University of Agder

Master

Reliability and Validity of a Wearable Shirt for Ventilatory Measurements in Team Sports

A quantitative evaluation of the Tyme Wear Smart Shirt

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Acknowledgements

We want to start by thanking the team at Tyme Wear™ for lending us the Tyme Wear Smart Shirts for this study. The research of this study turned out to be harder to execute than anticipated as we faced some challenges along the way. Some of these include delays caused by equipment being out of order at the beginning of the test period. This led to the recruitment process taking longer than expected which resulted in postponements of the entire study.

Luckily, we were able to conduct tests in the laboratory at the University of Stavanger in addition to the laboratory at the University of Agder. We are beyond grateful for this as it helped us reach the finish line. Therefore, we would like to thank Håvard Myklebust, who gave us access to the laboratory at the University of Stavanger, and Andreas Mathingsdal Pedersen for the laboratory at the University of Agder. We could not have executed the research without this.

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Abbreviations

In order of appearance.

BR	Breathing rate (br/min)
TV	Tidal volume (vol/br)
VE	Ventilation volume (vol/min)
VO_2 max	Maximum oxygen uptake ($ml*kg^{-1}*min^{-1}$)
Yo-Yo IRL1	Yo-Yo intermittent recovery level 1
RPE	Rating of perceived exertion (Borg scale, 6-20)
VCO2	Volume of carbon dioxide (mL/min)
AT	Anaerobic threshold
ANS	Autonomic nervous system
HR	Heart rate
RFT	Readiness for testing
CPET	Cardiopulmonary exercise test
RER	Respiratory exchange ratio
VO_2	Oxygen uptake (mL/min)
LA-	Lactate sample ($mmol*L^{-1}$)
BR_{PEAK}	Peak breathing rate (br/min)
VE_{PEAK}	Peak ventilation volume (vol/min)

Abstract (ENG)

Title: Reliability and Validity of a Wearable Shirt for Ventilatory Measurements in Team Sports.

Aim: This study aims to make preliminary explorations of the suitability of a recently developed wearable monitoring device for ventilation measurement, the Tyme Wear Smart Shirt, in a team sports context. Can the smart shirt provide valid and reliable data on variables such as breathing rate (BR), tidal volume (TV) and their product, ventilation volume (VE), in team sports?

Methods: This study is an interventional study, following a descriptive design built on valid and reliable quantitative data. The subjects are in the age range of 19-35 years old, in a good physical fitness level and familiar with running-based team sport. Measurements of BR, TV and VE from a laboratory and Tyme Wear Smart Shirt were analyzed using Pearson`s correlation coefficient. Statistical significance is set as $P < 0.05$. The tests conducted are one clinical test (VO_2 max test) and one field test (Yo-Yo intermittent recovery level 1 test (Yo-Yo IRL1)).

Result: The project includes 18 subjects (15 male, 3 female), with complete data sets for all variables for 16 (13 male, 3 female). There was a positive significant correlation of the BR-data from the Yo-Yo IRL1 test (R^2=0.41) which is seen as promising data. The VE-data from the Yo-Yo IRL1 test (R^2=0.86) and TV-data from Yo-Yo IRL1 test (R^2=0.89) also appears promising. The shirt shows reliable measurements of BR for the VO_2 max test (R^2=0.68).

Conclusion: The Tyme Wear Smart Shirt has proven to the ability to make valid BR measurements during the VO_2 max test with reliable and significant data. For the VE and TV data however, there was no significant difference in the data even though they were reliable. More specific research must be done in order to determine the reliability and validity of Tyme Wear Smart Shirt in running-based team sports.

Key words: Wearable monitoring device, running-based team sport, VO_2 max, Yo-Yo IRL1, BR, TV, VE.

Sammendrag (NO)

Tittel: Reliabilitet og Validitet av en Bærbar Skjorte for Ventilasjonsmålinger i Lagsporter.

Formål: Formålet til denne studien er å utføre innledende undersøkelser av egenheten til et nylig utviklet bærbart måleverktøy for ventilasjonsmålinger, Tyme Wear Smart Shirt, i en lagsportkontekst. Kan måleverktøyet gi valide og reliable data om variabler som pustefrekvens (BR), tide volum (TV) og deres produkt, ventilasjonsvolum (VE), i lagsporter?

Metode: Denne studien er en intervensjonsstudie som følger et deskriptivt design basert på valid og reliabel kvantitativ data. Forsøkspersonene er i aldersgruppen 19-35 år med god fysisk form og er kjent med løpsbasert lagsport. Målinger av BR, TV og VE fra et laboratorium og Tyme Wear Smart Shirt ble analysert ved hjelp av Pearsons korrelasjonskoeffisient. Statistisk signifikans er satt til $P < 0.05$. Testene som ble gjennomført inkluderer en klinisk test (VO_2 max test) og en felt test (Yo-Yo Intermittent recovery test level 1 (Yo-Yo IRL1))

Resultat: Prosjektet inkluderer 18 forskningspersoner (15 menn, 3 kvinner) med komplette datasett for alle variabler for 16 (13 menn, 3 kvinner). Det var en positiv signifikant korrelasjon av BR-dataene fra Yo-Yo IRL1 test (R^2=0.41), som anses som lovende data. VE-dataene fra Yo-Yo IRL1 test (R^2=0.86) og TV-dataene fra Yo-Yo IRL1 test (R^2=0.89) fremtrer også lovende. Skjorten viser reliable målinger av BR for VO_2 max testen (R^2=0.68).

Konklusjon: Tyme Wear Smart Shirt har bevist at den evner å gjøre valide BR målinger under VO_2 maks testen med både reliable og signifikante data. For VE og TV dataen derimot, var det ingen signifikant forskjell i dataen selv om de viste seg å være reliable. Det må derfor utføres mer spesifikk forskning for å kunne fastslå reliabiliteten og validiteten av Tyme Wear Smart Shirt i løpsbasert lagidretter.

Nøkkelord: Bærbart måleverktøy, løpsbasert lagidrett, VO_2 max, Yo-Yo IRL1, BR, TV, VE.

Explanation of work distribution

The work has been distributed based on our strengths and weaknesses as academic writers and researchers. For the beginning of the writing process, we made a list of all the chapters we should include in our study and distributed the main responsibility of each chapter between us. At the beginning, Ester was in charge of writing the introduction and the theoretical chapters, while Tone was in control of the methodical chapters. After one was finished with writing a chapter, the other would read through it and make additional adjustments if this felt necessary. When going through each other's texts we would communicate and make the final adjustments together to make sure we both felt ownership of the entire study.

We wrote the remaining chapters (results, discussion of results, and methodical discussion) together and communicated throughout the entire writing process.

The work behind and throughout the recruitment period and the testing process was equally distributed as we both supervised the same number of test days and made the protocol together. This also counts for the data analysis, the making of tables and figures, and the finishing touches of the completed study.

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1 Introduction

When categorizing athletes by sport, we usually distinguish between individual and team sport athletes. Individual athletes compete as individuals but are often dependent on their teammates during a competition and in training. You often see this in cycling but also in sports such as cross-country skiing, the individual athletes depending on their teammates during a race. Team sports athletes need to work together and cooperate with their team during games, making them more dependent on each other when competing. Team sport athletes also compete as a team, such as one can see in soccer and handball. As a result of there being more physical interaction between team sport athletes than individual athletes, the movements and patterns become unpredictable and different second to second.

In this study, we examine the validity, reliability, and "field setting robustness" of the Tyme Wear Smart Shirt by comparing the recordings from the shirt during one clinical (VO_2 max test) and one field test (Yo-Yo IRL1 intermittent recovery level 1 test). Based on the results from these two maximal effort tests, the data from the wearable has been analyzed and assessed. This is to provide insight into whether this way of training monitoring is beneficial in a team sports context and whether it manages to measure data consisting of information that can further help optimize the development of each athlete. The number of devices and methods for training monitoring has increased in recent years and today, there are several tools for collecting data. Using combinations of smartwatches and other wearables, training monitoring technology choices have multiplied in recent years.

Monitoring athlete performance and total workload can provide valuable information regarding both physical and technical qualities (Cummins et al., 2019, p. 654). A fundamental goal in training monitoring is to simultaneously quantify both the external work performed (external workload) and the internal 'cost' of doing that work (physiological and perceptual responses). Being able to measure this internal/external work versus cost relationship can improve training decision-making (Bourdon et al., 2017, p. S2-161).
Monitoring team sport athletes is notably challenging due to the unpredictable nature of their physical movements, including changes of direction and accelerations/decelerations, during both training and competition. This complexity contrasts with individual endurance sports like running or cycling, where movements are more predictable and repetitive, simplifying training monitoring. A team sport athlete's total training load includes both internal and

external components. The external load refers to the volume and intensity of various physical movements, such as total distance run, sprint accelerations, changes of direction, jumps, etc. The internal load refers to the neuromuscular, metabolic, and perceptual demands of achieving the external work at the rate it is executed. This internal load can be estimated from systemic variables like heart rate, respiratory frequency, blood lactate concentration, and rate of perceived exertion (RPE) (Castillo et al., 2017, p. 922). Of these, breathing frequency is an attractive variable to monitor if feasible because it may be more responsive to rapid changes in external work rate than blood lactate or heart rate, and it is more highly correlated with perceived exertion than heart rate (Nicolo et al., 2017, p.1). When doing research and collecting data using wearable measurement tools, different movements and abrupt changes in direction and speed can generate 'noise' in raw signals of interest, like breathing movements in the chest.

We performed preliminary investigations evaluating the potential for 'repurposing' a new wearable technology designed for endurance training testing and monitoring to accurately quantify ventilation characteristics in a team sport movement context.

The technologies integrated into this wearable vest provide both simple external movement quantification metrics and filtered measurement of chest wall excursions, both frequency (breaths/min) and 'depth' of individual breaths, paralleling tidal volume (liters/breath) and allowing for estimates of ventilatory volume (liters/min). The Tyme Wear Smart Shirt consists of a built-in breathing sensor and an Inertial Measurement Unit (IMU) formed as a detachable and chargeable pod. The shirt measures breathing rate, ventilation volume, and breathing volume by tracking chest expansions and contractions via a stretch sensor. The shirt measures Tidal Volume (TV), Breathing Rate (BR) and Ventilation volume (VE) which are the variables measured in this study (Tyme Wear™, n.d., FAQ section). In short, the Tyme Wear Smart Shirt is a tool developed for measuring the individual athlete's ventilation while providing time synchronized information about basic movement characteristics. The information provided by the shirt's measurements make possible both ventilatory threshold estimates and evaluations of internal stress/load changes at a given external work rate during training sessions (Tyme Wear™, n.d.). These data can serve as a guide in individualizing one's training toward improved and optimal endurance.

As the Tyme Wear Smart Shirt has been developed as a measuring tool for endurance sports, it has mainly been tested on endurance athletes. Taking this into consideration, this study was envisioned as a preliminary investigation of applying wearable based ventilation measurements in the more variable movement environment of team sports, and more specifically, running-based team sports such as handball, soccer, basketball, etc.

While endurance athletes often produce one consistent, cyclical movement (e.g. running, cycling), team sport athletes generate more sudden, unpredictable movements with frequent changes of direction, rapid positive and negative accelerations, or jumping. All these movements involve the torso and could overwhelm the "signal" of breathing induced chest wall movements and make the shirt's measurements invalid. This study examined whether the Tyme Wear Smart Shirt can quantify the three main ventilation variables in a team sport movement context. Therefore, the thesis problem was: "Can a wearable "smart shirt" with integrated thoracic excursion sensor provide valid and reliable ventilatory data in team sports?". To answer this question, 18 subjects took part in 2 different endurance tests. The subjects were tested to determine their maximal oxygen consumption (VO_2 max) using treadmill testing and a metabolic cart system, in addition to performing an intermittent recovery Yo-Yo IRL1 test. All subjects completed both treadmill tests to exhaustion and Yo-Yo IRL1 tests to exhaustion twice on different days with a resting period of a minimum of 2 days and a maximum of 2 weeks in between. This led to a total of 36 test results for evaluating the shirt's validity compared with laboratory based metabolic cart and reliability in the test-retest condition.

The thesis is divided into different parts, each important in supporting the validity and reliability of the results. The study consists of one part describing the theoretical grounding and research applied in this thesis. In this part, all important aspects connected to this research will be explained and reasoned as to why they are relevant. The two physical tests the subjects took part in and why these were the tests chosen, will also be justified through the description of theory and earlier research. This explains why these exact tests were chosen as the interventions of this study. The methodological approach applied and why this is the most suitable for this project is explained and justified in the next part. Here, the method is thoroughly described and the connections between the research question and methodology are shown. As this study is part of the post-positivism paradigm of research, we aim to verify the hypothesis following the research question. To be able to accept or reject the null hypothesis, the post-positivistic recognition of the human ability to make mistakes

(Young & Ryan, 2020, p. 698) reminds us to stay critical of our own findings and how we got there.

1.1 Research question and hypothesis

"Can a wearable "smart shirt" with integrated thoracic excursion sensor provide valid and reliable ventilatory data in team sports?".
As the research question involves quantification of measurement reliability and validity, the null hypothesis is that the smart shirt does not provide valid and reliable ventilatory measurements which in this study include breathing rate (BR), tidal volume (TV), and ventilation volume (VE), in a team sport movement setting. Our research hypothesis is therefore that the smart shirt can provide valid and reliable data on these variables in team sports. The tests completed in this study and their results provided grounds for evaluating whether the null hypothesis should be kept or discarded. The Tyme Wear Smart Shirt is one of these newly developed tools, but does it actually measure what it is advertised to measure?

2 Theoretical grounding and earlier research

This chapter contains a review of earlier research and theory relevant to measuring ventilation, breathing rate, and tidal volume, as well as these three terms in association with Tyme Wear Smart Shirt, team sport, and VO_2 max. Ventilation is an important physiological variable that has historically been quantified in specialized laboratories. However, there are currently no practical tools to measure ventilation in a field setting, especially in team sports. We will therefore discuss in this chapter how this new technology is designed to measure ventilation both practically and precisely in team sports, and why this is potentially useful.

2.1 Ventilation

To accurately assess the technology of the Tyme Wear Smart Shirt, one must understand the breathing mechanism. On a physiological level, we refer to 'breathing' as pulmonary ventilation; the process of airflow into and out of the lungs during inspiration and expiration (SEER Training Modules, n.d., Mechanics of Ventilation section). The gas exchange (specifically, CO_2 and O_2) between the external environment and the circulatory system is facilitated by the lungs (Powers & Dhamoon, 2023, Introduction section). External air is inspired through the trachea which further splits into two bronchi before entering the lungs. The lungs consist of multiple airways that branch out into smaller bronchi; bronchioles that lead to the millions of alveoli, where gas exchange between lungs and capillaries occurs. Importantly, the lungs are covered by a membrane called the pleura which physically connects the muscle and bones of the thorax to the lungs and causes thorax and lungs to expand and contract in unison. During inspiration, the thoracic volume increases causing a negative pressure, or partial vacuum, in the airways which then leads to inwards airflow from the atmosphere. This thoracic volume expansion is caused by the contraction of the diaphragm and the expansion of the rib cage. (Schibye, 2017, pp. 317-321, see Figure 1 below). The diaphragm is the muscle located between the thorax and the abdomen, creating a separation between the two cavities.

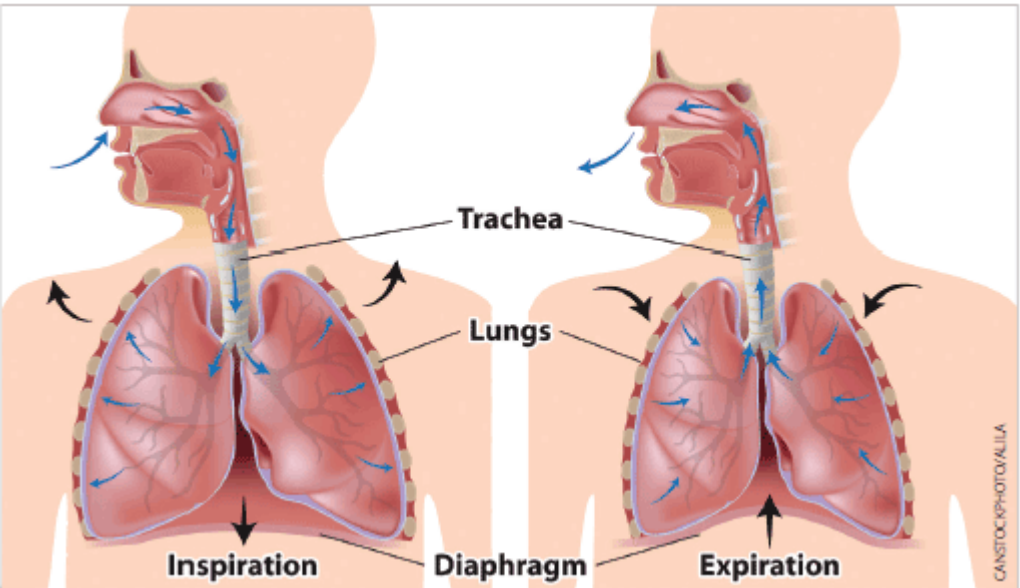


Figure 1. Cycle of breathing, inspiration and expiration (Can Stock Photo). Illustration depicting the airflow (blue arrows) in the lungs and torso during inspiration and expiration.

