Taking ventilatory measurements out of the lab and into the field

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ACKNOWLEDGEMENT

I would like to express my gratitude to my supervisor, Stephen Seiler. His guidance, knowledge, and great enthusiasm made the experience of designing and preforming the study truly remarkable.

I also want to take the opportunity to thank Espen Aareskjold and the participants from Uno-X Pro Cycling Team for cooperation. Working with them was a highlight in the project and attending the training camp was a memorable trip which I learned a lot from.

I would also like to thank Arnar Larusson at TymeWear and John Peters for their back-end engineering and improvements needed for the project, and quickly resolving technological issues underway.

I would also like to thank my research group for the last year for great discussion, lab experiences and contributions through this process.

ABBREVIATIONS

In order of appearance

LIT – Low-intensity-training
HIT – High-intensity-training
HR – Heart rate
bLa- - Blood lactate
RPE – Rate of perceived exertion
B_R – Breathing rate
VO_{2max} – Maximal oxygen consumption
IoT – Internet of things
LT – Lactate threshold
VT – Ventilatory threshold
HUD – Head-up-display
CO_2 – Carbon dioxide
LT1 – First lactate threshold
VT1 – First ventilatory threshold
VT2 – Second ventilatory threshold
LT2 – Second lactate threshold
VE – Minute ventilation
VO2 – Oxygen consumption
ECG - Electrocardiography
HR_{max} – Maximal heart rate
FTP – Functional threshold power
CP – Critical power
MMSS – Maximal metabolic steady state
PCG – Photoplethysmography
Brpm – Breaths per minute
LoA – Limits of agreement
IMU – Internal measuring unit
V_T – Tidal volume
AU – arbitrary units
AWS – Amazon web services
%HRR – Percent of heart rate reserve
%BRR – Percent of breathing rate reserve
NS = Not significant
rpm – rounds per minute
B_{Rmax} – maximal breathing rate

ABSTRACT

BACKGROUND: Measuring ventilation has priorly been limited to physiological laboratory testing, but now wearables allow for measuring in filed settings. The aim of the study was 1) to quantify breathing rate (B_R) response during typical training sessions performed by elite endurance athletes, 2) to investigate if breathing rate responds differently than heart rate during two different standardized field sessions in a group of elite cyclists, 3) to investigate the potential implementation of breathing rate as a practical measurement in training for intensity monitoring in cycling.

METHODS: Heart rate (HR), B_R and power output were quantified in 11 professional cyclists from the Uno-X Pro Cycling Team during at home training and two training camps in Spain during a 6-month period. The participants executed two standardized filed sessions, measuring their internal responses with wearable devices, in addition to power output.

RESULTS: Significant increases in HR and B_R were observed during the 5x10-minute session, and only significant HR increase during the 7x7-minuets session. Both variables showed tendencies of mean increases in relation to increases in power output in the 7x7-session. HR decreased (180 ± 7 to 177 ± 6) as workload decreased in the 5x10-session, while B_R remained the same (59 ± 10 to 59 ± 9).

CONCLUSION: This study demonstrates that measuring B_R during exercise and can provide valuable information for intensity monitoring in cycling training. These findings suggest that B_R could be a practical measurement for monitoring intensity during cycling training, and further research is recommended to explore its optimal applications.

KEYWORDS: Endurance, professional cyclist, breathing rate, heart rate, wearables, training intensity monitoring, practical applications

SAMMENDRAG

BAKGRUNN: Tidligere har måling av ventilasjon vært begrenset til fysiologiske laboratorietester. Teknologiske fremskritt innen «wearables» har gjort det mulig å måle ventilasjon under trening i feltforhold. Hensikten med studien var 1) å kvantifisere responsen i pustefrekvens under typiske treningsøkter utført av eliteutholdenhetsutøvere, 2) å undersøke om pustefrekvensen responderer annerledes enn hjertefrekvensen under to forskjellige standardiserte feltøkter i en gruppe elite syklister, 3) å undersøke potensialet for implementering av pustefrekvens som en praktisk variabel for intensitets monitorering i sykkel trening.

METODE: Det ble gjennomført kvantifisering av hjertefrekvens, pustefrekvens og kraft hos 11 profesjonelle syklister fra Uno-X Pro Cycling Team under trening hjemme og to treningsleirer i Spania i perioden oktober 2022 til mars 2023. Deltakerne gjennomførte to standardiserte økter og målte ventilasjonsresponsen med en smart skjorte, sammen med en hjertefrekvenssensor og kraftmålere.

RESULTATER: Signifikante økninger ble observert i puls og pustefrekvens under 5x10-minutters økten, og kun signifikant økning i hjertefrekvens under 7x7-minutters økten. Begge variabler viste tendenser til økninger i gjennomsnitt i forhold til økningene i kraft i 7x7-økten. Hjertefrekvens gikk ned (180 ± 7 til 177 ± 6) når arbeidsmengden gikk ned i 5x10-økten, mens pustefrekvens forble den samme (59 ± 10 til 59 ± 9).

KONKLUSJON: Studien demonstrer at å måle pustefrekvens under sykkeltreninger kan gi verdifull informasjon for intensitets monitorering. Funnene antyder at pustefrekvens kan være et praktisk mål for å monitorere intensitet under sykkeltreninger, og at videre studier bør undersøke mer dens optimale applikasjon.

NØKKELORD: Utholdenhet, Profesjonelle syklister, pustefrekvens, puls, wearables, treningsintensitets monitorering, praktisk applikasjon

STRUCTURE OF THESIS

Part 1 presents the theoretical background, a methodical chapter presenting the applied methods, a results chapter, and a methodical discussion chapter of the methods applied in the project, in addition a chapter of practical application.

Part 2 presents a research paper, written accordingly to the guidelines of the International Journal of Sports Physiology and Performance. The manuscript is written in an IMRaD-style: Introduction, methods, results, and discussion.

Part 3 consist of the additional appendices. Approvals, consent forums etc.

PART 1

THEORETICAL BACKGROUND
AND
METHODS

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1.0 Introduction

To perform at a high level as an endurance athlete, achieving large annual training volumes seems to be a necessity (Lucía et al., 2001; Seiler, 2010; Billat, 2001). A professional road cyclist rides 30,000 to 38,000km yearly, in both training and competition, with training sessions ranging from 2 hours up to 7 hours (Seiler, 2010; Lucía et al., 2001; Metcalfe et al., 2017). During the year, endurance athletes typically distribute their training sessions ~80%/20% between low intensity training (LIT, <LT1) and high intensity training (>LT1, threshold & HIT) respectively (Seiler & Tønnesen, 2009; Seiler & Kjerland, 2004; Seiler, 2010; Stöggl & Sperlich, 2015). When managing and performing this large amount of training volume, there is a need for “tools” to verify that the training is performed as prescribed, and to help quantify the training process. Measurements for training quantification typically include power and pace, heart rate (HR), blood lactate (bLa-) and rate of perceived exertion (RPE) (Lucía et al., 2001, Maunder et al., 2021). When quantifying training, coaches can also assess their athlete´s level of fitness and fatigue, detect illness and risk of injury by triangulating the relationships among external load (power), physiological responses (HR, bLa-) and perception of effort (RPE) (Seshardi et al., 2019; Aliverti, 2017).

Quantification of training allows for day-to-day monitoring of the physical effort put into each training session with these “tools”, to better understand how the individual athlete is responding during training. Numerous physiological tools are available, with HR and bLa- being the most usual measurements. However, one neglected variable is the measurement of breathing rate (B_R) during training (Nicoló er al., 2017). Similar to RPE, B_R increases almost linearly during different exercise protocols and reaches max values at exhaustion (Nicoló et al., 2014; Nicoló et al., 2016). The response is similar between the two with experimental interventions influencing performance as muscle damage or fatigue and elevated body temperature (Nicoló et al., 2016). During self-paced time trials RPE is a major indicator for level of fatigue and pace regulation, and Nicoló et al. (2016) highlighted that the strong link between RPE and B_R and suggests that B_R should be a parameter to be monitored during self-paced workouts. Historically, measuring and utilizing B_R during exercise has been limited to laboratory testing with gas analysis while performing maximal oxygen consumption (VO_{2max}) tests, but also then B_R and other aspects of ventilation are rarely the focus of laboratory testing. Measuring B_R out in the field has proven to be difficult with accuracy and user-friendliness both in need of further advancements from a textile engineering, data filtering, and application interface point of view (Aliverti, 2017). Recent advancement in wearables have opened the possibility to quantify B_R in the field with good accuracy and non-invasive methods for use during exercise (Aliverti, 2017; Gouw et al., 2022). Monitoring B_R regularly and continually during exercise as a variable for physical effort can lead to a more accurate and reliable training monitoring regime for athletes and coaches (Nicoló et al., 2020; Massaroni et al., 2019; Nicoló et al., 2016).

The term "Internet of Things" (IoT) has become a good description of modern training monitoring. IoT refers to connection of different types of hardware to data networks for collection and management of data (Aliverti, 2017). The IoT has impacted the modern training monitoring process with coaches and athletes visually seeing performance in graphs, curves and tables through software and network sites specifically developed for managing training data. Wearables today can automatically upload training data to the specific networks for management and interpreting the data (Figure 1). The potential of wearable technologies is in their ability to bring laboratory measurements, like ventilation, from a controlled environment to the field for use during daily training and key workouts.

Figure 1: Screenshot from TrainingPeaks.com™, as an illustration of the automatic uploads available from each workout for interpretation and session analysis. Visualizing average and maximal values on the right side, and the graphs the raw performance data from the session, and a map of the course taken during the session.

Traditionally, laboratory tests have been common to establish lactate thresholds (LT), ventilatory thresholds (VT) and VO_{2max}. Physiological testing laboratories are equipped with clinically validated equipment with high accuracy (i.e., ergometers, gas analyzers and bLa-analyzers). One limiting factor for laboratory testing is the "one-off"-nature of periodic testing that does not capture daily variations in fitness, dependent on the level of fatigue, mental energy, and health. Modern endurance athletes and coaches want the process of training, monitoring, and testing to be more integrated and performed in the real-world conditions of the field. This demand is particularly apparent in cycling.

For elite athletes performing daily training, knowing what variables to measure is critical. Keeping it simple and not monitoring too much has become a bigger challenge due to both more devices and more digital tools for data integration. When you monitor your training, the variables you have become your "head-up-display (HUD)". If you monitor too many variables and with little deep mechanistic knowledge about what information they can and cannot provide, they can inhibit your field of vision and the daily decision-making process can create confusion instead of clarity. Therefore, knowledge about what the different variables tell us and what changes in them tell us is a key part of endurance training monitoring. This means that when new wearables are introduced, how to use them in a training setting needs clinical research supporting the use of them (Aliverti, 2017). Wearables for training monitoring are characterized by anything that athletes can wear without inhibiting activity or limit mobility (Aliverti, 2017). With wearables making technological advancements, conducting field testing becomes a more relevant and useful topic. Field testing becomes relevant in being more similar to training and competition. Giving more information about how the athlete will physiologically respond in a corresponding situation.

Monitoring B_R has been overlooked and difficult to measure outside a laboratory without invasive equipment. However, wearables let users measure ventilation during exercise, and establishing VT without a laboratory. Monitoring B_R during exercise is giving a more accurate picture of the physiological responses to different loads during endurance training (Nicoló et al., 2016; Nicoló et al., 2017). Even a better physiological response than HR, especially during intermittent training and changes in workloads. Due to that ventilatory regulation seems to be less affected by the oxygen demand, rather more of the increasing production of carbon dioxide (CO_2) and its removal demand (Nicoló et al., 2020). Evidence is suggesting that monitoring the physical effort with B_R with a wearable shirt gives accurate and validated results (Massaroni et al., 2020). Together with power output, HR and bLa-, B_R gives a good picture of both the internal “cost” and external work during cycling exercise. This may lead to greater understanding of work demands under exercise, a unique method for training prescriptions and control and monitor the stress put on athletes.

1.1 Overall goals and purpose

The main goals of this research project were therefore:

1. To quantify breathing rate response during typical training sessions performed by elite endurance athletes.

2. To investigate if breathing rate responds differently than heart rate during two different standardized field sessions in a group of elite cyclists.

3. To investigate the potential implementation of breathing rate as a practical measurement in training for training intensity monitoring in cycling.

2.0 Theoretical framework

2.1 Endurance sport

Endurance sport is characterized by a race format from starting point to a finish line, with duration ranging from a few minutes up to several hours. We can define endurance as the capacity to sustain a power output or velocity for the longest time (Jones & Carter, 2000). Performance in an endurance event may therefore be evaluated in terms of duration to complete a given distance or the time duration a given power can be maintained (Coyle, 1999).

Endurance athletes maintain the velocity or power output with repetitive isotonic contractions of large skeletal muscles, such as a pedal-, swim stroke or running stride. During an endurance event, the muscles primarily rely on the oxidative metabolism of fats and carbohydrates as energy sources (McCormick et al., 2015). Although the duration and demand endurance events differ, the training processes are similar, involving manipulation of training intensity, duration, and frequency. This targets specific physiological adaptions over days, weeks, and months to better endurance performance (Seiler, 2010, Seiler & Tønnessen, 2009). Characterized by the demand to sustain an external load for a duration of time, endurance athletes annual training volume ranges from 500 hours to above 1000 hours (Tønnessen et al. 2014; Sandbakk et al., 2021; Haugen et al., 2022). The typical intensity distribution follows a polarized or pyramidal pattern with a distribution with 80% of training sessions being performed below first lactate threshold (LT1) and 20% as above LT1, threshold or HIT (Seiler & Kjernland, 2006; Seiler & Tønnessen, 2009). Which distribution model that is considered the "best-practice"-model is still undecided. A retrospective analysis from Stöggl and Sperlich (2015) showed greater key performance improvements using a polarized model, with most endurance athletes adapting a pyramidal model. However, individual differences to occur and which model presents the best performance adaptations is uncertain. The distinctive muscular demands of different sports disciplines are important to consider when evaluating the evaluate the training load and impact on performance. Successful endurance training involves optimizing adaptive stimulus and management of stressors that impacting the endurance performance. Achieving the optimal balance between stimuli and stress is challenging by itself, but endurance training for top performance is a delicate balance between avoiding underreaching and preventing overtraining.

2.1.1 Staying in your zone

Professional athletes expose themselves to prolonged exercise, alternating between stress and recovery. As training load increases, so does the necessary time to fully recover. Professional cyclists are known for riding between 4-6 hours and 100-200km in a single session, averaging 30,000-35,000km of distance annually (Faria et la.,2005; Lucía et al., 2001). Cycling has distinct characteristics, i.e., repeated surges to close gaps or bridging between groups, catching the breakaway, or getting in the breakaway. The ability to mobilize for these efforts and recover between them, requires specific implementing race scenarios in training under different physiological conditions.

Spragg et al., (2022) showed that professional road cyclists tend to spend most time during a competitive season between first and second ventilatory threshold (VT1/VT2) ranging between 61.7%-50.7% during the season. In addition to the total intensity distribution showing trends to shifting more polarized model during the season, but still pyramidical. Targeting fat utilization and aerobic glycolysis in longer and easier efforts, and carbohydrates and anaerobic glycolysis in harder and shorter efforts. To minimalize the risk of either underreaching or overtraining, keeping the intensity as intended is important. Maintaining in the intended intensity zone align the rider´s targeted physiological adaptions with the intended recovery. In cycling there are different methods for intensity regulation; power, HR, bLa- and RPE are all used as metrics for external work or internal cost. If used properly, these variables create an endurance training monitoring trinity (Figure 2). Training is associated with a degree of acute fatigue and temporary decrements in performance, but manageable with time to recover. Without sufficient recovery time increased risk of sickness, stagnation, and other negative outcomes is well established (Knicker et al., 2011). Thereby increasing the importance of performing LIT sessions as LIT and HIT as HIT. Maintaining your performance by exceeding your intensity zone, increases time to recover in a limited time window and decrement performance in next session by not having the appropriate recovery time.

