone model; zone 1 and zone 2 are both below the aerobic threshold, but are used for active recovery and endurance training, respectively. Zone 3 is used as threshold training between the aerobic and anaerobic threshold. Zone 4 and zone 5 are both supra-

anaerobic threshold, with zone 4 focusing on the VO_2max high-intensity, and zone 5 focusing on anaerobic power training. The five-zone model uses the same physiological thresholds but divides the zones into sub-categories in order to more specifically apply a training stimulus (44).

Training intensity, and its distribution within a specific micro- or mesocycle of a training program, has been identified as a key variable that can be manipulated to affect markers of performance (31). However, it turns out that TIDs are a hotly disputed topic among researchers, sport scientists, and coaches (39). Manipulating the distribution between the three (or five) training zones changes the relative demands put on the metabolic pathways. In response to this given training stress, the rate at which adaptations occur, and the type of adaptations, may differ (51).

In practice, it seems that athletes use a wide range of training intensity distributions (TIDs) (43). However, among endurance athletes, two TIDs are predominantly used: a polarized training model (POL) and a threshold training model (THR). A POL TID consists of elevated percentages of time in the high intensity zone 3 and low intensity zone 1, with limited or no training time spent in zone 2. Broadly speaking a POL training model would be designed as Z1 > Z3 > Z2 (50). Traditionally a polarized TID distributes intensity as roughly 80% zone 1, 20% zone 3, and minimal time spent in zone 2 (34). Thus, this model combines high-volume endurance training and a small amount of high intensity training (43). A THR training model would be designed as Z2 > Z1 > Z3. As an example, in a traditional threshold program, intensity is distributed roughly as 40% zone 1, 50% zone 2, and 10% zone 3 (50). Pyramidal training (PYR) is like threshold training in that there is a large focus on zone 2 training. However, traditionally a PYR training model would be designed as Z1>Z2>Z3 (50). The difference between PYR and THR being the volume of zone 1 training relative to zone 2 training. Some literature groups pyramidal (PYR) and THR training together, because of the focus on the zone 2 intensity.

Despite the ongoing debate regarding the optimal TID for endurance performance, there is a consensus that different TIDs, and hence different stimuli, result in distinct physiological adaptations (37). There is supportive data for optimal performance after both POL and THR TIDs, however, Foster et al. (2022) contend that many underlying physiological mechanisms that affect performance changes remain to be determined (13). Consequently, it is plausible that there is no single ideal TID and that

different TIDs are optimal for eliciting specific adaptations. Therefore, it may be important to investigate not only performance outcomes arising from various TIDs, but to also delve into the underlying physiological mechanisms that drive the observed changes in performance. Such insights may offer practitioners with useful information to more effectively periodize athlete's training programs.

In current literature focusing on the differences between a POL and a THR TID model, there is a scarcity of research comparing the performance and physiological improvements of each training model simultaneously. The aims of this review were to (a) summarize the changes in endurance sport performance, and (b) describe our current understanding of the underlying physiological adaptations following a polarized and threshold TID.

Methods

An online search using PubMed and Web of Science was conducted on June 30th, 2020. The following keywords with Boolean operators were used: "Training intensity distribution AND (polarized training OR threshold training OR pyramidal training)". These are widely used terms for these types of endurance training. However, if relevant studies have used other terminology, these will have been omitted. Studies were included if the following criteria were met; (a) articles written in the English language; (b) they included endurance-trained athletes (studies with sprint athletes were excluded); (c) included an analysis of training intensity distribution as observational reports, case studies, or interventions; (d) contained a polarized training and/or a threshold training group, and (d) assessed either internal (e.g., VO_2max) or external (e.g., 10-km running performance) measurements of endurance sport performance.

Figure 1 illustrates the steps followed to identify publications for this analysis. From 233 records found, 38 duplicates were removed, and 195 titles and abstracts were screened. A further 161 publications were excluded, based on the titles or abstracts not covering the required topics. Thirty-four

full-text articles met the broad inclusion criteria, but on further inspection, only 20 studies met all the inclusion criteria for qualitative analysis (8–12,14,18,19,30,32–35,39–43,47,49) (Figure 1).

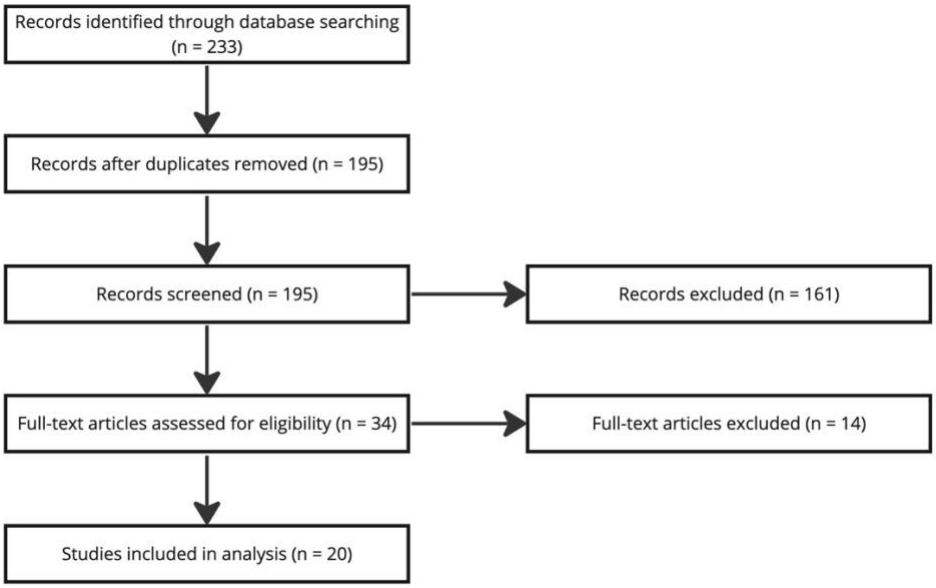

Figure 2.1 - Flow diagram of the literature search.

Results

The 20 studies that met the inclusion criteria are presented in tables organized by the dependent variable of interest (physiological adaptations and performance outcomes). Studies that compared TIDs and performance outcome measures are summarized in Table 2.1. Studies that compared TIDs and various physiological adaptations are summarized in Table 2.2.

Table 2.1 - Study characteristics with performance outcome measures.

Study	Sport	*Sample Size (M/F/U)*	Intervention Groups	Level	Outcome	Results	Supports
Seiler et al. (2004)	XC Skiing	11 (11/0)	Observational	Well-trained	TID	75% zone 1, 8% zone 2, 17% zone 3.	POL
Esteve-Lanao et al. (2005)	Running	8 (U)	Observational	Well-trained	TID	time in zone 1 vs 4.175-km race: r = -0.79, p = 0.06; and 10.130-km race: r = -0.97, p = 0.008.	HVLIT
Foster et al. (2007)	Running	20 (20/0)	POL PYR	Sub-elite	Race performance	POL > PYR for 10.4-km race: 157 ± 13 s vs -121.5 ± 7.1 s, p = 0.03	POL
Guellich et al. (2009)	Rowing	36 (36/0)	Observational	World-class	TID & Race Performance	Emphasis on zone 1 (95% zone 1 throughout season).	HVLIT
Guellich et al. (2010)	Cycling	51 (51/0)	Observational	Junior elite	Peak aerobic power	Most improved athletes performed highest volume in zone 1: 3722 ± 724 min vs 3128 ± 310 min, p < 0.01; and least volume in zone 2: 244 ± 103 min vs 442 ± 107 min, p < 0.01.	POL
Tjelta & Enoksen (2010)	Running	4 (4/0)	Observational	Junior elite	TID & Race performance	78.3% zone 1, 19.6% zone 2, 2.1% zone 3, during preparation period.	PYR
Enoksen et al. (2011)	Running	6 (3/3)	Observational	Elite	TID & Race performance	80% in zone 1, 20% zone 2, and almost no zone 3 training.	PYR
Stellingwerff (2012)	Running	3 (3/0)	Observational	Elite	TID	74% in zone 1, 11% in zone 2, 15% in zone 3.	POL
Muñoz et al. (2014)	Running	30 (U)	POL THR	Recreational	Race performance	5.0% POL vs 3.6% THR improvement in 10-km race: p = 0.226.	N
Muñoz et al. (2014)	Triathlon	9 (6/3)	Observational	Recreational	Race Performance	training time in zone 1 vs Ironman race time: r = -0.919, p = 0.40; training time in zone 2 vs Ironman race time: r = 0.939, p = 0.001.	HVLIT
Manzi et al. (2015)	Running	7 (7/0)	Observational	Recreational	TID & Race performance	time in zone 1 vs vLT1: r = 0.88, p < 0.01; vLT1 vs marathon time; r = -0.83, p < 0.01	HVLIT
Sellés-Pérez et al. (2019)	Triathlon	18 (18/0)	POL PYR	Recreational	Race Performance	POL: time in zone 2 vs 1.9-km swim time: r = -0.616, p< 0.05; and 90-km cycling time: r = -0.536, p < 0.05. PYR: time in zone 2 vs 21.1-km running time: r = -0.513, p < 0.05; and half Ironman race time: r = -0.526, p < 0.05.	PYR

M, male; **F**, female; **U**, unspecified; **PPO**, peak power output; **POL**, polarised; **PYR**, pyramidal; **THR**, threshold; **N**, neither; **TID**, training intensity distribution; **HVLIT**, high volume low intensity training; **vLT1**, velocity at LT1.

Table 2.2 - Study characteristics with physiological adaptation measures.

Study	Sport	Sample Size (M/F/U)	Intervention Groups	Level	Outcome Measures	Results	Supports
Evertsen et al. (2001)	Cross-country skiing	20 (11/9)	Moderate (POL) High intensity (THR)	Elite	LT [MCT1] [MCT4]	↑ Speed at LT2 for THR ($p = 0.003$), but not for POL ($p = 0.54$). No change in MCT1 for THR ($p = 0.30$), but ↓ for POL ($p=0.01$). No change in MCT4 in either group ($p > 0.10$).	THR
Seiler et al. (2007)	Running	17 (17/0)	Below VT1 short Below VT1 long At VT2 Above VT2	Trained and highly trained	ANS recovery	Improved HRV recovery with exercise below VT1 compared with exercise between VT1 and VT2, or above VT2 ($p < 0.05$)	POL
Neal et al. (2013)	Cycling	12 (12/0)	POL THR	Well-trained	TTE LT [MCT1] [MCT4]	POL > THR for PPO ($p < 0.05$), LT2 ($p < 0.05$), and TTE ($p < 0.05$). No change in mitochondrial enzyme activity and MCT1 in either group.	POL
Stöggl et al. (2014)	Mixed endurance sports	48 (U)	POL HIIT THR HVLIT	Competitive	Exercise economy LT TTE VO_2max	THR > POL for economy ($p < 0.05$) POL > THR for VO_2max ($p < 0.001$), TTE ($p < 0.001$), PPO ($p < 0.01$), LT2 ($p < 0.01$)	POL
Treff et al. (2017)	Rowers	14 (14/0)	POL PYR	Elite	LT 2000 m ergometer test VO_2max	No difference in 2000-m ergometer test, VO_2max, or LT between POL and PYR ($p > 0.05$)	N
Festa et al. (2020)	Running	38 (31/7)	POL THR	Recreational	CMJ Exercise economy LT SJ VO_2max 1RM estimation	No differences in any measured variable between POL and THR ($p > 0.05$)	N
Pérez et al. (2020)	Running	20 (U)	POL THR	Recreational	EMG Fat metabolism MVC RFD	POL ↓ RFD ($p < 0.001$), THR no change ($p > 0.05$). THR ↑ EMG ($p = 0.02$)	THR
Filipas et al. (2021)	Running	60 (60/0)	PYR POL PYRPOL POLPYR	Well-trained	LT 5 km race performance VO_2max	PYRPOL largest improvements in VO_2max ($p < 0.0001$), vLT1 ($p < 0.0001$), vLT2 ($p < 0.0001$), and 5-km race performance ($p = 0.0001$), compared to POL, PYR, or POLPYR.	PYRPOL

M, male; **F**, female; **U**, unspecified; **VO_2max**, absolute maximal oxygen uptake; **performance**, umbrella term for different performance tests (20-min all out run, 40 km time trial, time to exhaustion at 95% PPO, etc.); **LT**, lactate thresholds; **TTE**, time to exhaustion; **[MCT1]**, concentration of monocarboxylate transporter 1; **[MCT4]**, concentration of monocarboxylate transporter 4; **1RM**, 1 repetition maximum leg press; **SJ**, squat jump; **CMJ**, countermovement jump; **RMR**, resting metabolic rate; **Fat_{max}**, maximal fat oxidation rate; **RFD**, isometric rate of force development; **MVC**, maximal voluntary contraction; **EMG**, electromyographic amplitude; **POL**, polarized; **THR**, threshold; **HVLIT**, high volume low intensity training; **N**, neither.

It is apparent from the literature that high performance athletes and coaches see value in both polarized and threshold training. Several retrospective observational studies exploring the volume and TID of world-class athletes have been published, citing the performance advantage of training sessions

at- or just below the anaerobic threshold (or LT2) (4,45,46,48). Conversely, other retrospective observational studies looking at world-class athletes emphasize the importance of a polarized TID that does not include any zone 2 training on performance (18,36,39).

Performance Outcomes to POL and THR

Muñoz et al. (2014) compared the effects of POL and THR training on 30 recreational runners who were randomly assigned to either training intervention (33). Participants completed a 10-km race before and after the respective training intervention. Both groups improved their 10-km race times significantly (39.3 ± 4.9 min to 37.3 ± 4.7 for POL, $p < 0.001$; and 39.4 ± 3.9 to 38.0 ± 4.4 for THR, $p < 0.001$); however, no statistically significant differences were observed between the two groups ($p = 0.226$). Interestingly, when the impact of training volume was analysed, it was found that those who engaged in higher total training volumes (the POL group) showed greater performance improvements ($p = 0.038$).

These findings are in line with those of Esteve-Lanao et al. (2005), Guellich et al. (2010), Muñoz et al. (2014) and Manzi et al. (2015) who studied high-volume low-intensity training (HVLIT) in runners, cyclists, triathletes, and runners, and with Seiler et al. (2004), Foster et al. (2007), and Stellingwerff (2012) who investigated POL training in XC-skiers, and runners (9,14,18,30,32,39,42). In all studies, a three-zone intensity model was established, and participants' TID was determined during a specific period of their overall training program. The researchers of the HVLIT studies reported significant associations between total time spent in zone 1 and the magnitude of performance increase ($r = -0.79$, $p = 0.06$; $r = 0.88$, $p < 0.01$; $r = -0.92$, $p < 0.01$; $p < 0.01$). They also observed that world class rowers exhibit a constant and large emphasis on low intensity zone 1 training. Elite XC-skiers and elite marathon runners follow a POL approach and studies reported improved race performance following 5 months of POL training, compared with training focussed on zone 2 intensity ($p = 0.03$). In contrast to the HVLIT approach, the latter three studies (Seiler et al., 2004; Foster et al., 2007; Stellingwerff, 2012) adopted a more polarized training program, characterized by the same focus on

substantial low-intensity zone 1 training, as well as a significant emphasis on high-intensity zone 3 training.

In contrast, Tjelta & Enoksen (2010), Enoksen et al. (2011), and Sellés-Pérez et al. (2019) presented findings that challenge the high intensity zone 3 focus inherent to a polarized training approach (8,41,47). These studies explored the training characteristics of elite junior cross-country runners, elite senior long-distance runners, and amateur half-Ironman athletes, respectively. The first two studies reported the athletes trained at a high total volume at low intensities (65-82% HR_{max}), with an emphasis on some training near to- or at the anaerobic threshold (between LT1 and LT2) (i.e., zone 2). This is typical of a pyramidal TID, and similar to a THR TID. The rationale behind this approach is that athletes can sustain higher training volumes because of the limited inclusion of zone 3 work, arguing that type of training would favour changes in oxygen transportation and improved economy of movement. Sellés-Pérez et al. (2019) investigated the effect of 20-weeks of polarized or pyramidal training on half-Ironman race performance in amateur triathletes. They reported significant inverse relations between total training time spent in zone 2 and the race time ($r = -0.526$, $p < 0.05$).

Physiological Adaptations to POL and THR

Seiler et al. (2007) investigated the impact of TIDs on autonomic nervous system (ANS) recovery in runners (40). Notably, performance outcomes were not assessed as part of this study. The findings revealed that the first ventilatory threshold (VT1) may serve as a binary threshold for ANS recovery, showing that the magnitude of intensity above VT1 did not further affect ANS recovery. Exercise below VT1 showed significantly quicker heart rate variability (HRV) recovery than after exercise between VT1 and VT2 ($p < 0.05$). There was no difference in HRV recovery time between exercise at VT2 and exercise above VT2 ($p > 0.05$). Therefore, it was argued that when performing higher intensity training above VT1, it would be beneficial to prioritize high-intensity zone 3 training

over zone 2 training. Such an approach would maximize the adaptive signalling response compared to zone 2 training, while maintaining a similar stress response to zone 2 training.

Two studies investigated the impact of POL and THR training interventions on exercise economy (11,43). Exercise economy refers to the energy demand required to achieve a specific velocity or power output and plays a role in endurance sports performance (25). Stöggl et al. (2014) reported an improved exercise economy following a THR training intervention, while no significant change was observed following the POL training intervention ($p < 0.05$) (43). Conversely, Festa et al. (2020) found that both POL and THR training interventions resulted in an enhanced exercise economy (ES = 0.4, $p < 0.05$ in POL. ES = 0.6, $p < 0.05$ in THR); however, no statistically significant differences were found between the two TID groups ($p > 0.05$) (11).

Another important aspect of endurance performance lies in the capacity to metabolize fatty acids over carbohydrates. Hetlelid et al. (2015) reported that well-trained athletes exhibited approximately threefold higher fatty acid metabolism during a high-intensity interval session compared to recreationally trained athletes (22). Pérez et al. (2020) found that fat metabolism increased similarly following 12 weeks of POL and THR training in ultrarunners (35). The percentage fat that contributed to the output at LT1 rose by 7.5% after POL training ($p = 0.171$) and by 1.0% after THR training ($p = 0.867$), however, the between-group difference was not statistically significant ($p > 0.05$).

Endurance performance is also affected by VO_2max, which refers to the maximal rate of oxygen uptake by an individual, as measured during a progressive exercise test to exhaustion. Studies by Evertsen et al. (2001), Stöggl et al. (2014), Treff et al. (2017), Festa et al. (2020), and Filipas et al. (2021) reported on changes in VO_2max in response to POL and THR training (10–12,43,48). Stöggl et al. (2014) observed significant increases in VO_2max following a POL training intervention, but no significant changes after a THR training intervention ($11.7 \pm 8.4\%$, $p < 0.001$ after POL vs. $-4.1 \pm 6.7\%$, $p > 0.05$) (43). Conversely, Evertsen et al. (2001), Treff et al. (2017), Festa et al. (2020), and Filipas et al. (2021) did not find any significant differences in VO_2max between POL and THR training interventions (10–12,49). Treff et al. (2001) and Filipas et al. (2021) found improvements between 0.6% and 2.1% after both training interventions, but no difference in the training effect between groups ($p >$

0.05) (12,49). Festa et al. (2020) found a small increase in VO_2max of 0.6 mL·min·kg^{-1} (ES = 0.1) after POL (and a small decrease of -0.5 mL·min·kg^{-} (ES = 0.1) after PYR. Again, the between-group difference in the training response was not statistically significant (11).

Neal et al. (2013) and Evertsen et al. (2001) explored specific peripheral adaptations with POL and THR training, namely mitochondrial enzyme activity, monocarboxylate transporter (MCT) 1 and 4 expression and lactate threshold (10,34). MCT1 and MCT4 are transmembrane transport proteins responsible for the transport of lactate out of and into cells, respectively. Given the aerobic nature of endurance training, one expects an increase in MCT1. However, Evertsen et al. (2001) reported no changes in MCT1 expression after the THR training intervention ($p = 0.32$), and a decrease in MCT1 expression following the POL training intervention ($p = 0.04$) (10). The training response differed significantly between the two groups ($p < 0.05$). Additionally, they found that MCT4 expression remained unchanged after both training interventions ($p > 0.10$). In contrast, Neal et al. (2013) observed no changes in MCT1 following either TID intervention (12 ± 13% after POL vs 10 ± 13% after THR, $p > 0.05$) (34). However, they found that MCT4, along with markers of endurance performance, increased for both TID interventions, with a greater increase observed after POL training (MCT4: 133 ± 56% after POL vs 80 ± 41% after THR, $p > 0.05$; LT2: 18 ± 18 W after POL vs 4 ± 31 W after THR, $p < 0.05$; PPO: 27 ± 18 W after POL vs 9 ± 17 W after THR, $p < 0.05$).

Filipas et al. (2021) conducted a study in which they not only compared POL and PYR training interventions, but also investigated the effects of consecutive interventions (12). The study involved 16-weeks of POL training, 16-weeks of PYR training, as well as two sequential interventions, namely 8-weeks of POL followed by 8-weeks of PYR training (POLPYR), and 8-weeks of PYR training followed by 8-weeks of POL training (PYRPOL). They reported that the PYRPOL intervention induced significantly greater improvements in various performance and physiological parameters compared to the other training models. Changes included VO_2max (3% improvement, ES = 0.40), velocity at LT1 (1.7% improvement, ES = 0.22), velocity at LT2 (1.5% improvement, ES = 0.22) and 5-km running performance (1.5% improvement, ES = 0.28). These findings illustrate the potential benefits of combining TIDs at different stages in an athlete's preparation.

Discussion

A significant challenge in investigating TIDs is the limited involvement of elite athletes in intervention-based research studies. The training arrangements of elite athletes are often dictated by federations or coaches, which restricts their willingness or availability to report or modify their habitual training methodologies for research. Due to the already high fitness levels of elite athletes, introducing novel training programs may not elicit performance enhancements. Consequently, most studies focusing on TID in elite endurance athletes primarily rely on a retrospective analysis of athletes' training, with race performance as the primary outcome measure, rather than physiological changes (7 studies on elite athletes, compared to 5 studies on recreational athletes, with several n = 1 studies on elite athletes not included in this review, looking at performance outcomes; only 2 experimental studies on elite athletes, compared to 6 studies on recreational athletes).

The synthesis of the twelve studies in Table 2.1 focused on the comparison of different TIDs on performance outcomes. All studies reported improvements in performance, but notably, nine out of twelve studies found greater performance enhancements after POL or HVLIT training methods (9,14,18,19,30,32,33,39,42). The other three studies advocated a training approach that included training time in zone 2 (8,41,47). The consensus among studies is that a high total training volume, and a high volume of training performed in zone 1 plays a key role in endurance performance. On the contrary, there were conflicting findings regarding the optimal volume of zone 2 required, compared to zone 3 training. Four studies advocated for a POL training model, opposed to three studies advocating for a THR or PYR training model. Training, according to a HVLIT or a POL approach, was hypothesized to induce greater improvements in VO_2max and systemic adaptations when compared to a more zone 2 focused training program. Training, according to a PYR approach, was hypothesized to improve oxygen transport and exercise economy. However, because of the observational nature of these studies, limited physiological data are available to substantiate the claims supporting either zone 2 or zone 3 training.

The primary aim of the eight experimental studies presented in Table 2.2 was to compare the changes in both performance and physiological adaptations after different TIDs. Overall, findings were mixed regarding the physiological adaptations associated with specific TIDs and inconclusive whether one TID is superior to another.