The anatomy of the diaphragm is important to understand the mechanics of breathing. The diaphragm inserts into a central tendon and has sternal, costal, and lumbar origins (Bains et al., 2023, Embryology section). Being that the diaphragm is located as is, it causes movements in both the thoracic and abdominal cavities through contraction. During inspiration, the diaphragm muscle fibers contract. When contracting, the diaphragm, being a dome-shaped muscle, descends and flattens out, elevating the thorax cavity while the thoracic pleural pressure falls, and the abdominal pressure rises. This pressure change leads to the contraction of most of the thorax and the expansion of the abdominal walls. In addition to this, the accessory muscles of ventilation (i.e., external, and parasternal intercostals, and scalenes) cause the thorax to expand, increasing the diameter of the thoracic cavity (Schibye, 2017, p. 322; De Troyer & Boriek, 2011, p. 1273; Sieck et al., 2013, Respiratory Muscle Types section, para. 2; Higashino et al., 2022, p. 1). On average, the normal excursion of the diaphragm is 1-2cm at rest and up to more than 10cm during heavier breathing (Schibye, 2017, p. 322; Haji et al., 2026, p. 57). This large difference explains why we experience a greater thoracic and abdominal movement during exercise. A ventilation measuring "shirt" designed to integrate a thoracic stretch sensor must be able to 1) count and 2) quantify the magnitude of these small to large excursions during movement.

Expiration, on the other hand, occurs as the diaphragm relaxes. Relaxation of the diaphragm causes the abdominal pressure to increase, returning the thorax to its natural position. Contraction of the lungs due to the increased pressure within the airways, results in expiration. While expiration usually happens passively, physical exertion increases ventilation which activates the accessory muscles of expiration (i.e., internal intercostal, triangularis sterni, and four abdominal muscles). Activation of these muscles creates a greater constriction in the thoracic and abdominal cavities than from passive expiration, reversing the movements from the inspiration, pushing the diaphragm upwards, and pulling the thorax down (Hlastala & Berger, 2001, p. 37; Schibye, 2017, p. 324). The heavier and deeper the pulmonary ventilation is, the greater the movements that follow as more muscles are activated.

The magnitude of respiratory movement determines whether the ventilation is considered mainly thoracic (costal) or abdominal (diaphragmatic). The pliability of the abdominal wall affects which of the cavities is the primary; the more active the abdominal muscles are, the more of a thoracic movement will occur as the diaphragm will elevate the thorax, resulting in more thoracic ventilation. Whereas a more relaxed abdominal wall combined with a deeper breath, will cause a downward movement of the diaphragm while moving the abdomen forwards and be considered more of an abdominal ventilation (Schibye, 2017, p.322; Higashino et al., 2022, p. 1). Both breathing patterns are present in regular breathing, and the force of ventilation determines which muscles are activated.

Measurements of ventilation volume per minute (VE) are useful for describing mechanisms involved in the control of breathing during physical activity and during daily life (Dumond et al, 2017, p. 1534). Measuring VE is also useful to detect any abnormalities in breathing.

Earlier research by Dumond et al (2017, p.1536) demonstrated that using the Nomics RMP technique by Gastinger et al (2010a) and iWorx spirometer device by Gastinger et al (2010a) to measure V_E are valid and reliable in physical activities as long as the electromagnetic coils are small and can be integrated into clothing to allow even less invasive measurements of V_E and breathing patterns. Nomics RMP technique is a device with a recorder box that transmits a signal to a PC running the appropriate computer software and is based on an earlier device used by Gastinger et al (2010a) (Dumond, 2017, p. 1538). iWorx spirometer device measures volume variations in liters and has a four-channel data unit (Dumond et al, 2017, p. 1539). The inspiratory and expiratory flows are visualized in real-time on a PC (Dumond et al, 2017, p.1539).

2.2 Breathing rate

Breathing rate (BR), also known as respiratory rate or respiratory frequency, is suggested as a potentially informative variable during training monitoring (Nicolò et al., 2017, p. 1). BR is suggested to be among the most promising and measured physiological variables because of the fundamental information provided (Massaroni et al, 2019, p. 1). In emergency medicine, *BR* is considered one of the "vital signs" and refers to the number of breaths taken within one minute (Berman et al., 1991, p.81; Ali et al, 2021, p. 14569). It is considered one of the most informative physiological variables in an acute setting because of its sensitivity to a variety of physiological, psychological, and environmental stressors (Massaroni et al, 2019, p. 1). Measurements of BR serve as an important indicator of someone's overall health (Al-Khalidi et al., 2011, p. 523) as a too-high or too-low breathing rate may indicate underlying potentially pathological conditions. BR is directly connected to ventilation and is generated through the process of respiration. The respiratory system, as described in the previous chapter, allows airflow to circulate while providing the body with oxygen and disposing of carbon dioxide (Rolfe, 2019, p. 504). The respiratory process and the movements that follow are what determine the BR. During exercise and increased physical load, the body requires more oxygen to increase energy availability in working muscles. An increased demand for oxygen means that the lungs have to move more air in and out each minute, which in turn creates larger movements of the thoracic structure. The body's production of carbon dioxide increases due to the elevated oxidative metabolism at the mitochondrial level, triggering a higher BR. However, total ventilation volume is increased both by increasing BR and by increasing the volume of air inspired and expired each breath, the tidal volume (TV).

Together BR and TV determine the total ventilation measured in liters per minute (VE). Both BR and TV increase with metabolic demand to satisfy the O_2 intake and CO_2 removal requirements of the body (Massaroni et al, 2019, p. 1). Nicolò et al. have recently reviewed the importance of measuring *BR* and concluded that it is a better marker of acute variation in physical effort compared to traditionally monitored physiological variables such as oxygen uptake, heart rate, and blood lactate (Massaroni et al, 2019, p. 3).

Several factors affect the BR, such as physical effort, temperature, psychological stress, etc. These factors determine the body's need for oxygen leading to an increase or decrease of the breathing rate. We can distinguish between internal and external factors. Stress is an internal factor and increased stress will instigate processes internally and cause an increase in the body's need for oxygen. As for the external factors, the physical effort during exercise leads to the muscles working at a higher rate, requiring more energy and therefore also more oxygen. BR is shown to be strongly associated with perceived exertion (Borg Scale, RPE) in several exercise studies and responds rapidly to abrupt changes in work rate which occur during intermittent exercise. This sensitivity of BR to second-to-second changes in demand makes it a potentially useful measurement, as many sporting activities such as soccer and other team sports are highly variable in work rate (Nicolo et al, 2019, p. 3), see Figure 2.

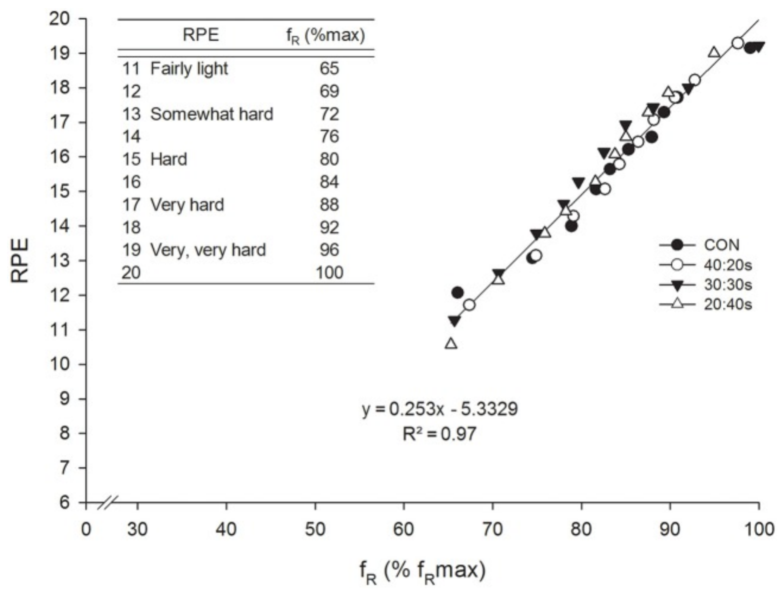


Figure 2. The correlation between BR and RPE during a continuous and three different HIIT trials. from Nicolo et al. (2019). The regression equation of the correlation obtained was used to associate BR normalized to BR_{max} with the 6-20 RPE scale. Done to facilitate the interpretation of BR-values obtained during exercise. (Nicolo et al, 2019, p. 5).

One must consider several factors when measuring BR, such as sports applications, measurement requirements, and user needs (Massaroni et al, 2019, p. 1). There are multiple technological approaches to monitoring breathing rate, most of which are only feasible in clinical settings (Chu et al., 2019, p.1). Breathing rate measurements provide valuable information within training monitoring and are classified technologically as either contact-based or contactless methods (Massaroni et al., 2019, p.1). So far, measuring BR during exercise has been very uncommon and there is a paucity of respiratory wearable devices designed for sporting activities. In recent decades, wearable monitoring devices have been developed to monitor athletes and individuals facing prominent levels of psychophysiological stress. However, they have not yet proven to be practical tools in team sports. Chest wall movement analysis devices are one of the measuring devices used for athletes, one of them being transthoracic impedance sensors which consist of 2 or 4 electrodes placed on the chest making the data unreliable and invalid because of the consistent body movements. In this study, the measurements are made through the use of the Tyme Wear Smart Shirt which is classified as a contact-based monitoring instrument. This wearable tool employs the technology of "chest and abdominal movement detection" (Al-Khalidi et al., 2011, p. 524). This specific wearable measures the movements of the thoracic cavity during physical effort, making it potentially practical for athletes to use during exercise. A measuring tool that measures *BR* similar to Tyme Wear, has already been tested and showed a better performance in terms of robustness and reduced movement artifacts, which would have caused the data to be more unreliable (Massaroni, 2019, p. 26). Comparisons with results from laboratory tests are necessary to determine the accuracy of the data measured by wearables in the field.

2.3 Tidal volume

Measurement of the tidal volume (TV) is useful when looking to detect abnormalities during breathing and for describing mechanisms involved in breathing during physical activity (Dumond et al, 2017, p. 1534). Within each respiratory cycle, air moves in and out of the lungs. The volume of air moved in and out of the lungs with which each breath is referred to as tidal volume. The inspired and expired air during respiration requires a certain volume in order to function. The metabolic demand for oxygen increases linearly as intensity increases and makes the lungs supply oxygen to both the working skeletal muscles and the respiratory muscles (Carey et al, 2008, p. 44). When respiration takes place, external air is inspired through the airways and down in the lungs. The alveolar gas exchange allows oxygen to diffuse and enter the blood, while carbon dioxide is expelled through expiration (Hallett et al., 2023, p. 1). When monitoring the lung and the volumes, we look at tidal volume as the volume of air moving in and out of the lungs during ‘normal breathing’, while the maximal volume of exhaled air in a single breath is called the vital capacity. After a maximal expiration (forceful expiration of as much air as possible), there is still some gas left in the lung, the residual volume. After a normal expiration, the remaining gas in the lungs is referred to as the functional residual capacity (West et al., 2012, p.13). During incremental exercise, the respiratory muscles consume 10-18% of whole-body oxygen consumption when VO_2 max is reached (Carey et al, 2008, p. 45). However, we have also examined breathing frequency, due to its practicality in a training setting.

Spirometry is the most common technique for measuring changes in respiratory volume and allows one to measure ventilation and the inspiratory and expiratory times. It is effective and useful for assessing the breathing efficiency of humans and can also be used as an airway assessment tool (Dumond et al, 2017, p. 1534). However, though the spirometry method is precise, it requires the use of a facial mask or mouthpiece which makes it very impractical for team sports and may also be uncomfortable over a longer period during high-intensity training.

Monitoring tidal volume is efficient when looking to estimate the ventilatory status of the athlete (Monaco & Stefanino, 2021, p. 2). In this case, the Tyme Wear Smart Shirt combines the monitoring of tidal volume with the other variables (BR and VE, amongst others) and creates indications for the athlete’s thresholds. Tidal volume plays a part in which the product of tidal volume and breathing rate is the lungs' ventilation volume. It is important to emphasize that the measurements from the Tyme Wear Smart Shirt only come as ‘index values’, as they are not calibrated as liters/min. Meaning that the values from these measurements are only comparable within the same person but not across people.

2.4 Tyme Wear Smart Shirt

The development and the use of consumer wearable technology have increased during the last 5 years and the goal has been to easily provide biometric information regarding the user`s physiology and lifestyle, which has previously been unknown (Gouw et al, 2022, p. 1).

Though the use of wearable devices is growing, there are still challenges associated with cost, poor data representation, lack of usability in especially team sports, and excessive information. The biggest challenge of wearable devices so far has been the reliability and validity of the biometric data, whereas reliability is defined as "the consistency of the data collected from a measurement" (Gouw, 2022, p. 2). Validity is defined as "the extent to which the data collected from a measurement accurately represent the reality of the variables intended to be measured" (Gouw et al, 2022, p. 2). As hardware and software development continue to be more advanced, devices can now measure and collect physiological data, which has previously only been collected in a laboratory environment. Meaning that the use of wearables allows researchers to work directly in the field without being dependent on a laboratory. If the wearables function as intended, conducting research directly in the field holds the potential to expand and introduce a more efficient method of health monitoring. This efficiency comes from the ability to gather real-time data in natural settings, providing more accurate insights into athletes' health and performance compared to clinical testing. The increase of available measuring sensors and different types of wearables for monitoring respiratory activity makes for an even bigger need for research within this area. The wearables need to be tested and reviewed to estimate the accuracy of the measurements. There are several studies and research done using wearable tools such as the smart shirt applied in this study.

Tyme Wear™ has developed a smart shirt and an application that measures VE to determine the ventilatory threshold of endurance athletes, both individual and in team sports. The Tyme Wear Smart Shirt monitors the pulmonary ventilation movements explained in this chapter through the shirt's breathing sensor and pod. Each breath taken is monitored by the sensor which provides measurements of breathing rate, tidal volume, and ventilation volume (Tyme Wear TM, n.d., FAQ section). The tests completed by the subjects in this study were chosen to provide information on the extent to which the breathing sensor and the pod can monitor and measure this type of data.

The Tyme Wear Smart Shirt is designed as a tight-fitting tank top, with technology that aims to provide measurements by analyzing chest wall excursions. The shirt allows the users to have affordable access to information previously only found in the laboratory (Gouw et al, 2022, p. 17). The shirt must sit tight as a non-fitted shirt could cause interference with the sensor's monitoring ability. The shirt's breathing sensor consists of a strain gauge that identifies, and time stamps the highs and lows of each thoracal movement of the excursion. The estimation of breathing rate is done "using a 3 out of 5 outlier rejection average using a 5-breath window shifting 1 breath at a time" (personal communication, Tyme Wear engineers, 2024). This means some of the breaths are rejected in the output. When calculating tidal volume, on the other hand, no breaths are rejected as this variable is calculated through "the amplitude change from the peak to the valley of each identified breath" (personal communication, Tyme Wear engineers). Through the breathing rate and tidal volume measurements, the smart shirt calculates the ventilation volume (VE) as the product of BR and TV.

The Tyme Wear application is a smartphone application that directly connects to the wearable pod and stores data from the recorded session. The app functions as the remote control for the smart shirt as long as it is connected to an active pod. The data is also available online on the Tyme Wear website "dashboard" which provides a more detailed data presentation for each training session. One will find all previously recorded sessions and visual graphs for comparing the variables measured. From here, the raw data can be downloaded and exported as either a CSV or FIT file for further analysis.

2.5 Ventilatory threshold and team sport

Endurance as a general term in sports refers to "your body's physical capability to sustain an exercise for an extended period" (Yetman, 2020). Endurance in sports is mainly associated with running, cycling or other 'classical' endurance sports. It is a form of training that leads to adaptations in the cardiovascular and musculoskeletal systems which supports an overall increase in both capacity and performance over time (Hughes et al, 2018, p. 2). This is beneficial in endurance team sports such as soccer, as it will increase the players' capacity for high intensity for a longer time. Local adaptations in the skeletal muscle aid the body's ability to transport and also use oxygen to generate energy and delay the onset of muscle fatigue during prolonged aerobic performance (Hughes et al, 2018, p. 2).