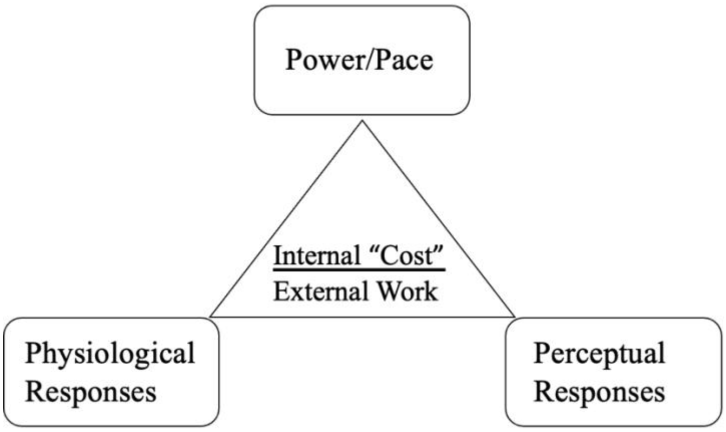


Figure 2: Presentation of the endurance training monitoring trinity and their relationship.

2.2 Current markers for physical effort

During prolonged endurance exercise, physical effort can be measured using physiological and perceptual responses, as well as power or pace. Physical effort refers to the amount of exertion required to complete an objective, and perceived exertion refers to the perceived level of stress of completing the objective (Hutchinson & Tenenbaum, 2006). These responses are categorized into internal cost or external load measurements. Internal "cost" measurements quantify the acute physiological stress of training, like uncoupling of HR, B_R and bLa-. In cycling external load is quantified as work on the pedal or cranks/time and measured as power (watts). Perceptual responses quantify an individual's subjective perception of effort, often measured using scales, typically Borg 6-20 or CR10 RPE-scales (Groslambert & Mahon, 2006). Perceptual responses can include a range of sensations, including strain, aches and fatigue in muscles and the cardiovascular and pulmonary systems (Pageaux, 2016). The training monitoring literature has also recently distinguished the terms *exertion* and *effort*. "Effort" can be described as a given exertion time. Maximal effort can take the form of extreme exertion for å short duration, or higher exertion over a long duration (Seiler & Sylta, 2017). Thus, RPE may not adequately describe" effort" during long durations at moderate to high intensity.

Training intensity can be classified physiologically into three intensity zones with the LT1 or VT1 separating zone 1 and 2, and the second (steeper) ventilatory turn-point (VT2) and LT2 separating zone 2 and 3 (Figure 3) (Seiler, 2010; Hoffman & Tschakert, 2017). Anchor points with the first and second ventilatory turn points are created using mathematical functions with the ventilatory variables minute ventilation (V_E), oxygen consumption volume (VO_2) and volume of CO_2 production (Gouw et al., 2022). Using ventilatory turn points as anchor points are not directly applicable to a five-intensity zone model (Seiler, 2010). Typically, an intensity described as threshold or in a 2-4mM range corresponds to an intensity zone between VT1 and VT2, thus making a three- or five-zone model comparable with common anchor points in lactate concentration (Seiler, 2010). Individualizing the intensity model requires testing in order assess individual response at the given workload. An incremental stage-test are of preference for bLa- measurements, giving results helping to divide intensity into zones anchored in first and second lactate threshold (LT1 and LT2 respectively). Physiological laboratories are commonly equipped with clinically graded gas exchange analyzer to measure the respiratory response variables during testing.

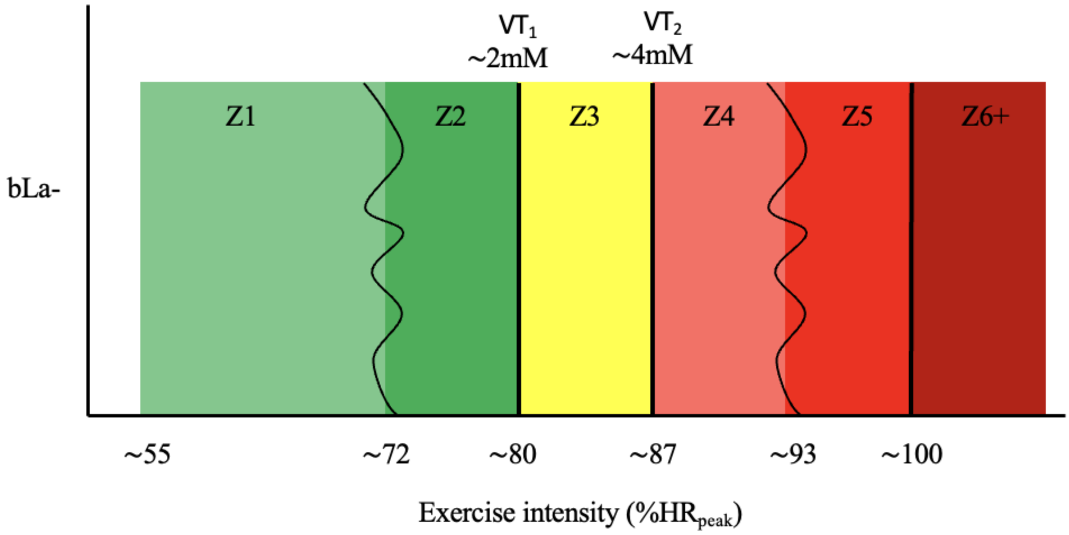


Figure 3: Illustration for an intensity calibration for a 3-zone and 5-zone model. Zones can be based on percent of peak HR, ventilatory thresholds, or blood lactate levels. Squiggly line visualizing the not so clear boundary between Z1 and Z2 and Z4 and Z5 in a 5-zone model, which are arbitrary values. bLa- = blood lactate; $\%HR_{peak}$ = percent of peak HR; mM= millimole; VT1/2 = $1^{st}/2^{nd}$ ventilatory threshold; Z=zone.

2.2.1 Heart rate monitoring

Race format sports involves being the fastest from start to finish. In some sports monitoring speed to evaluate intensity is reasonable, as in track running or swimming. In example cycling (or rowing, XC-skiing, etc.), movement speed don´t always reflect the intensity as external factors are interfering with the speed versus power relationship, either faster or slower. Factors like wind, aerodynamics, descending or ascending a hill, all interfere with the ability to maintain speed (Paton & Hopkins, 2001). Therefore, supplemental measurements are needed to validly measure physiological intensity. HR is a frequently used tool for monitoring and prescribing an exercise intensity (Acheten & Jeukendrup, 2003; Lucía et al., 2001). HR is considered a robust, whole-body measurement to describe overall internal work during exercise as an objective variable to reflect intensity.

Several types of devices can measure HR, chest straps, armbands, and wristbands are common wearables, it is an unobtrusive device to implement on regular basis. HR monitors are less accurate the further they are from the heart, meaning wrist straps are less accurate than chest straps (Acheten & Jeukendrup, 2003). Chest straps and arm worn monitors measure HR with one of two basic technologies, chest strap measurement using electrocardiography (ECG), or arm or wrist worn equipment use optical sensors that capture pulsatile changes in light reflection by red blood cells. HR monitors are capable to transmit live measurements to either smart watches, smart phones or cycling computers through Bluetooth to maintain control over the HR. The real-time measurement of HR makes it possible to manage the intensity during the effort to match the prescribed intensity. HR is calibrated to individualized training zones, typically prescribed as a percentage of maximal HR (HR_{max}). Prescribing intensity from HR_{max} is an inaccurate method when individualizing intensity, as the method does not account for individual differences in the contribution of resting heart rate to maximal heart rate. Instead, prescribing intensity as a percentage of HR reserve(%HRR) incorporates the whole range of heart beats and is comparable across different individual's (Karvonen & Vuorimaa, 1988; Acheten & Jeukendrup, 2003)

Endurance sport consist of manipulation of training, therefore only tracking HR isn´t enough. HR is variable influenced by other factors, such as temperature, altitude, hydration, and energy availability, while also vary from day-to-day (Acheten & Jeukendrup, 2003). Cardiovascular drift, or decoupling, is the phenomenon of increasing HR at a steady external workload. The drift is influenced by the mentioned factors with the severity dependent on the exposure. This phenomenon causes the HR response to a workload to increase during the effort, meaning an effort prescribed as zone 4 could drift into zone 5 if duration is too long. In general, work intensity can only be interpreted when duration is attached, and the intensity x duration interaction is individual and impacted by training. Consequently, interpreting HR during demanding training sessions requires evaluation of the entire training session.

2.2.2 Blood lactate measurements

Blood lactate (bLa-) is measurement quantifying the internal cost of an exercise. It is produced during both “anaerobic” and aerobic exercise during the enzymatic breakdown of glucose to maintain adenosine triphosphate concentration during muscle contraction, and it´s accumulation rate is related to the training intensity and the rate of glycolysis in the muscle. High intensity training has a greater rate of glycolysis therefore, higher bLa- production than low intensity training.

Measuring bLa- can be useful for helping maintain the targeted intensity zone. When blood lactate increases, we know that sympathetic stress is also increasing (Kenttä & Hassemén, 1998). Prescribing training intensity using bLa- can give more individually calibrated training prescriptions in a group conducting the same training, compared to prescribing training intensity with percentages of VO_{2}-$_{max}$ or HR_{max}, as bLa- profiling provides a more individual metric (Jacobs, 1986). However, measuring bLa- accurately depends on standardized conditions. The results of a lactate profile can be difficult to interpret if protocols are not standardized, including pre-test nutrition, sampling site, temperature and training load prior to test can influence the bLa- concentration (Billat, 1996; Jacobs 1986). In addition, day-to-day variation, training status, hydration, medication, and altitude may also have influence on bLa- measurements (Sylta et al., 2014)

Using LT1 and LT2 as intensity zone markers provide a basis for monitoring the changes in the lactate curve, either left or right shifts. Right shifts indicate the ability to sustain a higher intensity without accumulating more bLa- compared to previous tests, thus making a left shift indicating the opposite. Training above LT2 causes a non-linear increase in stress related to metabolic, respirational, and perceptual processes, and is increasing rate of fatigue with increases in metabolic acidosis or glycogen depletion (Jones & Carter, 2000). A right shift in LT is therefore a physical marker of performance improvements, with LT2 being at a higher workload then previously and greater ability to sustain greater workloads. However, sudden changes in submaximal and maximal lactate levels, as well as HR values, may also be indications of parasympathetic overtraining syndrome caused by increased parasympathetic activity during rest and exercise (Kenttä & Hassemén, 1998). Sympathetic overtraining syndrome show higher HR values at rest and during exercise with increase sympathetic activity. Preventing these signs are a challenge with only evaluation of the values, but drastically changes are important indicators as well as the athletes perceptual feeling (Kenttä

& Hassemén, 1998). Successful endurance training programs sees improvements in performance with sustaining higher workloads without inhibiting contractile functions and greater reliance on fat utilization than carbohydrates.

2.2.3 Functional threshold power or critical power in cycling

Functional threshold power (FTP) and critical power (CP) are power metrics that have become popular when assessing power thresholds unique to cycling disciplines. FTP can be defined as the highest power output that can be maintained in a quasi-steady state for 60-minutes, without the rider fatiguing (Maunder et al., 2021). To establishing FTP, an FTP-test is performed, this can either be performed as a field- or laboratory test. The FTP value is often practically defined as 95% of the mean power output during a 20-min time trial effort (Borczcz et al., 2018; Maunder et al., 2021).

CP can be defined as a power output that is sustainable without fatigue for 30-60-minnutes or the highest metabolic rate that solely utilize oxidative energy provision (Hill, 1993; Poole et al., 2016). CP is determined using of 3 or more series of timed max efforts, creating a power-duration curve describing the hyperbolic relationship between power output and time the power output is sustained (Hill, 1993; Brickley et al., 2002). Endurance performance is related to work rate at CP, showing a reflection of the aerobic fitness, hence its correlation to LT, VT and VO_2-max (Karsten et al., 2021; Hill; 1993). CP offers information about the maximal metabolic steady state (MMSS), whereas working above MMSS is increasing the physiological stress responses and perception of effort, related to increasing risk for performance loss (Karsten et al., 2021). De Lucas et al. (2013) showed that CP is a threshold between hard and severe intensity in trained cyclist. Showcasing that with working at 5% above estimated CP, shortens the time to exhaustion with 40% compared to working CP (De Lucas et al., 2013). The study included that VO_2-max was reached at the end of the test when working 5% above CP and not at all during working at CP (De Lucas et al., 2013). Although intensity affects performance, work over long duration result in decreased gross efficiency and high-intensity performance loss (Hopker et al., 2017). The physiological stress response to workloads above CP results in greater anaerobic energy provision, in example accumulation of bLa- or intramuscular creatine phosphate, further decreasing time to exhaustion and performance decrements (Borczcz et al., 2020; Guimarães-Ferrieira, 2014).

Studies about whether to use CP or FTP in cycling suggest that CP is to be considered a more valid and reproducible (Mackey & Horner, 2021; Karsten et al., 2021). Even though FTP show correlation to other physiological threshold concepts, the spread in level of agreements between FTP and each threshold concept does not make them interchangeable (Karsten et al., 2021; Mackey & Horner, 2021). Importantly, CP can be useful as a surrogate for LT2/VT2, but the CP model does not give information about the first lactate or ventilatory turn-point.

2.2.4 Ventilation as a marker for physical effort

Up until now, the collection of ventilatory data has been practically limited to physiological laboratory settings, collected as a necessary part of measuring VO_2, or performing lactate profiles relative to $\%VO_{2\text{-max}}$ with gas analyzers. Ventilation, like heart rate is a systematic measure of metabolic demand, but ventilation has not moved into the field in the same way due to technical challenges. Technology from the healthcare sector, where patients with lung diseases are monitoring their respirational variables with wearables, has been tested out by sport scientists to evaluate its performance in a sports context (Seshadri et al., 2019; Aliverti, 2017). Measuring respiration during exercise presents a challenge, as athletes are constantly in motion, talking, drinking, etc., which can disturb the registration and resulting in an unacceptably low signal-to-noise ratio. A common device for measuring ventilation are the respiratory airflow sensors combined with a mask or mouthpiece. This method is considered highly accurate in measuring ventilation, but it is a rather obtrusive and invasive method that cannot be transferred into the field where athletes train. Different contact-based measuring techniques to indirectly capture ventilatory response in field settings have been developed. HR based wearables "measuring respiration" are typically using ECG and photoplethysmography (PCG) and complex algorithms to estimate B_R (Seshadri et al., 2019, Aliverti, 2017). However, wearable devices that measure B_R based on heart rate algorithms often are positioned at the wrist. Using PCG and ECG to measure B_R is a reasonable alternative when measured at rest, but highly inaccurate during exercise. The most valid contact-based method for measuring respiration during exercise is, according to Massaroni et al. (2019), strain guage measurements that registers chest wall movements that are a direct result of breathing. The method is based on detecting the expansion of the chest and ribcage during inspiration and expiration. Strain guage (or stretch sensor) measurements are effective during both during indoor and outdoor exercise and has the benefit of easily being implemented to different apparels as shirts, crop-tops or singlets for less invasive feel on the athlete. Using torso stretch/strain measurements is however vulnerable to non-exercise related movements like bending the torso, drinking, talking, and coughing.

3.0 Methods

3.1 Study design

This master thesis is an observational and descriptive study in sport science from the Faculty of Health and Sport Science, Department of Sport Science and Physical education at the University of Agder. The present study is a part of larger research process, where field-based research is a further development from laboratory-based investigation. The overall projects data sampling methods consisted of three different data sampling methods consisting of:

1. Preliminary testing of the TymeWear smart shirt (TymeWear, Boston, USA) under various conditions, both in laboratory and field settings, with usability interactions with the producer happening in real time to solve basic hardware and user interface limitations.

2. Characterization of responses under standardized sessions in trained subjects and comparison with ventilation data collected using traditional gas exchange methods.

3. Field testing the TymeWear smart shirt (TymeWear, Boston, USA) on professional athletes engaged in high-volume training and exploring the relationship among different monitored variables during typical training sessions of a professional cycling team.

All data sampling for this part of the larger project was conducted between October 2022 and March 2023.

3.2 Preliminary testing

Prior to preliminary testing, preliminary assessment to explore the face validity of measurements and practicality of the shirt began in 2020. The assessment involved testing the smart shirt´s performance under controlled conditions with diverse training sessions on an ergometer bike. Encouraging results initiated the planning to use the smart shirt more systematic projects with additional controlled testing.