The key factors that limit endurance performance have long been recognised, namely maximal oxygen consumption (VO_2max), lactate threshold, and exercise economy (6,24,28). The Fick equation, which states that VO_2 is a product of cardiac output and arteriovenous oxygen difference, is classically interpreted to distinguish between "central" and "peripheral" adaptations. Central adaptations can be defined as physiological adaptations associated with improved oxygen delivery to the working muscles. In endurance exercise lasting longer than ~75 s, most of the energy used is yielded by aerobic metabolism (15). Thus, having an improved O_2 delivery to the working muscle, in other words, a greater cardiac output, is desirable. Peripheral adaptations are concerned with the oxygen utilization of the working muscle. The phenotype of human skeletal muscle is highly responsive to training (17). Local muscular adaptations, such as mitochondrial biogenesis and capillary density, aid in the transport and utilization of oxygen to yield aerobically formed ATP. These adaptations are critical in delaying the onset of muscle fatigue and improvement in performance during prolonged aerobic exercise (25). It has long been established that brief, intense exercise can increase VO_2max (27). It has also been observed that cellular stress occurs in proportion to exercise intensity (7). Some argue that as zone 2 and zone 3 training cause similar ANS responses, athletes should prioritize zone 3 training to maximize the adaptive response to increase aerobic adaptation. However, in the studies presented in Table 2.2, there was only slim evidence that VO_2max increased to a greater extent after POL than THR.

An individual's lactate threshold is the highest exercise intensity at which lactate production and lactate clearance are in balance (2). The lactate threshold has been observed to be strongly correlated to endurance performance (16,47). Lactate production comes as a by-product of glycolytic respiration,

which is an energy system that rapidly produces energy. The rapid energy production associated with glycolytic respiration is especially desirable at high exercise intensities, that have a greater total energy demand. Many endurance events require tactical pace changes, often above the lactate threshold. These pace changes require additional anaerobic energy to produce the desired output. Having an inadequately developed glycolytic system may thus compromise the speed required for these pace changes. As such, a sufficiently developed glycolytic system has been found essential to produce a high rate of ATP generation from glycolysis, and thus having the physiological capacity to metabolize glycogen is important for endurance athletes (2,20,21,48). Depending on the athlete's target event, they should have a sufficiently, but not over-developed glycolytic system, to maximize energy output for the duration of the event, without too many negative effects of fatigue-inducing metabolites associated with glycolytic respiration. However, as shown by the inconclusive results of the studies investigating MCT1 and MCT4, both of which play a key role in lactate transport in- and out of cells, the effects of POL and THR on glycolytic capacity are not yet established.

The slim evidence suggesting that exercise economy increases to a greater extent after THR than POL may serve as an indicator of substrate utilization for energy production. In both studies investigating running economy after POL and THR training, the THR training group used less O_2 at the same workload, i.e. had better exercise economy. This may show either improved mechanical efficiency, or a greater contribution from oxygen-independent metabolic pathways. This would be in line with previous findings showing an inverse relationship between muscle oxidative capacity and exercise economy; improved exercise economy seems to compensate for a lower aerobic capacity (23). However, the physiological basis by which these adaptations take place is still under debate. Therefore, it cannot be said with certainty that THR training improves glycolytic capacity and/or exercise economy.

A consensus on a single TID for optimal physiological adaptations is yet to be reached. In investigating responses to different TIDs, it has become apparent that certain physiological adaptations appear to be better achieved through a POL training approach, while others are more enhanced after a threshold training approach. Maximizing adaptive signalling, increasing VO_2max, and increasing PPO may be more effectively achieved through a POL training approach, whereas maintaining muscular strength and the enhancement of exercise economy may be better facilitated by a THR training approach.

It is evident that different TIDs have varying effects on physiological responses, potentially leading to different performance outcomes among individuals. Hence, incorporating different TIDs during different phases of an annual periodization may prove beneficial, to optimize the stimuli required to keep improving. As demonstrated by Filipas et al. (2021), adopting a pyramidal-into-polarized training approach may be a beneficial strategy, as it combines benefits from the combination of the distinct advantages and disadvantages of certain TIDs (10). An approach that embraces the nuances of different TIDs, rather than focusing on one singular TID, may prove most effective in enhancing an athlete's performance.

The challenge found in all research studies investigating TIDs is the quantification of exercise time-in-intensity-zone. Various metrics are employed to assess external workload (i.e., velocity, pace, power, distance), as well as internal workload (i.e., %HRmax, %VO_2max, lactate thresholds, ventilatory thresholds). There is some discrepancy among all these variables, putting the thresholds between zone 1 and zone 2, and zone 2 and zone 3 at slightly different relative intensities. Additionally, the classification of training sessions can be based on either time-in-zone or session goal, both of which yield different total durations spent in a particular intensity zone. The discrepancy arises from the inherent time lag between external workload and physiological response.

A challenge faced by retrospective studies analysing TID and race performance lies in their reliance on non-experimental approaches. Such studies offer valuable insights into the associations

between TID and race performance. However, in the absence of a TID group for direct comparison and the lack of physiological data to substantiate conclusions, caution must be exercised when applying findings to a broader athlete population.

A challenge with experimental studies investigating TIDs and physiological outcomes is the limited availability of research in this area. There remains a scarcity of studies that have specifically examined the physiological adaptations associated with different TIDs. Among the existing studies that have explored physiological outcomes of TIDs, a diversity of outcome variables has been assessed, making it difficult to establish consistent findings across the literature. The studies that have investigated similar physiological outcome variables have often yielded inconclusive or sometimes conflicting results. The varying methodologies, definitions, participant characteristics, training interventions, and outcome measures all contribute to the complexity of synthesizing the findings.

Future research could focus on exploring the intricate physiological adaptations occurring in response to different TIDs. Using the rapidly evolving technologies in sports medicine and health sciences, there may be exciting opportunity to investigate certain discrepancies from novel perspectives. Advancing our understanding of the performance- as well as the physiological outcomes resulting from various TIDs holds significant potential in supporting coaches and athletes in designing well-balanced and effective training programs.

Practical Applications

The prevailing trend from the studies analysed here, both observational and experimental alike, generally suggests that a high volume of low-intensity training might be a critical component in optimizing endurance sports performance. However, the optimal distribution between zone 2 and zone 3 training remains inconclusive, with diverging findings between observational and experimental investigations. Observational studies advocate prioritizing zone 3 work, while experimental studies report beneficial adaptations to both zone 2 and zone 3 training. It seems that POL is effective for

maximizing adaptive signaling, improving VO_2max, and increasing power/speed at a given intensity, whereas THR is more effective for maintaining muscular strength and enhancing exercise economy. Combining training models to suit individual needs may prove most ideal, as observed in the study by Filipas et al. (2021).

With diverging adaptations to different TIDs, it may prove beneficial to train focusing on desired physiological adaptations, rather than short-term performance increases. A nuanced approach with different TIDs at different times from a target event supports the development of an athlete's unique physiology and may aid in optimizing athletic performance and promoting long-term athletic success.

Acknowledgements

There is no disclosure of funding to report for this study. The authors declare no conflict of interest. The results of the present study do not constitute an endorsement of the product by the authors or the National Strength and Conditioning Association.

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Chapter 3 Methodology

Study Design

This study followed a pre-post experimental design, with a random assignment of participants into two experimental groups: a threshold (THR) or a polarized (POL) training group. Following the familiarization session and baseline testing, participants were randomly allocated to the two training groups for a six-week POL or THR training program. The researcher was not blinded to the training program for each cyclist, as this was not practically possible. Following completion of the six-week training intervention, participants were re-tested, and results were compared to baseline data.

Participants

Seventeen healthy individuals, comprising trained cyclists (13 men, 4 women), were recruited from the local cycling community, the local triathlon club, social media, and through word-of-mouth referrals. The required sample size was calculated with G*Power 3 and based on the relative oxygenated hemoglobin and relative deoxygenated hemoglobin (ΔO_2Hb and ΔHHb) results of Pramkratok et al. (2022) (Faul et al., 2007; Pramkratok et al., 2022). It was calculated that 7 to 10 pairs of participants would be needed to detect a statistically significant difference in the outcome variables between the two training methods (ES = 0.8, 95% power, and 5% level of significance).

Inclusion Criteria

Participants were included if they:

- were between 18-49 years old;
- had been training consistently for >2 years prior to entry into the study;
- trained 6-10 hours per week for at least the previous 6 months.;
- men: had a relative peak power output (PPO) of at least 3.60 W/kg, or an absolute PPO of at least 280 W (Pauw et al., 2013);
- *or*: had a relative VO_2max of at least 45.0 $mL \cdot min^{-1} \cdot kg^{-1}$, or an absolute VO_2max of at least 3.4 L/min;
- women: had a relative PPO of at least 3.0 W/kg, or an absolute PPO of at least 170 W (Decroix et al., 2015);

- or: had a relative VO_2max of at least 37.0 $mL \cdot min^{-1} \cdot kg^{-1}$, or an absolute VO_2max of at least 2.2 $L \cdot min^{-1}$.

Exclusion Criteria

Participants were excluded if they:

- suffered from a recurring injury which had not fully recovered, or they were taking medication which might lead to anomalies in the training responses during the time of the study (recommendation letter from a physician was required with a recurring injury to be considered for the study);
- had a skinfold thickness on the belly of the *Vastus Lateralis* that exceeds 17 mm. This was to ensure that the near-infrared spectroscopy (NIRS) probes were placed at the required distance from each other for valid readings (Myers C, 2020);
- performed strenuous exercise 24 hours before the laboratory test visits. On the day of each test, the participant was required to abstain from alcohol and caffeine for 12 hours pre-test and not consume food three to four hours before. Water could be consumed in moderation;
- missed three or more laboratory training sessions during the six-week intervention;
- missed five or more zone 1 rides during the six-week training intervention;
- were taking any kind of anticoagulant medicine during the time of the study.

Place of study

All familiarization, physiological performance tests, and weekly interval training sessions were conducted in the Sport Physiology Laboratory in the Department of Sport Science, Stellenbosch University. During the six-week intervention, participants performed one intensity-controlled interval session per week in the laboratory and under the supervision of the researcher. Participants completed all the other rides during the intervention period on their own, while they controlled exercise intensity using either heart rate or power. These sessions were overseen and analyzed remotely by the researcher, using TrainingPeaks (TrainingPeaks, Louisville, USA).

Procedures

The experimental period lasted 8 weeks from the initial familiarization test to the final post-intervention test. It comprised a familiarization test and a baseline test in the laboratory in week one, followed by six weeks of the prescribed training, and one post-intervention testing session (Figure 3.1).

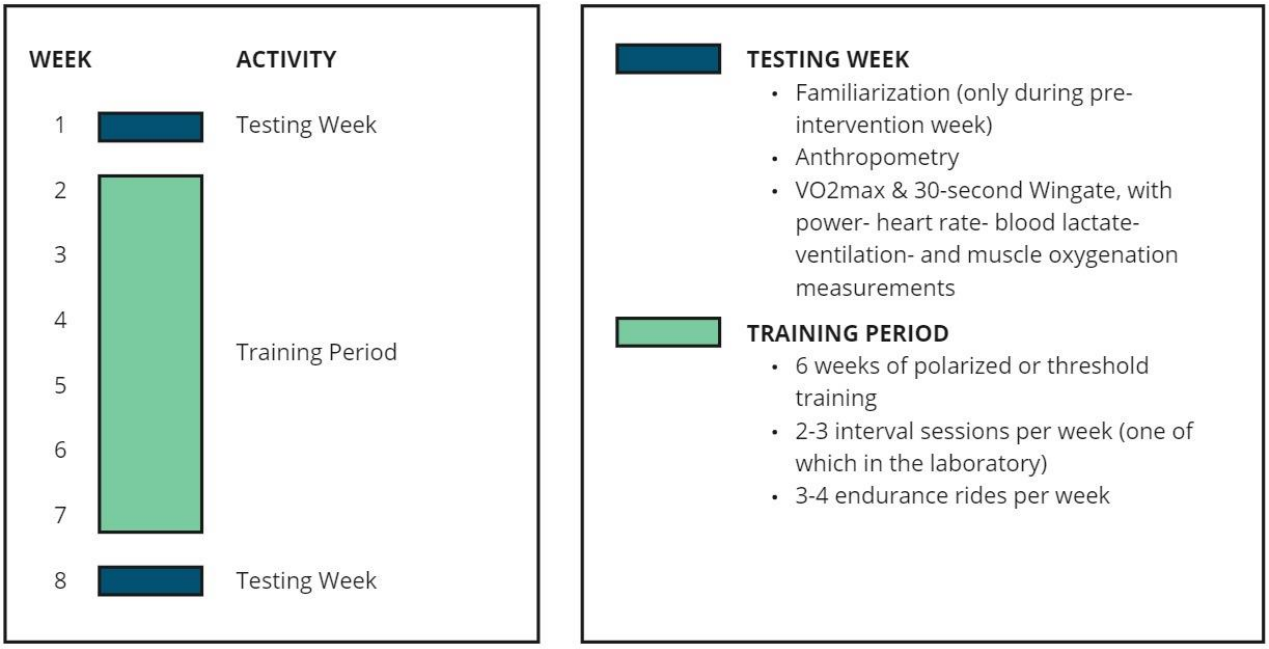

Figure 3.1 - Study design schematic detailing the timeline for the testing period and the training intervention period.

During the familiarization session, the participants completed a physical activity readiness questionnaire (Addendum B) and an informed consent form (Addendum C). The testing procedures were explained, anthropometric measures were taken, and finally participants performed the exercise test. This familiarization test was terminated at a submaximal level, namely 210 W for men and 140 W for women. Participants then also performed a 30-s Wingate sprint, at an all-out effort.

Once volunteers were found eligible to participate, they were randomly divided into either the POL group, or the THR group, with an online randomization program (randomizer.org). Prior to the second testing session participants were asked to consume a meal two hours before the testing session, avoid caffeine intake, and refrain from exercise on the day preceding the testing session. During the second visit participants' body mass, stature, and body fat percentage were measured. Participants then performed the complete pre-intervention test, which consisted of an incremental VO_2max test to exhaustion, and a 30-s Wingate sprint, with concurrent cardio-respiratory, blood lactate and NIRS

measurements. Post-intervention testing was performed following the six-week training intervention period, using the same testing protocols.

All exercise tests were performed on the Velotron Dynafit Pro (RacerMate, Seattle, USA), while the laboratory interval sessions were performed on the participant's own bike which was mounted to a Cyclus2 ergometer (RBM elektronik-automation GmbH, Leipzig, Germany).

Anthropometric Measurements

The anthropometrical measurements comprised stature (standing height), body mass and 3 skinfolds. These measurements were used to determine the participant's percentage body fat.

Stature was defined as the perpendicular distance between the transverse planes of the vertex and the inferior aspects of the feet (Stewart et al., 2011). The stretch stature method was used. Stature was measured using a sliding stadiometer (Seca, Germany). The participants were asked to stand barefoot on the scale with their heels together. Participants were asked to have their heels, buttocks and upper part of the back touching the scale, and their head in a Frankfort position. The participants were asked to take a deep breath while the headboard was firmly pressed down on the vertex, compressing the hair as much as possible. The measurement was then taken to the nearest 0.1 centimetre.

Body mass was measured using a calibrated electronic scale (SECA 813, Hamburg, Germany) recorded to the nearest 0.1kg. Participants were asked to stand barefoot in the middle of the scale, distributing their weight uniformly on both legs. They were clothed in minimal and lightweight cycling attire.

The BodyMetrix BX2000 (Hosand Technologies, Verbania) ultrasound instrument was used to estimate the percentage of body fat, fat mass, and fat-free mass. The device used the Jackson and Pollock 3-site protocol to assess body composition (Jackson et al., 1980; Jackson and Pollock, 1978). The estimations for men were based on the chest, abdominal, and thigh skinfolds, while for women it was based on the triceps, suprailiac, and the thigh skinfolds.

Cardio-Respiratory Measurements

Participants' cardio-respiratory parameters were measured throughout the incremental test to exhaustion. Heart rate was measured through telemetry from a chest-based heart rate strap (Garmin

International Inc., Olathe, USA). Chest straps have been found to produce high reliability and validity for measuring heart rate (Pasadyn et al., 2019). Ventilation data was measured using the Cosmed K5 metabolic analyser (Cosmed, Rome, Italy).

The raw data were recorded in Cosmed Omnia (Cosmed, Rome, Italy) in a breath-by-breath fashion. Data was filtered to a time average of 0.1 Hz and exported to Excel for further analysis.

Before the commencement of each exercise test, the Cosmed K5 was calibrated. The sampling line would first be connected to the scrubber, followed by the reference gas. Gas analysers were calibrated to 16% O_2, 4% CO_2, and balance N_2. Finally, the flowmeter was calibrated with a 3 L syringe and different stroke rates.

Capillary Blood lactate Measurements

Finger prick blood lactate concentration samples were taken before the start of the VO_2max test, and 30-s before the end of each completed workload. Samples were continuously taken until the lactate concentration was equal to- or above 4 mmol·L^{-1}. A final sample was taken as soon as possible after the termination of the test.

Blood samples were taken from participants' annular finger. The participants' finger was cleaned with an alcohol swab and then pricked with an Accu-Check Softclix (Roche Holding AG, Basel, Switzerland). The first droplet of blood was wiped away and the second droplet of blood was drawn into the capillary tube of the Lactate Pro 2 meter (Arkray, Kyoto, Japan). The reliability and validity of the Lactate Pro 2 meter has previously been determined (CV = 3.3%, limits of agreement ± 0.3 mmol·L^{-1} for blood lactate ≤ 4.0 mmol·L^{-1}) (Crotty et al., 2021).

Muscle Oxygenation Measurements (NIRS)

Near-infrared spectroscopy (NIRS) is a non-invasive technology capable of measuring in vivo oxidative metabolism in human tissue (Myers C, 2020). NIRS technology depends on near infrared light (650-1000 nm) penetrating human tissue and being absorbed or scattered by different compounds. Typically, O_2Hb and HHb reflect near-infrared light at 760 and 850 nm wavelengths, respectively. Together, these are used to determine muscle oxygenation saturation (S_mO_2) as indicated in the following formula (Myers et al., 2018):

$$SmO_2 = \frac{O_2Hb}{O_2Hb + HHb} \times 100$$

The PortaMon NIRS device (Artinis Medical Systems BV, Elst, the Netherlands, www.artinis.com) was used to detect relative changes in O_2Hb, HHb, and SmO_2 of the *Vastus Lateralis* of the right leg of each participant. The reliability and validity of this device and accompanying software have been determined previously (Desanlis et al., 2022). This device uses three light transmitters and one receiver, emitting near-infrared light at three different depths into the tissue.

NIRS data was recorded during the entire test, from the 5 min passive rest phase, through the 8 min warm-up, VO_2max test, 8 min active recovery, 30-s Wingate, and 5 min cool-down. The NIRS device was attached firmly, but without constriction, to the skin on the belly of the *Vastus Lateralis* in a longitudinal direction on the midpoint between the inguinal fold and the patella. The device was secured using a Velcro strap around the leg and covered by the participants' cycling shorts. This both secured the device and stopped outside light from interfering with the NIRS light sensors.

Before commencing the warmup, participants underwent a 5 min complete rest period, which was used to determine a baseline level of O_2Hb and HHb. Levels were set to an arbitrary zero, according to this 5-minute complete rest period. Once participants began the active warm-up, a fan was switched on and positioned in front of them, to ensure the surface temperature of the skin did not get too hot and affect the reading capability of the NIRS system.

The raw data were recorded in OxySoft (Artinis Medical Systems BV, Elst, the Netherlands, www.artinis.com) at 10 Hz. Before exporting from OxySoft, O_2Hb and HHb were set to an arbitrary zero according to the 5 min passive rest. Data were then filtered to a time average of 0.1 Hz and exported to Excel. If the tissue saturation index (TSI) fit factor, a variable representing measurement quality from absorption from the three light transmitters was consistently above 98% the three measurements were averaged for O_2Hb and HHb. These values, along with S_mO_2, were then used for further analysis.

Pre and Post Intervention Tests

Participants performed an incremental cycling test to exhaustion to determine their maximal aerobic capacity (VO_2max), and power output at different intensity zones, as well as a 30-s Wingate to establish anaerobic markers of performance. Participants' aerobic capacity test results were used to determine training zones.

All testing was conducted in the laboratory with an ambient temperature between 20° C and 22° C. To standardize the participants' metabolic states during the testing sessions, they were asked to not eat within two hours prior to testing, to avoid caffeine 12 hours prior to testing, and to avoid vigorous activities (RPE above 12 on the Borg scale) at least 24 hours before testing.

The exercise test was performed on the Velotron Dynafit Pro (RacerMate, Seattle, USA). The metabolic data were collected using the Cosmed K5 (Cosmed, Rome, Italy) metabolic analyser. Heart rate was measured through telemetry via a Garmin heart rate monitor (Garmin International Inc., Olathe, USA). The blood samples were analysed using a Lactate Pro 2 (Arkray, Kyoto, Japan). NIRS was measured using the PortaMon NIRS device (Artinis Medical Systems BV, Elst, the Netherlands, www.artinis.com).

Participants started the test with a 5 min passive rest to calibrate the NIRS equipment. They then performed an 8 min warm-up at 80 W and a cadence between 80-100 rpm. After this warm-up, the Cosmed face mask was fitted. Participants then started the incremental exercise test. For men, the incremental exercise test started at 120 W for one minute, after which power increased by 30 W every 2.5 minutes, until exhaustion. For women, the test started at 80 W, after which power increased by 30 W every 2.5 minutes, until exhaustion. Participants were asked to keep the cadence between 80-100 rpm throughout the test. In the last 30 s of each stage, a capillary blood sample (0.3 µl) was taken from a finger and analysed for blood lactate concentration. The intensity was increased until participants reached exhaustion or could not maintain the cadence at or above 80 rpm.

The American College of Sports Medicine (ACSM) outlined the VO_2max test termination criteria to ensure maximal responses from participants (McArdle et al., 2010). These criteria include (1) the VO_2 does not increase by more than 150 mL per successive workload; (2) a respiratory quotient (R- value) equal or above 1.15 is reached; or (3) the heart rate is more than 90% of the age-predicted maximal heart rate. Any of these criteria, in combination with the participant indicating they were exhausted, constituted a maximal incremental test.

Participants' peak aerobic power output was calculated from the time they lasted in their final power stage, using the following equation (Michalik et al., 2019):

$$PPO = W_f + (t \times D^{-1} \times P)$$

Where W_f is the value of the final completed workload, t was the time (s) of the final uncompleted load, D was the duration (s) of every stage, and P was the difference in power between loads (W).

The Cosmed face mask was then removed, and participants had an 8 min active recovery period pedalling at 80 W at a cadence between 80-100 rpm. They then completed a 30 s all-out Wingate sprint. The Wingate software calculated participants' peak power output, mean power output, minimum power output, explosive power, anaerobic capacity, anaerobic power, fatigue index, and total work done. The testing concluded with a 5 min active recovery cool down pedalling at 80 W at a cadence between 80 – 100 rpm.

Training Interventions

Both interventions lasted six weeks, with two interval sessions per week for the POL group and three interval sessions for the THR group. Participants performed one higher intensity session per week in the laboratory under supervision of the researcher, to ensure that the correct intensity stimulus was achieved. These interval sessions were supplemented with sub-ventilatory threshold, low intensity rides. The intensity was individualized according to participants' pre-intervention exercise test results.