The ventilatory threshold is a function of VE and VO_2 or VE and the volume of carbon dioxide produced (VCO_2). Both ventilatory threshold 1 (VT1) and threshold 2 (VT2) depend on the individual and correspond to specific exercise intensities or workload (Gouw et al, 2022, p. 2). Measurements of ventilatory thresholds can be calculated using a ventilation curve method; V-slope metaphors; or the ventilatory equivalent method (Gouw et al, 2022, p. 2). In recent years, elite team sport athletes, in particular soccer, have been exposed to highly competitive loads due to the increased frequency and intensity of domestic and international competitions during the season and off-season (Schneider et al, 2018, p. 6). Monitoring fitness, fatigue, and performance is crucial when looking to understand an athlete's individual response to training to optimize the schedule of training and recovery strategies (Schneider et al, 2018, p. 1). Physiological measurements of VO_2 max and metabolic thresholds (LT1/VT1 and LT2/VT2) have been used commonly to monitor the fitness and training status of athletes (Edwards et al, 2003, p. 23). Both VO_2 max and "thresholds" are potentially important markers of game readiness for soccer players as they give a status on their fitness, and previous studies have demonstrated that players with a higher VO_2 max cover a greater distance of running/sprints during a soccer game (Edwards et al, 2003, p. 23). A study from Slimani et al. in 2019 showed that the mean VO_2 max of elite soccer players is typically in the range of 59 to 63 $ml \cdot kg^{-1} \cdot min^{-1}$ (Slimani et al. 2019, p. 240).

In recent years, an increased interest in heart rate monitoring devices for athletes has occurred and are very useful within multivariate response monitoring. They provide non-invasive and time-efficient insights into the status of the autonomic nervous system (ANS) and aerobic fitness (Schneider et al, 2018, p. 1). The heart rate monitoring devices available for athletes now are practical in individual endurance sports such as cycling but not in team sports such as soccer and handball yet. This is due to the complex and multidimensional structure of the game, player, and team performance, as well as the logistics such as the high number of players along with busy training and competition schedules. The devices available are made for athletes that do not move suddenly due to the game's circumstances. Therefore, to be able to practically measure ventilation in team sports, a practical tool must be made that can handle the sudden movements and change of speed and direction. The Tyme Wear Smart Shirt is developed for athletes in team sports to use when measuring ventilation and measuring training responses after a period of training or matches, etc. HR data- and monitoring devices have been used for decades but only in limited aspects of performance or training responses such as the HR. As the HR monitoring devices only measure HR, one must combine this device with another device which measures other variables such as ventilation for example (Schneider et al, 2018, p. 2). Using Tyme Wear as a measuring device of ventilation in team sports will cover most of the measurements such as VE, BR, and TV. With an additional heart rate monitor, both ventilatory measurements and heart rate measurements data will be found in the same app making it more practical for players and managers to analyze the data.

Standardized running tests such as the Yo-Yo IRL1 test have been the most appropriate way to test the ventilatory threshold in team sports due to competitions, team budget, and squad size. With Tyme Wear one should be able to measure ventilatory threshold without using submaximal standard running tests and data from this study should show good reliability in the tests that can be transformed into normal training and games. The challenge of monitoring ventilatory thresholds in team sports is the complexion of sports performance, training, and game demands which includes factors such as technical, tactical, physiological, and social components (Schneider et al, 2018, p. 6).

2.6 VO_2 max

VO_2 max is the maximum oxygen intake or maximal oxygen consumption. As an absolute value, VO_2 max is expressed as liter per minute (l/min) and as milliliters per kilogram per minute (ml/kg/min) when referred to as relative. Estimation of VO_2 max can be done in several ways. Using direct or indirect methods, the VO_2 max is estimated through maximal or submaximal tests (Buttar et al., 2019, p.25). Most commonly, VO_2 max is measured during a running or cycling test but there are other ways of measurement as well such as using sport-specific ergometry (i.e., rowing, kayaking, double poling ergo). The most precise tests, although occasionally inconvenient due to the need for access to a laboratory and specialized equipment, involve measuring oxygen uptake during carefully controlled maximum effort activities (Ashfaq et al., 2022, p. 1), such as the tests included in this research. Measurements of oxygen uptake collected using a mask that covers both mouth and nose, such as the Hans Rudolph V2 Oro-Nasal mask, or with a nose clip and mouthpiece that connects to the subject (Hans Rudolph, INC., 2024), allow for direct analysis of gas exchange.

Prediction of VO_2 max is highly relevant in both sports- and health sciences for several reasons. Four of these are presented in the 2016 article by Abut et al. In this article they mention how VO_2 max can help indicate an athlete's endurance capacity as it suggests the limit of the individual's aerobic fitness. Abut et al. (2016) also bring up that awareness of one's VO_2 max can be an advantage when looking to plan effective and personalized training programs, how it can work as a criterion within admission of candidates in different programs for sport or physical education, and how VO_2 max can be used to predict values of other target variables when used as an input predictor variable (Abut et al., 2016, p.182). As explained, the estimation and knowledge of an athlete's VO_2 max is of use in several contexts. The advantageousness of estimating this variable makes the in-field measurement tools that provide VO_2 max predictions, such as wearables, practical as they do not require laboratory equipment or training.

The spirometry measurements from the treadmill test are what provide data for us to analyze and compare with the measurements from the Tyme Wear Smart Shirt. All variables described in this chapter of the study are the ones we will be focusing on in our analysis and evaluation of the results. These include ventilation volume, breathing rate, and tidal volume. The controlled protocol VO_2 max test on the treadmill is a direct method of estimating the maximum oxygen consumption as it is a laboratory method. The direct methods of estimation provide accurate measurements by measuring and analyzing each breath taken during the test (Buttar et al., 2019, p. 25). By monitoring each breath, we are provided with frequent measurements which make for useful data in the final analysis. As the wearable applied in this study can only predict the estimations of the variables, the direct estimations from the VO_2 max test measurements challenge the results from the shirt through the comparisons in the final analysis.

3 Method

This chapter contains a presentation of the methods used in this research to answer the research question.

3.1 Qualitative method and Quantitative method

When researching, one applies a qualitative or quantitative method. The latter being the one applied in this study as we follow a controlled protocol test period of 15-20 subjects in order to collect data for the final analysis, answer the research question and hypothesis.

3.2 Choice of method

The design for this study follows a descriptive design, built on validity and reliability in an interventional study, where the thesis problem will be answered through quantitative data. A descriptive design study is used when wanting to describe “the distribution of one or more variables, without regard to any casual or other hypothesis” (Aggarwal & Ranganathan, 2019). One could argue that this study could have followed an analytical design because we are testing a hypothesis, but we are not assessing the effect of an intervention on an outcome, and therefore the descriptive design is more fitted to this study as one can see in the analysis (Ranganathan & Aggarwal, 2018). We are analyzing the data to determine the distribution of several variables which make this study descriptive. However, if we had used the data to assess the connection between the presence of exposure and an outcome, this study would have benefited from an analytical design (Aggarwal & Ranganathan, 2019).

The following paragraphs will describe this study's epistemological position, how the tests were conducted, the selection of subjects, the methodology of the data collection, the ethical considerations, and the verification of this study.

3.2.1 Epistemological position

Enlightenment is used when talking about the scientific revolution (Farrow et al., 2020). Positivism was first introduced in social science and humanities, where Augustus Comte was the first sociologist to bring an objective and normative study from the 1800s (Kvarv, 2021, p. 131). This study has its roots in the positivist tradition, more specifically post-positivism because of the amount of valid and reliable data collection. Post-positivism is based on the fact that “there is an objective truth but also accept that it can be unlikely to find it" (Young, 2020, p. 695). Though this study is supported by valid evidence, the truth can still be hard to find, and that is something we have taken into consideration when completing this study. Kivunja & Kuyini (2017) has a good description of the essential features of positivism. One that stands out is “the belief that truth or knowledge is out there to be discovered by research” (Kivunja & Kuyini, 2017 (Farrow et al., 2020). This sentence emphasizes the foundation of this study, meaning that this study aims to investigate the abilities of the Tyme Wear Smart Shirt in order to provide the ‘truth’. This study does not provide the full answer to the research, but it is moving us closer to the truth of understanding how the Tyme Wear Smart Shirt (Tyme Wear Smart Shirt, Tyme Wear, Boston, MA, USA) is a valid and reliable measurement in team sport based on the data collection from this study.

3.2.2 Preparation

This study was approved by the Faculty Ethics Committee and by the Norwegian Center for Research Data (NSD). Subjects were recruited through a digital poster containing information regarding this study. The poster contained relevant information about the study's aim, ethical considerations, inclusion, and exclusion criteria, how to prepare for the test day, which tests the study included, and when the tests were meant to take place. In addition, contact information was provided, and the subjects could join this study voluntarily by contacting the researchers. Persons who reached out and showed interest in participating were then asked to fill out a Google Forms questionnaire to assess basic sports activity and background characteristics. They provided information such as their age, sex, previous and current training background, and their regular sleeping- and eating habits. Collection of this information was necessary for the results and applied to the final analysis of the measurements from the tests to identify if any of these habits could have had an impact on the results. Before starting the actual test period with the subject included in the study, the tests and protocols were practiced in the lab to make sure the test protocol was finished outlined and the test leaders were ready for the actual tests.

On testing days, the subjects completed a 'Readiness for testing' (RFT) form, see Figure 3. The information from this form indicates the current state of the subjects on the day of the test through their self-evaluation within the categories (fatigue, sleep quality, general muscle soreness, stress levels, and mood) and is included in the final analysis of the results. In addition to the RFT, it was also documented how long they had slept the night before the test and if they had been ill the week of the test. Lastly, both weight and height had to be measured before the test could start. The subjects' weight without shoes was measured with a digital scale accurate to 0,1 kg (BW-0520, Lidén Weighing AB, Sweden). Bodyweight was registered in the SentrySuite Software (SentrySuite V3.20, Vyaire Medical GmbH, Höchberg, Germany) of the Vyntus metabolic cart (Vyaire Medical GmbH, Höchberg, Germany). The Vyntus system was used to quantify metabolic responses and VO_2 max test with mouthpiece/nose clip on D1.

	5	4	3	2	1	Record Score
Fatigue	Very fresh	Fresh	Normal	More tired than normal	Always tired	
Sleep quality	Very restful	Good	Difficulty falling asleep	Restless sleep	Insomnia	
General Muscle Soreness	Feeling great	Feeling good	Normal	Increase in soreness/tightness	Very sore	
Stress Levels	Very relaxed	Relaxed	Normal	Feeling stressed	Highly stressed	
Mood	Very positive mood	A generally good mood	Less interested in others &/or activities than usual	Snappiness at team-mates, family and co-workers	Highly annoyed/ irritable/down	

Figure 3. Readiness for testing (RFT) questionnaire (Olson, 2016). Filled out by each subject before both tests to see if the scores from RFT had an impact on the results from the tests. The results are used to identify and understand the test results.

3.2.3 Test Procedure

The testing and monitoring took place in the Physiological Testing Laboratories at the University of Agder (n=12) and at the University of Stavanger (n=6) from November 2023 to February 2024. In both laboratory settings, the Yo-Yo IRL1 test was conducted in the hallway right outside the laboratory. The subjects were monitored with the Tyme Wear Smart Shirt continuously while completing the treadmill warm-up, the VO_2 max test, the recovery period with easy jog, and the Yo-Yo IRL1 test. All subjects were measured and weighed before starting the test and each test day (D1 and D2) consisted of 4 measurements; (I) the incremental treadmill test to exhaustion; one test day with VO_2 measurement via mouthpiece/nose clip (D1) and one as a treadmill test to exhaustion following the same test protocol but without mouthpiece/nose clip or VO_2 measurement (D2), (II) measurement of blood lactate concentration 1 minute after the treadmill test (Biosen, EKF Industrial Electronics, Magdeburg, Germany), (III) a low intensity 10 minute jog between tests, and (IV) a Yo-Yo IRL1 test till exhaustion. The subject selection included both men (n = 15) and women (n = 3) between the ages of 19-35 years.

D1 and D2 were completed in randomized order with a minimum of 48 hours and a maximum of 10 days between each test day. The minimum time of 48 hours was set to give the body sufficient time to recover before the next test day (Parra et al., 2000). Each subject wore the same sized Tyme Wear Smart Shirt on both test days and all data from the complete duration of the measurements is monitored. During the monitoring of the VO_2 max test with mouthpiece/nose clip (D1) the subjects were simultaneously monitored through the mouthpiece connected to the SentrySuite Software Solution in addition to the smart shirt. Each subject wore the same sized shirt with the same pod ID connected during both D1 and D2; e.g. if a subject wore a size small shirt with pod ID: 3C31 for D1, the same would be used for D2. Even though the subjects wore the same sized shirt on both test days, the possibility of it not being the exact same shirt is something to take into consideration as there were more shirts of each size available. This could be a source of variation since each sensor can be slightly different. Since both the VO_2 max test and the Yo-Yo IRL1 test are tests requiring physical activity of maximal effort, all subjects were encouraged verbally and motivated to keep going till exhaustion. They also wore the same shoes for on D1 and D2.

The subjects were asked to come well-rested to the laboratory on the day of their test and instructed to refrain from high-intensity training or team matches within the last 48 hours before testing. No heavy meals or caffeine were allowed within 2 hours before the test. No further instructions were given as to what the subjects could do during their recovery period between the test days. For each subject, testing on D1 and D2 was scheduled to the same time of day (+/- 2 hours) to optimize the conditions for D1 and D2 to be as identical as possible.

The first measurement was a standard VO_2 max test following the test protocol from Olympiatoppen. This included a 10-minute low-intensity warm-up, with the last minute before test start of treadmill testing on D1 being with the subject connected to the mouthpiece to allow them to become accustomed to the feeling. After the treadmill test, a finger stick venous blood sample was taken, approximately 1 minute after the VO_2 max test and subjects recovered passively for ~10 minutes. Following passive recovery, subjects completed a 10-minute slow run on the treadmill with no incline at a self-selected pace. Finally, a Yo-Yo IRL1 test was performed. Figure 4 shows a visual of the Yo-Yo IRL1 test layup.

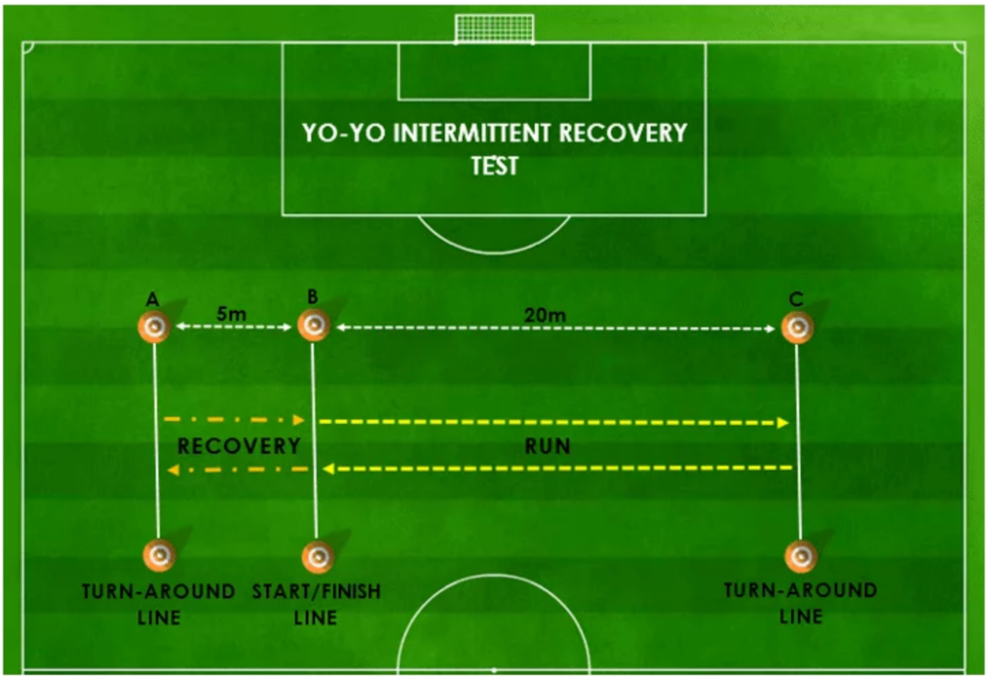


Figure 4. Yo-Yo IRL1 (Walker, 2023). The protocol of the Yo-Yo intermittent recovery test level 1. There is an increase in speed after each level. One level is from the starting line to the turn-around line, back to the start/finish line, around the turn-around recovery line, and again back to the start. The recovery area is a walking area meaning that they could not run around the turn-around line at the back of the recovery area.