In December 2021, the preliminary field testing started, during which the smart shirt was applied in the field with a small group of professional cyclists on the Uno-X Pro-Cycling Team during a training camp, together with an unpublished laboratory study. The preliminary testing aimed to evaluate the limitations and functionality under different environmental settings to examine the shirt´s functionality and improve key technical aspects. Only a few selected riders at Uno-X wore a smart shirt during a December training camp. The riders were instructed to wear the shirt and provide feedback on their experience, such as how it felt to wear and the overall comfort of the shirt. Based on feedback during the preliminary testing with Uno-X, improvements were made to the technical aspect of the shirt, improving storage capacity in the pod for it to handle quantities of data for the long sessions the riders performed, and interface improvements with live display of B_R. Additionally, feedback and testing revealed issues with the shirts ability to handle moisture, leading to overheating and rider discomfort, especially during descending or climbs. The issue was addressed with developing a prototype for a shorter "vest" version covering a smaller surface area of the torso, to minimalize risk of overheating and greater rate of sweat production.

Preliminary testing with a laboratory study was performed to evaluate the shirt´s validity and reliability. In the lab breathing frequency, tidal volume, and minute volume were measured simultaneously with the smart shirt and via spirometry using a mixing chamber (Vyntus system). The subjects performed preliminary testing and 2 different high intensity training sessions. The testing from the unpublished master thesis with running subjects by Ringot (2022) showed that breathing rate measured with the TymeWear smart shirt and the Vyntus system had a very low systematic bias of 0.2 breaths per minute (brpm). Limits of agreement (LoA) were also promising at of -2.3 to +2.8 brpm. Next, Ask (2023), completed an (currently) unpublished master thesis with a larger sample of running subjects, describing the relationship between B_{Rmax} measurements from the Vyntus system and TymeWear smart shirt in 17 trained runners with the equation: Y = 1.0307x - 3.9944, with a correlation of R^2 = 0.9754.

Following the period of field and laboratory testing, complementary testing of the shirt was conducted to further explore the functions and limitations for the short. The shirt was subjected to different training conditions and environments to assess if measurements were affected, or if altering characteristics of the shirt, conditions or environment would alter the measurements. This process is ongoing.

3.3 Standardized training sessions

The standardized training sessions consisted of regularly performed sessions both during off-season and competition-season training that were suitable for all the involved riders. The Uno-X lead head coach decided what sessions were prescribed and no intervention was made in this project. The sessions examined for this project is:

- 5x10-minute threshold sessions
- 7x7-minute high-intensity-training, long interval sessions

3.3.1 5x10-minute threshold session

The 5x10-minute training sessions is a "threshold range" sessions used within the team for controlling and estimating critical power (Figure 4). The training session starts at 96% of estimated FTP, increasing with 2%, from 96% to 102%, the first four efforts, before coming down at 98% of FTP the last 10-minutes. Each effort was separated by 4-minute active recovery period. These sessions were completed both at home and outdoors, but always on the same bike using the same power meter. During the training session, power output was continually measured with the DURA-ACE HOLLOWTECH II – Dual Sided Power Meter (Shimano Inc., Sakai, Japan), HR was monitored with their personal HR sensor, and ventilation was measured using the TymeWear smart shirt (TymeWear, Boston, USA). Each athlete was provided with a shirt that was specifically sized to sit tightly, but comfortable on their torso.

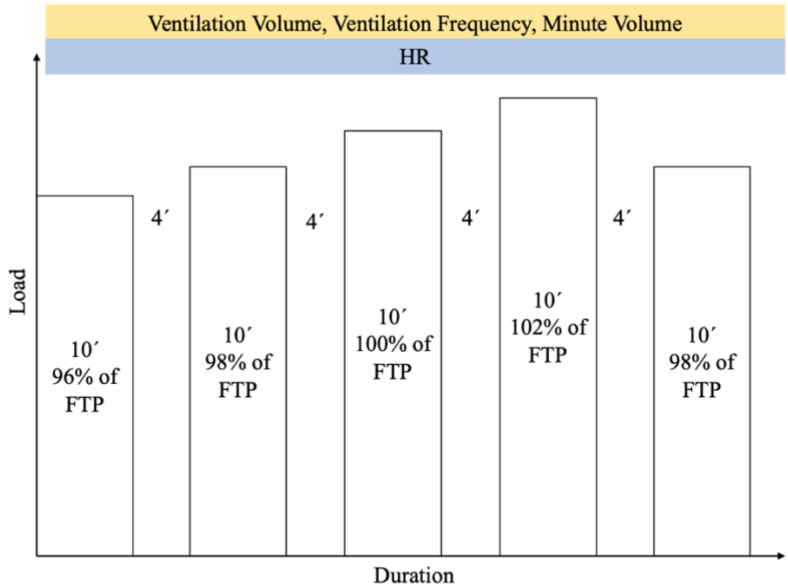


Figure 4: An illustration of the prescription for the 5x10-minute session. HR = Hear rate; FTP = Functional Threshold Power.

3.3.2 7x7 high-intensity-interval-training session

The high-intensity-training, long interval session consists of 2x5-minutes warm-up efforts at an intensity of 95%-100% of FTP, followed by 5x7-minutes of 30s/30s, 30 seconds of work for 30 seconds of recovery (Figure 5). Working intensity for the 30 seconds was prescribed at 140% of FTP and the 30 seconds recovery phase was prescribed at 95% of FTP. Each 7-minute block was separated with a 5-minute active recovery block with no prescription of workload during recovery.

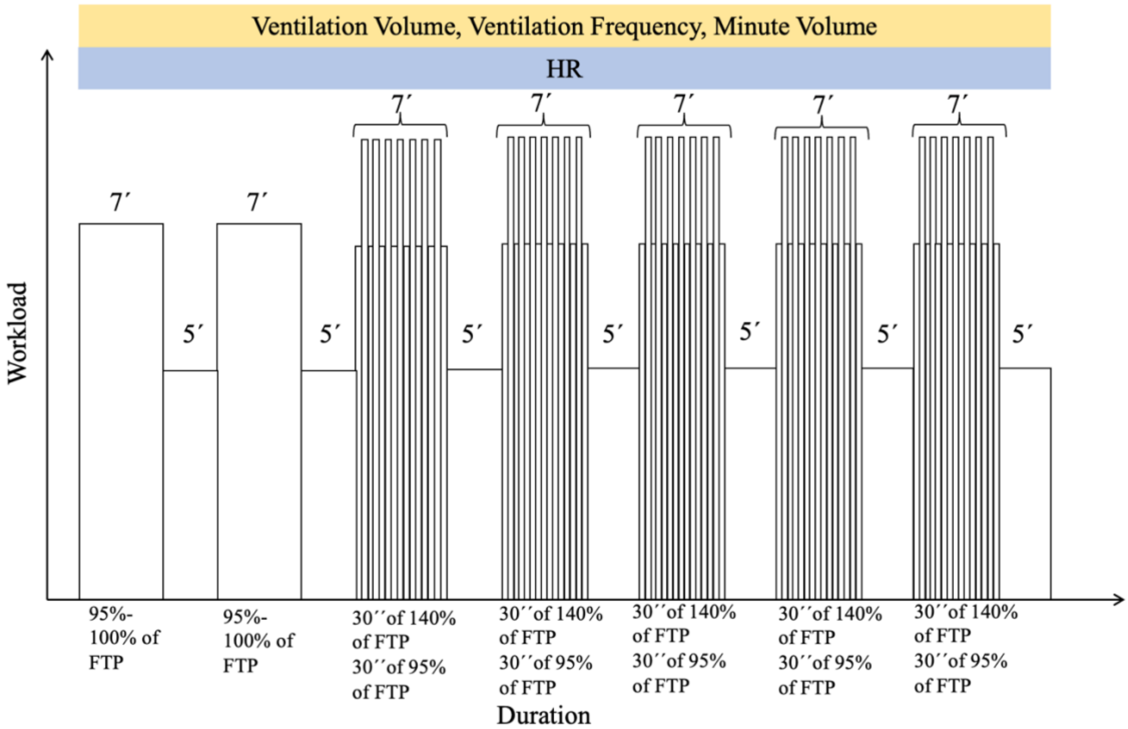


Figure 5: An illustration of the prescription for the 7x7-minute session. HR = Heart rate; FTP = Functional Threshold Tower.

3.4 TymeWear smart shirt technological solution

The TymeWear monitoring system contains a stretchable fabric shirt with integrated strain sensors, a detachable inertial measurement unit (IMU) pod that also stores data from the strain sensor, a mobile smart-phone application, back-end cloud services and a web-based dashboard (Figure 6). The smart shirt features built-in sensors that are capable of measuring breathing rate during exercise. The measuring sensor is located across the upper thoracic spine and utilizes a highly sensitive strain sensors to measure breathing frequency, tidal volume (V_T), and air flow. The sensor captures both the sensor´s stretch as binary phenomenon and also the rate and magnitude of sensor stretch. By measuring both the binary signal and the rate and magnitude of sensor strain, breathing V_T and V_E are also estimated based on algorithms, giving estimates of the respiratory response to the exercise intensity. However, measurements for V_T and V_E are not calibrated measurements in L/breath or L/min respectively, but instead an index with arbitrary units (AU)

The pod fitting onto the shirt above the sensor has a built-in IMU and elevation sensor that measure elevation and movements. The pod connects through Bluetooth to a smartphone application, transmitting a slightly delayed (data smoothing) measurement on B_R, V_T, V_E, and a displayed graph of air flow in real time. When ending a session, it automatically uploads the application file from the IMU to the back-end cloud service, after the post-processing is completed, which smooths and filters the data. The web-based dashboard allows coached and athletes to receive more information about the data throughout the session, giving individual graphs for the development of minute ventilation, tidal volume and breathing frequency. Athletes are also given the opportunity to share their profile with their coaches, by a manual login in the web-portal.

Registered data from the smart shirt is end-to-end encrypted starting from the pod before transmitted using Bluetooth low energy to the mobile app. The app uses AES-CCM encryption, and all stored data is encrypted with AES-256. The stored data is firewalled and protected by Amazon Web Services (AWS) authorization mechanisms. The user´s login passwords are encrypted by Argon2 cryptographic algorithm.

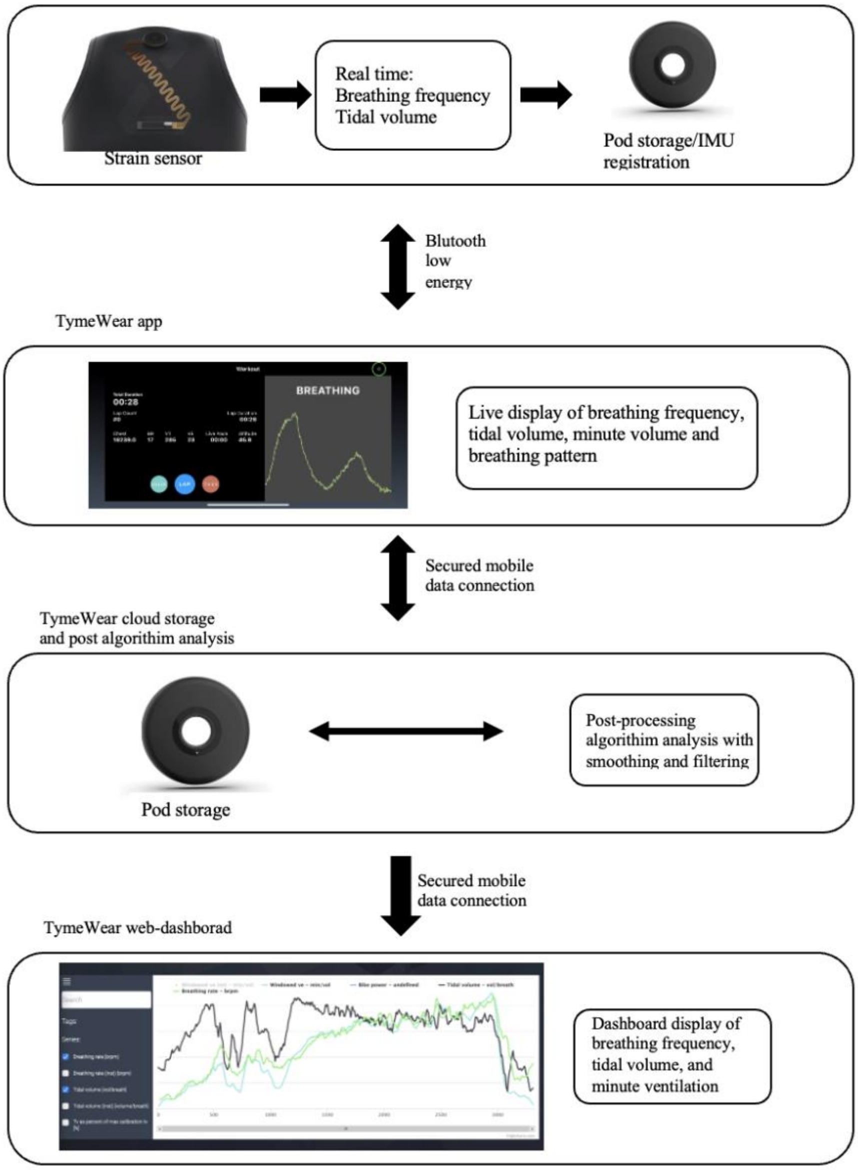


Figure 6: The TymeWear operating system: strain sensor, the IMU pod, real time measuring with display on mobile application, back-end cloud services with post-processing algorithms, smoothing and filtering and the web-dashboard.

3.5 Fitting smart shirt to athlete

Before equipping the athletes with the shirt, proper sizing, clear instructions on how the shirt works, how to start and end sessions, calibrating the shirt, the purpose of using the shirt and its intended function are important. A few selected riders were equipped with a new shirt, in addition to those already in possession of a shirt. The new riders received verbal information about the shirt along with a walkthrough of all the needed information to start and end sessions and the calibration process.

To ensure correct sizes we followed the manufacture´s own sizing instructions and sizing guide (Figure 7), while also taking the riders opinion in fit into consideration if it was fit too tight or loose to find the correct size (Figure 8). The pods handed out were all operating with the latest software update at the time (Version 0.36). The instructions given for calibrating the shirt were to mount the bike in a riding position and then follow the manufactures instructions for calibration, three deep breaths with maximal expiration force (Figure 9). The riders were instructed to wear the shirt as the first layer of clothing, and to calibrate the shirt before every ride. For better maintenance of the shirt and it´s durability, the riders where informed to dislocate the pod and hand-wash the shirt, avoiding any excessive stretching and twisting around the area the senor located, and air dry the shirt.

Men:	**Perimeter (cm)**
Small:	77,47 - 85,09
Medium:	85,10 - 92,71
Large:	92,72 - 100,33
X-Large:	100,33 - 109,22
Woman:	
X-small:	67,31 - 72,39
Small:	72,90 - 80,01
Medium:	80,02 - 86,36
Large:	86,37 - 92,71

Size	Measurement (inches)
Small	30.5"-33.5"
Medium	33.5"-36.5"
Large	36.5"-39.5"
X-Large	39.5"-43"

Size	Measurement (inches)
X-Small	26.5"-28.5"
Small	28.5"-31.5"
Medium	31.5"-34"
Large	34"-36.5"

Figure 7: Figure from the manufactures measuring instructions and sizing guide in inches converted to centimeters, which was used to find the right size for the rider´s.

Figure 8: The TymeWear shirts on-body fit.