The THR and POL training programs were matched for total riding time, namely 9.5 h total per week. Training intensity distribution (TID) was calculated for each rider using a hybrid session-goal/time-in-zone approach (Sylta et al., 2014). As with previous intervention studies, the aim of the POL group was to achieve 80% of training time in zone 1 and 20% of training time in zone 3, with no zone 2 training time. The aim for the THR group was to achieve 45% of training time in zone 1 and 55% of training time in zone 2, with no zone 3 training time. Both training interventions were self-developed, but closely resemble those used in previous intervention studies done in trained cyclists (Addendum D; Addendum E) (Neal et al., 2012; Stöggl and Sperlich, 2014). Training intensity was prescribed in relation to the participants measured LT1 and LT2 power output and corresponding heart rate values obtained from the pre-intervention aerobic capacity test. Training zone calculation was based on the measured blood lactate response during the incremental exercise test. Lactate-E 2.0 Software (Department of Mathematics, National University of Ireland, Galway) was used to calculate participants' power at 2 and 4 mmol·L^{-1} blood lactate concentration. This software fits a lactate curve, based on measured lactate values at various work rates during the incremental step test. It then uses inverse prediction to calculate the work rates corresponding to the curves' 2 and 4 mmo'·L^{-1} markers. The reliability and validity of this software have been previously established (Newell et al., 2007). The heart rate corresponding to a participant's power output at 2 mmol·L^{-1} and 4 mmol·L^{-1} blood lactate concentration was used to identify the threshold between zone 1 and zone 2 (LT1) and between zone 2 and zone 3 (LT2). These thresholds were used to prescribe starting exercise intensity for the six-week training intervention.

Participants performed one weekly session in the laboratory under the supervision of the researcher. Participants completed the remaining training sessions independently, sharing their power and/or heart rate data with the researcher via TrainingPeaks. The polarized groups' zone 3 intervals in the polarized training approach were done at 110% of LT2 power. If the mean peak HR, mean minimum HR, and RPE decreased over two consecutive interval training sessions, then the power output for the intervals would be increased by 5 W to maintain a correct training stimulus. The threshold groups' zone 2 intervals were done at the power output or heart rate halfway between participants' respective LT1 and LT2 power. During the weekly laboratory training sessions, exercise intensity was monitored based on blood lactate concentration samples taken during the session. The target range was set between 3.0 and 3.5 $mmol \cdot L^{-1}$. Participants' power output was adjusted accordingly.

For the zone 1 rides, participants' heart rates were capped at a value corresponding to their LT1. Participants were asked to stay below this heart rate cap for the duration of their zone 1 training sessions. Participants shared the heart rate data with the researcher, via TrainingPeaks software. This heart rate data was not used in the data analysis and was exclusively for exercise intensity control.

Ethical aspects

Ethical clearance was obtained from The Stellenbosch University Health Research Ethics Committee (HREC) (S22/05/091). All testing and laboratory procedures were performed in accordance with the Declaration of Helsinki. The tests and measurements in the study were standard cycle performance tests that are routinely done in high performance laboratories. The reliability and validity, as well as the safety of the tests, have been determined (Gore et al., 2000).

Statistical analysis

Statistical analysis was conducted using SPSS version 29 software (IBM, Armonk, NY) and using Excel (Microsoft Office 2022). For all body composition-, incremental exercise test-, and Wingate test data, normality was assumed. For the NIRS data, a Kolmogorov-Smirnov test for normality was performed and confirmed that this data was normally distributed (K-S test statistic (D) of 0.23779).

A repeated measures ANOVA (2 x 2) was used to compare the performance and physiological adaptation measures between training-intensity distribution models (POL and THR) and changes over

time (pre- to post-training). Main effects (model and time), and interaction effects for the performance and physiological adaptation measures were reported. Bonferroni post hoc analysis was undertaken where significant main effects were obtained. Two-sample independent t-tests were used to determine whether statistically significant changes occurred between groups, and to determine the qualitative significance of the differences. In all cases, statistical significance was set at $P < 0.05$.

Descriptive statistics are presented as means ± SD and Cohen`s effect size (ES) ± 95% confidence interval (CI). Quantitative interpretation of the ES values was based on Cohen (1988). Effect sizes up to 0.20 were interpreted as a trivial difference, between 0.20 and 0.60 were interpreted as small, between 0.60 and 1.20 a moderate effect size, ES between 1.20 and 2.00 were regarded a large difference, ES between 2.00 and 4.00 were interpreted as very large, and ES > 4.00 as an extremely large difference. Effect sizes were included to compare the magnitude of change in performance and physiological adaptation. Simple linear regression was used to test the relationship between SmO_2 and VO_2max, and to test if changes in SmO_2 significantly predicted the changes in markers of endurance performance. Interpretation of correlation values was based on Schober et al. (2018).

Chapter 4 Results and Discussion

Introduction to Article

The results and discussion of the present study are presented in article format.

The article, titled *"Performance and Physiological Adaptations to a Six-Week Polarized and Threshold Training Intervention in Trained Cyclists"* aims to answer the research questions through an original investigation into the effect of different TIDs on performance and physiological adaptations in cyclists.

The article was written in accordance with the author's guidelines of the Journal of Applied Physiology (Addendum F). The American Physiological Society referencing style was applied.

[For convenience, the tables and figures are included in the text. They are numbered according to the chapter in this thesis. For submission, the tables and figures will be moved to the end of the document.]

RESEARCH ARTICLE

Adaptations to 6-week polarized and threshold training.

Performance and Physiological Adaptations to a Six-Week Polarized and Threshold Training Intervention in Trained Cyclists

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Abstract

The aim of this study was to investigate the effects of six weeks polarized (POL) and (THR) training on markers of endurance performance and physiological adaptations. In a pre-post experimental design with a random assignment into two experimental groups, 17 trained cyclists (VO_2max 50.0 ± 8.6 $mL \cdot min^{-1} \cdot kg^{-1}$) completed six weeks of POL (80/0/20% in zone 1/2/3) or THR (45/55/0%) training. An incremental step test and a 30-s Wingate test were performed. Muscle oxygenation data was collected via near-infrared spectroscopy (NIRS). Power output, blood lactate concentration, ventilation, and heart rate data were also assessed. Training intensity during the intervention was power and/or heart rate controlled. Both groups showed similar improvements in power at LT1 ($p = 0.800$), LT2 ($p = 0.289$), and PPO ($p = 0.567$). No changes in VO_2max were observed following training ($p = 0.240$). Qualitatively, meaningful changes were observed in SmO_2 at all measured intensities, favouring POL over THR ($p = 0.073$, ES = 0.72 at LT1; $p = 0.067$, ES = 0.91 at LT2; $p = 0.147$, ES = 0.74 at PPO). A significant qualitative change was observed in SmO_2 after Wingate, favouring POL over THR ($p < 0.001$, ES = 1.76). Qualitatively, meaningful changes were observed in work economy at LT2 and PPO favouring THR over POL ($p = 0.195$, ES = 1.11 at LT2; $p = 0.156$, ES = 0.45 at PPO). Both POL and THR are effective at improving power output over six weeks of training. Measures of SmO_2 suggest peripheral adaptations after POL.

New & Noteworthy

After six weeks of polarized and threshold training, both groups significantly improved in power output at LT1, LT2, and PPO. In the polarized group, this is likely because of increases in muscle oxygen saturation (SmO_2). In the threshold group, the improvement in power output is likely because of improvements in anaerobic capacity and exercise economy. SmO_2 correlates strongly with VO_2max, but pre-to-post change in SmO_2 is not an accurate predictor of endurance performance.

Keywords: Exercise; peripheral adaptation; polarized training; threshold training; training intensity distribution.

Introduction

Understanding the performance and physiological outcomes of varied training intensity distributions (TIDs) is required to help coaches and athletes in developing individualized training regimens that will promote the athlete's performance, his/her potential, and longevity in the sport. However, the optimal training intensity, and its distribution over weeks of training, is a topic of healthy debate among researchers, sport scientists, and coaches alike (1–3). Much of this disagreement stems from qualitative analysis observing elite athletes performing various TIDs, and from different methods to quantify time-in-zones (4–6).

To guide our understanding of different exercise intensities, distinct intensity zones have been identified according to a 3-zone model or a 5-zone model. Much of the literature refers to a 3-zone model, which uses measurable physiological thresholds (1, 3, 7). Zone 1 is characterized by exercise intensity at or below the aerobic threshold; zone 2 encompasses intensities between the aerobic and anaerobic thresholds; and zone 3 represents exercise intensities at or above the anaerobic threshold (8). Some literature refers to a 5-zone model, though this refers to the same physiological thresholds as a 3-zone model, but additionally separates the magnitude of low- and high-intensity training (8, 5, 9).

Among endurance athletes, two TIDs are predominantly used: a polarized (POL) training model and a threshold (THR) training model. A POL TID involves higher proportions of time spent in the low-intensity zone 1 (~80%) and high-intensity zone 3 (~20%), while minimizing or excluding training time in zone 2 (3,8). This model thus combines extensive basic endurance training with intensive high-intensity training (7). A THR TID involves a large focus on the intermediate, between thresholds zone 2 (55%) and low-intensity zone 1 (45%), with minimal training time dedicated to the high-intensity zone 3 (31).

Adaptations to POL and THR

Several studies investigated performance and physiological changes to POL and THR TIDs (10–13). Some studies focusing on TIDs rely on a retrospective analysis of athletes' training, with race performance as the primary outcome measure (1, 14–22). Such studies offer valuable insight into the

association between TIDs and endurance performance, however, in the absence of a comparative group, and the lack of physiological data and including small sample sizes, caution is necessary when extrapolating findings to a broader range of athletes, or different sport codes.

The collective findings of many published studies are the importance of a large proportion of training volume performed in zone 1 to enhance endurance performance (15, 23, 24). Significant associations have been reported between total volume spent in zone 1, and the magnitude of performance increase. E.g., Muñoz et al. (2014) reported an inverse correlation between total time in zone 1 and performance time in triathletes competing in an Ironman triathlon (r = -0.92) (16, 17, 23, 25, 26). On the contrary, most observational studies advocate the importance of zone 3 work, citing greater adaptations when compared to a more zone 2 focused training program (14, 21, 23, 26, 28).

Only a few studies investigated the effect of various TIDs on physiological adaptations and they lack agreement on which TID, if any, leads to optimal physiological adaptations (7, 10, 12, 26–30). Certain physiological adaptations appear to be better achieved through a POL training approach, while others are more enhanced after a THR training approach. For instance, muscular strength adaptations have been found to be better maintained after a THR training approach (18), while autonomic nervous system recovery seems to favour a POL training approach (27). Evertsen et al. (2001) has found greater monocarboxylate transporter (MCT) 1 expression and no change in MCT4 after a THR training approach, while Neal et al. (2012) found no change in MCT1 and more favorable MCT4 adaptations after a POL training approach (10, 28). Stöggl et al. (2014) observed a significant increase in VO_2max following a POL training intervention over a THR training intervention, whereas other studies did not find any significant differences in VO_2max between POL and THR training interventions (7, 12, 29). Consequently, it is evident that different TIDs exert varying effects on both performance and physiological outcomes. Studies investigating performance outcomes seem to favor a POL training approach. However, consensus regarding underlying physiological adaptations after various TIDs remains elusive.

Central vs peripheral adaptations

Physiological adaptations to exercise training are generally categorized as central (concerned with enhancing O_2 delivery to active muscles) and peripheral (concerned with enhancing O_2 utilization by the active muscle) (32). Central and peripheral adaptations do not function independently and rather refer to the physical location of the adaptation (33). Central adaptations are mainly accomplished

through changes in cardiac output, while peripheral adaptations are characterized by changes in the O_2 extraction of working muscles, through changes in the arterial-mixed venous O_2 difference (a-vO_2 difference). The largest increases in maximal aerobic capacity (VO_2max) have been found after high-intensity (zone 3) intervals were done at a workload near to- or at the individual VO_2max (34). Changes in O_2 utilization of exercising muscles primarily stem from changes in muscle capillary networks, and mitochondrial respiratory capacity (35, 36). There is limited evidence to suggest that increases in mitochondrial content are superior after high-intensity exercise training, compared to threshold training (37). The effect of exercise intensity on muscle capillary density is similarly understudied (39). As such, NIRS-based assessments of muscle oxygen saturation (SmO_2) can detect peripheral adaptations in trained muscles. Strong correlations have been found between SmO_2 during incremental exercise at exhaustion, and VO_2max (38). A decrease in SmO_2 is an indicator of increased muscle O_2 utilization relative to O_2 supply, while a greater decrease in SmO_2 in response to training would signify improvements in a-vO_2 difference (35).

To our knowledge, no study explored changes in muscle O_2 utilization after threshold training or compared the effect of different TIDs on central and peripheral adaptations. Therefore, the purpose of this study was to use NIRS technology to compare the physiological responses of trained cyclists to a six-week POL and THR training intervention. We hypothesized that the POL training intervention would elicit greater muscle oxygenation adaptations through heightened metabolic signalling stemming from the higher exercise intensity (39, 40). Additionally, we hypothesized that the THR training intervention may cause an improved submaximal exercise economy, because of the substantial volume of training performed at sub-threshold intensity (7).

Materials and Methods

Participants

Seventeen healthy and trained cyclists (13 male, 4 female) between 18 and 49 years old took part in the study. All participants had a minimum of 2 years of training experience when they signed up for the study. While most participants were road cyclists, some also engaged in mountain biking as part of their training regimen. The study protocol was approved by the institutional Health Research Ethics Committee (HREC) (S22/05/091), following the guidelines of the Declaration of Helsinki. Written informed consent was obtained from all participants prior to testing.

Study Design

This study followed a pre-post experimental design, with a random assignment of participants into two experimental groups: a threshold (THR) intervention group and a polarized (POL) intervention group. All participants were in the study for 8-weeks. The study started with a familiarization session and baseline testing during the first week. Subsequently, participants underwent a six-week training intervention period. The POL training-intensity distribution was 80% Z1, 0% Z2, 20% Z3 and the THR training-intensity distribution was 45% Z1, 55% Z2, 0% Z3. The post testing was conducted three days after the last training session for each participant. The study was undertaken in the late summer and autumn months (January–May), after most of the South African races and events ended.

The inclusion criteria required male participants to have a relative PPO of at least 3.6 W/kg, or an absolute PPO of at least 280 W; or had a relative VO_2max of at least 45.0 mL·min^{-1}·kg^{-1}, or an absolute VO_2max of at least 3.4 L·min^{-1}. Female participants were included if they had a relative PPO of at least 3.0 W/kg, or an absolute PPO of at least 170 W; or had a relative VO_2max of at least 37.0 mL·min^{-1}·kg^{-1}, or an absolute VO_2max of at least 2.2 L/min. These criteria were in line with guidelines to classify subject groups as recreationally trained and trained (41, 42). All participants were between 18 and 49 years old, had been training consistently for >2 years prior to entry into the study, and had trained 6-10 hr per week for at least 6-months prior to the start of the study.

Performance Testing

During the first laboratory session, participants completed a physical activity readiness questionnaire, training history questionnaire, and an informed consent form. The testing procedures were explained, and participants performed a few stages of the incremental exercise test to familiarize themselves with the test protocol. Participants then also performed a 30-s Wingate at an all-out effort.

Prior to the second testing session, participants were asked to consume their final meal two hours before the testing session, avoid caffeine intake, and refrain from exercise on the day preceding the testing session. They were also asked to abstain from any exercise on the day preceding the test. During the second visit, participants' body mass, stature, and body fat percentage were measured. Body mass was measured using a calibrated electronic scale (SECA 813, Hamburg, Germany) recorded at the nearest 0.1 kg. Stature was measured using a sliding stadiometer (Seca, Germany). The BodyMetrix BX2000 (Hosand Technologies srl, Verbania) ultrasound instrument was used to estimate the percentage of body fat, fat mass and fat-free mass.

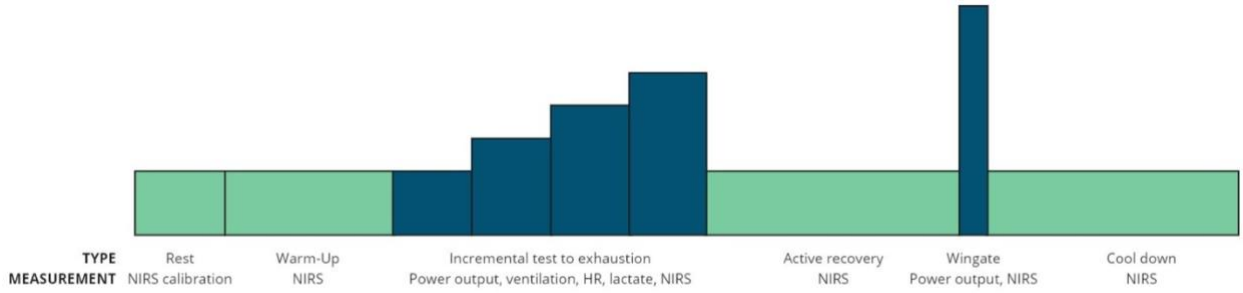

Figure 4.1 - Testing protocol schematic detailing the protocol, and concurrent measurements.

The exercise test began with a 5-min period of passive rest to calibrate the NIRS equipment and establish a baseline level of O_2Hb and HHb. A fan was switched on and positioned in front of the cyclist to ensure the surface temperature of the skin did not get too hot and affect the reading capability of the NIRS system. Following a warm-up period of 8 min at 80 W, participants were fitted with a face mask and the incremental test started. For male participants, the test started at 120 W for one minute, after which the power increased by 30 W every 2.5 min until exhaustion. For female participants, the test started at 80 W, after which the power increasing by 30 W every 2.5 min until exhaustion. Participants were asked to keep a cadence between 80-100 rpm throughout the test. In the last 30 s of each stage, a capillary blood sample (0.3 µL) was taken from the finger and analysed for blood lactate concentration. The intensity was increased until volitional exhaustion was achieved to assess the peak power output (PPO), heart rate (HR), blood lactate, as well as the power output and HR at 2 $mmol \cdot L^{-1}$ (LT1) and 4 $mmol \cdot L^{-1}$ (LT2).

Following the incremental exercise test, the face mask was removed, and participants underwent an 8-min active recovery period, pedalling at 80 W at a cadence between 80 and 100 rpm. Subsequently, a 30-s all-out Wingate sprint was performed to establish markers of anaerobic capacity. The testing concluded with a 5-min active recovery cool down, pedalling at 80 W at a cadence between 80 and 100 rpm.

The exercise test was conducted using a Velotron Dynafit Pro (RacerMate, Seattle, USA) stationary bike. Capillary blood lactate concentration was measured via finger prick using a Lactate Pro 2 meter (Arkray, Kyoto, Japan). Participants' training zones were based on the collected blood lactate samples. Lactate-E 2.0 Software (Department of Mathematics, National University of Ireland, Galway) was used to calculate each cyclist's power output at 2 $mmol \cdot L^{-1}$ and 4 $mmol \cdot L^{-1}$ blood [lactate]. The reliability and validity of this software have been previously established (43). Heart rate was measured through telemetry from a chest-based heart rate strap (Garmin International Inc., Olathe, USA). Metabolic data

were measured using the Cosmed K5 metabolic analyser, recorded in breath-by-breath fashion, but exported to a time average of 0.1 Hz (Cosmed, Rome, Italy).

NIRS

Muscle oxygenation was measured via NIRS, which is an estimate of the *in vivo* metabolism in human tissues and an indicator of O_2 uptake in the local muscle (44). Measurements were made using the Artinis PortaMon (PortaMon, Artinis Medical Systems, Elst, www.artinis.com). This device measures oxygenated hemoglobin (O_2Hb) and deoxygenated hemoglobin (HHb). These are relative values, but together can measure the absolute local oxygenation in the tissue beneath the sensor (SmO_2), using the following equation (44, 55):

$$SmO_2 = \frac{O_2Hb}{O_2Hb + HHb} \times 100.$$

The NIRS device was attached firmly, but without constriction, to the skin on the belly of the *Vastus Lateralis* in a longitudinal direction on the midpoint between the inguinal fold and the patella. The device was secured using a Velcro strap around the leg and covered by the participants' cycling shorts, which both secured the device and stopped outside light from interfering with the NIRS light sensors.

Outcome Variables

A list with all measured variables, and an explanation and/or formula can be seen in Table 4.1.

Table 4.1 - Dependent variables and their explanation and calculation.

Dependent Variable	Explanation	Calculation
LT1 (W)	Power output at 2 mmol·L^{-1} blood [lactate]	Using Lactate-E 2.0 software
LT2 (W)	Power output at 4 mmol·L^{-1} blood [lactate]	Using Lactate-E 2.0 software
PPO (W)	Power output at volitional exhaustion	$PPO = W_f + [(t \times D^{-1} \times P)]$
Wingate PPO (W)	Peak power during Wingate	Using VeloTron Wingate 1.0.2 software
Wingate MPO (W)	Mean power during Wingate	Using VeloTron Wingate 1.0.2 software
Wingate Min. PO (W)	Minimum power during Wingate	Using VeloTron Wingate 1.0.2 software
SmO_2	Muscle oxygen saturation	$SmO_2 = [O_2Hb] / ([O_2Hb] + [HHb]) \times 100$
VO2max (ml·kg^{-1}·min^{-1})	Maximal oxygen uptake	Highest measured 10 s time average
Fractional Utilization (%)	Sustainable percentage of VO_2max	Percentage VO_2max at LT2
Explosive Power (W·s^{-1})	Time to reach peak power	Using VeloTron Wingate 1.0.2 software
Anaerobic Capacity (W/kg)	Total work during test duration, per kg of body weight	Using VeloTron Wingate 1.0.2 software
Economy (VO_2/W)	Absolute oxygen uptake per watt produced	Economy = VO_2 / W

LT1, lactate threshold 1; **LT2**, lactate threshold 2; **PPO**, peak power output; **MPO**, mean power output; **Min. PO**, minimum power output; **W_f**, power at final completed workload; **t**, time; **D**, duration of every stage; **P**, difference in power between loads; **SmO_2**, muscle oxygen saturation; **O_2Hb**, oxygenated hemoglobin; **HHb**, deoxygenated hemoglobin; **VO_2**, volume of oxygen; **W**, watts.

Training interventions

Following the completion of baseline testing, participants were randomly assigned to either a POL or THR training group. The interventions included two or three intensity interval training sessions for the POL and THR groups, respectively. These interval sessions were supplemented with additional zone 1 rides for both groups. The prescribed training intensity distribution was calculated using a hybrid session-goal/time-in-zone approach (5). The aim for the POL group was to spend 80% of training time in zone 1, and 20% of training time to include zone 3 intervals, with no training time allocated to zone 2. The THR group aimed to allocate 45% of the training time to zone 1 and 55% to include zone 2 intervals, with no time spent in zone 3. One weekly training session was conducted in the laboratory and under the supervision of the researcher for intensity monitoring purposes. Participants completed the remaining training sessions independently, sharing their heart rate data with the researcher. In the POL group, zone 3 intervals were performed at 110% of LT2 power. If the mean peak HR, and mean minimum HR decreased over two consecutive interval training sessions, the target power output for the intervals would be increased by 5 W to maintain a sufficient training stimulus. For the THR group, zone 2 intervals were performed at a power output halfway between LT1 power and LT2 power. In this group, intensity was monitored based on blood lactate concentration samples collected during the laboratory interval sessions, with the target range set between 3.0 and 3.5 mmol·L^{-1} blood [lactate]. If required, the power output was adjusted accordingly. For the zone 1 rides, all the participants were capped at a heart rate corresponding to their LT1 power output. The two training

interventions were matched for total training stress; a number that considers the intensity, as well as the duration of a training session (TrainingPeaks, Louisville, CO). Participants would be excluded if they did not fulfil the required intervention adherence; they should not have missed five or more zone 1 or independent interval rides during the six-week training intervention, and they should not have missed one or more laboratory sessions during the six-week training intervention.

Laboratory exercise sessions were conducted using participants' own bikes mounted on a Cyclus2 ergometer (RBM elektronik-automation GmbH, Leipzig, Germany). Independent training sessions were completed on their own bikes.