3.2.4 Subjects and variables

The recruitment period was from October-December 2023, at first in the Kristiansand area and then also in the Sandnes/Stavanger area. The subjects (n=19) were mainly recruited from the University of Agder, as well as within communities and friends, via advertising on social media and through other friends and family members. To be included in this study the subjects had to be on a good physical fitness level and be able to last long enough in the tests to provide enough measurements for the results to be considered reliable regarding the Tyme Wear Smart Shirt. This means that individuals who are at higher physical fitness levels could provide us with more and better data as they would manage to last longer in the tests, than someone at a lower physical fitness level would. Other inclusion criteria state that the subjects must have a background from one or more running-based team sports such as soccer, handball, basketball, etc. The subjects also had to be comfortable with needles because of the blood lactate sample tests that were taken after the treadmill tests. The exclusion criteria for this study were that the subjects could not have any medical condition that affected the respiratory system during the testing, including asthma and long-term infections such as aftereffects of COVID-19. In addition, subjects with reduced physical capacity due to other diseases or injuries which affected their running were not able to partake in this study either. The characteristics for the subjects included are presented in Table 1.

Table 1. Descriptive data for the subjects.

	N=18
Age (y)	25 ± 4
Weight (kg)	78.6 ± 6.7
Training habits	
Endurance training (days/week)	3 ± 2
Strength training (days/week)	2.4 ± 1.4
Team sport participation (years)	4 to 10+ years

All values are presented as mean ± standard deviation (SD), except for 'Team sport participation' which is presented as range of years participated. N = number of subjects.

The subjects of this study included 19 previously or currently active team sports players. Of these, 16 were male, and 3 were female. The average age of the subjects was 25 ± 4 years with the youngest aged 19 and the oldest aged 30. We, along with our supervisor, agreed that we needed 15-20 subjects to gather enough data sets for the final analysis. As the study design required all subjects to take part in all test interventions twice with a minimum of 48 hours and a maximum of 10 days in between, we anticipated dropouts and difficulties with the planning logistics. During the recruitment period, we managed to recruit 23 subjects, and of these, 19 were able to participate in the actual tests. Four of the 23 originally registered subjects had to drop out before the test period's start due to injuries, illness or were unavailable when the tests took place. Of the remaining 19, one was not able to participate in the second test due to illness. We decided to randomize whether the subjects did the test day with the mouthpiece/nose clip on (D1) or off (D2) for the VO_2 max test to prevent bias. The subject that was not able to take part in the retest was only able to complete the test without mouthpiece/nose clip (D2) and therefore we decided to exclude these results from our analysis as we did not have comparable data for this subject.
The age limit for the subjects was set to be between 19-35. We originally intended to exclusively test currently active soccer players within a team, but we realized this would be difficult and therefore changed the criteria. The aim was also to recruit students from the University of Agder as the testing took place at the university campus and it became the most

efficient arena for recruitment. As we were not able to recruit enough subjects in Kristiansand, we contacted the University of Stavanger who had the same laboratory instruments and procedures as the ones used in Kristiansand and could conduct tests there too.

The subjects had to complete two identical (except from the 'mouthpiece/nose clip-no mouthpiece/nose clip' element) test days (D1 and D2) for us to collect comparable data within the different variables. Because of technological errors, some of the data was lost or simply not registered during the tests which is the reason for the difference in sample size of each variable included. The exact number of test results included for each variable in the final analysis is presented in Figure 5.

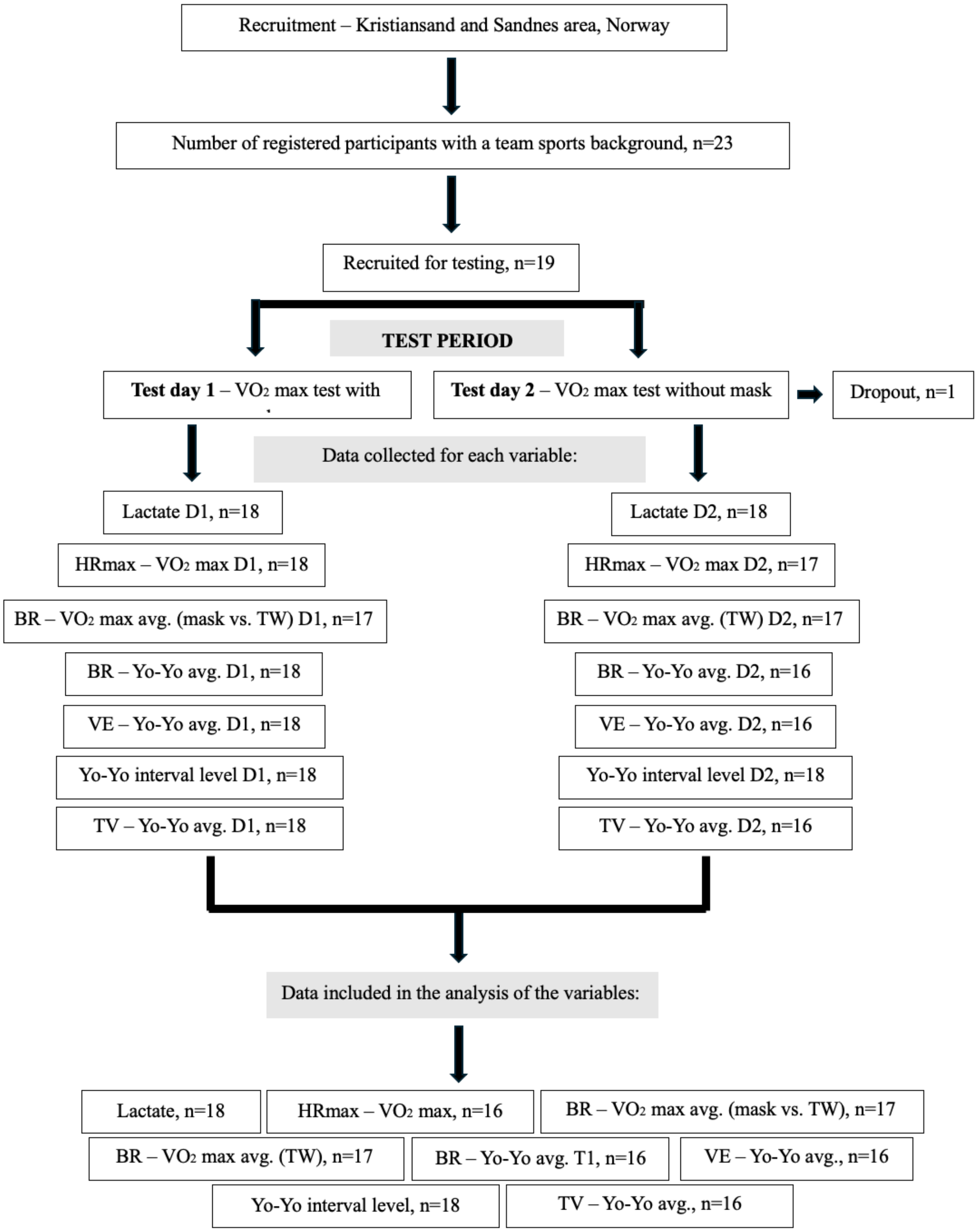


Figure 5. Recruitment of subjects with a running-based team sports background, dropouts, number of subjects with complete data collected within each variable, and number of subjects included in the final analysis.
n = number of subjects, D1 = Test Day 1, D2 = Test Day 2, HR = heart rate, BR = breathing rate, VE = ventilation volume, TV = tidal volume.

The use of technology when measuring variables can be unreliable and differ from time to time. In this case we experienced some issues during the tests of some of our subjects which caused a difference in quantity of the collected data for each variable. As shown in Figure 5, all measurements of the variables for all subjects, except 'BR - VO_2 max avg. (mouthpiece/nose clip vs. TW) D1', consist of complete data (n=18) from D1 (test day consisting of VO_2 max test with mouthpiece/nose clip). On the other hand, D2 (test day consisting of VO_2 max test without mouthpiece/nose clip) only has two variables with complete data measurements for all subjects (n=18); 'Lactate D2' and 'Yo-Yo IRL1 interval level D2'. 'HRmax - VO_2 max D2' and 'BR - VO_2 max avg. (TW) D2' include complete measurements from 17 subjects, while 'BR - Yo-Yo IRL1 avg. D2', 'VE - Yo-Yo IRL1 avg. D2', and 'TV - Yo-Yo IRL1 avg. D2' have complete measurements from 16 subjects. Thus, the only variables with complete data sets (n=18) for the final analysis were 'Lactate' and 'Yo-Yo IRL1 interval level'. These variables are the only ones not monitored by the smart shirt and therefore support the statement that the shirt technology is the cause of the lost data. The original goal was to recruit at least 15 subjects and gather complete data sets within this sample for analysis. Although data for some of the variables were lost or not measured during the tests due to technological errors, the remaining variables still consist of 16-17 data sets.

3.2.5 Data collection methodology

The subjects were monitored through the Tyme Wear Smart Shirt with a connected pod (Tyme Wear smart shirt, Tyme Wear, Boston, MA, USA) during both test days. The shirt was used to measure BR, TV, and VE and the D1 and D2 measurements were compared to each other as well as the D1 measurements from the smart shirt were compared to the results of the clinical measurements from the VO_2 max test. The Tyme Wear Smart Shirt consists of a breathing sensor and an IMU pod. The pod is detachable and can be directly attached to the shirt via a connecting hub (see Figure 6). The built-in breathing sensor and the pod (through the hub) collect and stores the recorded data prior to uploading the completed file to a cloud-based database in the Tyme Wear application dashboard. The cloud-based application offers data analyses of the different variables the shirt has monitored and measured during the recorded session in addition to the possibility to download the raw data.

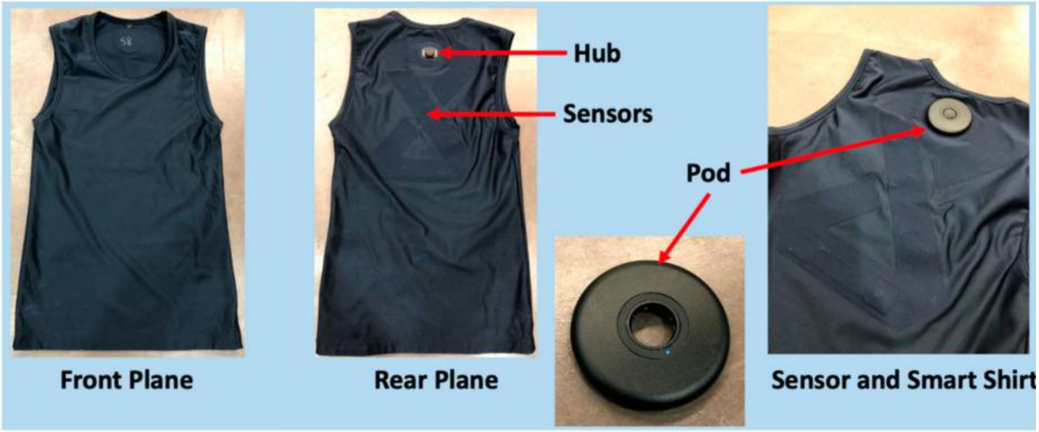


Figure 6. The Tyme Wear Smart Shirt (Gouw et al., 2022). The hub is where the pod is connected to the shirt and the sensors, which will catch the data flow. It is placed at the upper back along the triangle.

The Tyme Wear Smart Shirt analyzes chest wall excursions using a strain gauge to identify and time stamp the peak and valley of each chest wall excursion. The raw data of breathing measurements is smoothed using a 3 out of 5 outlier rejection average using a 5-breath window shifting 1 breath at a time. The tidal volume index value is estimated by calculating the chest sensor excursion amplitude change from the peak to the valley of each identified breath. The tidal volume measurements from Tyme Wear are not calibrated as Liters/minute but presented as index values of Vol/br (TV) which also cause ventilation volume to calibrate as index values of Vol/min as this variable is the product of TV and BR (TV x BR = VE). Since both these variables are presented as index values, they can only be compared within the results from the same individual but not across subjects.

3.2.5.1 Calibration of equipment

All equipment used in the interventions during the tests was calibrated prior to each test. This is because all monitoring devices and technological equipment consist of some sort of uncertainty. Due to this, regular calibration was included in the test procedure within the study protocol. Calibration is important on all devices to "measure its accuracy and also make adjustments to ensure its precision in the future" (Conquer Scientific, 2023). The smart shirt was calibrated before each test started. The calibration is done after the subject has taken on the smart shirt and the pod is connected to the application. The application dashboard includes a calibration alternative that requires the subject to take 3-5 deep and rapid breaths. After completing this, the stretch sensor is calibrated and ready to use. The equipment used for the VO_2 max test was calibrated between each test subject using standard procedures provided by the manufacturer, with the device that measures ergo-spirometry (Cardiopulmonary Exercise Test (CPET)). The Jaeger Vyntus CPX was used as CPET equipment, and the temperature, humidity, and barometric pressure of the test room are updated in the machine's test system which is the SentrySuite Software. Gas concentrations were also calibrated between each subject, and the lactate machine was set to automatically calibrate every 60 minutes against a standard concentration of 12 mmol*L^{-1}.

3.2.5.2 Intervention protocol

Figure 7 shows the test protocol followed for both D1 and D2. The figure includes all interventions and warmups/recovery.

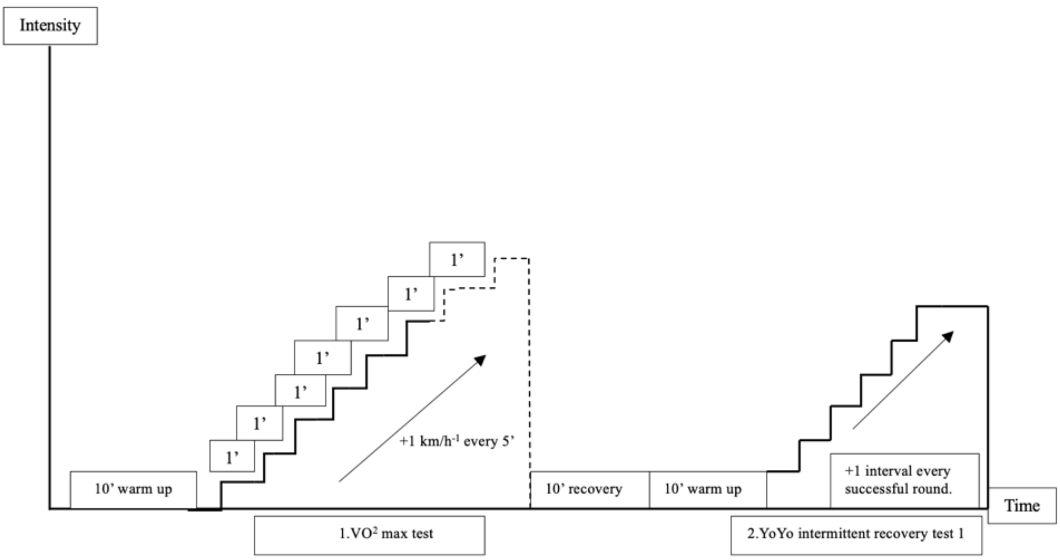


Figure 7. Test protocol for Test Day 1 and Test Day 2 which includes a 10-minute treadmill warm-up, the VO_2 max test till exhaustion with a speed increase every 1min. 10-minute recovery phase before 10-minute warm-up followed by the Yo-Yo IRL1 test. The x-axis shows the time while the y-axis shows the intensity.

3.2.5.3 Treadmill test to exhaustion with or without mouthpiece/nose clip

On D1 or D2, depending on randomization of test order, the VO_2 max of each subject was measured using an incremental treadmill test to exhaustion with gas exchange measurements via metabolic cart. The ventilatory data from the VO_2 max test was used to identify and validate the potential differences and/or similarities of parallel measurements from the Tyme Wear Smart Shirt. The treadmill test protocol applied in this study followed the standard test protocol of Olympiatoppen and all subjects completed this protocol twice; once with the mouthpiece and nose clip (D1), and once without (D2) – both monitored with the smart shirt. The purpose of this was to provide measurements of the variables both with and without the mouthpiece/nose clip to compare the measurements recorded by the Tyme Wear shirt with and without the added variable of having a Hans-Rudolph valve and nose clip in place.

The treadmill test protocol included a 10-minute warm-up and the VO_2 max test lasted for 4-10 minutes, depending on how long the subject manages to keep going before exhaustion. The test starts at a low-medium speed (here: depending on the speed of the warm-up and physical fitness level for each subject) and increases with 1 km/h per minute (Olympiatoppen, N.D.). Towards the end of the test, the subject can choose to only increase with 0.5 km/h or to not increase the speed at all. This is expressed through hand signals; thumbs up indicating they are ok with increasing the speed with 1 km/h, flat hand means 0,5 km/h, and thumbs down means no increase.