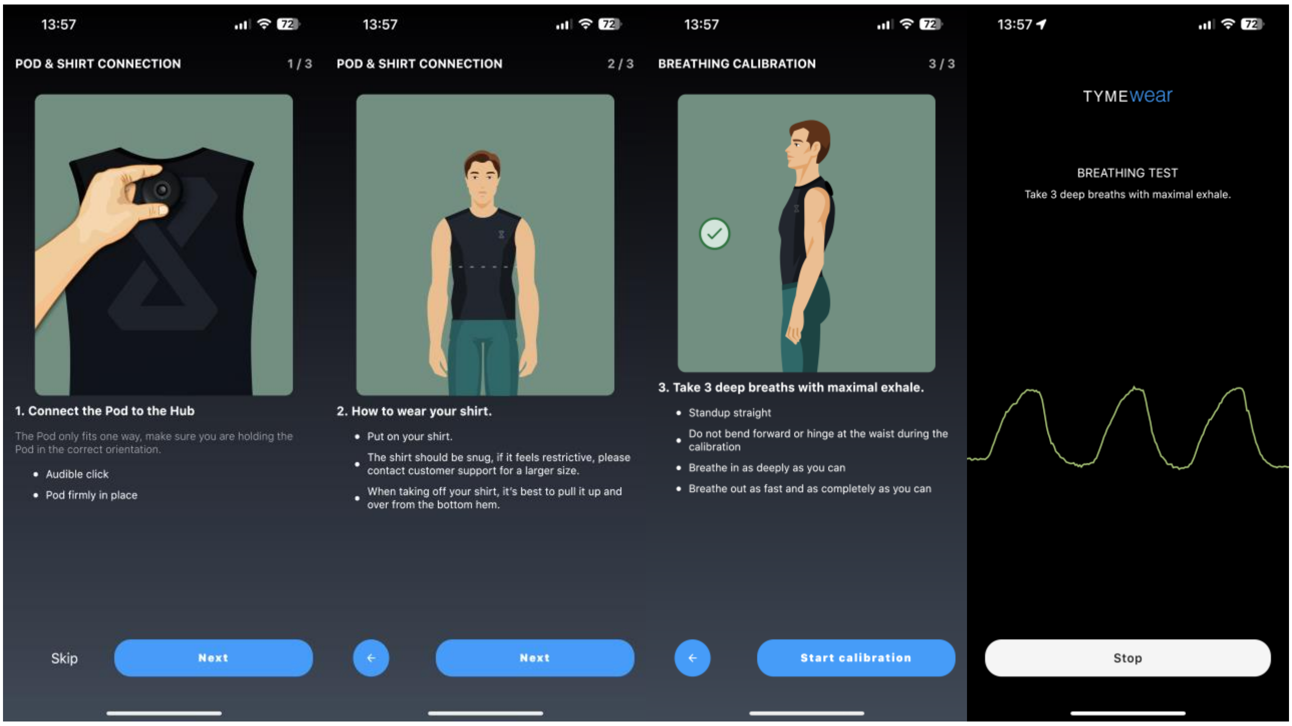


Figure 7: The in-app calibration instructions from the TymeWear application.

3.6 Uno-X Team

The Uno-X Pro Cycling Team (https://www.unoxteam.no) is a Norwegian based professional cycling team, competing with three teams: Women's World Tour team (international composition, n=16), Men´s Pro team (Danish and Norwegian composition, n=28) and Men´s Continental team (U23 Danish and Norwegian composition, n=12). The data collection took place in the team´s off-season from October 2022 to March 2023, a period with high volumes of training, training camps and physical testing. A total of 11 riders (10 male) gave consent to participate in the project, participants were selected by the team´s leadership. The riders were given written information about what participation means and signed the consent forum for participation (Appendix 1 & 2). The project leader (the master´s student) was present for a week of testing while attending one of the training camps in Spain to overview the testing and answer any questions about the project from coaches and athletes, and assuring data were correctly collected during the camp. The participant's characteristics are presented in Table 1.

Table 1: *Descriptive data for the Uno-X participants*

	All (n=11)
Descriptives	
Age (y)	23 ± 2
Height (cm)	178 ± 8
Weight (kg)	67.5 ± 7.0
BMI	20.9 ± 1.5
Resting HR (bpm)	44 ± 6
Max HR (bpm)	200 ± 8
HRR (bpm)	156 ± 7
Resting B_R (brpm)	15 ± 2*
Max B_R (brpm)	82 ± 4*
BRR (brpm)	66 ± 5*
20min power (W)	410 ± 84

Values presented as mean ± standard deviation. BMI = body mass index; HR = heart rate; bmp = beats per minute; HRR= heart rate reserve; B_R= breathing rate; brpm = breaths per minute; BRR = breathing rate reserve; W = watts. *Breathing values are assumptions for participants that have adequately tested for resting or maximal values; 15 brpm for resting B_R; 80 brpm for max B_R.

3.7 Datafile preparation and synchronization

Before conducting any analysis, raw data was prepared and synchronized for analysis. Each training session was split in two files, one .FIT-file from the cycling computer uploaded to intervals.icu and one .CSV-file uploaded to the TymeWear dashboard. To view both files simultaneously, both files were downloaded from their respective cloud service and uploaded to EnDuRA (Endurance Durability and Repeatability Analyzer) for preparation and synchronization. The performance coaches within the team had set up individual accounts for each rider with their performance variables within EnDuRA, which makes individual and improvement analysis possible. With both files uploaded to EnDuRA, each session was reviewed to assure power, heart rate and ventilation measurements was measured and fully useable. In cases with missing data, any clearly wrong measurements, or file errors the session was discarded from any more reviewing. Before any data was transcribed into Microsoft Excel version 16.69.1 (Microsoft, Redmond, USA), the working efforts during each session was sectioned off to the last 2-minutes of each effort and further transcribed to Microsoft Excel.

3.8 Statistical analysis

All statistical analysis were performed using SPSS (version 28, IBM, Chicago, USA). The quantitative data are presented as group mean and ± standard deviation. All the tables and figures were made in Microsoft Excel (version 16.71, Microsoft, Redmond, USA). Repeated measures ANOVA adjusted with Bonferroni confidence interval adjustment was appropriately used to evaluate the change in means in between the efforts for physiological and performance variables. A statistically significant value was seen as $p<.05$.

3.9 Ethical considerations

The project was performed according to the regulations of the Declaration of Helsinki, and the methods for data collection and storage was approved by the Norwegian Center for Research Data (Appendix 3) to assure the data security and approved by the Ethics Committee of the Faculty for Health and Sport Science, University of Agder (Appendix 4). It was not possible to trace any personal information or collected data back to individuals, and all. All the collected data was anonymized during the project, and not possible to link to the any individual subject.

Riders chosen for participation were not randomly selected by the Uno-X team leadership. However, the riders already possessing a TymeWear shirt, and those in the plans of possessing one were selected. Despite participation not being randomly selected, all participation in the project was voluntarily.

4.0 Results

4.1 5x10-minute-session

The physiological responses in the 5 efforts are presented in table 2 and figure 9 as means ± standard deviation. Displaying HR means responding to the prescribed intensity, HR increased to 4th effort and decreased in the 5th. B_R increased even when prescribed intensity is supposed to decrease. Average power displays the external work during the 5 efforts, and how the riders executed the segments. Relatively small changes in power output, however the 4th effort indicates some riders fail to increase power.

Table 2: *Physiological response during the 5x10-min with power measurements*

Effort	HR (bpm)	B_R (brpm)	Power (W)
1	172 ± 6	50 ± 9	326 ± 38
2	175 ± 5*	53 ± 7	335 ± 42*
3	178 ± 6**	57 ± 9*	345 ± 45*
4	180 ± 7**	59 ± 10*	345 ± 52
5	177 ± 6***	59 ± 9*	342 ± 43

Physiological responses during the 5x10-min session (n=9), presenting significant mean differences between the 5 efforts. Data from the last 2 minutes. HR = Heart rate; bpm = beats per minute; B_R = Breathing rate; brpm = breaths per minute; W = Watts; * = Significant from 1st effort; ** = Significant from 1st & 2nd effort; *** = Significant from 4th effort

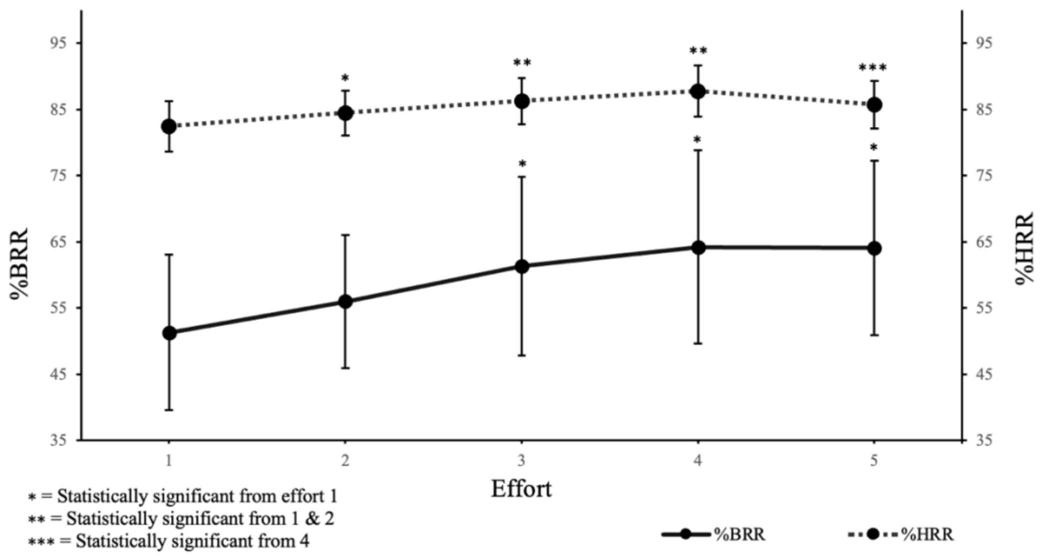
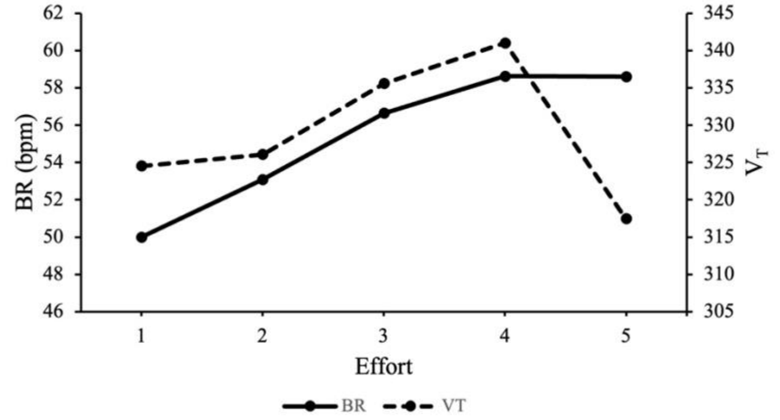


Figure 9: Presenting means and standard deviation for %HRR and %BRR in the 5 efforts, with statistical significance level. %BRR = Percent of breathing rate reserve; %HRR = Percent of heart rate reserve. Figure based on 9 quantified sessions. Data from the last 2 minutes.

No significant increases in V_T and V_E were found between efforts (p=NS), both variables increased in means from 1st (325 ± 110, 115 ± 40, respectively) to 4th (341 ± 102, 191 ± 39, respectively) effort, before decreasing between 4th (341 ± 102, 191 ± 39, respectively) and 5th effort (317 ± 92, 178 ± 36, respectively). No significant difference in cadence during the session (p=NS). Generated torque (Nm) showed a statistically significant increase in the 2nd (36 ± 4) to 5th efforts (37 ± 5) compared to the 1st (35 ± 4) ($p<.05$), generated torque decreased between the 4th (39 ± 5) and 5th effort (37 ± 5) but not statistically significant.

Figure 10 is displaying the relationship between B_R, V_T, and V_E during the 5 segments. The breakpoint in VT with no following response B_R, does indicate some riders experiencing some sort of a physiological crisis.

A)



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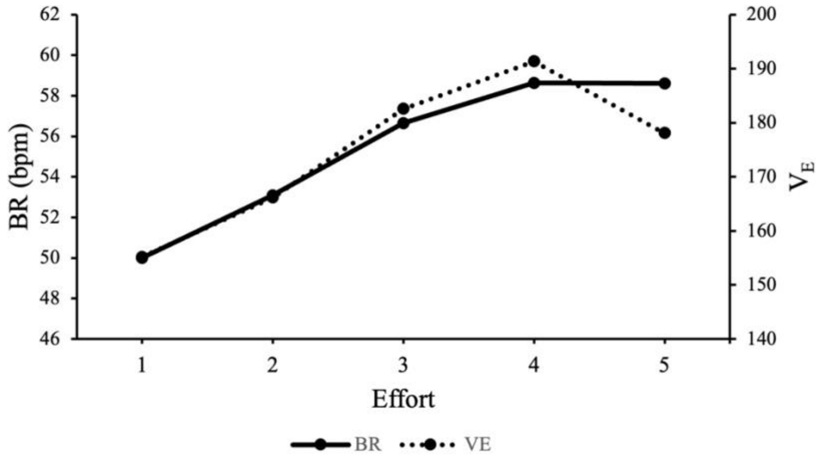


C)

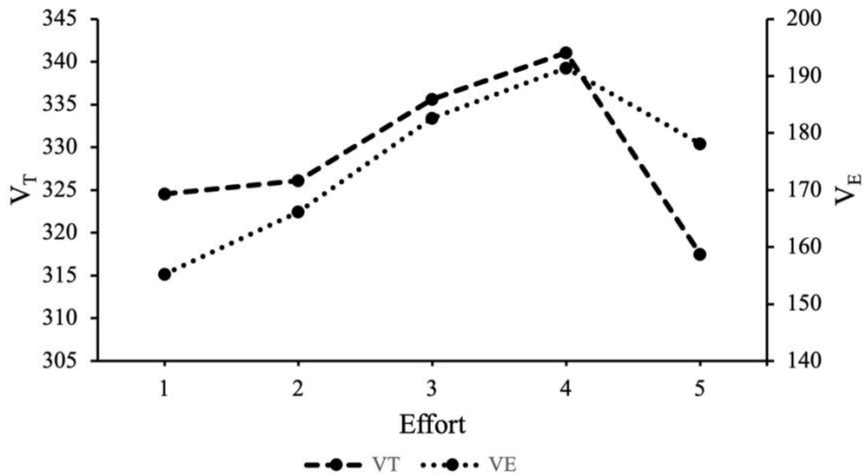


Figure 10: Presenting means for B_R, V_T and V_E, and the development for the variables during the session in relation to each other; **(A)** B_R and V_T, **(B)** B_R and V_E, **(C)** V_T and V_E. Data from the last 2 minutes. B_R = Breathing rate; bpm = breaths per minute; V_T = Tidal volume; V_E = Minute ventilation. Error bars for standard devotion are cut out for clear and easy interpretation. Scaled to easier display changes.

4.2 7x7-minute-session

During the 7 high-intensity segments (n=6) mean B_R, and power increased, however not at a significantly acceptable level. Mean HR gradually increased with time, with one significant increase from 1st to 2nd effort. The means for HR and B_R gradually increased in relation to the power output.

Table 2: *Physiological response and power output during the 7x7-minute session*

Effort	HR (bpm)	BR (brpm)	Power (W)
1	172 ± 6	55 ± 11	333 ± 53
2	174 ± 7*	56 ± 12	335 ± 53
3	177 ± 7	59 ± 12	346 ± 55
4	178 ± 8	60 ± 10	349 ± 61
5	178 ± 7	62 ± 12	351 ± 59
6	180 ± 7	63 ± 13	360 ± 65
7	182 ± 8	64 ± 13	369 ± 76

Presenting means and standard deviations for the 7 segments. Data from the last 2 minutes. HR = Heart rate; bpm = beats per minute; B_R = Breathing rate; brpm = breaths per minute; W = Watts; *= Significant from 1st effort

There was no significant increase in percent of breathing- and heart rate reserve (%BRR, %HRR) (p=NS), despite that means for each effort increased from 1st (57 ± 15, 84 ± 5, respectively) to 7th effort (70 ± 16, 91 ± 2, respectively) (Figure 11). The figure shows the gap between %HRR and %BRR narrowing, indicating increased internal "cost" of power production.