Statistical analyses

Statistical analysis was conducted using SPSS version 29 (IBM, Armonk, NY) and using Excel (Microsoft Office 2022). For all body composition, incremental exercise test, and Wingate test, normality was assumed. For NIRS data, a Kolmogorov-Smirnov test for normality was performed and confirmed that this data was normally distributed (K-S test Statistic (D) of 0.23779).

A repeated measures ANOVA (2 x 2) compared the performance and physiological adaptation measures between training-intensity distribution models (POL and THR) and over time (pre- to post-training). Main effects (model and time), and interaction effects for the performance and physiological adaptation measures were reported. Bonferroni post hoc analysis was undertaken where significant main effects were obtained. Two-sample t-tests were used to determine whether statistically significant changes occurred between groups, and to determine the qualitative significance of the differences. In all cases, statistical significance was set at $P < 0.05$.

Descriptive statistics are presented as means ± SD and Cohen`s effect size (ES) ± 95% confidence interval (CI). Quantitative interpretation of the ES values was based on Cohen (1988) (45). Effect sizes were included to compare the magnitude of change in performance and physiological adaptation. Simple linear regression was used to test the relationship between SmO_2 and VO_2max, and to test if changes in SmO_2 in response to training significantly predicted the change in markers of endurance performance. Interpretation of correlation values was based on Schober et al. (2018) (46).

Results

Participants and Training

Seventeen participants were found eligible to participate in- and completed the study. The participants were randomly split into the POL and the THR training group (POL = 8; THR = 9). Male and female participants were grouped together, as all female data fell within the minimum to maximum range of the male participants. There were equal number of women (n = 2) in both groups.

There were no statistically significant differences in physical characteristics between the two groups (P > 0.05) (Table 4.2). The cyclists' body fat percentage ranged from 9.5% to 22.8%, with one outlier (32%) in the POL group. There were no statistically significant changes in body mass or body fat percentage in either group (P > 0.05).

Table 4.2 - Descriptive characteristics of participants

Dependent Variable	Total	POL	THR	p-value	ES (95% CI)	Qualitative difference
n	17	8	9			
Age (yrs)	31.4 ± 10.94	31.1 ± 10.33	31.7 ± 12.07	0.910	0.06	Trivial
Height (cm)	174.3 ± 8.10	172.5 ± 7.91	175.9 ± 8.39	0.410	0.41	Small
Mass (kg)	77.2 ± 12.98	76.4 ± 13.46	77.9 ± 13.32	0.822	0.11	Trivial
Body fat (%)	16.0 ± 7.66	16.1 ± 7.83	15.8 ± 7.98	0.936	0.04	Trivial

Values are means (± SD). **POL**, polarized; **THR**, threshold.

Total training volume was significantly higher for POL than for THR 54.4 ± 3.69 h vs. 45.9 ± 6.67 h, respectively (Table 4.3; P < 0.05). However, because of the difference in intensity distribution, there was no statistically significant difference in training stress. There were statistically significant between-group differences for time spent in zone 1 (P < 0.001), zone 2 (P < 0.001), and zone 3 (P < 0.001). All participants completed the six-week training intervention within the required six weeks, and according to the set adherence limits.

Table 4.3 - Between-group comparison in training intensity distribution during the study intervention.

Dependent Variable	POL	THR	P-value	ES (95% CI)	Qualitative Significance
Zone 1 (min)	2208.6 ± 533.32	953.2 ± 373.92	0.006	1.57	Large
Zone 2 (min)	308.8 ± 282.08	1724.6 ± 353.22	<0.001	2.73	Very Large
Zone 3 (min)	744.1 ± 127.36	75.6 ± 80.22	<0.001	4.43	Extremely Large
Total training time (hr)	54.4 ± 3.69	45.9 ± 6.67	<0.001	6.28	Extremely Large
TSS	2927.0 ± 496.32	2405.6 ± 623.67	0.078	0.93	Moderate

Values are means (± SD). **POL**, polarized training intervention; **THR**, threshold training **TSS**, training stress score.

The percentage of time spent in each training-intensity zone (zone1:zone2:zone3) was 67:10:23 for POL and 35:63:2 for THR (Figure 3). Both training programs were close to the intended 80:0:20 for POL and 45:55:0 for THR.

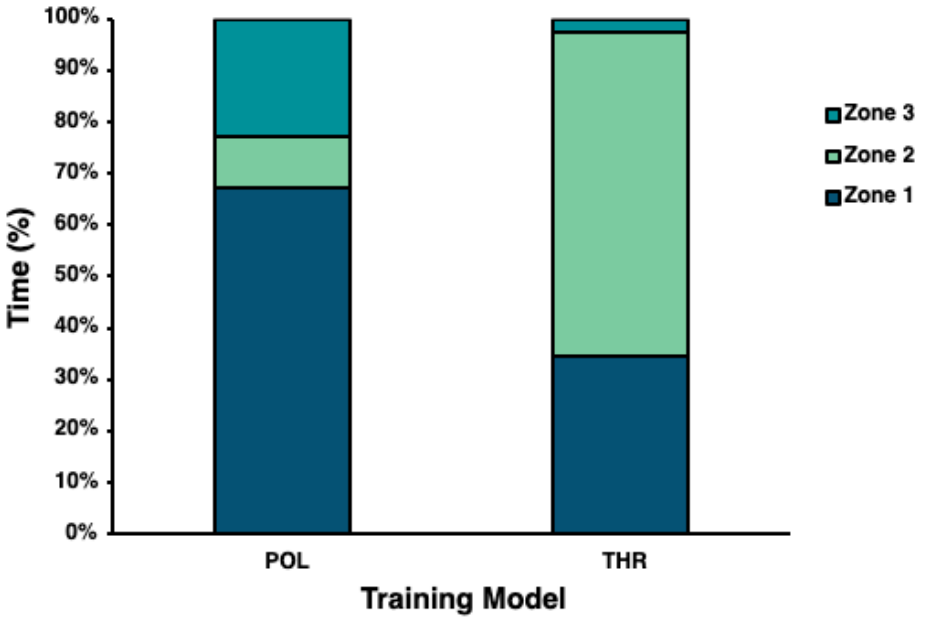

Figure 4.2 - Percentage of total time spent in zone 1 (<LT1), zone 2 (between LT1 and LT2), and zone 3 (>LT2), during six weeks of polarized or threshold training.

Power

A post-test statistical power analysis was conducted. The analysis revealed a *posteriori* calculated power of 87%, assuming an alpha level of 0.05. The power calculation was based on the Time*Group interaction effect sizes for the NIRS data. These results indicate that the present study had an acceptable statistical power.

Aerobic and Anaerobic Power Output

Table 4.4 shows the changes in power output at specific markers of endurance performance. There was a main effect over time for LT1, LT2, and PPO after both POL and THR training interventions ($P < 0.05$). There was no interaction effect between time and training model for any power output metrics. The mean changes in power output at LT1, LT2, and PPO were higher in THR, but not significantly different from POL. Improvements at LT1 were 21.0 ± 30.13 W after THR compared to 17.6 ± 22.88 W after POL ($p = 0.800$, ES = 0.004). Improvements at LT2 were 20.3 ± 22.82 W after THR compared to 9.6 ± 16.27 W after POL ($p = 0.289$, ES = 0.075). Improvements at PPO were 18.7 ± 15.86 W after THR compared to 14.8 ± 10.89 W after POL ($p = 0.567$, ES = 0.022). The magnitude of differences in LT1 between groups was deemed trivial (ES = 0.13). The magnitude of difference in LT2 and PPO between groups was deemed small, and also favoring THR over POL (ES = 0.54, ES = 0.29, for LT2 and PPO, respectively).

Changes in anaerobic capacity are also shown in Table 4.4. There were no main effects for time or training model for PPO, mean PO, or minimum PO ($P > 0.05$). Absolute changes in PPO were 24.9 ± 91.52 W after POL and 8.8 ± 66.25 W after THR ($p = 0.681$, ES = 0.012). Improvements in mean PO were 4.6 ± 35.82 W after POL and 6.4 ± 27.53 after THR ($p = 0.907$, ES = 0.001). Both groups had a lower minimum PO, namely –25 ± 77.24 W after POL and –25.8 ± 64.01 after THR ($P = 0.982$, ES = 0.000). There was a small meaningful increase in PPO for POL over THR (ES = 0.20), and trivial differences between groups in mean PO and minimum PO (ES = 0.06, 0.01, respectively).

Table 4.4 - Power output corresponding to the aerobic threshold (LT1), anaerobic threshold (LT2), and PPO before (Pre) and after (Post) the 6-week training interventions.

Dependent Variable	POL			THR			Significance		
	Pre	Post	Change	Pre	Post	Change	Time	Time x group	ES of change
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	p-value	p-value	
LT1 (W)	184.5 ± 53.15	202.1 ± 39.18	17.6 ± 22.88	179.9 ± 51.05	200.9 ± 38.37	21.0 ± 30.13	0.010	0.800	0.13
LT2 (W)	236.0 ± 46.28	245.6 ± 44.51	9.6 ± 16.27	237.8 ± 44.76	258.1 ± 40.32	20.3 ± 22.82	0.008	0.289	0.54
PPO (W)	302.1 ± 61.37	316.9 ± 63.07	14.8 ± 10.89	315.4 ± 57.19	334.1 ± 60.58	18.7 ± 15.86	0.000	0.567	0.29
Wingate PPO (W)	982.4 ± 196.67	1007.3 ± 195.3	24.9 ± 91.52	958.9 ± 231.69	967.7 ± 217.15	8.8 ± 66.25	0.395	0.681	0.20
Wingate MPO (W)	722.5 ± 189.77	727.1 ± 190.7	4.6 ± 35.82	789.7 ± 156.21	796.1 ± 155.39	6.4 ± 27.53	0.483	0.907	0.06
Wingate Min. PO (W)	524.0 ± 143.52	499.0 ± 164.24	-25.0 ± 77.24	612.9 ± 131.69	587.1 ± 115.9	-25.8 ± 64.01	0.159	0.982	0.01

Values are means (±SD) and change values are means. **POL**, polarized training intervention; **THR**, threshold training intervention; **LT1**, power output at LT1; **LT2**, power output at LT2; **PPO**, peak power output during maximal aerobic test; **Wingate PPO**, peak power output during 30-s Wingate; **Wingate MPO**, mean power output during 30-s Wingate; **Wingate Min. PO**, minimum power output during 30-s Wingate.

Aerobic and Anaerobic Adaptations

Table 4.5 depicts aerobic and anaerobic markers of endurance adaptations within and between groups. There were no main effects over time or training model for VO_2max, fractional utilization of oxygen uptake (VO_2) at LT2, explosive power, anaerobic capacity, resting lactate, or maximal lactate ($P > 0.05$). Absolute changes in VO_2max and fractional utilization at LT2 were larger after POL than THR, whereas absolute changes in explosive power and anaerobic capacity were larger after THR than POL. The magnitude of change in VO_2max, explosive power, and anaerobic capacity between groups were small (ES = 0.40, 0.40, and 0.34, respectively), while the change in fractional utilization at LT2 between groups was moderate (ES = 0.62). The magnitude of change in resting lactate and maximal lactate was trivial (ES = 0.12, 0.09, respectively). There were no significant interaction effects for any of these variables.

Table 4.5 - VO_2max, fractional utilization of oxygen at LT2, explosive power, and anaerobic capacity after 6-week training interventions.

Dependent Variable	POL			THR			Significance		
	Pre	Post	Change	Pre	Post	Change	Time	Time x group	ES of change
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	p-value	p-value	
VO2max ($ml \cdot kg^{-1} \cdot min^{-1}$)	49.0 ± 9.41	51.9 ± 8.17	2.9 ± 6.29	50.9 ± 8.21	51.4 ± 5.36	0.6 ± 5.27	0.240	0.421	0.40
Fractional Utilization (%)	82.4 ± 6.17	85.5 ± 6.57	3.1 ± 9.13	85.7 ± 7.14	84.1 ± 5.69	-1.6 ± 5.50	0.671	0.215	0.62
Explosive Power ($W \cdot s^{-1}$)	1.6 ± 1.47	1.7 ± 1.66	0.1 ± 0.45	4.4 ± 3.15	3.6 ± 3.18	-0.8 ± 3.30	0.564	0.435	0.40
Anaerobic Capacity (W/kg)	9.6 ± 1.93	9.6 ± 2.22	-0.0 ± 0.60	10.1 ± 1.19	10.3 ± 1.36	0.2 ± 0.36	0.555	0.489	0.34
Resting lactate ($mmol \cdot L^{-1}$)	1.68 ± 0.53	1.53 ± 0.49	-0.15 ± 0.51	1.40 ± 0.21	1.56 ± 0.34	0.16 ± 0.28	0.979	0.171	0.12
Max. lactate ($mmol \cdot L^{-1}$)	13.7 ± 5.2	13.3 ± 3.7	-0.44 ± 3.05	14.6 ± 4.2	14.5 ± 3.8	-0.10 ± 3.86	0.757	0.846	0.09

Values are means (±SD) and change values are means. **POL**, polarized training intervention; **THR**, threshold training intervention; **Fractional Utilization,** percentage VO_2max at LT2.

Muscle Oxygen Saturation (SmO_2)

There were no main effects over time or with the training-intensity distribution model on SmO_2 at any significant threshold or intensity (LT1, LT2, PPO, or Wingate) ($P>0.05$) (Figure 3). However, the increase in O_2 utilization (demonstrated by the decrease in SmO_2) at LT1 (Figure 3, A), LT2 (Figure 3, B), PPO (Figure 3, C), and after the Wingate (Figure 3, D) was greater in POL than in THR (LT1: -7.5 ± 11.78% vs. -0.9 ± 5.38%, ES = 0.72; LT2: –8.5 ± 11.97% vs. -0.7 ± 5.37%, ES = 0.91; PPO: –8.8 ± 16.58% vs. 0.1 ± 3.72, ES = 0.74; Wingate: –9.2 ± 16.93% vs. 2.8 ± 8.48%, ES = 1.76). Notably, there are two high-responders in the POL group, who showed a decrease in SmO_2 of > 1 SD. However, without these two

participants, the increase in O_2 utilization still showed a larger practically significant effect size in POL than THR (LT1: -1.3 ± 2.65% vs. -0.9 ± 5.38%, ES = 0.09; LT2: -2.5 ± 4.09% vs. -0.7 ± 5.37%, ES = 0.38; PPO: -3.4 ± 6.94% vs. 0.1 ± 3.72, ES = 0.62; Wingate: -3.74 ± 7.75% vs. 2.8 ± 8.48%, ES = 0.80). These values showed moderate meaningful improvements in LT1, LT2, and PPO in SmO_2 after POL compared to THR, and a large improvement after POL compared to THR after the 30-s Wingate.

Among both groups, there was large individual variation in SmO_2 adaptation at all levels. However, in the POL group, 5 out of 8 participants improved at all measured intensities, compared to 1 out of 9 participants in the THR group. In the POL group, 4 out of 8 participants improved more than the total group average at three or more measured intensities, compared to 1 out of 9 participants.

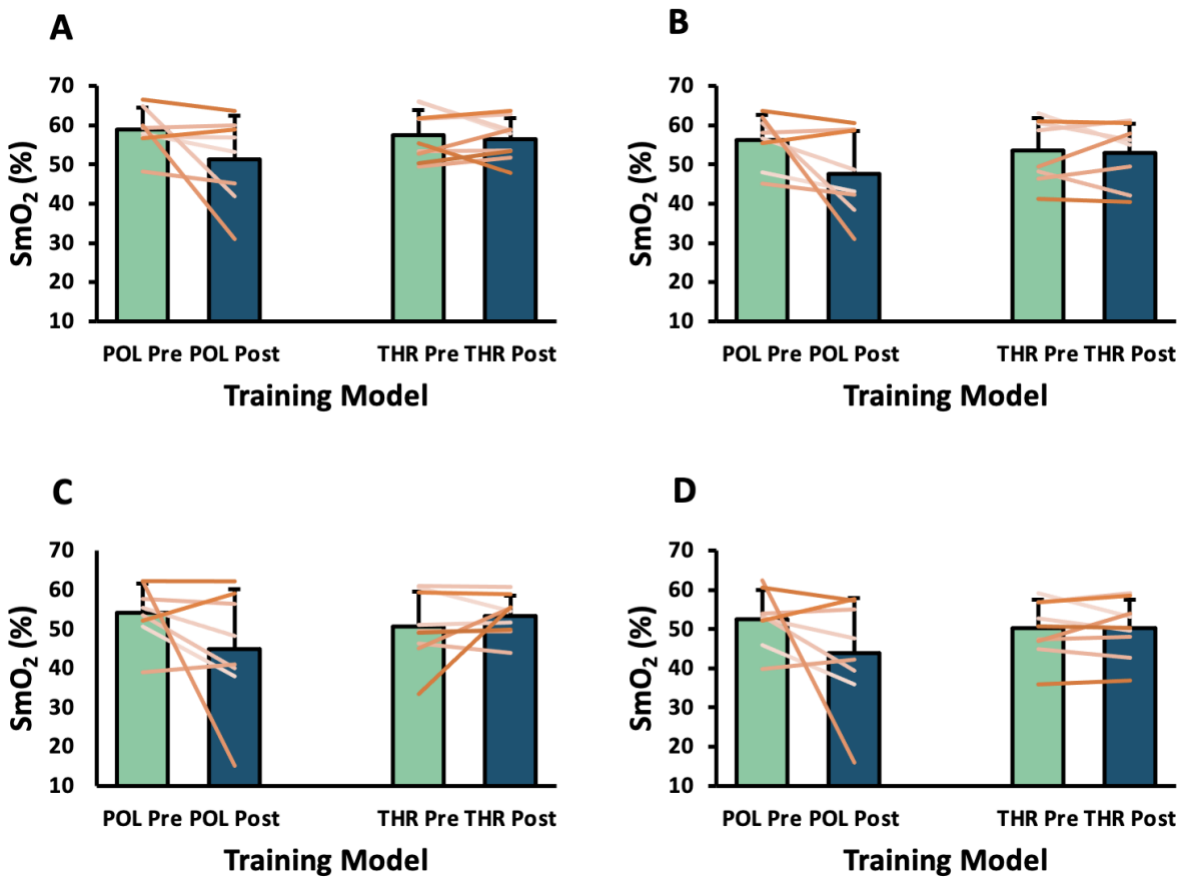

Figure 4.3 - Mean (±SD) pre and post total muscle oxygen saturation values at LT1 (A), LT2 (B), PPO (C), and after 30-s Wingate (D), after both POL and THR training interventions.

SmO_2, muscle oxygen saturation; **POL**, polarized training intervention; **THR**, threshold training intervention; **Pre**, pre-intervention; **Post**, post-intervention.

Exercise economy (VO_2 / W)

There were no main effects over time, or with the training-intensity distribution model for exercise economy at any significant threshold or intensity (P > 0.05) (Figure 5). However, THR showed a larger absolute improvement in exercise economy than POL at all measured intensities. Trivial differences in changed scores were observed between groups at LT1 for POL (-1.1 ± 2.72 mL/W) and THR (-0.8 ± 2.11 mL/W) (p = 0.848, ES = 0.09) (Figure 5, A). The mean change in exercise economy at LT2 between groups was significant (p = 0.034) (Figure 5, B). The magnitude of difference between groups was deemed large at LT2 (0.4 ± 2.11 mL/W after POL, -1.4 ± 0.82 mL/W after THR; ES = 1.11). The between-group difference at peak intensity was small (-0.2 ± 1.44 mL/W after POL, -0.7 ± 1.06 mL/W after THR; p = 0.368; ES = 0.45) (Figure 5, C). No interaction effect between time and training model was observed at any intensity.

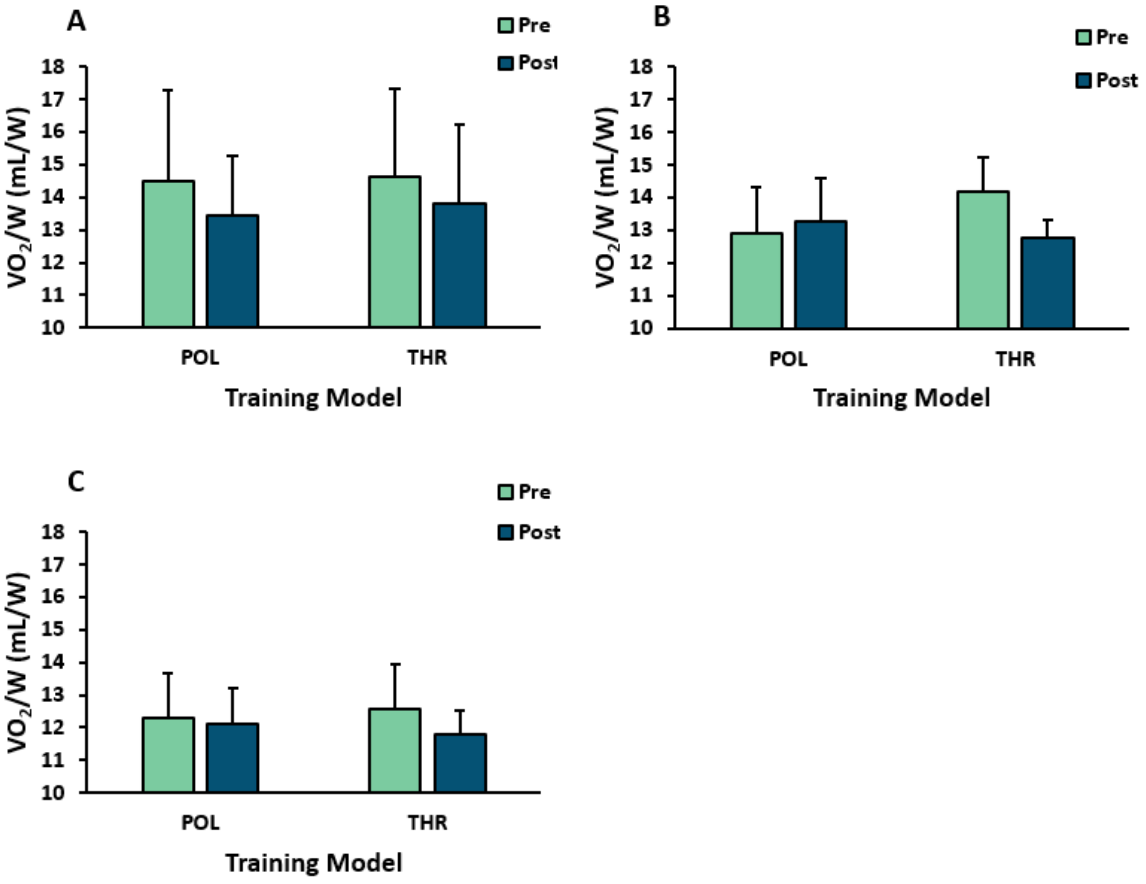

Figure 4.4 - Mean (± SD) exercise economy corresponding to the aerobic threshold (LT1) (A), anaerobic threshold (LT2) (B), and PPO (C) before (Pre) and after (Post) the training interventions.

VO_2/W, exercise economy; **POL**, polarized training intervention; **THR**, threshold training intervention; **Pre**, pre-intervention; **Post**, post-intervention.

Relationship between Muscle Oxygenation (SmO_2) and Performance Indicators

A strong negative correlation was found between post-test SmO_2 and VO_2max across both groups (r = 0.56, R^2 = 0.31) (Figure 5); participants with higher VO_2max values showed lower SmO_2 at PPO values.