The test in which the subjects completed the VO_2 max test, was done with a tube-connected mouthpiece and a nose clip. The tube was connected to the mixing chamber of the Vyntus CPX system and connected to SentrySuite Software. The repeat treadmill test without mouthpiece/nose clip followed the same protocol but without oxygen consumption measurement via the use of the mouthpiece and the nose clip. The selection of whether the subject would complete the test with mouthpiece/nose clip (D1) or without (D2) first was randomized and some subjects completed the mouthpiece/nose clip test first while others second. Randomizing the order of the tests prevents bias as the subjects were not aware of which version of the test they would conduct before arriving on the test day.

The test consists, as mentioned, of a 10-minute, self-controlled warm-up on the treadmill with a 0% incline. Towards the end of the treadmill warm-up during the subjects' first and second test day (the last couple of minutes), they were asked to practice jumping off with one leg on each side of the treadmill to prevent accidents. The treadmill used in this research was a little wider than regular treadmills and we wanted to make the subjects aware of this and feel comfortable with jumping off at the end of the test. After this, they were connected to the spirometry mouthpiece/nose clip (for D1) and completed the warm-up with the mouthpiece/nose clip on. The treadmill was then adjusted to a 5.25% incline and the oxygen uptake was measured using a mixing chamber. Oxygen intake readings were done every 30 seconds through Vyntus CPX which was connected to the SentrySuite Software. The starting speed on the treadmill was determined based on each of the subjects' individual fitness level. The average starting speed was 10 km/h, and the subjects did not exceed a heart rate higher than 80% of the maximum heart rate at the beginning of the test. The subjects ran to exhaustion during the VO_2 max test with an average duration of 8 minutes for when the test was stopped. Besides the subjects running to exhaustion, 3 consecutive VO_2 measurements with peak results (e.g. 62) were used for the calculation of the VO_2 max test. The subjects were encouraged by test leaders to continue the test until they could not go on any longer and to try and push through the last 30 seconds to get the final VO_2 reading. During and towards the end of the VO_2 max test, the test leaders carried out an individual assessment of the subject's physiological condition. The test terminated, in addition to voluntary exhaustion, by the following criteria: flattening in its maximum oxygen uptake corresponding to a maximum of 1mL in VO_2 over two incremental periods (30 sec). In addition to this, the parameters respiratory exchange ratio (RER) value (RER $\geq$ 1.05) and heart rate ($\geq$ 95% of HR max) were also monitored and assessed continuously and in the final phase.

The results from the VO_2 max test take part in determining the validity and reliability of the measurements collected from the Tyme Wear Smart Shirt. Comparing the results from the treadmill test and those from the shirt creates grounds to determine the accuracy of the technology of the shirt. The data that have been included in the analysis from the VO_2 max test with the mouthpiece/nose clip are the results of the VO_2 max (mL/kg/min), VO_2 (mL/min), RER, VE (L/min) and the average breathing rate (1/min). These are the data included in the results and compared to some from the Tyme Wear data results. All subjects were handed a Polar Verity Sense armband (Polar Verity Sense, Kempele, Finland) which was connected to Tyme Wear through the application. The heart rate monitor stayed on during the entire testing, on both test days.

3.2.5.4 Blood lactate measurement post-test

A post-test blood lactate sample (LA-) was taken approximately one minute after finishing the VO_2 max test. The sample was analyzed using the Biosen C Line machine. The test was taken because of the two different versions of the VO_2 max test; one with a mouthpiece/nose clip and one without. The lactate test was performed by pricking the finger and filling up blood in a capillary tube which was put in the Biosen C Line machine and analyzed. The results from the lactate threshold test are being used to verify any differences to the Tyme

Wear smart shirt combined with the results of the VO_2 max tests. The result from the lactate threshold test itself does not justify the results from the VO_2 max tests but can be used for validation if any differences or deficiencies are found from the results of the two VO_2 max tests and Tyme Wear.

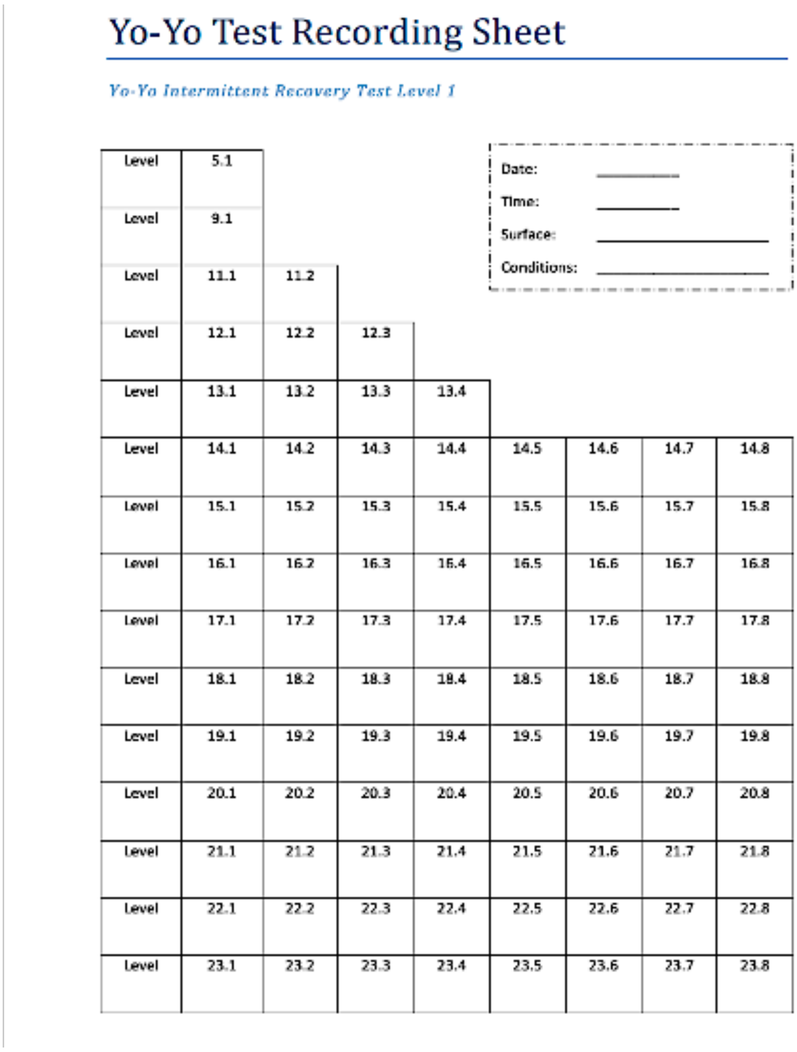
3.2.5.5 10-minute recovery jog on treadmill

A 10-minute 'regular jog' was performed between the VO_2 max test and the Yo-Yo IRL1 test on each test day, to capture breathing data for normal running. The data from this intervention is used in comparison with the data from the Yo-Yo IRL1 test. This intervention took place on the same treadmill as the VO_2 max, with no incline, to be as similar to the surface of the Yo-Yo IRL1 test as possible. The pace of the intervention was a 10-12 on the 6-20 Borg Scale. For these athletes involved in the study, it meant an easy, low intensity jog.

3.2.5.6 Yo-Yo IRL1 test

The Yo-Yo IRL1 test is a test lasting for about 10-20 minutes depending on each individual's fitness. There are two levels of the Yo-Yo IRL1 intermittent recovery tests where level 1 is suited for recreational or sub-elite athletes and level 2 is more suited for professional athletes. In this study, the level 1 test was applied as the subjects included are not considered professional athletes. Level 1 starts on a speed level of 5 up to speed level 23, whereas level 2 starts on a speed level of 11 up to 26 (Bangsbo et al. 2008, p.38). The equipment used in this test was three marking cones, a non-slip surface, and a speaker for the sound. The sound was obtained from The Norwegian Soccer Association (Ravnaas, 2019, 00:00).
As shown in Figure 8 the subjects started on a speed level 5 as part of the warm-up after the VO_2 max test. The subjects had a recovery break of 10 minutes between the VO_2 max test and regular running on the treadmill where they ran for 10 minutes. Speed levels 5, 9 and 11 in Figure 8 were also part of the warmup between the VO2 max test and the Yo-Yo IRL1 test, and these levels lasted about 2 minutes. There was no break between the level interval-warm up and the subjects kept going with the test until the second failed attempt to reach the finish line and at this point the test was stopped. As the speed levels 5, 9 and 11.1, 11.2 were all warm-up rounds, the subject could not 'lose' if they were to miss the line during these intervals. Each subject had one warning before they went out, meaning that if they did not reach the second beep ending at the start/finish line (see Figure 4) they got one warning. If this happened a second time (not reaching that second beep), the test was over. The last

unfinished round the subjects started was included as the final lap on their scoresheet, but they could not continue to the next interval/level.



Yo-Yo Test Recording Sheet

Yo-Yo Intermittent Recovery Test Level 1

Date: ________
Time: ________
Surface: ________________
Conditions: ________________

Level	5.1							
Level	9.1							
Level	11.1	11.2						
Level	12.1	12.2	12.3					
Level	13.1	13.2	13.3	13.4				
Level	14.1	14.2	14.3	14.4	14.5	14.6	14.7	14.8
Level	15.1	15.2	15.3	15.4	15.5	15.6	15.7	15.8
Level	16.1	16.2	16.3	16.4	16.5	16.6	16.7	16.8
Level	17.1	17.2	17.3	17.4	17.5	17.6	17.7	17.8
Level	18.1	18.2	18.3	18.4	18.5	18.6	18.7	18.8
Level	19.1	19.2	19.3	19.4	19.5	19.6	19.7	19.8
Level	20.1	20.2	20.3	20.4	20.5	20.6	20.7	20.8
Level	21.1	21.2	21.3	21.4	21.5	21.6	21.7	21.8
Level	22.1	22.2	22.3	22.4	22.5	22.6	22.7	22.8
Level	23.1	23.2	23.3	23.4	23.5	23.6	23.7	23.8

Figure 8. Yo-Yo IRL1 scoresheet (Wood, 2018). Used to control which level and distance each subject completed during the test. The scoresheet was used in D1 and D2.

This test was chosen for this specific study mainly because of the hypothesis of this study: "Can the Tyme Wear Smart Shirt be a valid and reliable source of ventilation data in team sports?". Elements in this test resemble some of those found in a soccer/handball game with changes in direction, high-speed runs, and sprints. All elements are included except from tackles, which are hard to create in a test like this and would require specific field tests from the training pitch. The level one test focuses on intermittent exercise leading to a maximal activation of the aerobic system (Bangsbo et al, 2008, p. 37). The results from this test will give a good estimate of how the Tyme Wear Smart Shirt captures the ventilation data compared to the VO_2 max test and regular running. What is interesting about this test is exactly how the Tyme Wear reacted to the sudden changes in direction and speed, as well as how the subjects' breathing frequency changed during this test compared to the VO_2 max test.

3.2.6 Ethical considerations

Before collecting data, a poster with information regarding the study was made and published through researchers' social media. The researcher's email and phone number were listed at the bottom end of the poster and the subjects reached out voluntarily. After meeting all criteria, the subjects were emailed the aims of the study and a more detailed text describing how and when the study would take place, in addition to a consent to participate form that had to be signed before the beginning of data collection. They had the right to withdraw from the study at any time with no explanation given to the researchers as participation in this study is completely voluntary.

An ethical approval from the Faculties Ethics Committee and the Norwegian Center for Science Data was granted before collecting data and subjects for this study. The subjects have been kept anonymous with a special ID number with no personal identifiers, e.g., 'MT20231'. The ID number was used when creating their profiles in the SentrySuite Software for the VO_2 max test, as well as on all papers regarding information about the subjects. Only the researchers are familiar with the identity of the subjects and the research data has been treated confidentially during the whole research period to protect the subjects from any unwanted disclosure. For this reason, pseudonyms were used to protect anonymity. The data collected by the Tyme Wear Smart Shirt have been anonymous as well by the use of the ID number, which means the cooperation team of the Tyme Wear software are not aware of the identity of the subjects. The ID number of each subject helped with keeping track of all data that was collected in the test period as there were not any challenges when sorting the data and connecting it to each subject as the same ID number was used for all the collection of data.

3.3 Statistics

All statistical calculations have been analyzed in Microsoft Excel 2024 for Macintosh, Apple Inc. Organized excel- sheets were made with all the including data. Microsoft Excel 2 has also been used for all tables and figures. Mean (average) and standard deviation was used for all measurements. Measurements which are compared to each other such as BR from the VO_2 max test vs BR from the VO_2 max test from Tyme Wear, were analyzed using a T-test along with mean and standard deviation. A T-test was used to better indicate characteristics and achievements from the different measurements. Statistical significance is set as $P = < 0.05$ in two-tailed tests. All data are presented as mean ± standard deviation and P-value. Pearson's correlation coefficient/ linear regression was used to calculate R^2 value where values of –1 or +1 indicate a perfect linear relationship between two variables (Steward, 2024).

3.4 Formulas and terms related to calculation

VO_2 max = ml*kg^{-1}*m^{-1}; oxygen consumption when running in milliliters per kilograms of body mass per meter.
VO_2 = L*min; oxygen consumption when running in liters per minute.
RER = Respiratory Exchange Ratio; the volume of CO_2 produced by the body and the O_2 consumed.
VO_2 max pace = km/h; maximal pace on the treadmill when the subject reached VO_2 max.
Lactate VO_2 max = mmol/L; amount of lactate found in the body one minute after finishing the VO_2 max test.
HR max avg = beats per minute (BPM); maximum HR when reaching VO_2 max, on average using the values 1 minute before, the exact minute and the 1 minute after reaching VO_2 max.
BR VO_2 max mouthpiece/nose clip = number of breaths/min; breathing rate during the VO_2 max test with a mouthpiece/nose clip.
BR VO_2 max TW = number of breaths/min; breathing rate during the VO_2 max test with results from Tyme wear.
BR Yo-Yo IRL1= number of breaths/min; breathing rate during the Yo-Yo IRL1 test.
Ventilation volume Yo-Yo IRL1 = volume/min; volume of gas inhaled or exhaled from a person's lung per minute during the Yo-Yo IRL1 test.
Yo-Yo IRL1 level interval = the level and interval the subject reached during the Yo-Yo IRL1 test.
TV Yo-Yo IRL1 = volume/breath; the amount of air moved through the lungs each time you exhale and inhale during the Yo-Yo IRL1 test.

4 Results

In this chapter, the results from the VO_2 max tests and the Yo-Yo IRL1 test will be presented. The physiological measurements from the VO_2 max test with mouthpiece/nose clip will be presented first, followed by the physiological characteristics from the tests compared to each other. Lastly, a graphic presentation of the linear regression figures.

4.1 Presentation of results

To give a better understanding of the results, the data is sorted and presented in tables and figures. The physiological measurements from Test Day 1 (D1, with mouthpiece/nose clip and full metabolic measurements) are presented in Table 2. During Test Day 2 (D2), the same treadmill progression was used as in D1, but subjects ran to exhaustion without a mouthpiece/nose clip, with BR measured by the Tyme Wear Smart Shirt only.

Table 2. Results of VO_2 max test

	Peak Values (N=18)	**Range**
VO_2 max ($ml*kg^{-1}*min^{-1}$)	54.3 ± 7.9	38-67
VO_2 (ml*min)	4238 ± 682	2814-5180
Respiratory exchange ratio (RER)	1.16 ± 0.1	1.05-1.27
VO_2 max pace ($km*h^{-1}$)	14.7 ± 1.9	11-18

Values are presented as mean ± standard deviation. VO_2 max = maximum oxygen uptake; VO_2 = milliliters of oxygen consumed per minute; RER = ratio between the volume of CO_2 produced by the body and the amount of O_2 consumed; VO_2 max pace = maximum pace during VO_2 max test; Peak values = the highest measurement during test-peak; N = number of subjects; Range = the range from the lowest data result to the highest data result.

The mean VO_2 max of the subjects was 54.3 but with a range of 38 to 67 ml/kg/min which the standard deviation also showed with the value being 7.9, shows us that the subjects on average performed on a moderate fitness level when comparing them to the results from Slimani et al.'s study (2019, p.) indicating that sub-elite soccer players and junior soccer players VO_2 max is within the range of 48-62 ml/kg/min. Despite potential variation in fitness, RER values obtained (1.16 ± 0.1) in the last phase of the test, suggested that all subjects reached, or were close to reaching, their maximal effort during the VO_2 max test.

Table 3 presents the physiological data from the treadmill tests. These data give an indication of the subjects' responses for the VO_2 max test with and without the mouthpiece and nose clip where the P-value is presented as significant (P = < 0.05) or not significant (P = > 0.05).

Table 3. Physiological responses from treadmill tests (VO_2 max test) with and without mouthpiece/nose clip.