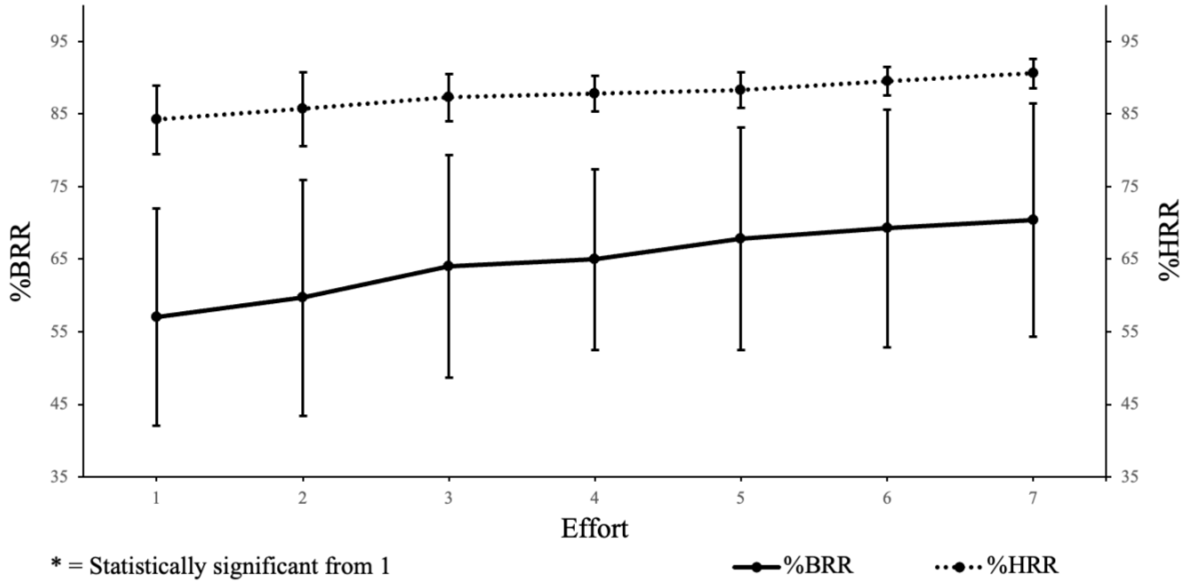
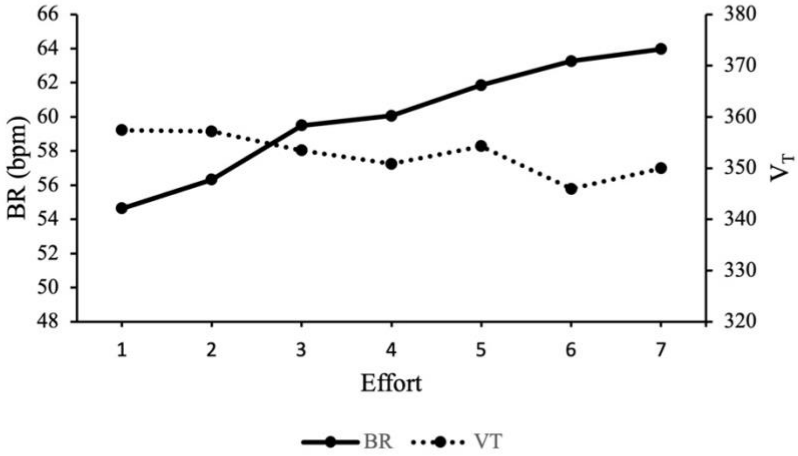


Figure 11: Presenting group means and standard deviation from the 7x7-minute session (n= 6). %BRR = Percent of breathing rate reserve; %HRR = Percent of heart rate reserve

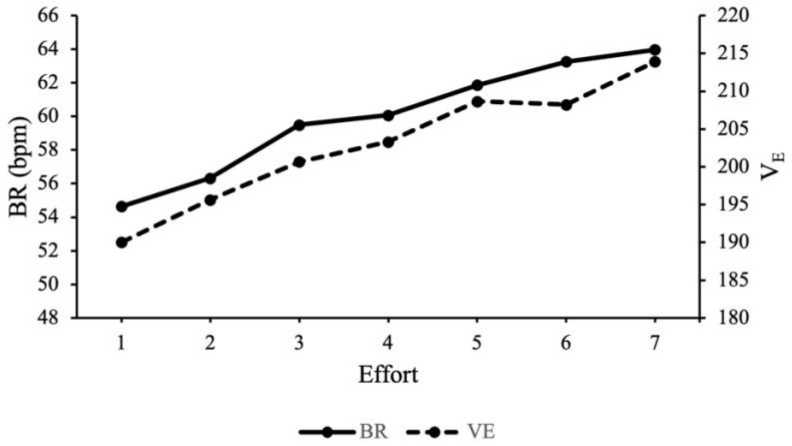
No statistically significant changes in B_R, V_T, V_E, average power, percent of 20-minute-power or generated torque between either of the efforts (p=NS). No statical significant change in cadence, despite means decreasing from 89 rounds per minute (rpm) (±3 rpm) to 85 rpm (±6 rpm) during the session.

Figure 12 is displaying the relationship between B_R, V_T, and V_E during the 7 segments. Showing B_R increasing in response to increased work production, while V_T has minimal changes resulting in the greater ventilatory response during the segments.

A)



B)



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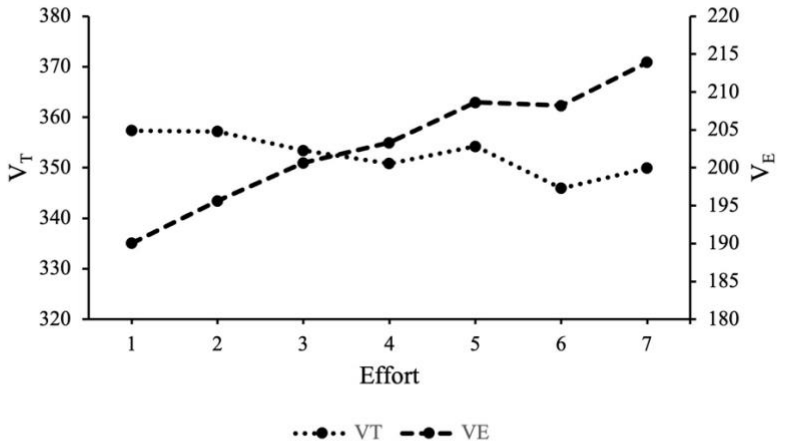

Figure 12: Presenting group means at each effort for B_R, V_T, and V_E up against each other, and their development during the session. **(A)** B_R and V_T; **(B)** B_R and V_E; **(C)** V_T and V_E. B_R = Breathing rate; brpm = breaths per minute; V_T = Tidal volume; V_E = Minute ventilation. Error bars for standard devotion are cut out for clear and easy interpretation. Scaled to easier display change in variables.

5.0 Methodical discussion

5.1 Study design

This was an observational study, a non-interventional field-based test investigating using breathing rate as a marker for physical effort using an unobtrusive wearable. Observational methods allow for systematic processes to collect data while observing a phenomenon in a natural environment (Queirós et al., 2017). Therefore, the study mixes elements of control with filed conditions that are more organic and variable. This method allows for examination of details in the phenomenon while maintain its natural setting. Compared to controlled environments such as physiological laboratories, observational methods provide greater flexibility and applicability in real-life situation, allowing a more comprehensive examination of variables (Williams & Kendall, 2007). An observational approach was applied to capture the rider's physiological responses in their natural training environment, to better understand their breathing responses in isolation and in the context of other physiological and perceptual changes during these training sessions. The methodical approach meant less control in variable measurements and the environmental impact. This project involved measuring the physiological responses in a more natural setting than what achievable in laboratory. Controlling for confounding variables is implemented into the protocol conducted in the laboratory, making the protocol less likely to resemble the performance in a natural life exposure (Williams & Kendall, 2007). The results from these tests will therefore not be applicable in the field or predict chances of enhanced performance. Using a gas analyzer and mouthpiece or mask, would also not reflect the true B_R during exercise, as the B_R is affected by the equipment with breathing resistance, as shown from data in two unpublished master thesis, showing higher breathing frequencies without any mouth obtrusion (Ask, 2023). Ask (2023), show the relationship between B_{Rmax} measurements in runners from the Vyntus system and TymeWear smart shirt with the equation $Y=0.986x + 5.496$ ($R^2=0.67$, $p<0.05$), and a systematic bias of 8.5 brpm (12.5%) and a LoA of ± 9.2 brpm (± 14%), during two different maximal test.

Working with high performance athletes also includes restricted options in what research and methods is possible to conduct with them, since sudden altercation of their training process could jeopardize long time work for upcoming events (Seiler & Kjerland, 2004). The sessions performed by the riders would be a session they would be more likely to perform again in a later training block and have a degree of familiarization to.

5.2 Field observation

Field testing any new technology with its intended users and environment provides insightful feedback for product improvement. However, testing a new product in the field requires understanding about the environmental factors influences on the measuring variables and the product itself. Capturing and controlling for the environmental influence is challenging, thus on-site observation is necessary to determine the impact of the factors and their impacting level. Extensive preliminary testing, in addition to three laboratory projects, showed encouraging results to plan and perform the present study and, in addition to supplementary knowledge about expected measurements. The aim for the field test in the present study was to investigate the use of B_R in the field to monitor training intensity in endurance athletes performing high volumes of training, with purpose to investigate the practical aspects of including the monitoring variable in a sport scientific way. The riders at Uno-X Pro Cycling team fit the description for the purpose of the study, performing testing with them in various environments, such as at training camp or at home, would enhance the results.

5.4 Strengths and limitations

The study has several strengths, including: 1) the extensive preliminary testing prior to the project, providing solid knowledge of the behavior of the phenomenon in examination (B_R monitoring and response in endurance athletes), 2) the participants from Uno-X Pro Cycling Team, who represent an elite level of athletes in cycling, 3) the cooperation with Uno-X Pro Cycling Team, which provided great environments for field testing under different conditions.

The observational phase generated both quantitative and descriptive data of the phenomenon of B_R among a group of professional cyclists. However, to assure accurate measurements with the smart shirt, the calibration process before each session is important, as emphasized to the participants. One of the limitations of the study is that some sessions included to the analysis did not contain a calibration prior to training, which could affect the measurements. Without being present at every session included in the analysis, it is possible that human error or neglect may have led to the lack of calibrations.

The study´s small sample size also needs to be considered when evaluating the results. In total 15 training sessions were included between the two training sessions. The small size can be a result of the shirt´s characteristics, being uncomfortable to wear or unawareness of the shirts functionality, which could tell more about future improvements. However, the project was as much a research project as much as an innovation process, working to improve the shirt and bring our observations back to the manufacture to optimize its technical aspects and comfort, while also collecting data for the project.

Using HRR, the range between resting HR and HR_{max}, creates a scale that is well correlated with $\%VO2_{max}$ (Lounana et al., 2007), and more comparable across individuals compared to $\%HR_{max}$. Converting the scale to a %HRR allows to access the proportion of the range an athlete utilizes during training. The same concept can be used on B_R, measured as %BRR. However, finding an athlete’s B_{Rmax} requires an athlete to perform a maximal session or test in the same way that is required to identify HR_{max}. Since the concept of B_R is somewhat neglected in the sports, standardized test, or sessions to access B_{Rmax} needs further development. The Uno-X Pro Cycling Team did not perform any maximum exercise test on their riders, and most of the participants lacked the measurements of resting B_R and B_{Rmax} in their EnDuRA profile. As a result, set values for resting B_R and B_{Rmax} was 15 brpm and 80 brpm respectively, where used for those riders that missing these values. In the cases where a rider exceeded the set value of 80 brpm during a session, the assigned value was changed to the nearest rounded up number. The values are based on experienced values from the preliminary testing, where neither resting B_R at 15 brpm or B_{Rmax} at 80 brpm were deemed reasonable to expect. However, individual differences are to expect but unable to access without proper testing. Therefore, some riders have had their BRR incorrectly estimated, and the results for %BRR could be different if it was correctly scaled. The study is limited to the use of pre-set values to estimate BRR, rather than correctly measured values obtained adequate testing, but study design limiting the possibilities for adequate testing.

A review of the Shimano Dura-Ace dual-sided power meter has raised concerns about its reliability and validity, which is the power meter used in the project. According to Marker (2018), the power meter´s watt measurements were found to be inconsistent and inaccurate. As a result, it is uncertain if the power measurements in the present study is consistent and accurate.

The field observation with a professional cycling team as Uno-X provided an ideal environment to assess the potential use of B_R as a training monitoring tool. Performing testing in different weather conditions, riding in a training groups and riding positions. The strain sensor measuring B_R is vulnerable to changes in riding position i.e., riding seated versus standing. Upper body movements related riding out of the saddle shows signs of entrainment to measurement of B_R, however controlling the rider´s execution of the task is a challenging and may have affected the measurements.

Since the study is a non-interventional and have no comparison to another reliable and valid measuring device, as a gas analyzer, the results should not be generalized or extrapolated to other endurance sports.

5.4 Practical application

Incorporating a new variable and measuring tool into group is challenging, especially something as new as monitoring breathing. Introducing such measurements into a team, will bring out different opinions about the use of the equipment. Thus, generating more knowledge about this phenomenon is suggested, to increase the knowledge about the mechanisms regulating breathing and how it responds in various training modalities. The findings in the present study are at a group level, but when applying this measurement, individual assessment should be emphasized over group-level assessment. Individual assessment using BRR are of preference and requires adequate testing, since B_R show great variability between individuals. The presented results are showing encouraging trends towards what is expected to physiologically occur during the types of sessions performed in the present study (Nicoló et al, 2014). Figure 13 and 14 is a screenshot from EnDuRA and one rider´s data from participating in the study. The figure displays the evolution of HR and B_R during the two sessions, expressed as both bpm and brpm, and %HRR and %BRR, with produced power output, session is color graded into how the present study split the watt measurements to use for the analysis, dividing and using the last 2 minutes of each effort. This rider has both HRR and BRR correctly scaled using correct resting and maximal values.

The present study used EnDuRA to synchronize data. It allows to use fixed intervals to highlight different part of the sessions, the program generates graphs and tables customizable with different performance variables. Figure 13 reveals that HR and B_R have different responses to the intermittent session. HR show a gradual upwards drift within each effort, with greater drift in the later efforts. Additionally, peak HR in each effort is increasing as the efforts are completed. There are small fluctuations in HR within the efforts, which is expected internal response during an intermittent session as HR´s response time to change in workload is slower with a high work-to-recovery ratio (Nicoló et al., 2014). However, B_R is showing a bigger increase in the drift within the effort and have more fluctuations in the measurements. The fluctuations may be caused by the sensitive response B_R have towards change in workload, or that the rider is deliberately trying to slow down that B_R (Nicoló, Marcora, et al., 2017). According to Nicoló et al. (2017), regulation of B_R is affected by central command and muscle afferent feedback, but the influence level was difficult to determine. Implying lower workload don´t require as fast B_R as the higher workloads. It is also possible that the fluctuations are a result of talking, drinking, or eating during exercise, as it causes holding your breath before it spikes up when you resume breathing.

In 7x7 workout with changing workload every 30s, observation show that the rider can slow down the breathing when the workload is decreased and in non-working periods, causing measurement fluctuations. The %BRR indicates the workout and intensity is tough but not as tough as the HRR response is implying. The point at which HR and B_R corresponding lines crosses is an indication of a physiological struggle, regardless of duration to infliction point. Figure 13 (outlined in blue circled) show the gap between the line closing during the session, indicating the efforts are becoming harder with time, and the exhaustion level is high. The HR response show HRR quickly increasing ~75% of HRR, while B_R increases to ~50% of BRR. These responses suggest that B_R possess more room to increase intensity before reaching maximal values, meanwhile HR would reach maximal values sooner. The responses displayed in figure 13 show similarities to the indications of Nicoló et al. (2014) and Nicoló, Marcora, et al., (2017).