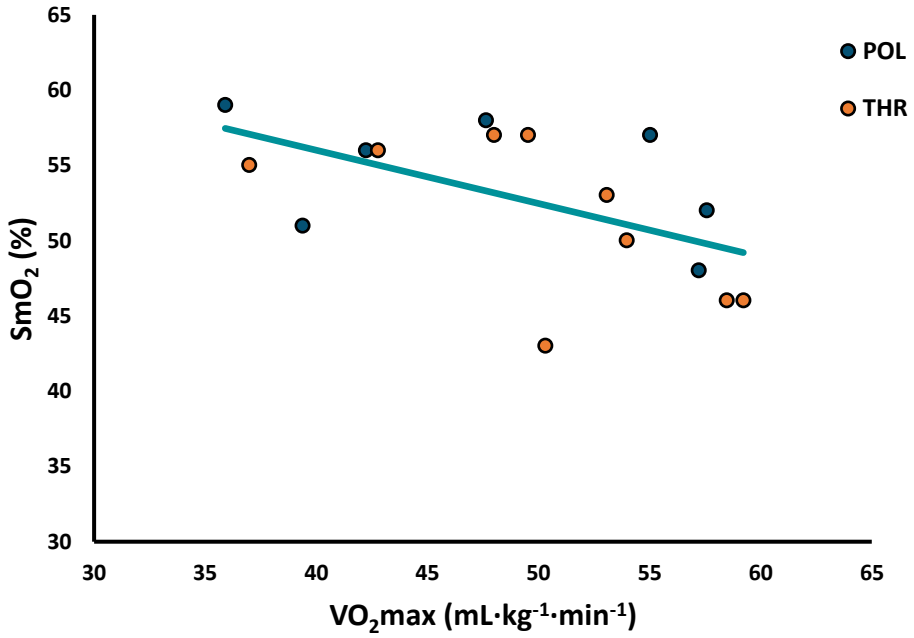

Figure 4.5 - Relationship between post-intervention SmO_2 and relative VO_2max among participants.

Table 4.6 shows that changes in SmO_2 following the interventions were not statistically significantly associated with changes in LT1, LT2, PPO, VO_2max, VO_2/W at LT1, VO_2/W at LT2, VO_2/W at PPO, Wingate PPO, or Wingate MPO (P > 0.05). Moderate effect sizes were observed between change in SmO_2 and power at LT1 and LT2. A large effect size was observed between the changes in SmO_2 and PPO. A trivial effect size was observed between the changes in SmO_2 and VO_2/W at LT1. Small effect sizes were observed between SmO_2 and all other variables.

Table 4.6 - Correlation coefficient (r), coefficient of determination (R^2), standard error of estimate, P-value, and effect size between change in SmO_2 and change in various indicators of endurance performance.

Dependent Variable	r	R^2	Standard Error of Estimate	P-value	ES
LT1	0.136	0.019	14.441	0.617	1.06
LT2	0.244	-0.059	14.127	0.346	1.04
PPO	0.255	-0.065	14.086	0.324	1.42
Rel. VO_2max	0.179	-0.032	14.331	0.492	0.42
VO_2/W @ LT1	0.316	0.100	13.820	0.216	0.19
VO_2/W @ LT2	0.316	0.100	13.821	0.217	0.23
VO_2/W @ PPO	0.032	-0.001	14.559	0.904	0.24
Wingate PPO	0.048	0.002	14.549	0.854	0.35
Wingate MPO	0.211	0.044	14.239	0.417	0.35

LT1, power output at LT1; **LT2**, power output at LT2; **PPO**, peak power output during maximal aerobic test; **Rel. VO_2max**, relative maximum rate of oxygen uptake; **VO_2/W @ LT1**, exercise economy at LT1; **VO_2/W @ LT2**, exercise economy at LT2; **VO_2/W @ PPO**, exercise economy at PPO; **Wingate PPO**, peak power output during 30-s Wingate; **Wingate MPO**, mean power output during 30-s Wingate.

Discussion

Previous research has identified polarized and threshold training to be prominent TIDs among endurance athletes. Prior investigations have highlighted enhanced performance benefits from adopting a polarized training approach, while other studies have underscored physiological benefits from implementing a threshold training approach (10, 16). The purpose of the present study was to compare performance and physiological responses to a six-week POL and THR training intervention. The findings showed there were no interaction effects for any of the measured variables; thus, statistically, the POL and THR training interventions are equally beneficial.

In the present study, the training volume was matched between the two intervention groups. All participants were within the protocol adherence limits. However, the THR training group trained 10.9% less hours than the POL group. In terms of total training stress, the difference is not significant, but the THR group achieved 12.6% less training stress than the POL group. Several studies have noted the relation between total training time and endurance sport performance (15, 24). It is feasible that this difference may have affected the outcome measures of the present study, however, this cannot be said with certainty. Secondly, because of the relatively small sample size of 17 participants, and substantial variation among participants, the statistical power may have been affected. Hence, effect sizes were calculated throughout, in order to show the magnitude of differences between groups.

The main findings of this study were that over a 6-week training period, there were (1) no statistically significant pre-to-post changes between groups for SmO_2 at any significant threshold or intensity, though the magnitude of change was larger for POL than THR, (2) THR and POL training yielded similar improvements in power at each significant threshold or intensity, though the numerical effect sizes of power at LT1, LT2, and PPO were larger for THR than POL, (3) neither group displayed statistically significant changes in VO_2max, though a numerically greater effect size was observed for POL than THR, (4) no statistically significant changes were observed in explosive power and anaerobic capacity but the effect sizes were numerically greater after THR than POL, (5) moderate and small effect sizes were observed in exercise economy at LT2 and PPO, respectively, favouring THR over POL and (6) the change in SmO_2 following training was not a significant predictor of markers of endurance performance.

It is widely believed that three primary factors play a key role in endurance performance, namely, VO_2max, lactate threshold, and exercise economy (47). The interaction of VO_2max and lactate threshold represent the interplay between aerobic and anaerobic metabolism at a given output, while exercise economy reflects the speed or power that can be generated at a given metabolic cost. The improvements in cycling performance in response to the training interventions observed in both groups should be attributed to improvements in VO_2max, lactate threshold, and/or exercise economy.

Neither group showed a statistically significant change in VO_2max, though the POL group showed a greater change over the THR group (5.9% vs. 1.1%, respectively). Previous literature has found that 4 to 6 weeks of aerobic and interval training elicits significant improvement in VO_2max in habitually active people (48, 49). The participants in this study had a higher pre-intervention training level than those in other literature, and as such may have had lesser capacity for further increases. However, the findings that POL displayed a larger improvement than THR is in line with the findings of Stöggl and Sperlich (2014), who found that POL training showed the greatest increase in VO_2max over a 9-week training period, compared to THR, high-volume training, and high-intensity interval training (7). The higher intensity at- or near the individual VO_2max, associated with POL training, may be more effective for enhancing VO_2max compared to THR, because of the enhanced adaptive signalling compared to zone 2 training (50).

Improvements in VO_2 uptake are a function of changes in cardiac output (CO) and arteriovenous O_2 difference. While we cannot speculate to what extent adaptations in CO were made, we did measure

SmO_2 which is a measure of arteriovenous O_2 difference. We observed greater numerical effect sizes in SmO_2 at every measured marker of intensity in the POL group, compared to the THR group. This is a new finding that has not yet been shown by previous literature. This new finding suggests that there may have been increases in muscle capillary networks and/or mitochondrial respiratory capacities, leading to the observed improved O_2 utilization. A decrease in SmO_2 would indicate more O_2 utilization relative to O_2 supply. Thus, a decrease in SmO_2 would signify an increase in O_2 utilization by the active muscles. This may be supported by the correlation between SmO_2 and VO_2max, which found that 31% of variance in VO_2max is explained by SmO_2. This is in line with previous findings that found correlations between improved muscle O_2 extraction and higher VO_2max values (38, 51, 52). A key factor in endurance race performance is fatigue resistance (53). To improve fatigue resistance, it is imperative that an athlete maintains adequate O_2 supply to match O_2 demand (54). As such, a lower SmO_2 has been found to cause improvements in power output (55). In the present study, this is also shown by the relation between change in SmO_2 and change in power output. Pre-to-post training intervention change in SmO_2 did not significantly correlate with any other metrics of endurance performance, but change in power output at LT1, LT2, and PPO showed moderate qualitative correlations to change in SmO_2: athletes who showed the most improvement in SmO_2 showed larger improvements in power output.

In the present study, intramuscular changes were not assessed directly, so the changes in SmO_2 cannot be attributed to a specific adaptation. Typically, improvements in peripheral adaptations to exercise are largely due to skeletal muscle capillarization, increased mitochondrial density or capacity, and increased oxidative enzyme function (35, 56, 57). Gibala et al. (2018) observed that exercise intensity plays a key role in improvements in physiological markers of endurance performance (40). High intensity (zone 3) activity was found to activate signalling cascades linked to mitochondrial biogenesis, through a heightened AMPK and MAPK response. It could be proposed that a POL training model may cause peripheral adaptations, through enhancements in mitochondrial density or capacity, increased skeletal muscle capillarization, or increased oxidative capacity. The practically meaningful improvement in SmO_2 would suggest increased muscle O_2 utilization and would be consistent with previous findings that suggest improved peripheral adaptations following high intensity (zone 3) training. On the contrary, the THR training group showed negligible changes in SmO_2 at LT1, LT2, PPO and after Wingate, implying that there may be lesser peripheral adaptations than after a POL training intervention.

Improvements in aerobic peripheral adaptations would imply that a larger fraction of the total power output may be produced through aerobic respiration (58). This may also be reflected by the moderate increase in fractional utilization at LT2 observed in the POL group. Fractional utilisation reflects the O_2 uptake relative to an individual's VO_2max. As the fractional utilisation increases at a given exercise intensity, more O_2 is taken up. This means that a larger proportion of power produced at this intensity comes from O_2 derived ATP. Hence, the increase in power output at all markers in the POL group may be caused by aerobic adaptations. In the THR group, however, the VO_2max, SmO_2, and fractional utilization only showed trivial change. This would suggest that the improvement in power output observed in the THR group was not related to changes in O_2 uptake and/or utilization. Thus, in the THR group, the improvement in power output at the different markers may be caused by systems other than VO_2 uptake or usage.

The improvement in power output in the THR group could be attributed to improvements in either the lactate threshold or the exercise economy. An individual's lactate threshold is affected by both their anaerobic- and their aerobic capacity. Anaerobic capacity plays a role in the aerobic power as the glycolytic capacity provides part of the total energy output (59). The total energy contribution during endurance events comes largely from aerobic metabolism, but the substrate metabolized depends heavily on the intensity and duration of the effort (60). The total contribution of glycolysis and lipolysis in aerobic respiration has been estimated to be similar after around 3 to 5 hours (61). Athletes competing in shorter events would benefit from increased glycolysis, and athletes competing in longer events would benefit from increased lipolysis. Most of the THR training was broken into intervals ranging from 7 to 15 minutes at the threshold intensity. At this intensity and duration, an individual is largely dependent on glycolysis for ATP production. It could be feasible to attribute at least part of the improvement of power output to an improvement in the glycolytic system. This may also be reflected by the small meaningful enhancement of anaerobic capacity and explosive power in the THR group, as glycolytic activity has been found to play a key role in explosive activities (62). The finding that THR training may improve glycolytic capacity is in line with findings that THR training affects lactate clearance, rather than production: it does not cause an athlete to produce more power aerobically, but rather aids in lactate shuttling (63).

Where an individual's VO_2max and lactate threshold interact to determine the rate and duration of energy production, their economy determines the output that can be achieved with that given amount of energy (64). Previously, an inverse relationship has been established between VO_2max and exercise

economy in runners and cyclists: athletes with high VO_2max values have a lower exercise economy (65). The exact reason for this has not yet been determined, but some suggest that individuals with higher VO_2max values also have a higher lipid oxidation rate, which requires more O_2 than carbohydrate oxidation. Thus, more oxygen would be required to overcome a given workload (66). In the present study, VO_2/W did not change significantly at LT1, LT2, or PPO, but a moderate and a small improvement was observed in VO_2/W at LT2 and PPO in the THR group, respectively. This would be in line with prior studies, which found significant improvements in exercise economy following a THR training intervention (7, 12). This improvement in exercise economy may thus reflect increased glycolysis or decreased lipid oxidation.

Conclusion

The findings of the present study on the performance and physiological effects of POL and THR training interventions have showed no significant differences between the two TIDs over a 6-week training period in trained cyclists. Both POL and THR training groups showed a similar improvement in power output after 6 weeks of training. No significant different physiological adaptations were measured between the groups. Perhaps the high-intensity component of the POL training group stimulated more aerobic peripheral adaptations, as shown by the practically meaningful enhancement of SmO_2, VO_2max, and fractional utilization. On the contrary, the zone 2 training intensity may have stimulated more glycolytic adaptations in the THR group. The data reported in this study appear to support the findings of prior literature that a THR training program improves exercise economy.

These findings may be of interest to practitioners, coaches, or athletes: The results from this research suggest that individuals with a lower aerobic capacity may benefit from a more polarized training approach, as this may elicit greater improvements in performance through aerobic adaptations. Individuals with lesser developed glycolytic capacity may benefit from a threshold training approach, as this may lead to improvements in performance through more anaerobic adaptations. However, despite these arguments, the evidence here is limited and should be approached with caution. Large randomized controlled trials could provide more definitive evidence to support these notions.

Previous research has established that decreased SmO_2 is correlated with improved VO_2max and power output, and as such may be an indicator of endurance performance. The present study has found a large variety of individual responses in muscle oxygenation to training stimuli. This would suggest that SmO_2 is a trainable physiological quality, but that some individuals may be better

predisposed to short term peripheral adaptations. Even though peripheral adaptations after POL training seemed to improve to a greater extent than after THR training, there were individuals in both groups that improved and deteriorated. Future research should investigate individual predisposition to training intensity models.

This study has some limitations. Notably, the present study lacked sufficient power for hypothesis testing (n = 17), and data showed large inter-personal variation (e.g., 18-49 years old, male and female participants), which over the short 6-week period may have increased the possibility of a type II statistical error. Second, there was a non-significant, but large difference in total training stress between training groups. Hence, effect sizes were calculated as this metric is not dependent on sample size and gives a better indication of practically meaningful changes and differences. These insights may provide some preliminary evidence regarding the central and peripheral adaptations and performance adaptations to POL and THR training interventions. Future work in larger-scale studies may help to verify some findings of this study.

It has become clear that both POL and THR training interventions caused meaningful improvements in power output at every significant threshold or intensity. However, the physiology by which these improvements came about is different between groups. It has become clear that both POL and THR training philosophies have their own respective strengths and weaknesses. By delving deeper into these adaptations, researchers can contribute valuable insights to coaches and athletes regarding the optimization of training for individual needs, athletic performance, and long-term success.

Data Availability

The data are available from the corresponding author on request.

Acknowledgements

The author would like to thank Louise Engelbrecht for her technical assistance with the laboratory equipment. The author would also like to thank the participants for dedicating their time during the six weeks of training.

Grants

No funding was received for this project.

Disclosures

No conflicts of interest, financial or otherwise, are declared by the authors.

Author Contributions

C. Fleming, E. Terblanche conception and design of research; C. Fleming performed experiments; C. Fleming analyzed data; C. Fleming interpreted results of experiments; C. Fleming prepared figures; C. Fleming drafted manuscript; C. Fleming, E. Terblanche edited and revised manuscript; C. Fleming, E. Terblanche approved final version of manuscript.

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Chapter 5 Conclusion

Various training intensity distribution (TID) models have arisen to optimize adaptation and maximize performance. A broad body of literature exists on the performance outcomes of varying TIDs. However, there is a lack of experimental research investigating the physiological adaptations of POL and THR training models. This may interest competitive athletes and coaches, and to exercise physiologists in comprehending the physiological adaptations to different training methods.

The present study aimed to determine the magnitude of change in power output, aerobic capacity, anaerobic capacity, and muscle oxygenation following a 6-week polarized and threshold training intervention in trained cyclists. Second, the study aimed to determine the relationship between the changes in muscle oxygenation markers and changes in performance indicators following a 6-week polarized and threshold training intervention in trained cyclists. Aerobic, anaerobic, and muscle oxygenation adaptations were measured before- and after a 6-week POL or THR training intervention, using an incremental exercise test, a 30-s Wingate, and concurrent NIRS measurements.

Main findings

A summary of the main findings is presented in table 5.1.

The findings of the study show that both THR and POL training methods stimulate improvements in power output at LT2 and PPO, but that a THR training program stimulates larger numerical power output adaptations over a 6-week training period, compared to POL. The THR training program may be optimal for promoting improvements in markers of endurance performance mainly through glycolytic adaptations, whereas a POL training program favors improvement in markers of endurance performance primarily through aerobic adaptations.

These findings underscore the importance of an optimal training intensity distribution to elicit specific adaptations. Tailoring a training program according to an athlete's current physiology and the optimal physiological profile for their target event could prove valuable in fine-tuning an athlete's performance potential. Coaches can be encouraged to prescribe a high volume of zone 1 training for athletes in all endurance sports. It is also recommended that before prescribing higher intensity training, coaches should first identify athlete's weaknesses. Higher intensity sessions should then be prescribed accordingly. For athletes desiring aerobic adaptations, a polarized training intensity distribution model may be optimal. For athletes desiring glycolytic or exercise economy adaptations, training according to a threshold training intensity distribution model may be better suited.

Table 5.1 - Summary of the adaptations to 6 weeks' POL or THR training.

Dependent Variable	Outcome
LT1	Similar improvement in both groups ($p = 0.010$, ES = 0.13)
LT2	Similar improvement in both groups ($p = 0.008$) Small meaningful improvement in THR over POL (ES = 0.54)
PPO	Similar improvement in both groups ($p < 0.001$) Small meaningful improvement in THR over POL (ES = 0.29)
Wingate PPO	Trivial changes in both groups ($p = 0.483$) Small meaningful improvement in POL over THR (ES = 0.20)
SmO_2 at LT1	Trivial changes in both groups ($p = 0.073$) Moderate meaningful improvement in POL over THR (ES = 0.72)
SmO_2 at LT2	Trivial changes in both groups ($p = 0.067$) Moderate meaningful improvement in POL over THR (ES = 0.91)
SmO_2 at PPO	Trivial changes in both groups ($p = 0.147$) Moderate meaningful improvement in POL over THR (ES = 0.74)
SmO_2 after Wingate	Significant changes in both groups ($p < 0.001$) Large meaningful improvement in POL over THR (ES = 1.76).
VO_2max	Trivial changes in both groups ($p = 0.240$) Small meaningful improvement in POL over THR (ES = 0.40)
Fractional $Utilization_{LT2}$	Trivial changes in both groups ($p = 0.671$) Moderate meaningful improvement in POL over THR (ES = 0.62)
Explosive power	Trivial changes in both groups ($p = 0.564$) Small meaningful improvement in THR over POL (ES = 0.40)
Economy at LT2	Trivial changes in both groups ($p = 0.195$) Moderate meaningful improvement in THR over POL (ES = 1.11)
Economy at PPO	Trivial changes in both groups ($p = 0.156$) Small meaningful improvement in THR over POL (ES = 0.45)
Relationship between SmO_2 and markers of performance	No relationship was found between change in SmO_2 and change in markers of endurance performance.

Aims and Hypotheses

H_1: *A THR training intervention will lead to a higher workload at a sub-maximal exercise intensity, compared to a POL training model.*

A small meaningful improvement in power output at LT2 and PPO was observed, favoring THR over POL. Based on these observations, this hypothesis is **accepted**.

H_2: *There will be no difference in change in aerobic capacity between training interventions.*

Small meaningful improvements in absolute- and relative VO_2max after POL training, but not THR training, were observed. Based on these findings, the hypothesis is **accepted**.

H_3: *A threshold training model may lead to greater improvements in anaerobic capacity compared to a polarized training model.*

The small qualitative improvement in explosive power and anaerobic capacity observed after THR training, but not after POL training, indicates improved anaerobic capacity. Based on these findings, this hypothesis is **accepted**.

H_4: *A polarized training intervention will elicit greater muscle oxygenation adaptations than a threshold training model*.

The POL group showed moderate and large meaningful differences in SmO_2 at all measured intensities after the training intervention, whereas the THR group showed trivial changes. Based on these findings, the hypothesis is **accepted**.

H_5: *A THR training model will improve exercise economy (VO_2/W) more than a POL training model.*

The magnitude of increase in VO_2/W was greater after THR than after POL at LT1, LT2, and PPO. Based on these findings, the hypothesis is **accepted**.

H_6: *There will be positive correlations between changes in muscle oxygenation and changes in markers of endurance performance.*

Post-intervention peak aerobic SmO_2 correlated strongly with post-intervention VO_2max. However, changes in peak aerobic SmO_2 did not correlate with changes in any other markers of endurance performance. Based on these findings, the hypothesis is **rejected**.

Limitations

The group of participants in the current study was homogeneous in athletic performance; all participants fit in to the 'trained' category of endurance sports (Decroix et al., 2015; Pauw et al., 2013). However, the age range of 18-49 yrs, and the participant group comprising mixed sexes, may have caused larger standard deviations than the statistical power would have indicated. It may have limited the statistical power of the study.

Secondly, the study only included trained cyclists. On top of this, there was high and low responders to the training stimulus. Therefore, the findings cannot be extrapolated to other athlete populations or sport codes.

Thirdly, the training intervention used in this study only lasted 6 weeks. Therefore, it is unknown whether a longer training intervention may have affected the type- or magnitude of adaptations observed.

This study may be regarded as an exploratory study paving the way for more research in this area of physiological adaptations to various TIDs.

Future studies

Being the first study to investigate the muscle oxygenation adaptations to a POL and THR training program, more research is needed to validate these findings. This study found preliminary evidence of the peripheral adaptations to both POL and THR training. Future studies could use different methods to confirm these findings. (E.g., the notion that THR training improves anaerobic capacity may be confirmed through the use of muscle biopsies identifying metabolic adaptations, or muscle fiber type shifting).

Future research should examine the adaptations observed in this study in different athletic populations (e.g., an elite athlete population) or sports (e.g., runners, or rowers).

The present study found large individual peripheral responses to both TIDs. Future studies could investigate individual predisposition to respond to certain training intensity stimuli (e.g., athletes with better maximal aerobic capacity may benefit more from THR training as it may stimulate a potentially under-trained part of their physiology). Incorporating sex as a variable of adaptation to different TIDs may be important. There is evidence that female athletes derive a larger proportion of total energy from fat oxidation, whereas male athletes derive more from carbohydrate oxidation (Horton et al., 1998). Physiological responses to different TIDs may differ between sexes. It would be valuable to conduct sex comparisons in response to different TIDs, as this may aid in enabling optimal training methods, ultimately promoting athletic success in all humans.

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Addenda

Addendum A – Journal of Strength and Conditioning Research Author Guidelines

Author's guidelines of the Journal of Strength and Conditioning research can be found online at https://edmgr.ovid.com/jscr/accounts/ifauth.htm

Journal of Strength & Conditioning Research

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The Journal of Strength and Conditioning Research (JSCR) is the official research journal of the National Strength and Conditioning Association (NSCA). The JSCR is published monthly. Membership in the NSCA is not a requirement for publication in the journal. JSCR publishes original investigations, systematic, and narrative reviews and meta-analyses, symposia, research notes, and technical and methodological reports contributing to the knowledge about strength and conditioning in sport and exercise. All manuscripts must be original works and present practical applications to the strength and conditioning professional or provide the basis for further applied research in the area. Manuscripts are subjected to a "double blind" peer review by at least two reviewers selected by Senior Associate Editors who are experts in the field. In some cases a "single blind" peer review may occur if a Senior Associate Editor is forced to serve as a reviewer. All editorial decisions are final and will be based on the quality, clarity, style, rank, and importance of the submission relative to the goals and objectives of the NSCA and the journal. Manuscripts can be rejected on impact alone as it relates to how the findings impact evidence based practice for strength and conditioning professionals, end users, and clinicians. Thus, it is important authors realize this when submitting manuscripts to the journal.