	With Mouthpiece (N=16)	**Without Mouthpiece (N=16)**	**P-value**
Peak Lactate (mmol*L^{-1})	13.4 ± 2.8	12.8 ± 2.8	0.31
HR max (bpm)	187 ± 7	186 ± 6	0.34
BR from shirt (br/min)	55.5 ± 6.3	57.9 ± 6.3	0.019

Values are presented as mean ± standard deviation. Peak lactate = lactate concentration after exhaustion from exercise; HR max = maximum heart rate measured in beats per minute; BR from shirt = number of breaths per minute on average during VO_2 max test with mouthpiece/nose clip versus number of breaths per minute on average during VO_2 max test without. With Mouthpiece = VO_2 max test performed on treadmill with mouthpiece and nose clip; Without Mouthpiece = VO_2 max test performed on treadmill without mouthpiece and nose clip; N = number of subjects; P-values ≤ 0.05 are considered significant, while values > 0.05 are considered non-significant.

The peak lactate measurement presented in Table 3 shows higher values for the subjects during D1 than D2. However, the standard deviation for D1 and D2 are the same; 2.8, with a mean difference of 13.4 in D1 vs. 12.8 in D2. This suggests that the subjects, on average, were running closer to exhaustion on D1 than D2. The lactate P-value is 0.31, meaning there is no significant difference between the test's measurements, and that they offer close to equal measurements. Similar findings are also to be seen within the HR max measurements, except from the higher values of mean and standard deviation for D1 = 187 ± 7 compared to D2 = 186 ± 6. P = 0.34 for HR max and there is no significant difference within this variable either. These results show that Tyme Wear offers almost the same exact measurements of the VO_2 max test conducted with the mouthpiece and nose clip (D1) as the VO_2 max test without (D2). The measurements from the test with the mouthpiece show an average of 55.5 ± 6.3 br/min and the measurements from the test without show an average of 57.9 ± 6.3 br/min. The standard deviation of ± 6.3 is the same for the measurements from both test days and indicate that the range within the results were not noticeably big from the lowest measured

BR- data to the highest measured BR- data. This means that results from Tyme Wear can be compared to the results of a VO_2 max test when looking at the BR results only from Tyme Wear. There was a significant difference of P = 0.019 on the BR with mouthpiece/nose clip vs. Tyme Wear but only because the measurements were so consistent between D1 and D2.

The responses from the Yo-Yo IRL1 tests will show if Tyme Wear Smart Shirt can be used in running based team sports. Table 4 presents the results from the Yo-Yo IRL1 test D1 and D2 and these data also show a non-significant P-value (P = > 0.05).

Table 4. Responses from repeated Intermittent Yo-Yo IRL1 tests

	Yo-Yo IRL1 Day 1 (N=16)	**Yo-Yo IRL1 Day 2 (N=16)**	**P-value**
HR max (bpm)	187 ± 7	186 ± 6	0.34
BR Yo-Yo IRL1 Peak	56.0 ± 7.3	55.4 ± 4.4	0.71
TV Yo-Yo IRL1 avg	299 ± 200	270 ± 132	0.21
VE Yo-Yo IRL1 Peak	143 ± 94	135 ± 74	0.41
Yo-Yo IRL1 level completed	15.9 ± 2.2	16.0 ± 2.2	0.93

Values are presented as mean ± standard deviation. HR max = maximum heart rate measured in beats per minute; BR Yo-Yo IRL1 Peak = peak number of breaths per minute on average during Yo-Yo IRL1 test; TV Yo-Yo IRL1 avg = amount of air moved in or out with each respiratory cycle on average during Yo-Yo IRL1 test; VE Yo-Yo IRL1 Peak = peak volume of gas exhaled or inhaled per minute on average during Yo-Yo IRL1 test; Yo-Yo IRL1 level completed = completed interval level of Yo-Yo IRL1 test; Yo-Yo IRL1 Day 1 = Yo-Yo IRL1 test during Test day 1; Yo-Yo IRL1 Day 2 = Yo-Yo IRL1 test during Test day 2; N = number of subjects.

The BR_{peak} -data from the Yo-Yo IRL1 test does not show a significant difference, as the P-value is 0.71 after a T-test of the results from D1 and D2. It does in fact show us that the subjects took a greater number of breaths during Yo-Yo IRL1 test on D1 (56.0 ± 7.3) than during the same test on D2 (55.4 ± 4.4). The standard deviation shows a much higher value for the Yo-Yo IRL1 test on D1 than D2 meaning that the data from D1 (7.3) is much more spread out and further from the mean, than the results from D2 (4.4). The TV has a significant difference of 0.21 in the Yo-Yo IRL1 test for D1 and D2, and the measurements of VE show a significant difference of 0.41 between the test days. The results from both measurements indicate that the subjects were running at a higher intensity in D1 vs D2; VE, D1 = 143.1 ± 94.2 while VE, D2 = 135.2 ± 74.1, and TV, D1 = 299 ± 200 while TV, D2 = 270 ± 132. VE_{peak} during Yo-Yo IRL1 test indicates that there was no significant difference with P = 0.41. The VE_{peak} values are also higher during D1, indicating that the subjects reached higher to maximal effort as the peak values are 143 for D1 and 135 for D2. The range between lowest and highest measured data is higher during D1, with the standard deviation being 94 vs. 74 in D2. The completed level interval from the Yo-Yo IRL1 test shows that the subjects reached a higher level during the test in D2 vs. D1 with it being only 0.1 mean interval longer in D2 (16.0 ± 2.2) than D1 (15.9 ± 2.2). There was not a significant difference in D1 vs. D2 as P = 0.91.

4.1.1 Ventilation volume

Measurements of ventilation volume during D1 and D2 are graphically presented in Figure 9. Figure 9 shows how the ventilation volume measurements from the Yo-Yo IRL1 test are reliable measurements as the $R^2 = 0.86$. You can see that most of the results besides the results from two subjects have gotten almost the same results from the test on D1 and D2. The two results, far from the rest of the group, are something one must investigate. A likely reason could be the fact that the subjects only wore the same sized shirt, not the same exact shirt. The sensor of each shirt is slightly different, and this could cause results like these for the final analysis. It would be interesting to state the R^2 without these two data points. The R^2 and P-value is most likely to be different if these data points were not there.

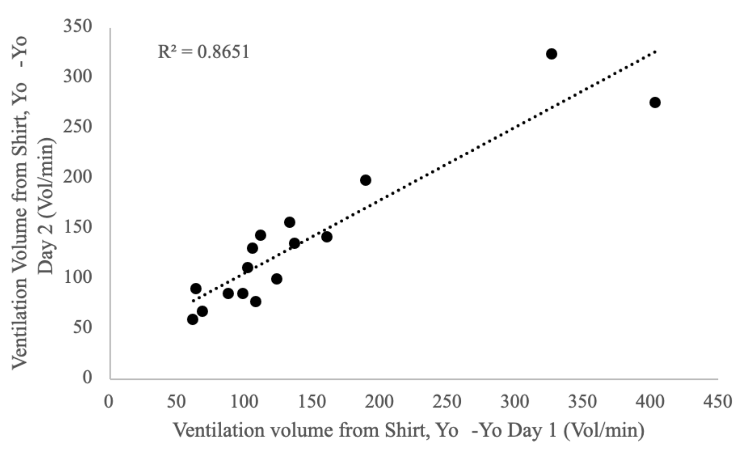


Figure 9. Correlation of ventilation volume measurements from Test Day 1 and Test Day 2 measured with Tyme Wear during the Yo-Yo IRL1 test. Measurements from Test Day 2 are presented on the x-axis and measurements from Test Day 1 are on the y-axis.

4.1.2 Breathing rate

Figures 10 and 11 are graphic presentations of the breathing rate measurements from D1 and D2.

A comparison of simultaneous measurements of peak BR from shirt and from metabolic cart is presented in Figure 10. The breathing rate monitoring from the mouthpiece/nose clip and from Tyme Wear showed high reliable data if one says that +1 is perfect linear regression, suggesting that that Tyme Wear shirt provided a valid measurement of breathing frequency during treadmill running (Steward, 2024).

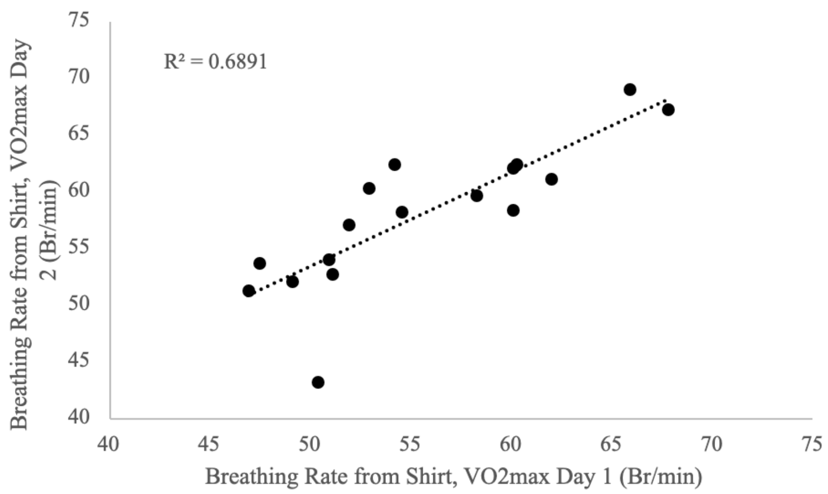


Figure 10. The breathing rate average from Test Day 1 and Test Day 2 was measured with Tyme Wear during the VO_2 max test with and without mouthpiece and nose-clip. BR avg is analyzed using the last measurement before max, the max measurement and the first measurement after max. Example 56, 62, 59 which equals 59.

In Figure 10, maximal BR measured by the Tyme Wear shirt during a treadmill test to exhaustion with and without mouthpiece and nose-clip are compared. The Pearson's R value is greater than 0.5 (R^2 = 0.689). However, most of the subjects had a higher breathing frequency when not wearing a mouthpiece and nose-clip, suggesting a likely systematic effect of this difference.

For the measurements presented in Figure 11, the data cannot be seen as reliable here as R^2 = 0.41. As shown in Table 3, the P-value for this exact same data is 0.71 meaning there is no significant difference.

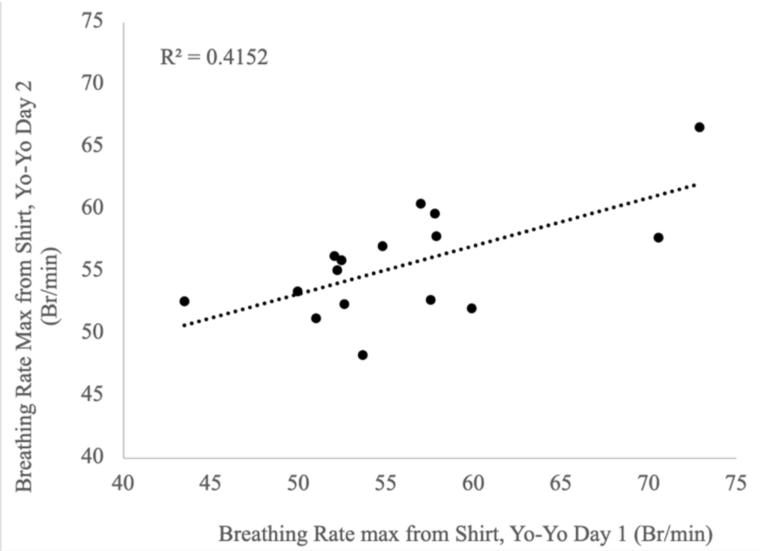


Figure 11. The correlation of the breathing rate average from Test Day 1 and Test Day 2 was measured with Tyme Wear during the Yo-Yo IRL1 test. Measurements from Test Day 1 are presented on the x-axis and measurements from Test Day 2 are on the y-axis.

4.1.3 Tidal volume

The average tidal volume measurements from D1 and D2 are presented in Figure 12. The results show reliable data with $R^2 = 0.89$. The measurements for one of the subjects which is located on the upper right corner are uncertain as the data contains a big difference between D1 and D2.

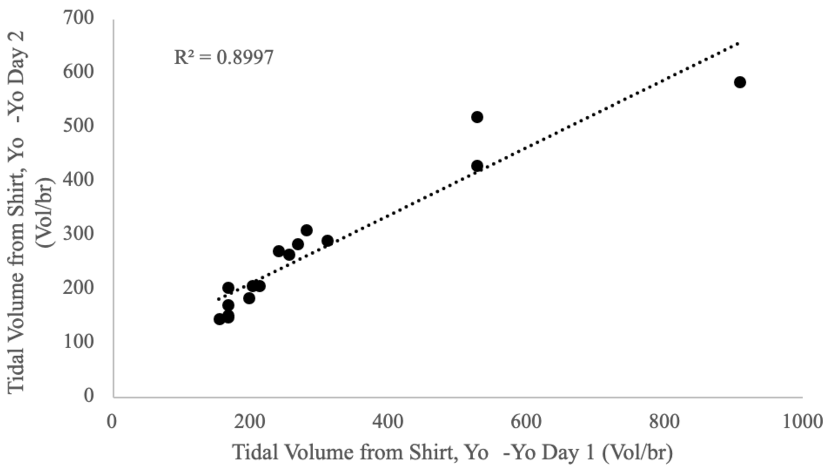


Figure 12. Correlation of tidal volume average from Test Day 1 and Test Day 2 measured with Tyme Wear during the Yo-Yo IRL1 test. Measurements from Test Day 1 are presented on the x-axis and measurements from Test Day 2 are on the y-axis.

4.1.4 Yo-Yo IRL1 test

The level interval each subject reached for the Yo-Yo IRL1 test during D1 and D2 are presented in Figure 13. $R^2 = 0.66$, meaning the data is considered reliable.

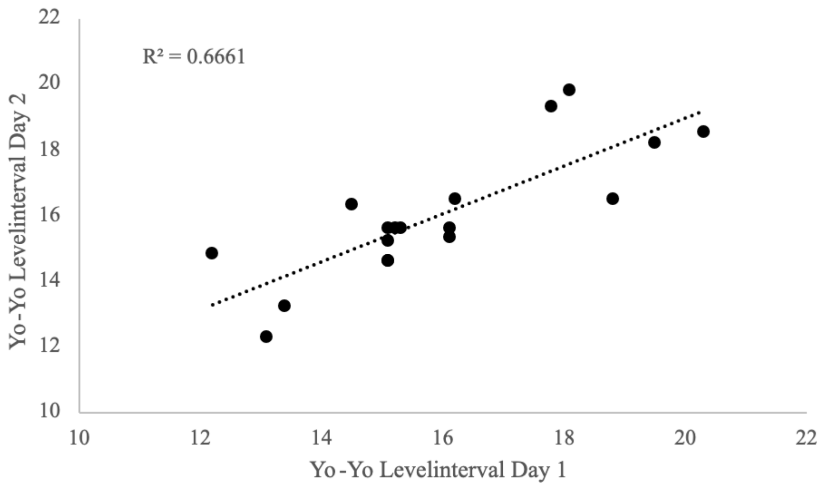


Figure 13. Correlation of the Yo-Yo IRL1 level interval data. The results from the Yo-Yo IRL1 test show which distance covered by each subject (N=18) was reached in Test Day 1 and Test Day 2. Results from Test Day 1 are presented on the x-axis and results from Test Day 2 are on the y-axis.

4.2 Challenges

A quantitative research approach relies on a large sample of data for the study to be considered reliable. As a quantitative method emphasizes objective measurements and statistical, mathematical, or numerical analysis, there are some limitations to this study. One of the limitations is the closed-ended questions included in the subject-questionnaires. Having the subjects answer questions where their answer selection is limited could be disadvantageous as they must choose an estimated reply. This can cause the collected answers to appear as 'false' since they lack accuracy because of the subjects' not having the opportunity to write down a specific answer. On the other hand, it works advantageously in research settings just like this. By limiting the answer selection and categorizing the options in groups (i.e., type of sport, number intervals of workout hours a week etc.), we get a more compact collection of answered questionnaires. This makes the data for subject characteristics and habits easier to classify and sort in the final table.

Another limitation a study of the quantitative research design brings with the method is the difficulty in confirming feedback from the subjects regarding RFT, meaning that it can be difficult to know if the data collected at a time is accurate. With this, it means the fact that the subjects were told not to do high intensity training two days before the test and also not consume any caffeine on the day of the test. This, along with the RFT, can have affected the results, but it is difficult to confirm what the subjects were doing before the tests.