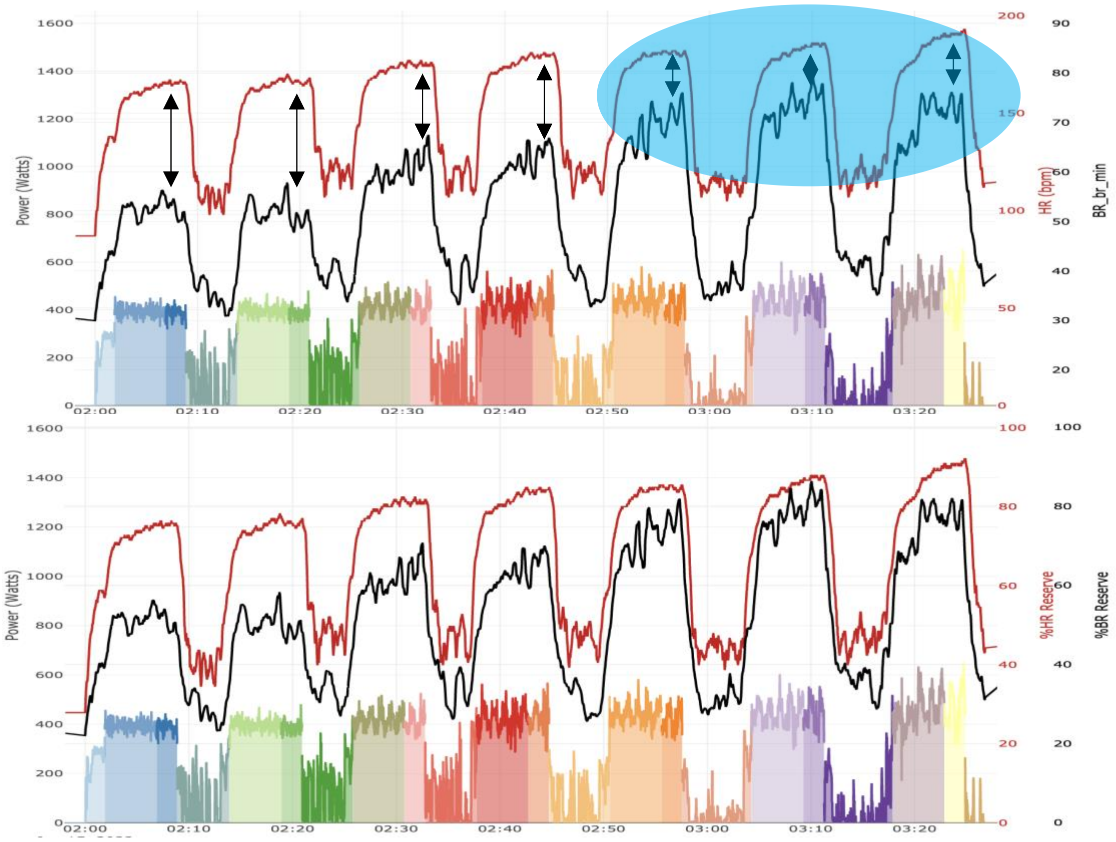

Figure 13: Screenshot from a 7x7-session with HR and B_R expressed as bmp and brpm, and %HRR and %BRR. Blue circle highlights a narrowing gap between %HRR and %BRR indicating an increasing exhaustion level to maintain power output. HR = Heart Rate; BR = Breathing rate; bpm = beats per minute; brpm = breaths per minute.

Figure 14 display the same rider from figure 13 in a 5x10-minute session. It displays a similar drift pattern in HR with little fluctuations within each effort as in the 7x7-session, indicating that to intensity in the external work is getting harder. In contrast, B_R have greater fluctuations which can imply the rider is at times focusing on breathing and trying to control it within the effort. %BRR and %HRR (outlined in blue circle) indicates this workout is not nearly as hard as the 7x7-session, and that according to %BRR there is easier to mobilize after each effort. However, HR response is decreased in the 5^{th} effort compared to the 4^{th}, while B_R is continuing an upward drift. This indicates the rider is working at a lower cost in the 5^{th} than in the 4^{th} using only HR measurements, however B_R imply a higher effort in the 5^{th} effort in contrast to HR´s decrease. Between efforts the workload is decreased, and B_R show more unsystematic decreases compared to HR who stabilize ~60% of HRR. This can be explained by lower %BRR values indicating an intentional breathing control, than at higher workloads. During hard and severe intensities, higher B_R is accompanied a high V_T and breathing is to a degree controllable, but during lower intensities breathing is more controllable, and B_R and

VT can show either higher frequency with lower volume, indicating low breathing control, or lower frequency and higher volume indicating a higher degree of breathing control.

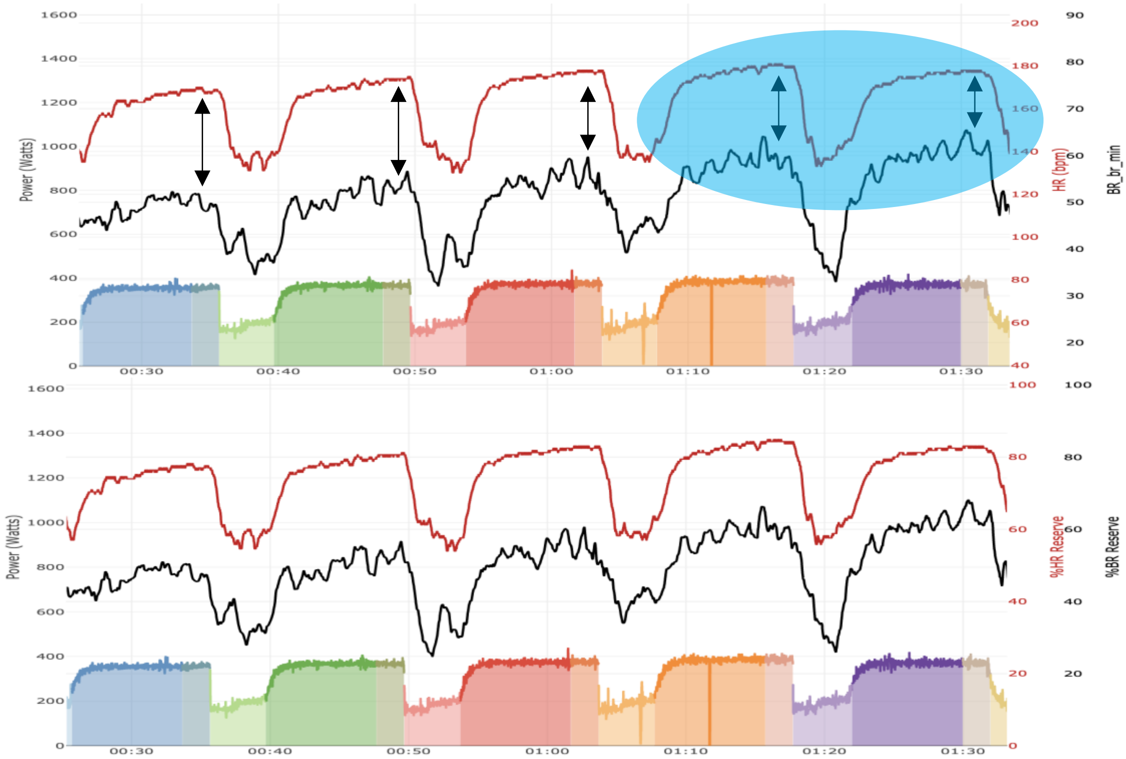

Figure 14: Screenshot from a 5x10-session with HR and BR expressed as bmp and brpm, and %HRR and %BRR. Blue circle highlights a narrowing gap between %HRR and %BRR indicating an increasing exhaustion level to maintain power output. HR = Heart Rate; BR = Breathing rate; bpm = beats per minute; brpm = breaths per minute.

From a cyclist perspective, using BR during training has been a retrospective "tool" used after the training is completed. As a rider, the point of using intensity measurements is to control if intensity as prescribed. Therefore, cyclist is depended on BR being displayed on the cycling computer to fully use the measurement´s. The possibilities with the IoT are that it allows for partner integration and connections between devices. With the cycling computer being a cyclist main source for information during training, TymeWear have supplied with an application for Garmin cycling computers that integrates and display the measurement´s from the smart shirt on the cycling computer (figure 15).

Figure 15: Display of the measurements from the TymeWear smart shirt on a Garmin 1040 cycling computer. Picture from April 2023.

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PART 2

Article manuscript

Taking ventilatory measurements out of the lab and into the field

The following manuscript is written according to the following journal:

International Journal of Sports Physiology and Performance

IJSPP

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Taking ventilatory measurements out of the lab and into the field

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ABSTRACT

PURPOSE: The aim of the study was 1) to quantify breathing rate (B_R) response during typical training sessions performed by elite endurance athletes, 2) to investigate if B_R responds differently than heart rate during two different standardized field sessions in a group of elite cyclists, 3) to investigate the potential implementation of B_R as a practical measurement in training for intensity monitoring in cycling.

METHODS: Heart rate (HR), B_R and power output were quantified in 11 professional cyclists (23 ± 2 y, 67.5 ± 7.0 kg) from the Uno-X Pro Cycling Team during training at home and two training camps in Spain in the period between October 2022 to March 2023. Participants executed two standardized field sessions, in which ventilatory response was quantified with a wearable smart shirt, along with HR sensors and power cranks.

RESULTS: Significant increases in HR and B_R were observed during the 5x10-minute session, and only significant HR increase during the 7x7-minuets session. Both variables showed tendencies of mean increases in relation to the increases in power output in the 7x7-session. HR decreased (180 ± 7 to 177 ± 6 bpm) as workload decreased in the 5x10-session, while B_R remained the same (59 ± 10 to 59 ± 9 brpm).

CONCLUSION: This study demonstrates that measuring B_R during exercise can provide valuable information for intensity monitoring during cycling training. These findings suggest that B_R could be a practical measurement for monitoring intensity during cycling training, and further research is warranted to explore its potential applications.

KEYWORDS: Breathing rate, training intensity monitoring, wearables, Endurance athletes, practical application

INTRODUCTION

To perform at a high level as an endurance athlete, a necessity seems to be achieving large annual training volumes, ranging from 500 to 1000 hours[7, 10, 17, 19, 22-25]. Professional road cyclists ride 30,000 to 38,000km yearly, in both training and competition, with training sessions ranging from 2 hours up to 7 hours[4, 7, 22, 23]. During the year, endurance athletes typically distribute their training sessions ~80%/20% between low intensity training (<LT1) and high intensity training (>LT1, threshold & HIT) respectively in a polarized or pyramidal intensity distribution model[23, 24, 25, 28]. When managing and performing this large amount of training volume, there is a need for “tools” to validate that the training is performed as prescribed, to help quantify the training process and reducing risk of injuries and illness[1, 6]. Training quantification allows for day-to-day monitoring of physiological and perceptual responses, and power/pace in each training session, with these “tools”, to better understand how the individual athlete is responding during training[1, 2, 5, 21]. However, endurance sport mainly is about being the fastest from start to finish, but speed is not always reflecting intensity, as in cycling(or rowing, cross-country skiing, etc.) where other factors affect speed increments or reductions [1, 9] Therefore supplementary tools are needed, in which physiological and perceptual tools are frequently applied. Numerous physiological tools are available, with heart rate (HR) and blood lactate (bLa-) being the most usual measurements to use during trainig[3, 9]. However, recent discoveries have strengthened the importance of monitoring breathing rate (BR) during exercise[11-16] Despite breathing´s role in health care as a vital sign, it is a neglected “tool” to utilize and measure during training[2,8, 11-16]. BR increases almost linearly during different exercise protocols, reaching max values at exhaustion, which is a similar response to RPE [11-16].

Measuring and utilizing BR has been limited to laboratory testing with gas analysis, but also then BR is overlooked [5, 14-16]. Measuring BR with field settings has been difficult with accuracy and user-friendliness both in need of further advancements from a textile engineering, data filtering, and application interface point of view[2, 8]. Advancements in wearables have unlocked the possibility to quantify BR in the field with good accuracy and non-invasive methods to use during exercise[2]. Monitoring BR regularly and continually during exercise as a variable for physical effort can lead to a more accurate and reliable training monitoring regime for athletes and coaches [8,11-16]. One limiting factor for laboratory testing is the unique nature of testing that does not account for daily variations in fitness, dependent on the level of fatigue, energy available and health[1]. Endurance athletes and coaches nowadays seek that training, monitoring, and testing are integrated, and performed with the real-world conditions of the field.

Monitoring BR has been overlooked and difficult to measure outside a laboratory without invasive equipment. However, wearables let users measure ventilation during exercise, and establishing ventilatory thresholds without a laboratory equipment. Monitoring BR during exercise is giving a more accurate picture of the physiological responses to different loads during endurance training [11-16]. Even a better physiological response than HR, during both intermittent-, high-intensity- and constant load training[11,13,14]. Evidence suggested that monitoring the physical effort with BR with a wearable shirt with strain sensors gives validated results[8]. Together with power output, HR and bLa-, BR gives a good picture of both the internal "cost" and external work during cycling exercise, creating a trinity of training intensity monitoring. This can lead to greater understanding of work demands under exercise, a unique method for training prescriptions, and control and monitor the stress put on athletes. Monitoring BR regularly and continually during exercise as a variable for physical effort can lead to a more accurate and reliable training monitoring regime for athletes and coaches[8, 14, 16]. Therefore, the aim of the study was 1) to quantify breathing rate response during typical training sessions performed by elite endurance athletes, 2) to investigate if breathing rate responds differently than heart rate during two different standardized field sessions in a group of elite cyclists, 3) to investigate the potential implementation of breathing rate as a practical measurement in training for intensity monitoring in cycling.

METHODS

Subjects

The Uno-X Pro Cycling Team (https://www.unoxteam.no) is a Norwegian based professional cycling team, competing with three teams: Women's World Tour team (international composition, n=16), Men´s Pro team (Danish and Norwegian composition, n=28) and Men´s Continental team (U23 Danish and Norwegian composition, n=12). A total of 11 riders (10 male) between 19-26 year (23y ± 2y), gave consent to participate in the project, the participants were selected by the team´s leadership. All the participants were provided with written information about what participation means and signed the consent forum for participation. The study was approved by the Norwegian Center for Research Data and the

Ethics Committee of the Faculty of Health and Sport Science, University of Agder, and conducted according to the Declaration of Helsinki. The participations descriptive characteristics are displayed in table 1.

Table 1: *Descriptive data for the Uno-X participants*

	All (n=11)
Descriptives	
Age (y)	23 ± 2
Height (cm)	178 ± 8
Weight (kg)	67.5 ± 7.0
BMI	20.9 ± 1.5
Resting HR (bpm)	44 ± 6
Max HR (bpm)	200 ± 8
HRR (bpm)	156 ± 7
Resting B_R (brpm)	15 ± 2*
Max B_R (brpm)	82 ± 4*
BRR (brpm)	66 ± 5*
20min power (W)	410 ± 84

Values presented as mean ± standard deviation. BMI = body mass index; HR = heart rate; bmp = beats per minute; HRR= heart rate reserve; B_R= breathing rate; brpm = breaths per minute; BRR = breathing rate reserve; W = watts. *Breathing values are assumptions for participants without adequate testing for resting or maximal values; 15 brpm for resting B_R; 80 brpm for B_{Rmax}.

Design

This was a non-interventional and observational study conducted with field setting. The study observed the participants under to standardized cycling session quantifying their physiological response during exercise. The session was categorized as one long-interval and one threshold session, a 7x7- (Figure 1) and 5x10-minute (Figure 2) session, respectively. The data collection took place between October 2022-March 2023. The cycling sessions was mainly conducted on training camp in Spain, with me present. However, sessions are also performed elsewhere without my presence.

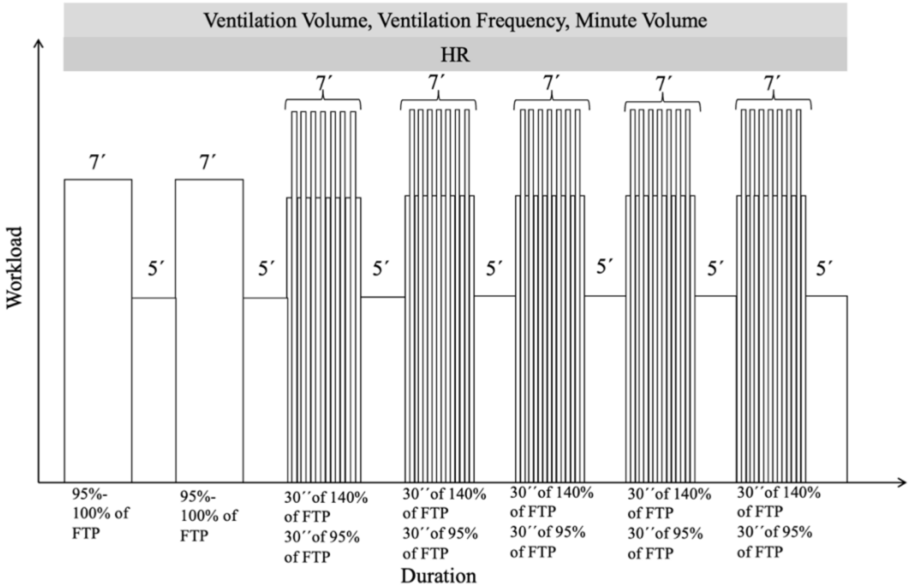

Figure 1: An illustration of the prescription for the 7x7-minute session. HR = Heart rate; FTP = Functional threshold power.