JSCR Senior Associate Editors will administratively REJECT a paper before review if it is deemed to have very low impact on practice, out of scope of the journal, poor experimental design, improperly formatted, and/or poorly written. Additionally, upon any revision the manuscript can be REJECTED if experimental issues and impact are not adequately addressed to reviewers, Senior Associate Editor, or Editor-in-Chief's satisfaction. The formatting of the manuscript is of great importance and manuscripts will be rejected if NOT PROPERLY formatted.

EDITORIAL MISSION STATEMENT

The editorial mission of the JSCR, formerly the Journal of Applied Sport Science Research (JASSR), is to advance the knowledge about strength and conditioning through research. Since 1978 the NSCA has attempted to "bridge the gap" from the scientific laboratory to the field practitioner. A unique aspect of this journal is the inclusion of recommendations for the practical use of research findings. While the journal name identifies strength and conditioning as separate entities, strength is considered a part of conditioning. This journal wishes to promote the publication of peer-reviewed manuscripts that add to our understanding of strength training and conditioning for fitness and sport through applied exercise and sport science. The conditioning process and proper exercise prescription impact a wide range of populations from children to older adults, from youth sport to professional athletes. Understanding the conditioning process and how other practices such as such as nutrition, technology, exercise techniques, and biomechanics support it is important for the practitioner to know.

Original Research

JSCR publishes research on the effects of training programs on physical performance and function to the underlying biological basis for exercise performance as well as research from a number of disciplines attempting to gain insights about sport, sport demands, sport profiles, conditioning, and exercise such as biomechanics, exercise physiology, motor learning, nutrition, and psychology. A primary goal of JSCR is to provide an improved scientific basis for conditioning practices. JSCR will ONLY CONSIDER original manuscripts not currently under consideration from other journals. JSCR will NOT CONSIDER any manuscripts previously published on preprint servers or resubmitted manuscripts previously rejected by JSCR.

Article Types

JSCR publishes original investigations, symposia, brief systematic, and narrative reviews and meta-analyses, technical reports and research notes that are related to the journal's mission. A symposium is a group of articles by different authors that address an issue from various perspectives. The reviews and meta-analyses should provide a critical examination of the literature and integrate the results of previous research in an attempt to educate the reader as

to the basic and applied aspects of the topic. There is no word limit to the reviews. However, appropriate length will be determined by Senior Associate Editors and reviewers during the review process. We are especially interested in applied aspects of the reviewed literature. In addition, the author(s) should have experience and research background in the topic area they are writing about in order to claim expertise in this area of study and give credibility to their recommendations. A research note is a brief research study (~1500-2000 words) that typically consists of a simple research design and only few dependent variables. It is formatted identical to an original study with the same features, i.e. Abstract, Introduction, Methods, Results, Discussion, Practical Applications, and References, but with limited tables, figures, and reference numbers.

The JSCR strongly encourages the submission of manuscripts detailing methodologies that help to advance the study and improve the practice of strength and conditioning.

Manuscript Clarifications

Manuscript Clarifications will be considered and will only be published online if accepted. Not all requests for manuscript clarifications will be published due to costs or content importance. Each will be reviewed by a specific sub-committee of Associate Editors to determine if it merits publication. A written review with needed revisions will be provided if it merits consideration. Manuscript Clarifications are limited to 400 words and should only pose professional questions to the authors and not editorial comments. If accepted, a copy will be sent to the author of the original article with an invitation to submit answers to the questions in the same manner again with a 400 word limit. It will be reviewed by the sub-committee and revisions requested if needed before it is published. Only one round of correspondence between the research group initiating the Manuscript Clarification and the authors of the investigation in question will be permitted.

Submissions should be sent to the JSCR Editor-In-Chief via email:
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MANUSCRIPT SUBMISSION GUIDELINES

All manuscripts must be submitted online at http://www.editorialmanager.com/JSCR following the instructions below. Manuscripts submitted via e-mail WILL NOT be considered for publication.

1. A cover letter must accompany the manuscript and state the following: "This manuscript is original and not previously published in any form including on preprint servers, nor is it being considered elsewhere until a decision is made as to its acceptability by the JSCR Editorial Review Board." Please include the corresponding author's full contact information, including address, email, and phone number. The corresponding author assumes full ownership for all communication related to the manuscript with the journal office.

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3. All authors should be actively involved in the publication, be able to defend the paper and its findings, take full responsibility for all of its content, and should have signed off on the final version that is submitted. For additional details related to authorship, see "Uniform Requirements for Manuscripts Submitted to Biomedical Journals" at http://www.icmje.org/. All authors must have made significant contributions to manuscript to justify authorship and individual author contributions may be disclosed in the Acknowledgments section. The order of authorship must be agreed upon by all authors prior to initial submission to JSCR.

The development of Artificial Intelligence (AI) authoring tools (e.g., ChatGPT) presents the scientific community with unique challenges. In concordance with the recommendations of other publishers, it is our position that an AI authoring tool does not meet the standards required for authorship as defined by the ICMJE, and authors may not include an AI tool as a co-author of a paper. Thus, it is the position of the JSCR that *authors who use AI tools in the writing of a manuscript, production of images or graphical elements of the paper, or in the collection and analysis of data, must be transparent in disclosing in the Methods section of the paper how the AI tool was used, and which tool was used. Authors are fully responsible for the*

content of their manuscript; even those parts produced by an AI tool, and are thus liable for any breach of publication ethics.

4. The NSCA and the Editorial Board of the JSCR have endorsed the American College of Sports Medicine's policies with regards to animal and human experimentation. Their guidelines can be found online at http://www.editorialmanager.com/msse/. Please read these policies carefully. Each manuscript must show that they have had Institutional Board approval for their research and appropriate consent has been obtained pursuant to law. All manuscripts must have this clearly stated in the methods section of the paper or the manuscript will not be considered for publication. Exempt studies involving human subjects (i.e. retrospective data analysis, analysis of publically available data, educational research, analysis of surveys and interviews) must include a statement of Institutional Review Board approval per journal policy.

5. All manuscripts must be double-spaced with an additional space between paragraphs. The paper should include a minimum of 1-inch margins and page numbers in the upper right corner next to the running head. Authors must use terminology based upon the International System of Units (SI). A full list of SI units can be accessed online at http://physics.nist.gov/.

6. The JSCR endorses the same policies as the American College of Sports Medicine in that the language is English for the publication. "Authors who speak English as a second language are encouraged to seek the assistance of a colleague experienced in writing for English language journals. Authors are encouraged to use nonsexist language as defined in the American Psychologist 30:682- 684, 1975, and to be sensitive to the semantic description of persons with chronic diseases and disabilities, as outlined in an editorial in Medicine & Science in Sports & Exercise_, 23(11), 1991. As a general rule, only standardized abbreviations and symbols should be used. If unfamiliar abbreviations are employed, they should be defined when they first appear in the text. Authors should follow Webster's Tenth Collegiate Dictionary for spelling, compounding, and division of words. Trademark names should be capitalized and the spelling verified. Chemical or generic names should precede the trade name or abbreviation of a drug the first time it is used in the text."

7. There are no word limitations to original studies and reviews but authors are instructed to be concise and accurate in their presentation and length will be evaluated by the Editor and reviewers for appropriateness.

8. Scientific misconduct (i.e. data fabrication, falsification, deceptive image manipulation, plagiarism, ethics violations, undisclosed conflicts of interest, duplicate publication, and human/animal research violations) will not be tolerated. Concerns of alleged scientific misconduct should be brought to the attention of the Editor-in-Chief for review using procedures established by the Committee on Publication Ethics (COPE) (publicationethics.org/resources/flowcharts). Pending review of the claims, consequential actions may include rejection of the submitted manuscript of interest, informing the authors' institution of the alleged misconduct, retraction of a previously-published paper, and potential debarment of the author(s) from future JSCR publication. Additional scientific misconduct details may be found at http://www.icmje.org/. Acknowledgment of honest error, omission, or differences in data interpretation that do not alter the findings of a paper may occur via the Manuscript Clarification process or publication of an Erratum.

Please Note

- Please make sure it is noted under the "Subjects" section in the METHODS that the study was approved by an Institutional Review Board (IRB) or Ethics Board and that the subjects were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study. Additionally, if anyone who is under the age of 18 years of age is included, it should also be noted that parental or guardian signed consent was obtained. Please give the age range if the mean and SD suggest the subjects may have been under the age of 18 years. Authors are encouraged to include the IRB protocol or approval number.
- Please make SURE you have all your tables and figures attached and noted in the text of paper as well as below a paragraph of where it should be placed.
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MANUSCRIPT PREPARATION

1. Title Page

The title page should include the manuscript title, brief running head, laboratory(s) where the research was conducted, authors' full name(s) spelled out with middle initials, department(s), institution(s), full mailing address of corresponding author including telephone and fax numbers, and email address, and disclosure of funding received for this work from any of the following organizations: National Institutes of Health (NIH); Wellcome Trust; Howard Hughes Medical Institute (HHMI); and other(s). Regarding authorship, each contributor should have played a role in at least two of the following areas: research concept and study design, literature review, data collection, data analysis and interpretation, statistical analyses, writing of the manuscript, or reviewing/editing a draft of the manuscript.

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A second title page should be included that contains only the manuscript title. This will be used to send to the reviewers in our double blind process of review. Do not place identifying information in the Acknowledgment portion of the paper or anywhere else in the manuscript.

3. Abstract and Key Words

On a separate page, the manuscript must have an abstract with a limit of 250 words followed by 3 - 6 key words not used in the title. The abstract should have sentences (no headings) related to the purpose of the study, brief methods, results, conclusions and practical applications, and should include a statement denoting the level of significance set for the study (i.e. $\rho \leq 0.05$).

4. Text

The text must contain the following sections with titles in ALL CAPS (i.e. INTRODUCTION, METHODS, RESULTS, DISCUSSION, PRACTICAL APPLICATIONS, ACKNOWLEDGMENTS, and REFERENCES) in this exact order:

A. Introduction. This section is a careful development of the hypotheses of the study leading to the clear purpose of the investigation. It should include the practical question that forms the basis of the study and how it may influence strength and conditioning practices. In most cases use no subheadings in this section and try to limit it to 4 - 6 concisely written paragraphs. The subject matter does not have to be exhaustively reviewed in this section.

B. Methods. Within the METHODS section, the following subheadings are required in the following order: ''Experimental Approach to the Problem,'' where the author(s) show how their study design will be able to test the hypotheses developed in the introduction and give some basic rationales for the choices made for the independent and dependent variables used in the study; ''Subjects,'' where the authors include the Institutional Review Board or Ethics Committee approval of their project and appropriate informed consent has been gained. Eligibility criteria for subject selection should be included in the manuscript. Authors should include relative descriptive information such as age, height, body mass, and when appropriate the training status and training history of the subjects, e.g. years of training or sport experience. When appropriate, dietary controls and supervision should be described. All subject characteristics that are not dependent variables of the study should be included in this section and not in the RESULTS; ''Procedures,'' in this section the methods used are presented with the concept of ''replication of the study'' kept in mind. Authors should describe the research design used in the study. Training programs and testing methods used should be described in detail. Authors are strongly encouraged to include a Control group/condition when appropriate. If a Control group/condition is not used, authors MUST provide test-retest reliability coefficients of the measures used during protocols involving multiple testing periods. Test-retest reliability data should be generated from the authors' laboratory and not merely cited from literature obtained in other laboratories. Additionally, reviewers will look for experimental control for time of day, hydration, sleep and nutritional status. ''Statistical Analyses,'' here is where you clearly state your statistical approach to the analysis of the data set(s). It is important that you include your alpha level for significance (e.g., $\rho \leq 0.05$). Please place your statistical power in the manuscript for the n size used and reliability of the dependent measures with intra-class correlations (ICC Rs). Additional subheadings can be used but should be limited. Authors should report effect sizes and confidence intervals when appropriate. Traditional statistical

procedures must be used. The magnitude-based inference (MBI) approach may be used BUT ONLY IN CONJUNCTION with traditional methods.

C. Results. Present the results of your study in this section. Put the most important findings in Figure or Table format and less important findings in the text. Do not include data that is not part of the experimental design or that has been published before. Authors should not replicate data present in the text in tables or figures.

D. Discussion. Discuss the meaning of the results of your study in this section. Relate them to the literature that currently exists and make sure you bring the paper to completion with each of your hypotheses. Authors should emphasize the new and unique findings of the study. Conclusions should be supported by the data presented. Limit obvious statements like, "more research is needed." No subtitles should be included in the Discussion section.

E. Practical Applications. In this section, tell the "coach" or practitioner how your data can be applied and used. It should reflect the answer to the question posed in the Introduction. It is the distinctive characteristic of the JSCR and supports the mission of "Bridging the Gap" for the NSCA between the laboratory and the field practitioner. This section should be limited to 350 words or less.

5. References

All references must be alphabetized by surname of first author and numbered. References are cited in the text by numbers [e.g., (4,9)]. All references listed must be cited in the manuscript and referred to by number therein. For original investigations, please limit the number of references to fewer than 45 or explain why more are necessary. The Editorial Office reserves the right to ask authors to reduce the number of references in the manuscript. It is acceptable to cite a published Research Abstract ONLY if it is a sole source of information in that specific scientific area. JSCR forbids the citation of manuscripts published on preprint servers. For journal entries with 6 or more co-authors, please list the first 3 names followed by "et al." When citing chapters within an edited textbook, authors MUST specifically cite the chapter author names (not the editors). Authors must also include the chapter name and page range for all book references. Please check references carefully for accuracy. Changes to references at the proof stage, especially changes affecting the numerical order in which they appear, will result in author revision fees. For End Note Users, the software currently is using an older style of formatting for JSCR references. It is recommended that authors update the final reference list by either manually checking each reference to ensure proper formatting or updating their End Note software. To update the software, End Note users may edit "Output Styles" for JSCR and save the changes. Users may click "Citations" and "Author Lists" to edit "Author Separators" "and "Abbreviated Author List". This will allow users to remove the term "and" and use "et al." for referencing. Questions regarding End Note use or software editing are directed to Clarivate support at 1-800-336-4474. If using End Note please double-check citations and make sure journal article titles do not have all words capitalized and journal titles are abbreviated properly and italicized.

Below are several examples of references:

Journal Article
Hartung GH, Blancq RJ, Lally DA, Krock LP. Estimation of aerobic capacity from submaximal cycle ergometry in women. *Med Sci Sports Exerc* 27: 452–457, 1995.

Kraemer WJ, Hatfield DL, Comstock BA, et al. Influence of HMB supplementation and resistance training on cytokines responses to resistance exercise. *J Am Coll Nutr* 33: 247-255, 2014.

Book
Lohman TG. *Advances in Body Composition Assessment*. Champaign, IL: Human Kinetics, 1992.

Chapter in an edited book
Yahara ML. The shoulder. In: *Clinical Orthopedic Physical Therapy*. J.K. Richardson and Z.A. Iglarsh, eds. Philadelphia: Saunders, 159–199, 1994.

Software
Howard A. Moments software. University of Queensland, 1992.

Proceedings
Viru A, Viru M, Harris R, et al. Performance capacity in middle-distance runners after enrichment of diet by creatine and creatine action on protein synthesis rate. In: Proceedings of the 2nd Maccabiah-Wingate International Congress of Sport and Coaching Sciences. G. Tenenbaum and T. Raz-Liebermann, eds. Netanya, Israel, Wingate Institute, 22–30, 1993.

Dissertation/Thesis
Bartholmew SA. Plyometric and vertical jump training. Master's thesis, University of North Carolina, Chapel Hill, 1985.

6. Acknowledgments

In this section you can place the information related to identification of funding sources; current contact information of corresponding author; and gratitude to other people involved with the conduct of the experiment. In this part of the paper the conflict of interest information must be included. In particular, authors should: 1) Disclose professional relationships with companies or manufacturers who will benefit from the results of the present study, 2) Cite the specific grant support for the study and 3) State that the results of the present study do not constitute endorsement of the product by the authors or the NSCA. Failure to disclose such information could result in the rejection of the submitted manuscript. In addition, individual author contributions to the manuscript may be listed here.

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The units of measurement shall be Systeme International d'Unite´ s (SI). Permitted exceptions to SI are heart rate—beats per min; blood pressure—mm Hg; gas pressure—mm Hg. Authors should refer to the British Medical Journal (1:1334 – 1336, 1978) and the Annals of Internal Medicine (106: 114 – 129, 1987) for the proper method to express other units or abbreviations. When expressing units, please locate the multiplication symbol midway between lines to avoid confusion with periods; e.g., $ml \cdot min^{-1} \cdot kg^{-1}$.

The basic and derived units most commonly used in reporting research in this Journal include the following: mass—gram (g) or kilogram (kg); force—newton (N); distance—meter (m), kilometer (km); temperature—degree Celsius (_C); energy, heat, work—joule (J) or kilojoule (kJ); power—watt (W); torque—newton-meter (N_m); frequency— hertz (Hz); pressure—pascal (Pa); time—second (s), minute (min), hour (h); volume—liter (L), milliliter (mL); and amount of a particular substance—mole (mol), millimole (mmol). Please note that the correct way to express body mass of the subjects is in kg and not "weight (lbs)" or "weight (kg)."

Selected conversion factors:
_ 1 N = 0.102 kg (force);
_ 1 J = 1 N_m = 0.000239 kcal = 0.102 kg_m;

_ 1 kJ = 1000 N_m = 0.239 kcal = 102 kg_m;
_ 1 W = 1 J_s-1 = 6.118 kg_m_min-1.

When using nomenclature for muscle fiber types please use the following terms. Muscle fiber types can be identified using histochemical or gel electrophoresis methods of classification. Histochemical staining of the ATPases is used to separate fibers into type I (slow twitch), type IIa (fast twitch) and type IIb (fast twitch) forms.Thework of Smerdu et. al (AJP 267:C1723, 1994) indicates that type IIb fibers contain type IIxmyosin heavy chain (gel electrophoresis fiber typing). For the sake of continuity and to decrease confusion on this point it is recommended that authors use IIx to designate what use to be called IIb fibers. Smerdu, V, Karsch-Mizrachi, I, Campione, M, Leinwand, L, and Schiaffino, S. Type IIx myosin heavy chain transcripts are expressed in type IIb fibers of human skeletal muscle. Am J Physiol 267 (6 Pt 1): C1723–1728, 1994.

Addendum B – Physical Activity Readiness Questionnaire

2023 PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

The health benefits of regular physical activity are clear; more people should engage in physical activity every day of the week. Participating in physical activity is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

GENERAL HEALTH QUESTIONS

Please read the 7 questions below carefully and answer each one honestly: check YES or NO.	YES	NO
1) Has your doctor ever said that you have a heart condition ☐ **OR** high blood pressure ☐?	☐	☐
2) Do you feel pain in your chest at rest, during your daily activities of living, **OR** when you do physical activity?	☐	☐
3) Do you lose balance because of dizziness **OR** have you lost consciousness in the last 12 months? Please answer **NO** if your dizziness was associated with over-breathing (including during vigorous exercise).	☐	☐
4) Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)? **PLEASE LIST CONDITION(S) HERE:** _____	☐	☐
5) Are you currently taking prescribed medications for a chronic medical condition? **PLEASE LIST CONDITION(S) AND MEDICATIONS HERE:** _____	☐	☐
6) Do you currently have (or have had within the past 12 months) a bone, joint, or soft tissue (muscle, ligament, or tendon) problem that could be made worse by becoming more physically active? Please answer **NO** if you had a problem in the past, but it **does not limit your current ability** to be physically active. **PLEASE LIST CONDITION(S) HERE:** _____	☐	☐
7) Has your doctor ever said that you should only do medically supervised physical activity?	☐	☐

If you answered NO to all of the questions above, you are cleared for physical activity.
Please sign the PARTICIPANT DECLARATION. You do not need to complete Pages 2 and 3.

- Start becoming much more physically active – start slowly and build up gradually.
- Follow Global Physical Activity Guidelines for your age (https://www.who.int/publications/i/item/9789240015128).
- You may take part in a health and fitness appraisal.
- If you are over the age of 45 yr and NOT accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.
- If you have any further questions, contact a qualified exercise professional.

PARTICIPANT DECLARATION

If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for its records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME _____ DATE _____

SIGNATURE _____ WITNESS _____

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER _____

If you answered YES to one or more of the questions above, COMPLETE PAGES 2 AND 3.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ at www.eparmedx.com before becoming more physically active.
- Your health changes - answer the questions on Pages 2 and 3 of this document and/or talk to your doctor or a qualified exercise professional before continuing with any physical activity program.

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FOLLOW-UP QUESTIONS ABOUT YOUR MEDICAL CONDITION(S)

1. Do you have Arthritis, Osteoporosis, or Back Problems?

If the above condition(s) is/are present, answer questions 1a-1c — If **NO** ☐ go to question 2

1a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
1b.	Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)?	YES ☐ NO ☐
1c.	Have you had steroid injections or taken steroid tablets regularly for more than 3 months?	YES ☐ NO ☐

2. Do you currently have Cancer of any kind?

If the above condition(s) is/are present, answer questions 2a-2b — If **NO** ☐ go to question 3

2a.	Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and/or neck?	YES ☐ NO ☐
2b.	Are you currently receiving cancer therapy (such as chemotheraphy or radiotherapy)?	YES ☐ NO ☐

3. Do you have a Heart or Cardiovascular Condition? This includes Coronary Artery Disease, Heart Failure, Diagnosed Abnormality of Heart Rhythm

If the above condition(s) is/are present, answer questions 3a-3d — If **NO** ☐ go to question 4

3a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
3b.	Do you have an irregular heart beat that requires medical management? (e.g., atrial fibrillation, premature ventricular contraction)	YES ☐ NO ☐
3c.	Do you have chronic heart failure?	YES ☐ NO ☐
3d.	Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?	YES ☐ NO ☐

4. Do you currently have High Blood Pressure?

If the above condition(s) is/are present, answer questions 4a-4b — If **NO** ☐ go to question 5

4a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
4b.	Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer **YES** if you do not know your resting blood pressure)	YES ☐ NO ☐

5. Do you have any Metabolic Conditions? This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes

If the above condition(s) is/are present, answer questions 5a-5e — If **NO** ☐ go to question 6

5a.	Do you often have difficulty controlling your blood sugar levels with foods, medications, or other physician-prescribed therapies?	YES ☐ NO ☐
5b.	Do you often suffer from signs and symptoms of low blood sugar (hypoglycemia) following exercise and/or during activities of daily living? Signs of hypoglycemia may include shakiness, nervousness, unusual irritability, abnormal sweating, dizziness or light-headedness, mental confusion, difficulty speaking, weakness, or sleepiness.	YES ☐ NO ☐
5c.	Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, **OR** the sensation in your toes and feet?	YES ☐ NO ☐
5d.	Do you have other metabolic conditions (such as current pregnancy-related diabetes, chronic kidney disease, or liver problems)?	YES ☐ NO ☐
5e.	Are you planning to engage in what for you is unusually high (or vigorous) intensity exercise in the near future?	YES ☐ NO ☐

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6. Do you have any Mental Health Problems or Learning Difficulties? This includes Alzheimer's, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome

If the above condition(s) is/are present, answer questions 6a-6b — If **NO** ☐ go to question 7

6a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
6b.	Do you have Down Syndrome **AND** back problems affecting nerves or muscles?	YES ☐ NO ☐

7. Do you have a Respiratory Disease? *This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure*

If the above condition(s) is/are present, answer questions 7a-7d — If **NO** ☐ go to question 8

7a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
7b.	Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?	YES ☐ NO ☐
7c.	If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week?	YES ☐ NO ☐
7d.	Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?	YES ☐ NO ☐

8. Do you have a Spinal Cord Injury? *This includes Tetraplegia and Paraplegia*

If the above condition(s) is/are present, answer questions 8a-8c — If **NO** ☐ go to question 9

8a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
8b.	Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?	YES ☐ NO ☐
8c.	Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)?	YES ☐ NO ☐

9. Have you had a Stroke? *This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event*

If the above condition(s) is/are present, answer questions 9a-9c — If **NO** ☐ go to question 10

9a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
9b.	Do you have any impairment in walking or mobility?	YES ☐ NO ☐
9c.	Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?	YES ☐ NO ☐

10. Do you have any other medical condition not listed above or do you have two or more medical conditions?

If you have other medical conditions, answer questions 10a-10c — If **NO** ☐ read the Page 4 recommendations

10a.	Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months **OR** have you had a diagnosed concussion within the last 12 months?	YES ☐ NO ☐
10b.	Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)?	YES ☐ NO ☐
10c.	Do you currently live with two or more medical conditions?	YES ☐ NO ☐

PLEASE LIST YOUR MEDICAL CONDITION(S) AND ANY RELATED MEDICATIONS HERE: _____

GO to Page 4 for recommendations about your current medical condition(s) and sign the PARTICIPANT DECLARATION.