The aim for this study was to recruit 15-20 subjects. One of the first challenges occurred during the recruitment process. The recruitment of individuals who matched the inclusion criteria for this research became more difficult than anticipated due to injuries or illnesses as the test period started. The two-test protocol of this study also offered challenges. Since being dependent on the laboratory to access the tools needed for the tests, the availability of the laboratory had to accord with the availability of the subjects. The laboratory treadmill, which we needed for the VO_2 max test and regular running intervention of the tests, was out of order when we originally planned to start testing (end of October-November 2023). This forced us to postpone the test period by a month (end of November-December 2023), leading to the test period taking place in the middle of the exam period and flu season making it even harder to recruit subjects as most of them were university students. Some of the originally recruited subjects were affected by the flu season and fell sick, resulting in them having to withdraw before the tests. Others fell sick in the restitution period, after completing only one of the two tests. Booking the laboratory also turned out to be a bit difficult as it had to be done through a third party (either our supervisor or the laboratory engineer), we did not have access to the schedule depicting the availability of the laboratory ourselves. Balancing the availability of the laboratory and the subjects became a logistical challenge, especially in ensuring each subject could return for the second test within the 2-10 days restitution period as described in the protocol. Due to the challenges following the recruitment of subjects and scheduling of the tests, the test period became longer than anticipated. Instead of lasting for the estimated time of a month, originally aiming to complete all tests by the end of 2023, the test period ended up lasting over the course of 3 months (December 2023-February 2024). The delays and inconveniences during the tests resulted in everything taking longer than expected and therefore led to an overall postponement of the writing process.

As the study revolves around testing a newly developed wearable smart shirt connected to an application, there were also some technological issues with the application software during some of the test interventions. During most of the tests, both smart shirt and application technology worked without problems, but this was not always the case. For a couple of the tests, the shirt recordings would take longer to upload to the app and for some the recordings would not upload at all before several hours later. This inconvenience could cause delays on test days as the waiting time between the subjects was extended, some even had to be rescheduled. Luckily, the tests that appeared to be lost because of this issue were possible to retrieve and are included in the final analysis. The application offered more challenges as it, in January 2024, broke down because of an expired license. This occurred on a day when several subjects were scheduled for testing and caused further delays and rearrangements of the test schedule had to be made. In addition to this, there were some challenges with the wireless connection between the application and the pod of the smart shirt as well. During some of the tests, the connection between the application and the pod was lost which caused gaps of missing measurements in the final file. However, most of these gaps occurred in the resting period between interventions leaving sufficient measurements for the final data analysis. The disruption following the connection between pod and application was most noticeable during the Yo-Yo IRL1 test interventions. As this is the part of the test where the subject moves the furthest away from the recording phone with the application, the disturbance of the wireless connection could possibly be explained with the range.

Lastly, the smart shirt failed to upload an entire recording; D2 of subject ID: MT20235. The application showed no sign of anything not working as usual during the test monitoring, but the recorded file was completely unable to upload afterward. Because of this, the measurements from Day 2 for this subject are excluded from the final analysis. These technological issues are the reason the number of data sets is different for each variable. Even though the breakdown of the application along with the other technological problems caused issues during parts of the test period, it also offers interesting information regarding the abilities of the shirt and opens new questions and ideas about the technology applied in the Tyme Wear Smart Shirt. Such as, 'How can the smart shirt be adapted to improve the range between the wearable pod and the app?', and 'What causes disturbances of the connection during activities such as the Yo-Yo IRL1 test?'. Questions like these are important to investigate when looking to improve the functionality of a device.

4.3 Summary of the results

The results show the reliability of the Tyme Wear Smart Shirt when compared to a standard VO_2 max test in which ventilation volume, tidal volume and breathing frequency are measured. The data's overall results indicate that Tyme Wear is a reliable monitoring device of some variables such as BR when comparing BR measurements during the VO2 max tests. Indicating that the results are reliable can be justified in figure 9 where $R^2 = 0.689$ for the comparison of the Tyme Wear measurements from D1 during the VO_2 max test with the mouthpiece and nose clip, and from D2 without. Also, the P-value of both comparisons is < 0.05 ($P = 0.023$ for BR of VO_2 max avg in D1 clinical measurements compared to the Tyme Wear measurements, and $P = 0.019$ for BR of VO_2 max avg D1 compared to D2 Tyme Wear measurements) meaning there is a significant difference between the data of these comparisons.

5 Discussion of the results

This study has investigated the validity and reliability of the Tyme Wear Smart shirt through one clinical test and one field test. The subjects included in this study took part in tests during D1 and D2 following a controlled protocol to collect data for the final analysis. All data was recorded with the Tyme Wear smart shirt from both the VO_2 max- and the Yo-Yo IRL1 test, as well as the data from the results of the VO_2 max test (clinical) which has been compared and analyzed to discover potential similarities and/or differences. These comparisons are made to determine the accuracy of the measurements recorded with the smart shirt. This chapter will connect the results presented in this study to the research question, hypothesis, theory, and the previous research presented. For this study, the research question is "Can a wearable "smart shirt" with integrated thoracic excursion sensor provide valid and reliable ventilatory data in team sports?", seeking to discover a solution by analyzing the outcomes obtained from comparing test results. The hypothesis of the research was that the smart shirt could provide valid and reliable data for the variables BR, TV, and VE in team sports.

5.1 Key findings

The most important findings regarding the thesis problem are the statistical significance correlation of BR between the measurements from Tyme Wear in D1 with mouthpiece and nose clip vs. Tyme Wear in D2 during the VO_2 max test without mouthpiece and nose clip. The results showed a significant difference $P = 0.019$ between the measurements from Tyme Wear during Day 1 and Day 2. The graphic presentations of the results show that $R^2 = 0.68$ (Figure 10). This means the data from these tests are reliable and that Tyme Wear manages to record measurements of BR that are accurate enough to be used as an alternative to clinical tests. The correlation between the measurements from the VO2 max test with mouthpiece/nose clip Day 1, and Tyme Wear Day 2 indicate a relation between the two measuring devices (Tyme Wear and spirometry). This supports the statement of Tyme Wear being a reliable and valid measuring device when it comes to BR monitoring. On the other hand, the correlation between the Tyme Wear measurements of BR during the Yo-Yo IRL1 test intervention of Day 1 and Day 2 showed no significant difference as the P-value was >0,05, with P = 0.71, along with the graphic presentation showing that $R^2 = 0.41$ (Figure 11). These values suggest that the data cannot be seen as highly reliable according to Pearsons's correlation coefficient.

As stated in 4.1, research by Slimani et al (2019, p. 240) found that the overall VO_2 max values for male sub-elite and junior soccer players was in the range of 48-62 ml/kg/min which can also be seen in the results of this study, with a mean of 54.3 ± 7.9. The results from Slimani et al.'s study (2019) are not directly comparable to our results as their subject selection only consisted of male soccer players within a wide age range, while the subject selection of this study consist of both male and female. However, the results show that the subjects in this study, on average, are at a good physical fitness level when compared to the soccer players in Slimani et al.'s study.

5.2 Breathing rate in clinical test vs field test

The results from the comparisons and the values show how Tyme Wear is a reliable monitoring device for BR in activities that require less motion and changes of direction, while in other, more unpredictable activities, there is still room for improvement. The VO_2 max test included in this study is a run-based treadmill test with no changes of direction or other sudden movements. The speed increases gradually and the test follows a controlled protocol as described in previous chapters. Just like the VO_2 max test, the Yo-Yo IRL1 test follows a controlled protocol. The main difference between the tests is that the Yo-Yo IRL1 test takes place over a bigger area as the subject runs back and forth and not on the same place, as they do on the treadmill during the VO_2 max test. The Yo-Yo IRL1 test also calls for more sudden speed changes and changes in direction as the subject must stop and turn at each level to then run back to start and walk before the next level begins.

As explained, the results are significant within the comparisons of recorded measurements from the smart shirt and the clinical tools during the VO_2 max test, but not for the comparison of the smart shirt measurements from the Yo-Yo IRL1 test. The reason for insignificant values for the measurements from the Yo-Yo IRL1 test could be caused by the fact that this type of test requires more sudden movements and motion than the VO_2 max test, and that these movements might have affected the monitoring and therefore also the results.

The findings of BR being statistically significant and reliable for the comparisons of the VO_2 max test support previous research that says BR is proved to be the most promising and measured variable (Massaroni et al, 2019, p.1). As Tyme Wear has been proved to be reliable in comparison to the clinical tests it also supports Chu et al.'s (2019, p.1) statement of the limitation to clinical tests with less measurements in field tests. Though Tyme Wear in this case has been proven to be a practical monitoring device for measuring BR out in the field, it has yet to prove its reliability when it comes to providing reliable data of more unpredictable physical activities, such as team sports, that consist of more sudden movements and changes in speed as well as direction, which is also concluded by other research.

5.3 Ventilation volume related to VO_2 max- and Yo-Yo IRL1 test

Though the BR data from the Yo-Yo IRL1 test are considered to not be reliable ($R^2 = < 0.5$), the ventilation volume data from the same tests were shown as high reliability with $R^2 = 0.86$. This value gives good indications that one can measure some ventilatory measurements in team sport with Tyme wear. The same test offered a P-value of $P = 0.41$ which did not come as a surprise as the subjects had different intensities during the two tests they performed and therefore only comparable within each specific workout. There was also a substantial difference in the standard deviation between D1 and D2, with values of 143.1 ± 94.2 vs. 135.2 ± 74.1 (Figure 6). This highlights the big leap between the lowest and the highest measured values of the test. This leap appears during both D1 and D2 and will make the data less significant but not necessarily affect the reliability. What this means in theory is that during D1, the subjects had a higher volume of gas inhaled and exhaled than during D2 (Powers & Dhamoon, 2023, p.1). Tyme Wear has shown that it can measure ventilation volume during the Yo-Yo IRL1 test which will make it easier for team sport athletes to monitor ventilation during training. Schneider et al (2018, p. 6) have stated that one of the challenges of ventilation monitoring in team sports is due to the complexity of the given sport. In this case, the measurements of ventilation volume from Tyme Wear during the Yo-Yo IRL1 tests indicate that the smart shirt can be considered a useful device when it comes to in-field ventilation volume monitoring.

The article of Gouw et al (2022) had an aim in which they compared the Tyme Wear smart shirt to Parvo Medics TrueOne 2400 to detect if the Tyme Wear smart shirt is as reliable and valid detecting ventilatory thresholds. They used a traditional VO_2 max test on treadmill similar to the VO_2 max test used in this study. Their conclusion in which Tyme Wear is reliable and valid detecting ventilatory thresholds, was that Tyme Wear at that time is less valid with similar reliability to the laboratory counterparts (Gouw et al, 2022, p. 17). Their findings in which Tyme Wear provides the same reliability as the laboratory counterparts are not exactly the results we have obtained through this study. We found that Ventilation volume cannot directly compare to VE on the VO_2 max test with mouthpiece/nose clip as they do not provide the same measurement units (L/min when measured with mouthpiece/nose clip vs. Vol/min when measured with Tyme Wear) but that the mean between the two of them are similar; 145.1 vs. 146.6. The data is not reliable with $R^2 = 0.13$. This conclusion is presented graphically in Figure 14.

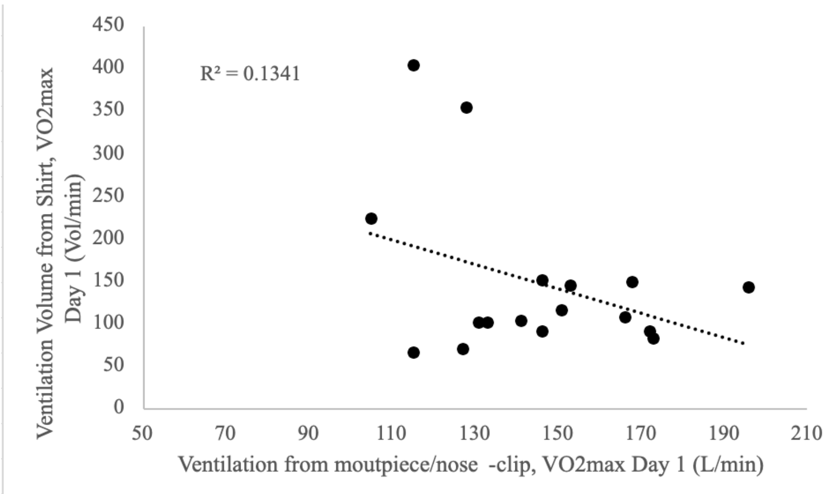


Figure 14. Correlation of the ventilatory data from the VO_2 max measurements during Test Day 1, with two different measurement units. D1 VO_2 max measurements from the mouthpiece/nose clip are presented on the x-axis as L/min, while VO_2 max measurements from Tyme Wear are on the y-axis as Vol/min.

The results of ventilation in relation to Tyme Wear show that the smart shirt compared to a mouthpiece/nose clip is not comparable and does not provide reliable data as they use different measurement units. When comparing the results of the Yo-Yo IRL1 test to the thesis question and detecting if Tyme Wear can be a reliable and valid measurement tool in team sport, the data are more positive. The data show a respectable number in reliability between Tyme Wear and field-tests such as a Yo-Yo IRL1 test. Gouw et al (2019) did not do any research in which Tyme Wear is a reliable tool in team sport and though our data show reliable results, more research in this field must be done such as using the same measure unit on Tyme Wear as a mouthpiece/nose clip during VO_2 max test.

5.4 Tidal volume related to Yo-Yo IRL1 test

In addition to the VE data, measurements of TV also showed a great reliability between the data from D1 and D2 with $R^2 = 0.89$. As the intensity increases during activity, the metabolic demand for oxygen increases linearly (Carey, 2008, p. 45) meaning the body's respiratory system requires more oxygen as the workload intensifies. Carey et al (2008, p. 46) states that when TV reaches a critical level, where further increases would result in an O_2-inefficient breathing pattern, increases in VE would be attained solely by increased BR. This is also what was found in this research with mean values of 299 ± 200 for D1 and 270 ± 132 for D2. The P-value for the same data was shown as $P = 0.21$, meaning there was no significant difference. Gouw et al (2022) aimed to measure some of the same variables as our study and how the Tyme Wear Smart Shirt can be used to estimate ventilatory thresholds. Gouw et al (2022) used a standard VO_2 max test for measurements of variables such as TV. Unlike this study, they did not research the Tyme Wear Smart Shirt in field tests like the Yo-Yo IRL1 test to investigate whether Tyme Wear could be used in running-based team sports like soccer. This study is the first to directly investigate whether Tyme Wear can be used in running-based team sports, and there is no earlier research to compare the ventilatory data from the Yo-Yo IRL1 test with.

The results of TV from Tyme Wear have not been compared to the VO_2 max test with mouthpiece/nose clip in this study as it was not possible to collect these data from the SentrySuite software. This has led to the fact that we have not been able to compare the results of TV from the VO_2 max test to the results of TV from the Yo-Yo IRL1 test. Because of this, the data of TV are less reliable, even though the results from the Yo-Yo IRL1 tests are very positive alone with the results showing high reliability; R^2=0.89.
The study by Mannée et al (2021) used similar technology to Tyme Wear, called Hexoskin. The aim was to investigate the accuracy of Hexoskin compared to spirometry while measuring TV in different settings. This study was carried out in order to use the shirt to monitor patients, but similar to our findings regarding the Yo-Yo IRL1 tests, both Hexoskin and Tyme Wear can be used to measure TV in activities with unpredictable movements and

sudden speed changes. The Tyme Wear Smart Shirt and Hexoskin cannot be directly compared to each other because of their different area of use. However, the technology behind them is similar and they both showed high reliability in their representative studies of measuring TV.

Until now, measurements of TV have been done using spirometry because of its efficiency and reliable results (Dumond et al, 2017, p. 1534). The downside of using spirometry in running-based team sports is that spirometry requires a mouthpiece or mask connected to a mixing chamber, which makes it very impractical in team sports and in-field testing. This does not only apply for measurements of TV but also the other ventilatory measurements, like VE and BR. The advantage of Tyme Wear is that it is an easy tool to use because it only requires a phone with the corresponding application, the pod, and the smart shirt itself.
The results from our study indicate that Tyme Wear manages to measure TV in tests such as the Yo-Yo IRL1 tests, which in fact is similar to a typical soccer practice where the use of Tyme Wear would be practical. The results presented in Table 4 support the results displayed in Figure 12, where one can see that 3 of the results have clearly higher values than the rest of the group during the Yo-Yo IRL1 test. These 3 results could explain the high values of standard deviation presented in Table 4. This does not only apply to TV, but also to the higher measurements of VE during the Yo-Yo IRL1 tests (Figure 9) and the BR data (Figure 11). The data from the 3 subjects with higher values than the others indicates that something may have disturbed the data in Tyme Wear and caused irregular measurements.

One disadvantage of this study, especially regarding the results of TV and VE during the Yo-Yo IRL1 tests, is the lack of previous research to compare with. This makes the evaluation of data validity challenging. In addition, the number of subjects (N = 18) may be a weakness as it would have been preferable to have a larger group over a longer period. The use of different field tests for comparisons of results would also have helped with elevating the validity and reliability of the results. For this study, one test and the same subjects have been compared to each other. This means that even though the data may be proven reliable within this study, it is difficult to state whether the Tyme Wear Smart Shirt will provide reliable results for other tests with more components similar to those in a running-based team sport training session or game.