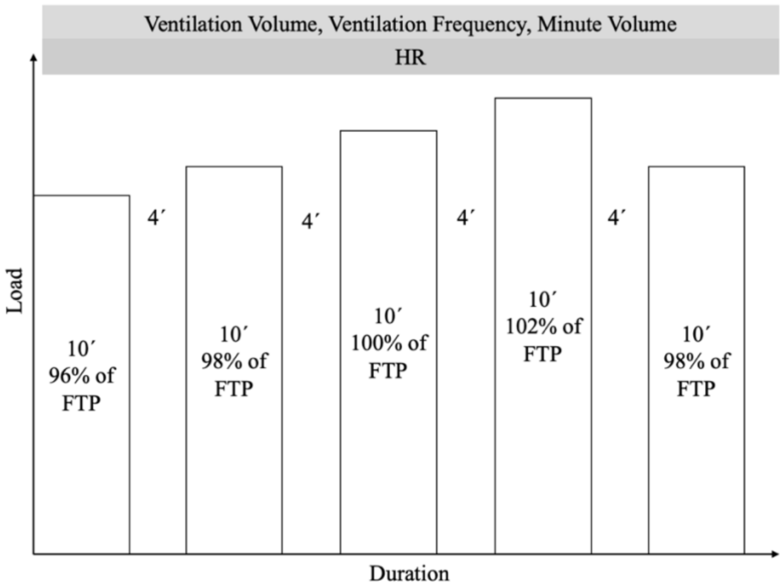

Figure 2: An illustration of the prescription for the 5x10-minute session. HR = Hear rate; FTP = Functional threshold power.

The rider´s themselves were in control of using the smart shirt and choose when they wore the shirt. My presence at training camp gave the opportunity for them to ask questions and assistance about the shirt or the study. Information about maneuvering the TymeWear application were also provided to the riders. The study did not interfere with the training plan for the riders, or any other aspect of their daily routines.

Equipment

Power output during the study were measured using the DURA-ACE HOLLOWTECH II – Dual Sided Power Meter (Shimano Inc., Sakai, Japan). Ventilatory response measurements were captured using the TymeWear smart shirt (TymeWear, Boston, MA, USA, version 0.36), each shirt correctly fitted to the rider. Heart rate were measured with the participants personal heart rate sensor, using a chest strap. Power meter and heart rate were both connected to their own Garmin cycling computer (Garmin, Olathe, KS USA). The TymeWear smart shirt were connected to the participants personal smart phones. The participants always used their personal team bike set-up with the mentioned equipment during all sessions for the data collection.

Datafiles were prepared and synchronized using .FIT-files and .CSV-files from intervals.icu and TymeWear, respectively, in EnDuRA (Endurance Durability and Repeatability Analyzer).

Statistical analysis

All statistical analysis were performed using SPSS (version 28, IBM, Chicago, USA). The quantitative data are presented as group mean and ± standard deviation. All the tables and figures were made in Microsoft Excel (version 16.71, Microsoft, Redmond, USA). Repeated measures ANOVA adjusted with Bonferroni confidence interval adjustment was appropriately used to evaluate the change in means between the efforts for physiological and performance variables. The transcribed means from each working bout is from last 2 minutes of each bout, manually divided in EnDuRA. A statistically significant value was accepted at $p<0.05$.

Analysis of individual response were performed using heart rate reserve (HRR) and breathing rate reserve (BRR). Participants without calibrations for resting and maximal breathing rate to calculate BRR, were assigned values of 15 breaths per minute (brpm) for resting B_R and 80 brpm for maximal B_R. Participants exceeding their maximal values during training were adjusted to peak value during training. Assigned values were based of knowledge and experience from extensive preliminary testing and were not considered unreasonable to assign.

RESULTS

The results from the 5x10-minute, characterizing physiological response to external workload are presented in table 2. The table indicate increases in HR and B_R, corresponding to increases in higher workload. These results indicate intensity increased over time within the session, with the riders exerting more effort to maintain power output during each working bout. Increased internal response presented in figure 3, expressed as %HRR and %BRR, presenting a narrowing gap between the graphs. The tighter gap indicating a higher exhaustion level. Both HR response and power output decreased for the last effort, while BR response showed no decrease. This can indicate that intensity has not decreased as prescribed and strengthens the indication of the riders working at the same intensity as the previous effort but producing less power.

Table 2: *Physiological response during the 5x10-min with power measurements*

Effort	HR (bpm)	B_R (brpm)	Power (W)
1	172 ± 6	50 ± 9	326 ± 38
2	175 ± 5*	53 ± 7	335 ± 42*
3	178 ± 6**	57 ± 9*	345 ± 45*
4	180 ± 7**	59 ± 10*	345 ± 52
5	177 ± 6***	59 ± 9*	342 ± 43

Physiological responses during the 5x10-min session (n=9), presenting significant mean differences between the 5 efforts. Data from the last 2 minutes of each bout. HR = Heart rate; bpm = beats per minute; B_R = Breathing rate; brpm = breaths per minute; W = Watts; * = Significant from 1st effort; ** = Significant from 1st & 2nd effort; *** = Significant from 4th effort

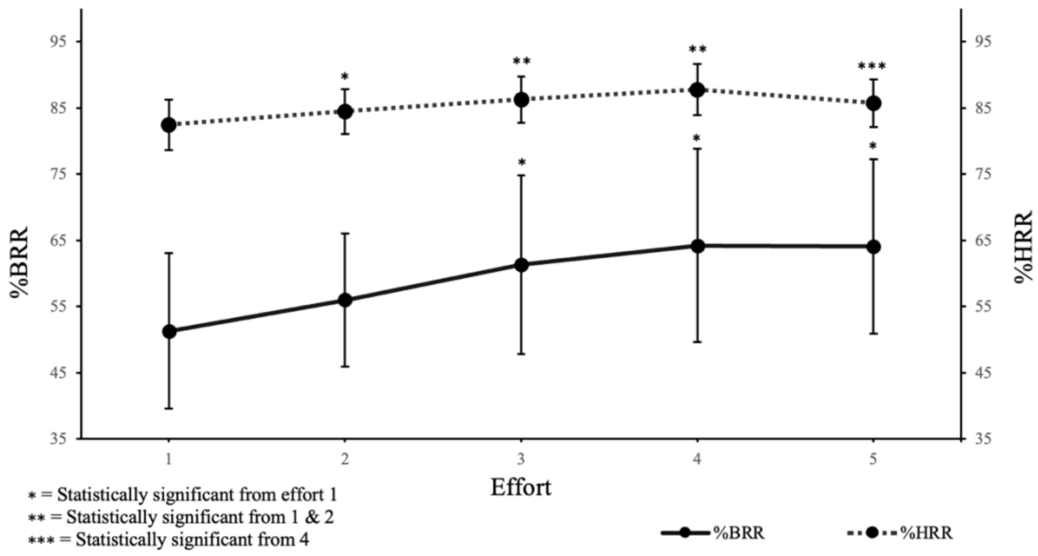

Figure 3: Presenting means and standard deviation for %HRR and %BRR in the 5 efforts, with statistical significance level. %BRR = Percent of breathing rate reserve; %HRR = Percent of heart rate reserve. Figure based on 9 quantified sessions. Data from the last 2 minutes.

The results from the 7x7-minute session, characterizing the physiological response in addition to power output (table 3). Physiological response sees both HR and B_R gradually increasing as more power output is produced during the workout. The means show increased intensity with duration in relation to increasing workload, however only one significant increase in HR during the session. Figure 4 showing the same tendencies as in the 5x10-minuet session, with the gap between %HRR and %BRR narrowing with duration, as an indication of increased intensity but B_R show a steeper incline as more power is produced.

Table 3: *Physiological response and power output during the 7x7-minute session*

Effort	HR (bpm)	BR (brpm)	Power (W)
1	172 ± 6	55 ± 11	333 ± 53
2	174 ± 7*	56 ± 12	335 ± 53
3	177 ± 7	59 ± 12	346 ± 55
4	178 ± 8	60 ± 10	349 ± 61
5	178 ± 7	62 ± 12	351 ± 59
6	180 ± 7	63 ± 13	360 ± 65
7	182 ± 8	64 ± 13	369 ± 76

Presenting means and standard deviations for the 7 segments. Data from the last 2 minutes. HR = Heart rate; bpm = beats per minute; B_R = Breathing rate; brpm = breaths per minute; W = Watts; *= Significant from 1st

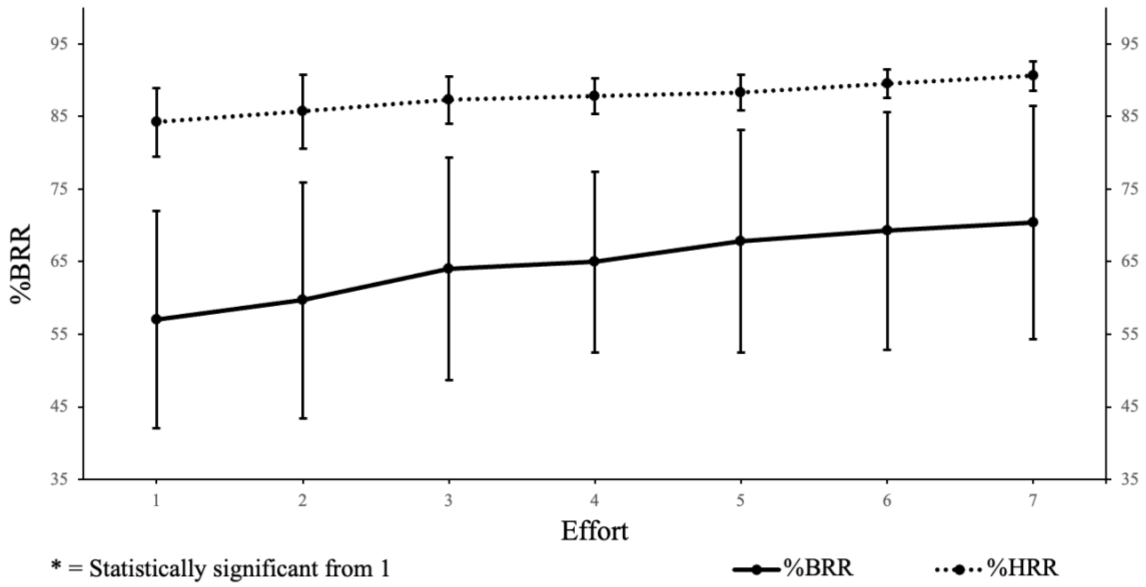

Figure 4: Presenting group means and standard deviation from the 7x7-minute session. Figure based on 6 quantified sessions. %BRR = Percent of breathing rate reserve; %HRR = Percent of heart rate reserve.

DISCUSSION

The study was performed with elite endurance athletes, performing various training modalities on regular basis. The high training volume and different environmental settings were ideal for quantifying physical response in elite athletes. Performing training according to the prescription is crucial to reduce the risk of underreaching or overtraining. Therefore, the intensity control during training is helpful for athletes to maintain intensity, and for coaches managing training load in their athletes.

The findings of the study are presented as means and standard deviations from a group, evaluating the groups on-average response during training. Their physiological response showed to increase in relation to increased power output, however when workload is supposed to decreased B_R showed no change, indicating that the riders are more exhausted than HR implies. If a session is prescribed at same workload at each working bout, the tendencies show that B_R will experience greater drift than HR. B_R could be showing a better reflection of the intensity to the workload under both constant load and intermittent training.

The present results show similar tendencies as previously conducted studies in B_R response[11-16]. However, most of the research are performed in controlled environments with masks or mouthpieces, whereas here it´s used a wearable device and causing that the result may differ.

To a degree, it is possible to control breathing frequency and depth during exercise. However, at which intensity or point breathing becomes unmanageable is unclear. With the present results, to what extent the participants intentionally controlled their breathing is uncertain and could possibly interfere with what would have been true measurements, regarding B_R response to workload.

The spread in standard deviation can be a result of incorrect scaling of BRR, supposedly assigning a too high or too low value form B_{Rmax}. Assigning a too high value give the individual a greater range than what is true, or opposite assigning a too low values giving a smaller range. This highlights the need for a standardized test for determining B_{Rmax} and performing adequate testing. The standard deviations for B_R as brpm indicate the individual differences, and why using BRR is a more preferable option.

PRACTICAL APPLICATIONS

HR and BR as bpm and brpm is not comparable measurements, therefor converting them both into %HRR and %BRR as the best option comparing them as internal responses. The reserve scale allows athletes and coaches to individualize how much of the scale the athlete is using during exercise. Therefore, to individually assess intensity with B_R, using %BRR is recommended, and users should perform adequate testing to determine B_{Rmax} to properly evaluate individual response. Using %BRR allows to compare between subjects in a group or team although the individual assessment is advised. For retrospective interpretation of exercise intensity, the gap between %HRR and %BRR can indicate level of exhaustion irrespectively of duration, the tighter the gap the higher level of exhaustion. Further research should investigate integrating B_R in intensity scales and utilizing %BRR as intensity marker to individualize in an appropriate matter.

Applying B_R to the field, requires cyclist to be able to display B_R on their cycling computer to use it as an intensity regulator. At the time of the data collection this wasn´t available, but the function was later made available for use. Displaying ventilation during cycling will allow riders to be in more control of their breathing and be more aware off their respiratory response during training and eventually for use in training. The function can also affect the rider´s breathing control, letting them have more control of B_R during training, and avoiding hyperventilation.

For coaches there is limited software for retrospective analysis with B_R. This study has used EnDuRA for synchronization of the two files, however programs capable of the same analysis and functionality is limited. For best potential use, B_R should be integrated to the same file as power output and HR and integrated into more frequently used analysis programs. This integration can potentially open for more optimal use.

The study´s limitations include assigned values to estimate BRR, which may have over- or underestimated the individual’s range, however the assigned values are to my knowledge not unreasonable to expect from this level of athletes.
In total 15 sessions were eligible for analysis, which makes a small sample size. However, the design of study and working with this level of athletes and demand them to use the shirt were not possible instead requested. In addition, their execution of the prescribed workout was not

controllable, meaning they could have increased or decreased the workload in the middle of a session.

Validating a contact-based wearable to measure ventilation during exercise is challenging without a something to compare it against. In example, using a mouthpiece or mask as measuring tool, seems to affect the measurements of B_R to be underestimated. Possibly due to the resistance of breathing in mask or mouthpiece and/or having to force air through the hose.

The presents study´s tendencies show B_R responding to workload at different rates and magnitude than HR, but the study is a non-interventional and have no comparison to another reliable and valid measuring device, therefore the results should not be generalized or extrapolated to other endurance sports.

Further research is suggested to 1) develop and standardized a physical test determining B_{Rmax}, 2) validate more wearables that are capable of capturing B_R measuring equipment, 3) further investigate B_R responses during various training modalities, and 4) further investigate the implementational value of B_R in daily training.

CONCLUSION

This study provides valuable insights into the use of wearable devices to measure breathing rate response during typical training sessions performed by elite endurance athletes. The findings indicate that breathing rate could be a practical measurement for monitoring intensity during cycling training, in addition to heart rate and power output. This highlights the potential of wearable technology for practical implementation in monitoring and optimizing training intensity in the field. However, further research is necessary to explore the full range of potential applications and benefits of using breathing rate as a monitoring tool.

ACKNOWLEDGEMENTS

The present study was performed in collaboration with the University of Agder and Uno-X Pro Cycling Team.

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PART 3

APPENDICES

Contents

Appendix 1

UiA Faculty of Health and Sport Sciences

Invitation to participate in the research project:

Triangulating physical effort in professional cycling

You are invited to participate in a research project where the purpose of the study is to triangulate power output, blood lactate and ventilation measurements to better understand how you respond to different training prescriptions. This letter describes the study and what is involved in participating on your part.