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If you answered NO to all of the FOLLOW-UP questions (pgs. 2-3) about your medical condition, you are ready to become more physically active - sign the PARTICIPANT DECLARATION below:

- It is advised that you consult a qualified exercise professional to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually - 20 to 60 minutes of low to moderate intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate intensity physical activity per week.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.

If you answered **YES** to **one or more of the follow-up questions** about your medical condition:

You should seek further information before becoming more physically active or engaging in a fitness appraisal. You should complete the specially designed online screening and exercise recommendations program - the **ePARmed-X+ at www.eparmedx.com** and/or visit a qualified exercise professional to work through the ePARmed-X+ and for further information.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ **at www.eparmedx.com** before becoming more physically active.
- Your health changes - talk to your doctor or qualified exercise professional before continuing with any physical activity program.

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The authors, the PAR-Q+ Collaboration, partner organizations, and their agents assume no liability for persons who undertake physical activity and/or make use of the PAR-Q+ or ePARmed-X+. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.

PARTICIPANT DECLARATION

- All persons who have completed the PAR-Q+ please read and sign the declaration below.
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME _____ DATE _____

SIGNATURE _____ WITNESS _____

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER _____

For more information, please contact
www.eparmedx.com
Email: eparmedx@gmail.com

Citation for PAR-Q+
Warburton DER, Jamnik VK, Bredin SSD, and Gledhill N on behalf of the PAR-Q+ Collaboration. The Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) and Electronic Physical Activity Readiness Medical Examination (ePARmed-X+). Health & Fitness Journal of Canada 4(2):3-23, 2011.

The PAR-Q+ was created using the evidence-based AGREE process (1) by the PAR-Q+ Collaboration chaired by Dr. Darren E. R. Warburton with Dr. Norman Gledhill, Dr. Veronica Jamnik, and Dr. Donald C. McKenzie (2). Production of this document has been made possible through financial contributions from the Public Health Agency of Canada and the BC Ministry of Health Services. The views expressed herein do not necessarily represent the views of the Public Health Agency of Canada or the BC Ministry of Health Services.

Key References

1. Jamnik VK, Warburton DER, Makarski J, McKenzie DC, Shephard RJ, Stone J, and Gledhill N. Enhancing the effectiveness of clearance for physical activity participation; background and overall process. APNM 36(S1):S3-S13, 2011.
2. Warburton DER, Gledhill N, Jamnik VK, Bredin SSD, McKenzie DC, Stone J, Charlesworth S, and Shephard RJ. Evidence-based risk assessment and recommendations for physical activity clearance; Consensus Document. APNM 36(S1):S266-s298, 2011.
3. Chisholm DM, Collis ML, Kulak LL, Davenport W, and Gruber N. Physical activity readiness. British Columbia Medical Journal. 1975;17:375-378.
4. Thomas S, Reading J, and Shephard RJ. Revision of the Physical Activity Readiness Questionnaire (PAR-Q). Canadian Journal of Sport Science 1992;17:4 338-345.

Addendum C – Informed Consent Form

TITLE OF RESEARCH PROJECT:	
Muscle Oxygenation and Performance Adaptations in Trained Cyclists Following a Polarized and Threshold Training Intervention	
DETAILS OF PRINCIPAL INVESTIGATOR (PI):	
Title, first name, surname: Mr Colin Fleming	**Ethics reference number:** 25263
Full postal address: Department Sport Science, Stellenbosch University, Private Bag X1, Matieland, Stellenbosch, 7601	**PI Contact number:** 0797607149

We would like to invite you to take part in a research project. Please take some time to read the information presented here, which will explain the details of this project. Please ask the principal investigator any questions about any part of this project that you do not fully understand. It is particularly important that you are completely satisfied that you clearly understand what this research entails and how you could be involved. Also, your participation is **entirely voluntary,** and you are free to decline to participate. In other words, you may choose to take part, or you may choose not to take part. Nothing bad will come of it if you say no: it will not affect you negatively in any way whatsoever. Refusal to participate will involve no penalty or loss of benefits or reduction in the level of care to which you are otherwise entitled. You are also free to withdraw from the study at any point, even if you do agree to take part initially.
The Health Research Ethics Committee at Stellenbosch University has approved this study**.** The study will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, the South African Guidelines for Good Clinical Practice (2006), the Medical Research Council (MRC) Ethical Guidelines for Research (2002), and the Department of Health Ethics in Health Research: Principles, Processes and Studies (2015).

What is this research study all about?

- The purpose of the study is to broaden our understanding of the physiological adaptations to polarized and threshold training in cycling. This may aid coaches and cyclists to improve their training programs and optimize the training periodization throughout a training and racing season.
- If you agree to take part in the study and the screening procedure indicate that you are eligible, you will be invited to attend the first procedures in the laboratory, which will last roughly an hour. Your height, weight, and body metrics will be measured. You will then perform an incrementally increasing workload test, followed by a 30-second all-out test, to familiarize yourself with the tests. During your second visit, you will complete this incrementally increasing workload test, followed by the 30-second all-out test again, this time whilst different measurements will be taken. For the next six weeks you will complete either a polarized or threshold training program. This will require ~9.5 hours of cycling per week and involve two or three cycling training sessions. One of these weekly sessions will be performed in the Sport Physiology Laboratory under supervision. Each training session in the laboratory will last between

60-75 minutes. On other days you will be asked to ride under your own supervision. After the six-week training program you will be asked to return to the laboratory to undergo an incrementally increasing workload test and a 30-second all-out test again.

For all training sessions you will be asked to wear a chest heart rate monitor. You will not be allowed to consume any carbohydrate / nutrition during the pre- and post-tests.
The study will be conducted in the Sport Physiology Laboratory in the Department of Sport Science. The total duration of the study will be roughly 8 weeks. You will be expected to give a maximal effort for the two tests. Additionally, your own personal bike and cycling kit should accompany you the laboratory. At the end of the testing period, you will be provided with a report containing your test results.

Procedures of the familiarization, and pre/post-intervention tests
During the testing session you will be required to have a near infrared spectroscopy (NIRS) device attached to your side-upper leg. This is approximately 3cm wide, 8cm long, and 1.5cm thick, and will not constrict your movement. You will also be required to wear a face mask which measures your oxygen and carbon dioxide inspiration and expiration. This mask will cover your nose and mouth but will not obstruct, or aid, your breathing.
During the familiarization you will not be required to wear the NIRS or the face mask.
At the start of the test only the NIRS device will be applied for the warm-up. You will start the test with a 5-minute passive rest period. You will then perform a 10-minute warm up at 80 watts (W), at a cadence of between 80-100 rotations per minute (rpm). If desired, you can have a drink of water after the warm-up. Then the face mask will be fitted.
The incremental exercise test will start at 120 W, will increase to 150 W 60 seconds after that, and thereafter it will increase by 30 W every 2.5 minutes. In the last 30 seconds of each stage a blood sample will be taken, by fingerprick. You will be required to keep the cadence between 80-100 rpm, until exhaustion and you are no longer able to maintain the cadence above 80 rpm. At this point, the test will be terminated. You will then undergo a 5-minute active recovery period by pedalling against 80 W at a cadence of choice. You will then complete a 30-second all-out effort. After this effort you will undergo another 5-minute active recovery period against 80 W at a cadence of your choice.

Why do we invite you to participate?
You are invited to take part in this study because you have indicated your interest in the research project by responding voluntarily to the invitation and you meet the inclusion criteria for the study. The inclusion criteria stipulate that you are a recreationally trained road cyclist or mountain bike rider, actively participating in deliberate cycling exercise.

What will your responsibilities be?
We ask that you complete all questionnaires honestly and that you follow the instructions of the researchers during all phases of the testing procedures. You will also be asked to give your best efforts during the cycle ergometer tests. In case of not adhering to the pre-testing procedures (see the list below), we ask that you please inform the researcher.

Important pre-testing procedures:

1. eat your last meal / snack at least 3 hours before your testing;
2. avoid caffeine-containing drinks and alcohol ingestion at least 12 hours before testing;
3. avoid vigorous activities – perceived exertion above 12 (out of 20) - or any unaccustomed exercise at least 24 hours before testing;
4. stay well hydrated prior to testing.

Will you benefit from taking part in this research?
You will receive a full written report (via email) of your test results from the researcher. Additionally, you will receive a voucher for a maximal aerobic capacity (VO_2max) and body composition test, at a later stage. You will also receive a summary (via email) of the main findings of the study once the study has been completed.
If required, you may request a reimbursement of travel expenses for up to 500 ZAR.

Are there any risks involved in your taking part in this research?
There will be minimal risks involved in the study. However, you may experience dizziness, fainting, and discomfort during the different cycling tests and training sessions. However, the testing and training will not differ significantly from your usual training. The blood and lactate blood sampling will be done by non-invasive procedures, by means of a fingerprick, and will not exceed 2mL per test. Gloves, alcohol swabs and hermitically sterilized needles will be used, all sent for incineration post testing in a biohazard collection bin.
To minimize potential risks as much as possible, the procedure will be thoroughly explained to you, and the test or training will be stopped immediately if you indicate to stop, or if the primary researcher detects any unusual behavioural responses. You will also be phoned six hours post-test to confirm your well-being.

Even though it is unlikely, what will happen if you get injured somehow because you took part in this research study?
Stellenbosch University will provide comprehensive no-fault insurance and will pay for any medical costs that came about during laboratory exercise sessions due to you taking part in the research study. You will not need to prove that the researcher was at fault.
Should you complete any training sessions outside the laboratory, these will not fall under Stellenbosch University insurance, and they will be at your own risk, as these sessions are not part of the project.

Will you be paid to take part in this study and are there any costs involved?
You will not have to pay for anything. If required, you may request a reimbursement of travel expenses for up to 500 ZAR.

Is there anything else that you should know or do?
Raw exercise test and NIRS data collected during this study could potentially be used for future studies. This data will be completely anonymous. Additionally, the results from the study would be published in relevant national or international academic journals. Only group data and related statistics will be reported, and no participants will be identifiable in these publications.
If you have any questions or concerns about the study or procedures, please feel free to contact Colin Fleming [079 760 7149; 26364255@sun.ac.za] and/or the supervisor Prof Elmarie Terblanche [082 707 6501; et2@sun.ac.za]. You may phone the Health Research Ethics Committee at 021 938 9677/9819 if there still is something that the researchers have not explained to you, or if you have a complaint. You will receive a copy of this information and consent form for you to keep safe.

Declaration by participant

By signing below, I ……..……. agree to take part in a research study entitled *"Muscle Oxygenation and Performance Adaptations in Trained Cyclists Following a Polarized and Threshold Training Intervention."*

I declare that:

- I have read this information and consent form, or it was read to me, and it is written in a language in which I am fluent and with which I am comfortable.
- I have had a chance to ask questions and I am satisfied that all my questions have been answered.
- I understand that taking part in this study is **voluntary,** and I have not been pressurised to take part.
- I may choose to leave the study at any time and nothing bad will come of it – I will not be penalised or prejudiced in any way.
- I may be asked to leave the study before it has finished, if the study doctor or researcher feels it is in my best interests, or if I do not follow the study plan that we have agreed on.

Signed at (*place*) .....…..……. on (*date*) ……...……. 2023.

....

Signature of participant **Signature of witness**

Declaration by investigator

I *(name)* ……...…… declare that:

- I explained the information in this document in a simple and clear manner to ……..
- I encouraged him/her to ask questions and took enough time to answer them.
- I am satisfied that he/she completely understands all aspects of the research, as discussed above.
- I did/did not use an interpreter. (*If an interpreter is used then the interpreter must sign the declaration below.)*

Signed at (*place*) .....…..……... on (*date*) ……...…….. 2023.

....

Signature of investigator **Signature of witness**

Permission to have all anonymous data shared with journals:
Please carefully read the statements below (or have them read to you) and think about your choice. No matter what you decide, it will not affect whether you can be in the research study, or your routine health care.
When this study is completed, we would like to publish the results in academic journals. Most journals require us to share your anonymous raw exercise test and NIRS data with them before they publish the results. Therefore, we would like to obtain your permission to have your anonymous data shared with journals.

Permission for sharing anonymous raw data with other investigators:
Please carefully read the statements below (or have them read to you) and think about your choice. No matter what you decide, it will not affect whether you can be in the research study, or your routine health care.
In order to do the research, we have discussed, we must collect and store exercise and NIRS data. Once we have completed the data collection, we would like to store your exercise and NIRS data. Other investigators, in- and outside Stellenbosch University, can ask to use this data in future research. To protect your privacy, we will replace your name with a unique, anonymous, study number. We will only use this code for your data. We will do our best to keep the code private. It is however always possible that someone could find out about your name, but this is very unlikely to happen. Therefore, we would like to ask for your permission to share your exercise and NIRS data with other investigators.

Tick the option you choose for anonymous data sharing with journals:
I agree to have my anonymous data shared with journals during publication of results of this study
☐ Signature _____
OR
I do not agree to have my anonymous data shared with journals during publication of results of this study
☐ Signature _____

Tick the option you choose for sharing anonymous exercise and NIRS data with other investigators:
My anonymous data may be shared with other investigators for further analysis and future research
☐ Signature _____
OR
I do not want my anonymous data to be shared with other investigators
☐ Signature _____

Addendum D – Polarized Training Intervention

Day	Week	Date	Zone	Session	Duration
Monday	1	1/2/2023		15 min W/U - 5x 4 min Z3 (3 min r.) - 10 min C/D	60
Tuesday	1	1/3/2023		90 min Z1	90
Wednesda	1	1/4/2023		150 min Z1	120
Thursday	1	1/5/2023		15 min W/U - 5x 4 min Z3 (3 min r.) - 10 min C/D	60
Friday	1	1/6/2023		90 min Z1	90
Saturday	1	1/7/2023		150 min Z1	150
Sunday	1	1/8/2023		No ride	0
Monday	2	1/9/2023		15 min W/U - 5x 4 min Z3 (3 min r.) - 10 min C/D	60
Tuesday	2	1/10/2023		90 min Z1	90
Wednesda	2	1/11/2023		150 min Z1	120
Thursday	2	1/12/2023		15 min W/U - 5x 4 min Z3 (3 min r.) - 10 min C/D	60
Friday	2	1/13/2023		90 min Z1	90
Saturday	2	1/14/2023		150 min Z1	150
Sunday	2	1/15/2023		No ride	0
Monday	3	1/16/2023		15 min W/U - 5x 4 min Z3 (3 min r.) - 10 min C/D	60
Tuesday	3	1/17/2023		90 min Z1	90
Wednesda	3	1/18/2023		150 min Z1	120
Thursday	3	1/19/2023		15 min W/U - 5x 4 min Z3 (3 min r.) - 10 min C/D	60
Friday	3	1/20/2023		90 min Z1	90
Saturday	3	1/21/2023		150 min Z1	150
Sunday	3	1/22/2023		No ride	0
Monday	4	1/23/2023		15 min W/U - 5x 4 min Z3 (3 min r.) - 10 min C/D	60
Tuesday	4	1/24/2023		90 min Z1	90
Wednesda	4	1/25/2023		150 min Z1	120
Thursday	4	1/26/2023		15 min W/U - 5x 4 min Z3 (3 min r.) - 10 min C/D	60
Friday	4	1/27/2023		90 min Z1	90
Saturday	4	1/28/2023		150 min Z1	150
Sunday	4	1/29/2023		No ride	0
Monday	5	1/30/2023		15 min W/U - 5x 4 min Z3 (3 min r.) - 10 min C/D	60
Tuesday	5	1/31/2023		90 min Z1	90
Wednesda	5	2/1/2023		150 min Z1	120
Thursday	5	2/2/2023		15 min W/U - 5x 4 min Z3 (3 min r.) - 10 min C/D	60
Friday	5	2/3/2023		90 min Z1	90
Saturday	5	2/4/2023		150 min Z1	150
Sunday	5	2/5/2023		No ride	0
Monday	6	2/6/2023		15 min W/U - 5x 4 min Z3 (3 min r.) - 10 min C/D	60
Tuesday	6	2/7/2023		90 min Z1	90
Wednesda	6	2/8/2023		150 min Z1	120
Thursday	6	2/9/2023		15 min W/U - 5x 4 min Z3 (3 min r.) - 10 min C/D	60
Friday	6	2/10/2023		90 min Z1	90
Saturday	6	2/11/2023		150 min Z1	150
Sunday	6	2/12/2023		No ride	0

Zone	Colour Code
1	
2	
3	
Rest	

Minutes	Percentage	Zone
450	78.9	Z1
0	0.0	Z2
120	21.1	Z3
570	100	Weekly Total (min.)

Abbreviations:

W/U	-	warm up
Z1	-	zone 1 (<LT1)
Z2	-	zone 2 (between LT1 and LT2)
Z3	-	zone 1 (>LT2)
C/D	-	cool down
min.	-	minutes
s	-	second
max.	-	maximal

Addendum E – Threshold Training Intervention

Day	Week	Date	Zone	Session	Duration
Monday	1	1/2/2023		10 min W/U - 6x 7 min Z2 (3 min r.) - 10 min C/D	75
Tuesday	1	1/3/2023		90 min Z1	90
Wednesda	1	1/4/2023		10 min W/U - 6x 7 min Z2 (3 min r.) - 10 min C/D	75
Thursday	1	1/5/2023		90 min Z1	90
Friday	1	1/6/2023		15 min W/U - 3x 20 min Z2 (4 min r.) - 7 min C/D	90
Saturday	1	1/7/2023		150 min Z1 (every 20 min. a 15s max. sprint)	150
Sunday	1	1/8/2023		No ride	0
Monday	2	1/9/2023		10 min W/U - 6x 7 min Z2 (3 min r.) - 10 min C/D	75
Tuesday	2	1/10/2023		90 min Z1	90
Wednesda	2	1/11/2023		10 min W/U - 6x 7 min Z2 (3 min r.) - 10 min C/D	75
Thursday	2	1/12/2023		90 min Z1	90
Friday	2	1/13/2023		15 min W/U - 3x 20 min Z2 (4 min r.) - 7 min C/D	90
Saturday	2	1/14/2023		150 min Z1 (every 20 min. a 15s max. sprint)	150
Sunday	2	1/15/2023		No ride	0
Monday	3	1/16/2023		10 min W/U - 6x 7 min Z2 (3 min r.) - 10 min C/D	75
Tuesday	3	1/17/2023		90 min Z1	90
Wednesda	3	1/18/2023		10 min W/U - 6x 7 min Z2 (3 min r.) - 10 min C/D	75
Thursday	3	1/19/2023		90 min Z1	90
Friday	3	1/20/2023		15 min W/U - 3x 20 min Z2 (4 min r.) - 7 min C/D	90
Saturday	3	1/21/2023		150 min Z1 (every 20 min. a 15s max. sprint)	150
Sunday	3	1/22/2023		No ride	0
Monday	4	1/23/2023		10 min W/U - 6x 7 min Z2 (3 min r.) - 10 min C/D	75
Tuesday	4	1/24/2023		90 min Z1	90
Wednesda	4	1/25/2023		10 min W/U - 6x 7 min Z2 (3 min r.) - 10 min C/D	75
Thursday	4	1/26/2023		90 min Z1	90
Friday	4	1/27/2023		15 min W/U - 3x 20 min Z2 (4 min r.) - 7 min C/D	90
Saturday	4	1/28/2023		150 min Z1 (every 20 min. a 15s max. sprint)	150
Sunday	4	1/29/2023		No ride	0
Monday	5	1/30/2023		10 min W/U - 6x 7 min Z2 (3 min r.) - 10 min C/D	75
Tuesday	5	1/31/2023		90 min Z1	90
Wednesda	5	2/1/2023		10 min W/U - 6x 7 min Z2 (3 min r.) - 10 min C/D	75
Thursday	5	2/2/2023		90 min Z1	90
Friday	5	2/3/2023		15 min W/U - 3x 20 min Z2 (4 min r.) - 7 min C/D	90
Saturday	5	2/4/2023		150 min Z1 (every 20 min. a 15s max. sprint)	150
Sunday	5	2/5/2023		No ride	0
Monday	6	2/6/2023		10 min W/U - 6x 7 min Z2 (3 min r.) - 10 min C/D	75
Tuesday	6	2/7/2023		90 min Z1	90
Wednesda	6	2/8/2023		10 min W/U - 6x 7 min Z2 (3 min r.) - 10 min C/D	75
Thursday	6	2/9/2023		90 min Z1	90
Friday	6	2/10/2023		15 min W/U - 3x 20 min Z2 (4 min r.) - 7 min C/D	90
Saturday	6	2/11/2023		150 min Z1 (every 20 min. a 15s max. sprint)	150
Sunday	6	2/12/2023		No ride	0

Zone	Colour Code
1	
2	
3	
Rest	

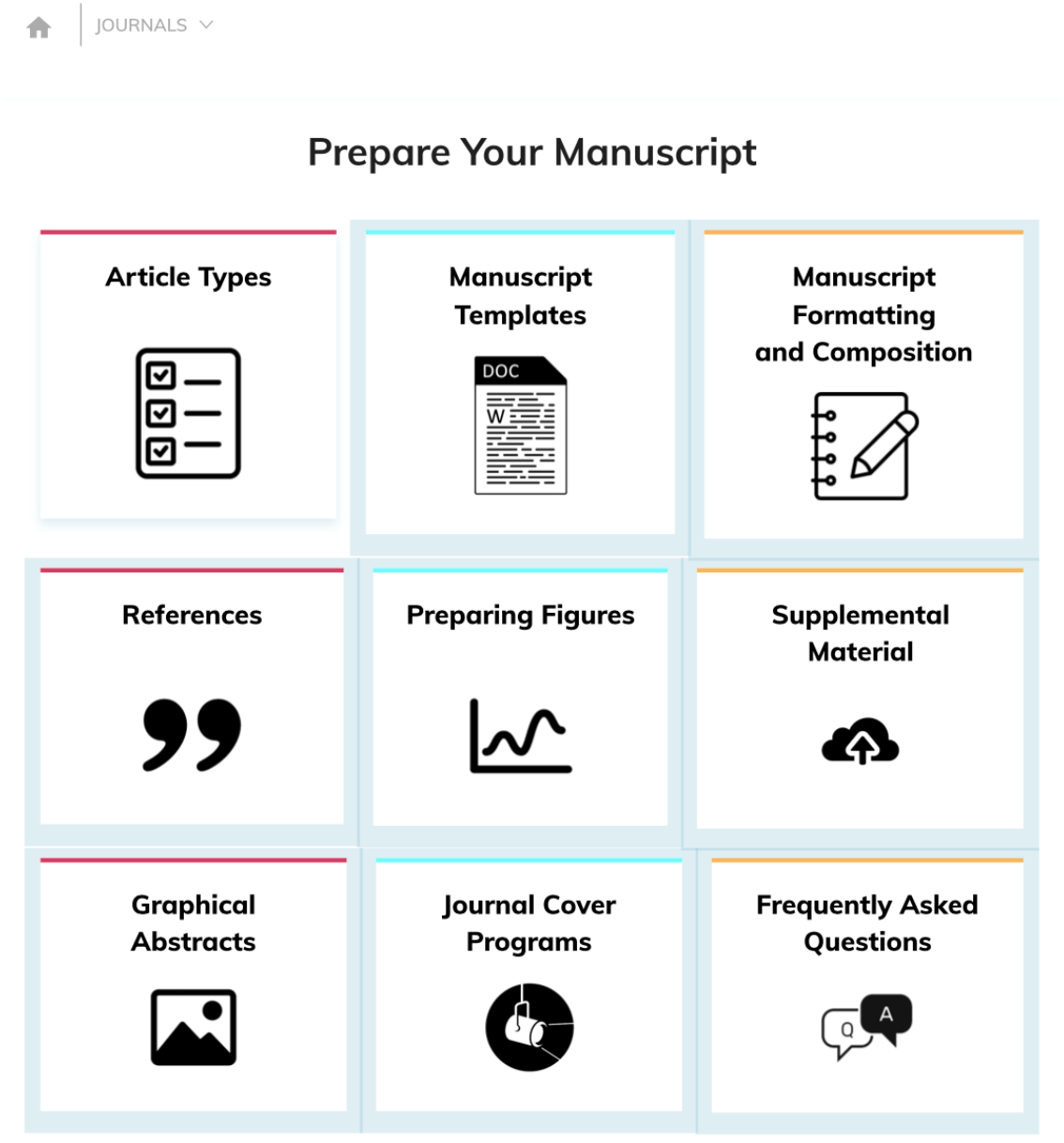
Minutes	Percentage	Zone
330	57.9	Z1
240	42.1	Z2
0	0.0	Z3
570	100.0	Weekly Total (min.)

Abbreviations:

W/U	-	warm up
Z1	-	zone 1 (<LT1)
Z2	-	zone 2 (between LT1 and LT2)
Z3	-	zone 1 (>LT2)
C/D	-	cool down
min.	-	minutes
s	-	second
max.	-	maximal

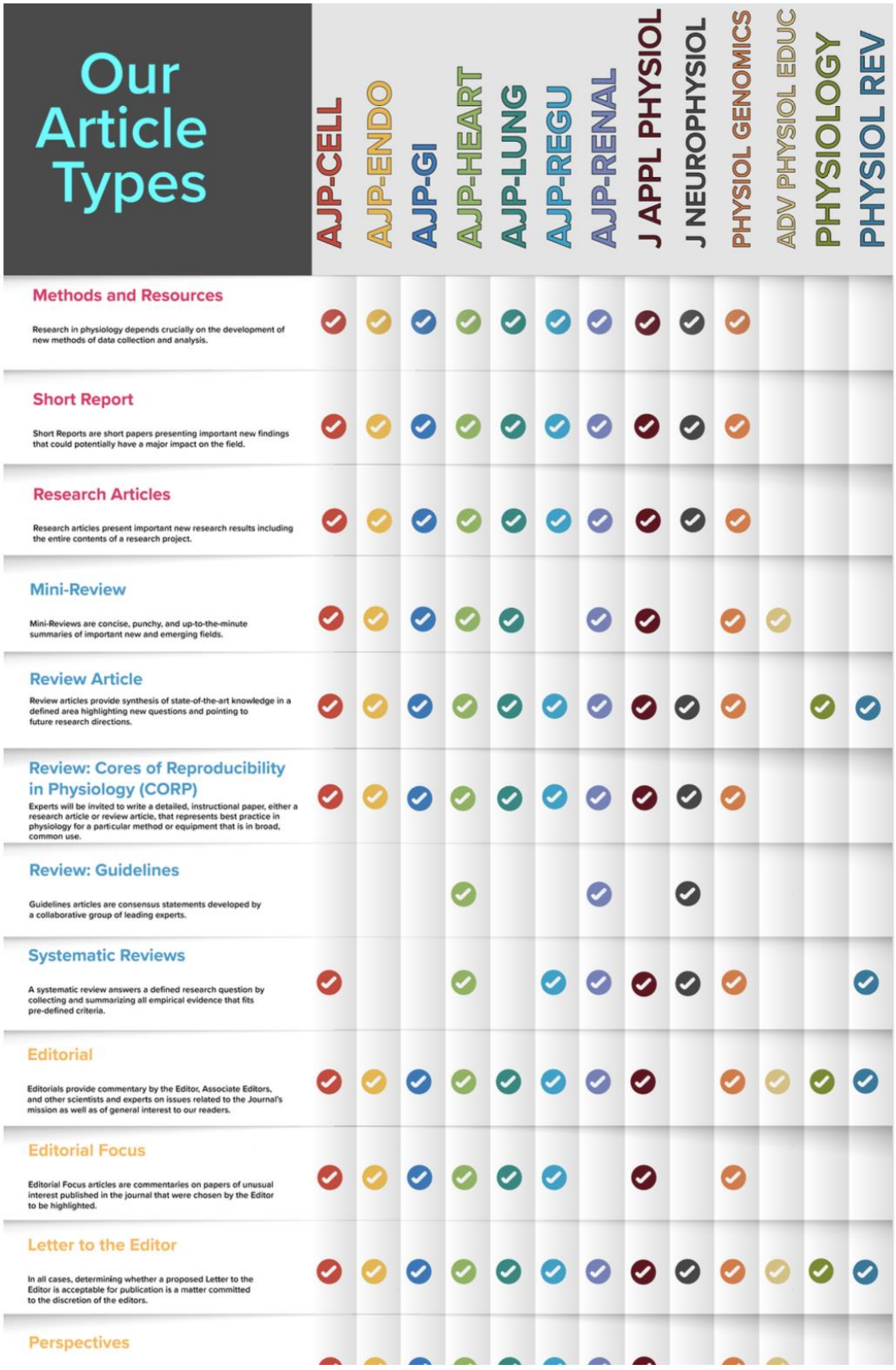
Addendum F – Journal of Applied Physiology Author Guidelines

Author's guidelines of the Journal of Applied Physiology can be found online at https://journals.physiology.org/manuscript-prep



Article Types

ARTICLE TYPES AT A GLANCE



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List of Article Types for *Advances in Physiology Education* (PDF)

ARTICLE TYPE FEATURES

ARTICLE TYPE	Abstract (250 words)	Word Limits	Figure/Table Limits	Reference Limits	Other Requirements
Methods and Resources	✓	none			Data Availability Statement; IRB Statement
Short Report	✓	4,000 words	Up to 4 figures and tables		Data Availability Statement; IRB Statement
Research Article	✓	none			Data Availability Statement; IRB Statement
Mini-Review	✓	3,000 words	1-3 figures and tables	Up to 50 references	Typically invited
Review Article	✓	6,000 words			Typically invited
Reviews for *Physiological Reviews*	✓	10,000-25,000 words	At least 10 figures		Invited only
Reviews for *Physiology*	✓	6,000 words			Invited only
Review: Cores of Reproducibility in Physiology (CORP)	✓	6,000 words			Typically invited

Review: Guidelines	✓			Typically invited
Systematic Review	✓	none		Adhere to **PRISMA statement**; study registration (see **PROSPERO**)
Editorial			Up to 10 references	Should use neutral language.
Editorial Focus		1,000 words	Up to 10 references, including the highlighted article	Should use neutral language.
Letter to the Editor		500 words	Up to 10 references, including the highlighted article	Should use neutral language.
Perspectives		1,500 words		
Viewpoint				Typically invited

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JOURNAL-SPECIFIC FEATURES

JOURNAL	Graphical Abstract	New & Noteworthy	Self-select Collections	Special Features
AJP-Cell Physiology	✓	✓		
AJP-Endocrinology and Metabolism	✓	✓		
AJP-Gastrointestinal and Liver Physiology	✓	✓		

AJP-Heart and Circulatory Physiology	optional	✓		**Sex and Gender requirement**
AJP-Lung Cellular and Molecular Physiology	optional	✓	✓	
AJP-Regulatory, Integrative and Comparative Physiology	optional	optional	✓	Perspectives and Significance
AJP-Renal Physiology	✓	✓		First Author Spotlight
Journal of Applied Physiology	✓	✓		
Journal of Neurophysiology	✓	✓		
Physiological Genomics	✓	✓		
Advances in Physiology Education	optional	✓		**Statistical requirements**
Physiology	optional			by invitation only
Physiological Reviews	✓	Clinical Highlights		by invitation only

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Manuscript Templates

RESEARCH ARTICLE

Research Article Template (.docx)

MEETING REPORTS (FOR *ADVANCES IN PHYSIOLOGY EDUCATION*)

Advances Meeting Reports Template (.docx)

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Manuscript Formatting and Composition

FLEXSUBMIT allows initial manuscripts to be submitted in a **format-neutral style**, even as a single merged PDF. If the required information is present (author details, full text, figures and tables, etc.), the manuscript will be evaluated on its scientific merit.

All revised manuscripts should be reformatted according to journal guidelines.

FORMATS AND STYLES

Manuscripts may be submitted to the **APS peer review system** in the following formats:

- Microsoft Word (.docx)
- Rich Text Format (.rtf)
- LaTeX (.tex)
- PDF (.pdf)

Manuscript submissions should contain all required elements, such as the title page, abstract, main text, references, and any hyperlinks to data supplements. Please note that PDF (.pdf) cannot be used for production of accepted articles.

LaTeX submissions must contain all necessary components to convert properly: .tex, .bbl / .bib, .cls, .bst. The fewer the number of components submitted, the easier conversion will be.

APS journals follow standard American English style and usage. Authors for whom English is not their native language are encouraged to seek the aid of a professional English language editorial service. **All manuscripts are edited by highly trained professional copy editors, according to the APS house style and guidelines.**

ABBREVIATIONS, SYMBOLS, AND TERMINOLOGY

Abbreviations should be defined at first usage. However, internationally accepted (or otherwise compellingly conventional) abbreviations do not need to be defined.

For **special characters** not available on the standard keyboard (e.g., Greek characters, mathematical symbols, figure symbols), use the Symbol font or use the "Insert Symbol" function in Microsoft Word; do not use image files (e.g., .gif) within the text.

Proprietary **trade names** should be capitalized, with the spelling carefully checked. The generic name or generic descriptor should accompany the trade name the first time it appears.

For **gene, protein, and species nomenclature**, follow current established conventions for properly presenting symbols and names, in accordance with the appropriate official organization.

- Human genes: HUGO Gene Nomenclature Committee (**HGNC**)
- Mouse genes: Mouse Genomic Informatics (**MGI**)
- Rat genes: Rat Genome Database (**RGD**)

TITLE PAGE

All submissions must contain a title page: full article title; author name(s); author affiliations where the work was done; a running head; the corresponding author's information, and abstract elements.

ARTICLE TITLE AND AUTHORS

THE **TITLE** should be succinct and informative. It should include key words to aid search discoverability. LIMIT: 160 characters and spaces

List all **AUTHORS** by surname and given names (or initials) *exactly* as they should appear online and in PDF.

"Group authorship" is allowed, with the name of a group (such as a consortium or program) listed as an author, with members of the group listed in the Acknowledgments section.

Authors may present their names in **non-Latin characters** (in their native writing system) alongside the standard English transliteration of their name; for example, "Ta-Ming Wang (王大明)."

For **AFFILIATIONS**, list all departments and institutions where the work was done, with city, state, and country. Affiliation must reflect the organization(s) supporting the author(s) *while the research was being done*. This may differ from the *current affiliations* of the author(s), which should be listed in the Acknowledgments section as the present address(es) of the author(s).

The **RUNNING HEAD** is an abbreviated version of the title, which will appear at the top of every PDF page after the first page. LIMIT: 60 characters and spaces

Only one author may be designated as the **CORRESPONDING AUTHOR** for manuscript invoicing and proofs; however, additional co-corresponding authors may be included for reader communication purposes.

ABSTRACT

A one-paragraph **ABSTRACT** should accompany all full-length manuscripts (e.g., Research Articles, Short Reports, Reviews). The abstract should state what was done and why, what was found, and what was concluded. LIMIT: 250 words

NEW & NOTEWORTHY is a brief summary of the novel findings in a research article. LIMIT: 75 words

Physiological Reviews requires a **Clinical Highlights** summary for all Reviews (200 words).

Include up to five **KEY WORDS** most relevant to the article. Avoid abbreviations. This is important for the most optimal discoverability of your article.

MAIN TEXT SECTIONS

The **INTRODUCTION** should provide a brief overview of the scope and relevance of the study, especially regarding previous advancements in related fields.

The **MATERIALS AND METHODS** section describes techniques, cell/animal models used (including species, strain, and sex), and lists of reagents, chemicals, and equipment, as well as the names of manufacturers and suppliers, including **Research Resource Identifiers (RRIDs)** when possible. Also in this section, describe the statistical methods that were used to evaluate the data. See **Rigor and Reproducibility Guidelines (PDF)** for more information.

All animal or human studies must contain an explicit statement that the protocols were submitted to, and approved by, an institutional review board or committee or that the protocols were performed under a license obtained from such a committee, board, or governing office (see **Guiding Principles for the Care and Use of Vertebrate Animals in Research and Training**).

For studies involving humans or animals, the **sex and/or gender** of participants or models must be reported. ***AJP-Heart and Circulatory Physiology*** expects authors to consider use of more than one sex or gender in experimental design, analysis, and reporting. See **Sex and Gender requirement**.

Experimental **RESULTS** present the experimental data and their statistical significance. Also see **Rigor and Reproducibility Guidelines (PDF)**.

APS has published an **editorial** on the use of statistics, and authors are encouraged to consult it. ***Advances in Physiology Education*** supports adherence of two of the guidelines:

- Guideline 5. Report variability using a standard deviation.
- Guideline 7. Report a precise P value.

Use the **DISCUSSION** to explain your interpretation of the data, especially compared with previously published material cited in the References. Significance and limitations may also be present. ***AJP-Regulatory, Integrative and Comparative Physiology*** requires a Perspectives and Significance section at the end of the Discussion.

An **APPENDIX** may be included in mathematical modeling or computational papers, e.g., to provide details of a solution strategy.

A **GLOSSARY** may be included in equation-laden articles with many different symbols (such as mathematical modeling or computational papers). The glossary will appear before the Acknowledgments. See **this article** for an example.

The **ACKNOWLEDGMENTS** section is where to thank people indirectly involved with the research (e.g., technical assistance, gifts of reagents, loans of equipment, suggestions during writing). Dedications of articles to persons living or deceased are not permitted.

Current addresses of authors (which may differ from those in the affiliation line) should be included here.

List the **GRANTS**, fellowships, and donations that funded (partially or completely) the research. Please include the grant identification number and the recipient name(s).

Authors must list all **DISCLOSURES** at the time of submission to disclose any perceived or potential conflict of interest, financial or otherwise. See **Author Conflict of Interest**. If the article is accepted for publication, this information, or the lack of potential conflicts, will be published in the Disclosures section.

Any **DISCLAIMERS** by the authors, their institution, or funding body may also be included. Example: "The content is solely the authors' responsibility and does not necessarily represent the official views of the [institution]."

Identify all **AUTHOR CONTRIBUTIONS** for the study: Conceived and designed research, performed experiments, analyzed data, interpreted results of experiments, prepared figures, drafted manuscript, edited and revised manuscript, approved final version of manuscript. The information must be the same as in the online journal submission site.

FIGURE LEGENDS AND TABLES

FIGURE LEGENDS should describe the relevant details of the figure, placing it in the proper context of the manuscript. Legends should sufficiently describe the figure on their own, without reference to the main text. Define all statistical symbols and abbreviations.

TABLES should adhere to the following guidelines:

- Tables must be submitted in Word table format, not as tabbed text or as embedded graphics.
- Table titles should briefly describe the data presented.
- Notes, symbols, and abbreviations should be defined in the table legend.
- Statistical measures of variations, SD, SE, etc., must be identified in the legend.

See **Rigor and Reproducibility Guidelines (PDF)** for more guidance.

MATH AND COMPUTER SIMULATIONS

EQUATIONS and complex math should be prepared using a math editor such as Microsoft Word Equation Editor or MathType (available from **wiris**). In-text math that can be regular text should be prepared using bold, italics, superscript, and subscript together with characters in the Symbol or Greek fonts (e.g., $x^2[n - 2\delta]$).

Mathematical equations should be simplified as much as possible and carefully checked.

- **Symbols** should be defined as they first appear in the text.
- A **glossary** may be included in articles with many different symbols, specifying the units (dimensions) as well as each definition.

Presentation of **MATHEMATICAL MODELS** should be sufficiently clear to allow physiologists with limited experience in modeling to follow the model development, limitations, and physiological relevance. Assumptions concerning the importance of physiological processes included in the model should be clearly stated. See **Mathematical Models policy**.

For **COMPUTER SIMULATIONS** using original author-generated code, authors are ***encouraged*** to deposit software and code via a public repository, such as **GitHub**, if not already deposited to a public repository. **Computer Simulations policy**.

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REFERENCES

References should be limited to **published or accepted articles**.

Reference lists for all APS journals should be arranged **by order of in-text citation** and numbered serially.

TEMPLATES

Appropriate templates for citation management software are available from the respective company websites.

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EXAMPLES

JOURNAL ARTICLE

Holowatz LA, Houghton BL, Wong BJ, Wilkins BW, Harding AW, Kenney WL, Minson CT. Nitric oxide and attenuated reflex cutaneous vasodilation in aged skin. *Am J Physiol Heart Circ Physiol* 284: H1662–H1667, 2003. https://doi.org/10.1152/ajpheart.00871.2002.

BOOK CHAPTER

Pollock DM. Endothelin receptor subtypes and tissue distribution. In: *Endothelin Molecular Biology, Physiology, and Pathology*, edited by Highsmith RF. Totowa, NJ: Humana, 1998.

ONLINE CONTENT

The general format is Author/editor (if known). (Revision or copyright date, if available). Title of page [Publication medium]. Page publisher. URL (Protocol://Site/Path/File) [Access date].

Dudoit S, Yang YH, Callow MJ, Speed TJ. Statistical methods for identifying differentially expressed genes in replicated cDNA microarray experiments [Online]. Dept. of Statistics, Univ. of California at Berkeley. http://www.stat.berkeley.edu/users/terry/zarray/Html/matt.html [3 Sept. 2000].

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Unpublished materials, observations, or personal communications should be cited only in the text. This includes, but is not limited to the following circumstances:

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Preparing Figures

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Double (side legend)	4–5	10–12	25–30
Full Width	6–7.15	15–18	36–43
Maximum Depth	9	22.8	54

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Adobe Photoshop tips

Adobe Illustrator tips

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> Supplemental Tables S1–SX: DOI.

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AJP-Endocrinology and Metabolism	✓	revision	Template A	Must be unique to other figures
AJP-Gastrointestinal and Liver Physiology	✓	revision		
AJP-Heart and Circulatory Physiology	optional			
AJP-Lung Cellular and Molecular Physiology	✓	revision	Template B	
AJP-Regulatory, Integrative and Comparative Physiology	optional			
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Journal of Neurophysiology	✓	revision		
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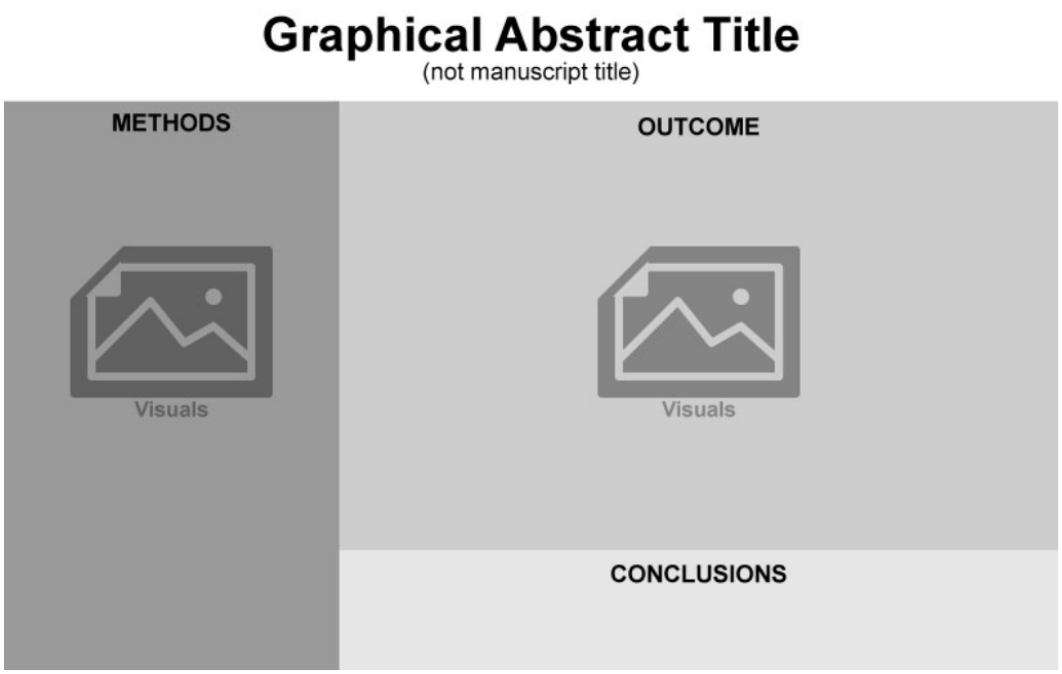

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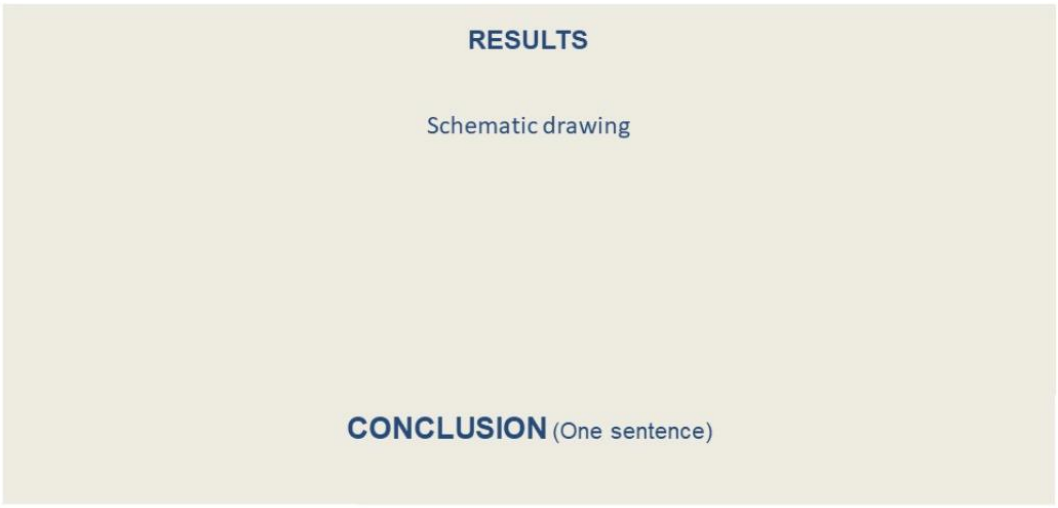

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Manuscript Preparation FAQ

APS Spotlight Cover FAQ

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