Project purpose

In this project we will triangulate lactate-, ventilation- and power from two field tests: the lactate profile stage-test and a standardized 5x10-min workout. Breathing frequency has proven to be a good indicator of physical effort during both continuous and intermittent training. Compared to heart rate, breathing frequency seems more responsive to acute increases and decreases in workload, combined with fatigue. Monitoring ventilation during training has the benefit of being an objective measurement that matches very well with mobilization and perceived exertion. Wearable technology makes it possible to measure ventilation continuously during training to quantify physical effort distribution during training sessions. Ventilation, together with power output and blood lactate will provide insight into the changing relationship between internal cost and external work during training and races. If successful, ventilation measurements can provide important insight to training monitoring, both for riders and coaches to reflect around the intensity distribution prescribed for training whether the training efforts have matched expectations.

Who is responsible for the research project?

The University of Agder, Faculty of Health and Sports Science is responsible for the project. Ole Henrik Mostad is the master´s student who has the practically responsibility for data collection. Dr. Stephen Seiler has overall responsibility as the academic supervisor and consulting sport scientist for Uno-X.

Why are you asked to participate?

You are a highly trained endurance athlete on the Uno-X team. The coaches have identified you as a potential person to help test out this new technology under field conditions. Our go with this project is to collect the training data with minimal impact on your training process and minimal extra effort on your part during the training camp.

What will it say to participate?

By participating in the project, you are training as normal, but you are giving permission to us to use your training data for research purposes. We will not interfere with the training you´ll complete. The permission is specifically for training data collected during the stage-test and 5x10-min workout. By participating in the project, you will need to provide us with login information to Tyme Wear (e-mail and password), for us to access the ventilation data. Login in information is to be sent to Ole Henrik Mostad (ohmost18@student.uia.no or +47 95289419).

Participation is voluntary
It is voluntary to participate in the project. If you choose to participate, you can at any given time withdraw your consent without a reason. All your personal information will be made anonymous. Withdrawing or not participating will not give any negative consequences for you.

Your privacy – how we store and use your information
We will only use your information to the study´s purpose as described here. We treat your information confidentially and in accordance with the privacy regulations of the Norwegian Center for Research Data (NSD) and University of Agder.

During the project, data material is only available to people connected to the project, respectively the master's student and supervisor. The data material is downloaded through TrainingPeaks™ and Tyme Wear™. For the duration of the project, the data files are stored on the university´s password protected servers (OneDrive) for further analyses.

Upon publication no data will be tied back to your name, and no other data than what is described in this letter will be published.

What happens to your data when the research project is completed?
The project will by the plan end when the master thesis is due in May 2023. Data material, which is stored in OneDrive will then be stored on a server only in anonymous form; the coupling key between name and ID-number will be destroyed.

Only you can give us permission to use your data
We treat information about you based on your informed, written consent.

Your rights
As long as you can be identified through the data material, you have the right to:
- insight into the information we process about you, and to be provided with a copy of the information
- to have information about you corrected that is incorrect or misleading
- to have personal data about you deleted
- to send a complaint to the Norwegian Data Protection Authority about the processing of your personal data

If you have questions about the project, or wish to know more about how your data will be used, contact:
- Faculty of health and sports science with Stephen Seiler, PhD (Stephen.Seiler@uia.no, tel: 91614578)
- Ole Henrik Mostad, masters student (ohmost18@student.uia.no , tel: 95289419)
- UiA data protection officier: Trond Hauso (trond.hauso@uia.no, tel: 93601625)

Yours sincerely,

Stephen Seiler
(Supervisor)

Ole Henrik Mostad
(Masters student)

Declaration of consent

I have received and understand the information about the project "*Triangulating physical effort in professional cycling"* and have been given time to ask questions.
I consent to:

- Participate in the project by giving access to my training data for use in the project

I consent that my information is available for research purposes for the duration of the project

----
(Signed by participant, date)

Appendix 2

UiA Faculty of Health and Sport Sciences

Vil du delta i forskningsprosjektet:

Triangulating physical effort in professional cycling

Dette er et spørsmål til deg om å delta i et forskningsprosjekt hvor formålet er å triangulere «power output», blod laktat og ventilasjon. I dette skrivet gir vi deg informasjon om hensikten til prosjektet og hva deltakelse vil innebære for deg.

Formål
Hensikten med studien er å triangulere laktat-, ventilasjon- og «power output» ved to tester; en vanlig laktatprofil test med stigende power, og 5x10min treningsøkt, på en felt anvendelig måte. Pustefrekvens har vist å være en god indikator på fysisk anstrengelse under både kontinuerlig og intervallpreget trening. I motsetning til hjertefrekvens, virker pustefrekvens mer sensitiv for økende eller minskede akutt trenings belasting, gitt den fysiologiske responsen under trening. Monitorering av ventilasjon under trening gir et objektivt mål, hvor «central command» regulerer ventilasjon under trening. «Wearable technology» gjør det mulig å kontinuerlig måle ventilasjon under trening for å kunne se fordelingen av fysisk anstrengelse igjennom treningsøkten. Vi tror at ventilasjon, tillegg til «power output» og laktat vil gi god innsikt i forholdet mellom den interne fysiologiske kostnaden og det ytre arbeidet. Ventilasjon kan gi et viktig innblikk i fysisk anstrengelse under trening og under sykkelritt, både for ryttere og trenere til å kunne reflektere rundt den foreskrevne intensitetsfordelingen og om treningen er gjennomført i henhold til forskrivelsen.

Hvem er ansvarlig for forskningsprosjektet?
Universitet i Agder, fakultetet for helse og idrettsvitenskap er ansvarlig for prosjektet. Ole Henrik Mostad er masterstudenten som er praktisk ansvarlig for datainnsamlingen. Dr. Stephen Seiler har overordnet ansvar som veileder og rådgivende idrettsforsker for Uno-X.

Hvorfor får du spørsmål om å delta?
Du er spurt om deltagelse, grunnet at lagledelsen sammen med forskere på UiA, vil test ut denne teknologien for ventilasjonsmåling under reale forhold, men samtidig på en systematisk måte som ikke forstyrrer treningen din.

Hva innebærer det for deg å delta?
Ved å delta i prosjektet vil du gi tillatelse til å bruke dine treningsdata i prosjektet. Det innebærer ingen endringer for deg eller treningen du skal gjennomføre. Tillatelsen er for trening gjennomført i forbindelse med «stage-test» og 5x10-min-økten. Deltagelse innebære å oppgi innloggings informasjon for Tyme Wear til Ole Henrik Mostad (ohmost18@student.uia.no eller + 47 95289419), for å kunne laste ned ventilasjons data. I tillegg, vil powerdata fra syklene under disse øktene, samt laktat målingen, gjøres tilgjengelige.

Det er frivillig å delta
Det er frivillig å delta i prosjektet. Hvis du velger å delta, kan du når som helst trekke samtykket tilbake uten å oppgi noen grunn. Alle dine personopplysninger vil da bli slettet. Det vil ikke ha noen negative konsekvenser for deg hvis du ikke vil delta eller senere velger å trekke deg.

Ditt personvern – hvordan vi oppbevarer og bruker dine opplysninger
Vi vil bare bruke opplysningene om deg til formålene vi har fortalt om i dette skrivet. Vi behandler opplysningene konfidensielt og i samsvar med personvernregelverket.

Under prosjektet er det kun personer tilknyttet prosjektet som har tilgang på datamaterialet, henholdsvis studenten og veileder. Datamaterialet hentes ned gjennom TrainingPeaks og Tyme Wear. Videre lager det på UiA´s passord beskyttede servere (OneDrive) for videre analyse.

Identifikasjonsnøkkelen som lages er skriftlig, og lagres separert fra datamaterialet.

Ved publikasjon vil ingen data kunne knyttes tilbake til deg, og det vil heller ikke publiseres annen data enn det som er beskrevet i dette skrivet.

Hva skjer med personopplysningene dine når forskningsprosjektet avsluttes?
Prosjektet vil etter planen avsluttes når oppgaven leveres i mai 2023. Datamaterialet som er lagret i OneDrive vil bli slettet fra serveren ved prosjektslutt, og koblingsnøkkelen mellom navn og ID-nummer i prosjektet destrueres.

Hva gir oss rett til å behandle personopplysninger om deg?
Vi behandler opplysninger om deg basert på ditt samtykke.

På oppdrag fra fakultetet for helse og idrettsvitenskap har Personverntjenester vurdert at behandlingen av personopplysninger i dette prosjektet er i samsvar med personvernregelverket.

Dine rettigheter
Så lenge du kan identifiseres i datamaterialet, har du rett til:

- innsyn i hvilke opplysninger vi behandler om deg, og å få utlevert en kopi av opplysningene
- å få rettet opplysninger om deg som er feil eller misvisende
- å få slettet personopplysninger om deg
- å sende klage til Datatilsynet om behandlingen av dine personopplysninger

Hvis du har spørsmål til studien, eller ønsker å vite mer om eller benytte deg av dine rettigheter, ta kontakt med:

- Fakultet for helse og idrettsvitenskap ved Stephen Seiler, PhD (Stephen.Seiler@uia.no, tlf: 91614578)
- Ole Henrik Mostad, masterstudent (ohmost18@student.uia.no , tlf: 95289419)
- Vårt personvernombud: Trond Hauso (trond.hauso@uia.no, tlf:93601625)

Hvis du har spørsmål knyttet til Personverntjenester sin vurdering av prosjektet, kan du ta kontakt med:

- Personverntjenester på epost (personverntjenester@sikt.no) eller på telefon: 53 21 15 00.

Med vennlig hilsen

Stephen Seiler
(Veileder)

Ole Henrik Mostad
(Masterstudent)

Samtykkeerklæring

Jeg har mottatt og forstått informasjon om prosjektet «*Triangulating physical effort in professional cycling*» og har fått anledning til å stille spørsmål.
Jeg samtykker til:

- å delta i prosjektet ved å gi tilgang til mine treningsdata til bruk i prosjektet

Jeg samtykker til at mine opplysninger behandles frem til prosjektet er avsluttet

----
(Signert av prosjektdeltaker, dato)

Appendix 3

Sikt

Meldeskjema / Respirational adaptions during altitude training; An observation stu... / Vurdering

Vurdering av behandling av personopplysninger

Referansenummer	Vurderingstype	Dato
245649	Standard	04.11.2022

Prosjekttittel
Respirational adaptions during altitude training; An observation study

Behandlingsansvarlig institusjon
Universitetet i Agder / Fakultet for helse- og idrettsvitenskap / Institutt for idrettsvitenskap og kroppsøving

Prosjektansvarlig
Stephen Seiler

Student
Ole Henrik Mostad

Prosjektperiode
03.11.2022 - 15.05.2023

Kategorier personopplysninger
Alminnelige
Særlige

Lovlig grunnlag
Samtykke (Personvernforordningen art. 6 nr. 1 bokstav a)
Uttrykkelig samtykke (Personvernforordningen art. 9 nr. 2 bokstav a)

Behandlingen av personopplysningene er lovlig så fremt den gjennomføres som oppgitt i meldeskjemaet. Det lovlige grunnlaget gjelder til 15.05.2023.

Meldeskjema

Kommentar
OM VURDERINGEN
Personverntjenester har en avtale med institusjonen du forsker eller studerer ved. Denne avtalen innebærer at vi skal gi deg råd slik at behandlingen av personopplysninger i prosjektet ditt er lovlig etter personvernregelverket.

Personverntjenester har nå vurdert den planlagte behandlingen av personopplysninger. Vår vurdering er at behandlingen er lovlig, hvis den gjennomføres slik den er beskrevet i meldeskjemaet med dialog og vedlegg.

VIKTIG INFORMASJON TIL DEG
Du må lagre, sende og sikre dataene i tråd med retningslinjene til din institusjon. Dette betyr at du må bruke leverandører for spørreskjema, skylagring, videosamtale o.l. som institusjonen din har avtale med. Vi gir generelle råd rundt dette, men det er institusjonens egne retningslinjer for informasjonssikkerhet som gjelder.

TYPE OPPLYSNINGER OG VARIGHET
Prosjektet vil behandle alminnelige personopplysninger og særlige kategorier av personopplysninger om helse frem til 15.05.2023.

LOVLIG GRUNNLAG
Prosjektet vil innhente samtykke fra de registrerte til behandlingen av personopplysninger. Vår vurdering er at prosjektet legger opp

til et samtykke i samsvar med kravene i art. 4 nr. 11 og 7, ved at det er en frivillig, spesifikk, informert og utvetydig bekreftelse, som kan dokumenteres, og som den registrerte kan trekke tilbake.

For alminnelige personopplysninger vil lovlig grunnlag for behandlingen være den registrertes samtykke, jf. personvernforordningen art. 6 nr. 1 a.

Behandlingen av særlige kategorier av personopplysninger er basert på uttrykkelig samtykke fra den registrerte, jf. personvernforordningen art. 6 nr. 1 a og art. 9 nr. 2 a.

PERSONVERNPRINSIPPER
Personverntjenester vurderer at den planlagte behandlingen av personopplysninger vil følge prinsippene i personvernforordningen:

• om lovlighet, rettferdighet og åpenhet (art. 5.1 a), ved at de registrerte får tilfredsstillende informasjon om og samtykker til behandlingen
• formålsbegrensning (art. 5.1 b), ved at personopplysninger samles inn for spesifikke, uttrykkelig angitte og berettigede formål, og ikke viderebehandles til nye uforenlige formål
• dataminimering (art. 5.1 c), ved at det kun behandles opplysninger som er adekvate, relevante og nødvendige for formålet med prosjektet
• lagringsbegrensning (art. 5.1 e), ved at personopplysningene ikke lagres lengre enn nødvendig for å oppfylle formålet.

DE REGISTRERTES RETTIGHETER
Vi vurderer at informasjonen om behandlingen som de registrerte vil motta oppfyller lovens krav til form og innhold, jf. art. 12.1 og art. 13.

Så lenge de registrerte kan identifiseres i datamaterialet vil de ha følgende rettigheter: innsyn (art. 15), retting (art. 16), sletting (art. 17), begrensning (art. 18) og dataportabilitet (art. 20).

Vi minner om at hvis en registrert tar kontakt om sine rettigheter, har behandlingsansvarlig institusjon plikt til å svare innen en måned.

FØLG DIN INSTITUSJONS RETNINGSLINJER
Personverntjenester legger til grunn at behandlingen oppfyller kravene i personvernforordningen om riktighet (art. 5.1 d), integritet og konfidensialitet (art. 5.1. f) og sikkerhet (art. 32).

Ved bruk av databehandler (spørreskjemaleverandør, skylagring, videosamtale o.l.) må behandlingen oppfylle kravene til bruk av databehandler, jf. art 28 og 29. Bruk leverandører som din institusjon har avtale med.

For å forsikre dere om at kravene oppfylles, må prosjektansvarlig følge interne retningslinjer/rådføre dere med behandlingsansvarlig institusjon.

MELD VESENTLIGE ENDRINGER
Dersom det skjer vesentlige endringer i behandlingen av personopplysninger, kan det være nødvendig å melde dette til oss ved å oppdatere meldeskjemaet. Før du melder inn en endring, oppfordrer vi deg til å lese om hvilken type endringer det er nødvendig å melde:
https://www.nsd.no/personverntjenester/fylle-ut-meldeskjema-for-personopplysninger/melde-endringer-i-meldeskjema

Du må vente på svar fra oss før endringen gjennomføres.

OPPFØLGING AV PROSJEKTET
Vi vil følge opp ved planlagt avslutning for å avklare om behandlingen av personopplysningene er avsluttet.

Kontaktperson hos oss: Lise Haveraaen

Lykke til med prosjektet!

Appendix 4

Ole Henrik Utne
Mostad

Besøksadresse:
Universitetsveien 25
Kristiansand

Ref: [object Object]

Tidspunkt for godkjenning: : 01/11/2022

Søknad om etisk godkjenning av forskningsprosjekt - Respiratoriske adaptasjoner under høydetrening; En observasjonsstudie

Vi informerer om at din søknad er ferdig behandlet og godkjent.

Kommentar fra godkjenner:

Hilsen
Forskningsetisk komite
Fakultet for helse - og idrettsvitenskap
Universitetet i Agder

UNIVERSITETET I AGDER
POSTBOKS 422 4604 KRISTIANSAND
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www.uia.no

FAKTURAADRESSE:
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FAKTURAMOTTAK
POSTBOKS 383 ALNABRU 0614 OSLO