5.5 Unexpected results

Even though the encounter of deviations in the data was expected before starting the research, some unexpected results still occurred. These have not only been negative but also positive. The results that may have offered the biggest positive surprise were those regarding BR during the VO_2 max test on D1. The accuracy of the smart shirt monitoring was presented through the comparisons between the BR measurements from the mouthpiece and the measurements from Tyme Wear. The BR data from the Yo-Yo IRL1 tests D1 and D2 are also promising and should be repeated with more game-like conditions. However, the TV measurements are somewhat questionable. This may have to do with the fact that the same exact shirt has not been used during D1 and D2 even though the subjects were using the same size. Using different shirts for each test day can cause the calibration to be different for D1 than D2 as the internal sensors are slightly different for every shirt. Despite this, both TV and VE data showed high reliability in the Yo-Yo IRL1 tests, and it would be interesting to see what the results would have been if we excluded the 3 subjects with higher measurements than the rest of the group. The reliability was surprisingly as high as R^2=0.86 for VE and R^2=0.89 for TV which is remarkably high when saying that 1 is the highest possible to reach using Pearson's correlation coefficient (Steward, 2024).

5.6 Practical implications

An implication of the results from this study will be to focus on, and further develop, the use of the Tyme Wear Smart Shirt in the training field related to running-based team sports. This is because of the problems with the pod connection that occurred during the Yo-Yo IRL test. These problems led to imbalance in the measurements and gaps of missing data in the final file. Using the measurements from the Yo-Yo IRL1 test to compare with an actual soccer- or handball training session simplifies the practical implications regarding the conduction of test related to running-based team sports and the reliability and validity of Tyme Wear.
There are also other tests that can be used to test the Tyme Wear Smart Shirt in running-based team sports. One of these being a beep test which is similar to the Yo-Yo IRL1 test, and the CODA test which is a "change of direction ability" test developed for soccer referees (Wood, 2019). A CODA test consists of several elements of movements which can indicate the areas Tyme Wear needs improvements to be considered reliable enough to be used as a valid measuring device in running-based team sports. A possible way to do this is to apply both the Yo-Yo IRL1 test and the CODA test in a study researching the smart shirt and compare the

measurements form both tests. Assessing the smart shirt though several different tests could work as an alternative to clinical testing. The use of physical tests that include sudden changes in direction and other team sport related elements could be an interesting method in further studies to improve the use of Tyme Wear. Gouw et al (2022) proved the reliability of Tyme Wear in clinical tests such as the VO_2 max test and other spirometry tests.

5.7 Further research

To keep improving the reliability and validity of Tyme Wear smart Shirt in running-based team sports, further in-field studies should be conducted. One possible method could be intervention studies combined with observation of Tyme Wear in an actual team sport setting such as soccer, over an extended period. This includes conducting a study using only in-field tests, like the use of the Yo-Yo IRL test in this study, while also testing the smart shirt on team sport athletes during practice and actual games. To further improve the smart shirt, focus should be on in-field tests including components such as sprints, acceleration/deceleration, and sudden changes of direction to better determine the reliability of the shirt.

6 Methodical discussions

This chapter will discuss the strengths and weaknesses of the method used and presented in this study. This part will also include what we consider to be the factors that make the results supporting the thesis valid and reliable, in addition to the weaknesses following this.

As mentioned, important equipment that this study's research was dependent on was out of order when the test period was intended to start. This caused delays which resulted in the test period being re-scheduled and forced to take place during the exam- and flu season causing several recruited subjects to withdraw from the study. With this negatively affecting the already challenging task of recruiting enough subjects, we decided to expand the area of where to conduct the tests and recruit subjects to include the University of Stavanger in addition to the University of Agder. This allowed us to simultaneously test in two locations and helped us get back on track.

A reliable measurement implies that the measurement is considered trustworthy and stable, and that repeated measurements will show the same results (Ringdal, 2013, p. 96). The concepts of validity and reliability are connected as a high reliability is a prerequisite for high validity (Ringdal, 2013, p. 96). This is important to eliminate possible sources which can lead to errors in the data. This study followed a test protocol to make sure the same equipment and procedures were followed. As a result, more than 80% of the data consist of highly reliable values. The more detailed and thorough the test protocol is, the higher the chances are for reliable results as it will lead to the tests being conducted identically and therefore also able to be repeated in the exact same way in later research. This study was conducted in test laboratories approved by Olympiatoppen Norway (one located in Kristiansand and the other located in Stavanger), which means that weather, temperature, and equipment cannot have had any impact on the interventions taking place in the laboratory. The only difference would be whether there was any climate variance between the two locations, but all equipment applied were the same for all tests conducted and included in the final analysis of the data within this study. This could be considered one of the strengths of this study because the variables from the laboratory are considered both reliable and valid due to controlled conditions.

One of the study's weaknesses, which also weakens the data's validity, is the use of the Tyme Wear Smart Shirt. In this case, even though the same equipment was used for the tests on D1 and D2, the shirt may have been stretched or shrunken in between the tests causing different conditions for the calibrations. In addition to this, even though the subjects wore the same size of the smart shirt, we had a double set of sizes for most of the shirts – the shirt selection available for this study included: 1 female shirt size extra small (XS), 1 female shirt size small (S), 2 male shirts size small (S), 2 male shirts size medium (M), and 3 male shirt size large (L). The protocol followed during this test period did not include the requirement of the subjects wearing the exact same shirt, only the size of the shirt was considered of importance. What was not taken into consideration in regard to this is that even though each subject used the same sized shirt for both tests, the possibility of it being a different shirt with the same size could have had an impact on the final results as there is no certainty that the shirts of the same size are identical and therefore, we cannot be sure that the shirts can offer identical recordings to one another. Also, the design of the male and female shirt is different. The male shirts are shorter and resemble a longer sports bra while the female shirts are in full length like a standard tank top. This might have interfered with the results as well and offered differences in the measurements as the fit of the shirt might have affect how the variables were monitored. Even though these differences may seem minor they are still important to keep in mind when evaluating the validity and reliability of the results.

A typical challenge with intervention studies such as this is recruiting enough subjects who meet the inclusion criteria. This study was no exception; a difficult recruitment process was anticipated but less than what we faced. In a study like this, the more subjects recruited, the better it would be for the results, and we would originally like to have recruited a greater number of subjects to increase the amount of data collected which would also improve the argumentation supporting the validity of the data. If the age criteria of this study had been adjusted from 19-35 to 16-35 years, more people would have had a chance of meeting the inclusion criteria and could have been recruited as subjects for this study as the age limitations would open for more people to apply for participation. The reason we decided to only include subjects between 19-35 years is the challenge of using subjects under the age of 18 in research. The process of getting the research approved from the research ethics committee is longer and would have further delayed the start of the study. In addition to this, approval from the parent or other adult supervisor with responsibility for the subjects under 18 would be required before they would be able to take part in the study.

To facilitate the conditions of achieving identical test days, both D1 and D2 were completed within the same time-period (+/- 2 hours) for each subject. Though the test interventions followed specific protocols to make sure the tests were conducted as identical as possible, the period before and in-between the test days took place in uncontrolled environments. Possible uncontrolled factors that could have affected the data during these periods include the subjects' quality and hours of sleep the night before the test days, their caffeine intake through the duration of the period, their exposure to physical effort e.g. number and intensity of workouts prior to or in-between the test days, and the general mental and physical condition of the subject on the days of the tests. The subjects were informed of how they were expected to show up on the test day in the informative poster describing the tests and all the inclusion and exclusion criteria (see 3.2.3 Test Procedure). As mentioned, this demanded the subjects not to consume heavy meals or caffeine within 2 hours before the test. They were also instructed to avoid high-intensity training at least 48 hours before the given test day. There is no way of knowing whether the subjects followed these instructions or not as they were not monitored before their first test and in the recovery period before their second. This could have had an impact on their performance on the test days but in what way it could have affected the results is uncertain as it is not known to what extent these instructions were adhered to by the subjects.

In total, 18 subjects with a moderate to good physical fitness level participated in the study, and this is a small sample size considering the generalization of the findings. Although only some of the findings in this study can be considered reliable, the other results are still interesting for further development of the Tyme Wear Smart Shirt.

7 Conclusion

In this study, we have used a clinical test and a field test on a group of subjects familiar with running-based team sports, to test the reliability and validity of a newly developed wearable monitoring device. A standard t-test was used to analyze the data's significance, along with Pearson's correlation coefficient, used to state its reliability and validity.

The research question for this study was:

> *Can a wearable "smart shirt" with integrated thoracic excursion sensor provide valid and reliable ventilatory data in team sports?*

The comparisons made in the final analysis led to a conclusion of the Tyme Wear Smart Shirt being a reliable monitoring device for BR measurements as the results show significant differences and reliable data for the VO_2 max measurements. However, for the other variables included in this study (TV and VE) there were no significant differences in the comparisons of the results of the measurements. As the smart shirt was not tested in an actual team sport activity, but in a field test with components found in team sports (unpredictable and sudden changes of direction, and accelerations/decelerations), the last part of the research question becomes difficult to answer without further research. More specific research must be done in order to determine the reliability and validity of this wearable in team sports.

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9 Attachments

Attachment 1. SIKT registration form

Sikt

Norsk ▾ Tone Brit Paulsen Haga ▾

Meldeskjema / Reliability and Validity of a wearable shirt for ventilation measurement in Team Sports / Eksport

Meldeskjema

Skriv ut

Referansenummer
830763

Hvilke personopplysninger skal du behandle?

- Fødselsdato
- Andre personopplysninger

Beskriv de andre personopplysningene
Trenings og idrettsbakgrunn, for eksempel fotball eller håndball. Type og mengde trening i løpet av en vanlig uke.

Prosjektinformasjon

Tittel
Reliability and Validity of a wearable shirt for ventilation measurement in Team Sports

Sammendrag
Formålet med dette masterprosjektet er å undersøke om en nylig utviklet skjorte med innbygd sensorteknologi er et valid og pålitelig måleinstrument for ventilasjonsvariabler (ventilasjon, pustefrekens og tidevolum).

Begrunn behovet for å behandle personopplysningene
Fødselsdato samles inn kun for å brukes i intern testdatabase i fysiologilabben. I tillegg vil fødselsdato danne grunnlag for alder, som er deskriptiv data for utvalget.

Ekstern finansiering
Ikke utfyllt

Type prosjekt
Master

Kontaktinformasjon, student
Tone Brit Haga, tbhaga18@uia.no, tlf: +4746825430

Behandlingsansvar

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

Prosjektansvarlig
Kerry Stephen Seiler, stephen.seiler@uia.no, tlf: +4791614587

Er behandlingsansvaret delt med flere institusjoner?
Nei

Utvalg 1

Beskriv utvalget
Studenter ved universietet i Agder, hovedsakelig fra idrettsutdanningen. Studentene vil være friske uten medisinsk diagnose, fysisk aktive og aktive i lagidrett. Testene vil ikke være mer fysisk utfordrende enn deres daglige trening.

Beskriv hvordan du finner frem til eller kontakter utvalget
Informasjon om prosjektet blir presentert i sosiale medier og på universitetets sosiale nettverk. Rekrutteringen skjer gjennom at deltaker tar kontakt med ansvarlige for prosjektet om de er interessert i å delta i studien.

Aldersgruppe
19 - 35

Hvilke personopplysninger vil bli behandlet om utvalg {{i}}? 1

- Fødselsdato
- Andre personopplysninger

Hvordan innhentes opplysningene om utvalg 1?

Papirbasert spørreskjema

Vedlegg

participant questionnaire (1).docx

Lovlig grunnlag for å behandle alminnelige personopplysninger

Samtykke (Personvernforordningen art. 6 nr. 1 bokstav a)

Informasjon til utvalg 1

Mottar utvalget informasjon om behandlingen av personopplysningene?

Ja

Hvordan mottar utvalget informasjon om behandlingen?

Skriftlig (papir eller elektronisk)

Informasjonsskriv

samtykke - infoskriv.docx

Tredjepersoner

Innhenter prosjektet informasjon om tredjepersoner?

Nei

Dokumentasjon

Hvordan dokumenteres samtykkene?

- Manuelt (papir)

Hvordan kan samtykket trekkes tilbake?

Deltaker sender skriftlig at han eller hun ønsker å trekke seg fra prosjektet. Samtykkeerklæring blir dermed ugyldig og makulert.

Hvordan kan de registrerte få innsyn, rettet eller slettet personopplysninger om seg selv?

Deltakere kan til en hver tid be ansvarlige for prosjektet om å få innsyn i data om seg selv, og be disse bli endret eller slettet. Deltaker vil motta personopplysninger og datainnsamling digitalt på email.

Totalt antall registrerte i prosjektet

1-99

Tillatelser

Vil noen av de følgende godkjenninger eller tillatelser innhentes?

Ikke utfyllt

Sikkerhetstiltak

Vil personopplysningene lagres atskilt fra øvrige data?

Ja

Hvilke tekniske og fysiske tiltak sikrer personopplysningene?

- Fortløpende anonymisering
- Andre sikkerhetstiltak

Hvilke

Fysiske skjema låses inn, og alle dataenheter inneholder tastelås. Ingen av personopplysningene inneholder navn. Alle deltakere anonymiseres i kode.

Hvilke tekniske og fysiske tiltak sikrer personopplysningene?

- Fortløpende anonymisering
- Andre sikkerhetstiltak

Hvilke

Fysiske skjema låses inn, og alle dataenheter inneholder tastelås. Ingen av personopplysningene inneholder navn. Alle deltakere anonymiseres i kode.

Hvor blir personopplysningene behandlet?

- Mobile enheter

Hvem har tilgang til personopplysningene?

- Prosjektansvarlig
- Student (studentprosjekt)

Overføres personopplysninger til et tredjeland?

Nei

Avslutning

Prosjektperiode

23.10.2023 - 31.05.2024

Hva skjer med dataene ved prosjektslutt?

Data slettes (sletter rådataene)

Vil enkeltpersoner kunne gjenkjennes i publikasjon?

Nei

Tilleggsopplysninger

Attachment 2. FEK registration from and approval

Din henvendelse er mottatt

Nummer RITM0239830

Opprettet av Tone Brit Paulsen Haga

Status Closed Complete

Opprettet 7 måneder siden

Oppdatert 7 måneder siden

Fase

- ◯ Tilbake hos søker for redigering
- ◯ Venter på godkjenning
- ◯ Forskningsetisk komitebehandling
- ◯ Søknad godkjent
- ◯ Fullført

Søknad om etisk godkjenning av forskningsprosjekt

Generelle opplysninger

* 1.1 Studienivå

Master

* 1.2 Søker

Tone Brit Paulsen Haga

1.3 Navn på veileder som har godkjent innsending av søknad

Kerry Stephen Seiler

1.3.1 Eventuelle andre veiledere

Matthew Spencer

* 1.4 Prosjekttittel

Reliabilitet og validitet av en bærbar skjorte for vent

Prosjektopplysninger

* 2.1 Hensikt med forskningsprosjektet

Hensikten med dette masterprosjektet er å undersøke om en nylig utviklet skjorte med innbygd sensorteknologi er et valid og pålitelig måleinstrument for ventilasjonsvariabler (ventilasjon, pustefrekens og tidevolum)

2.2 Forskningsdata

* 2.2.1 Skal du samle inn/behandle direkte personsensitive opplysninger?

Les mer om om personopplysninger og meldeplikt her.

Nei

* 2.2.3 Skal du samle inn/behandle bakgrunnsopplysninger som kan identifisere enkeltpersoner (indirekte personidentifiserende opplysninger)?

Les mer om personopplysninger og meldeplikt her

Nei

* 2.2.5 Skal du samle inn/behandle personopplysninger på bilde-, video eller lydopptak? Hvis ja, beskriv. Beskrivelsen må være konkret, og mer utfyllende enn ordlyden «i tråd med UiAs retningslinjer».

Nei

Forklar hvordan du planlegger å bruke, lagre, og destruere digitale bilde-, video- og lydopptak:

* 2.2.6 Skal du bruke tidligere innsamlet data som inkluderer personopplysninger? Hvis ja, beskriv hvor disse er hentet fra

Nei

Beskriv hvor du henter inn tidligere innhentet data fra:

* 2.2.7 Skal du samle inn humant biologisk materiale? Hvis ja, beskriv innsamling, oppbevaring og destruksjon

Nei

Beskriv hvordan du samler inn, lagrer og destruerer humant biologisk materiale

2.3 Utvalg

2.3.1 Beskrivelse av forskningsdeltakere/utvalg

- [ ] Mindreårige under 16 år
- [ ] Personer mellom 16 og 18 år
- [x] Personer over 18 år
- [ ] Personer med redusert samtykkekompetanse
- [ ] Andre personer i en sårbar eller avhengig situasjon

* 2.3.2 Beskriv hvordan disse personene skal inkluderes

Informasjon om prosjektet blir presentert i sosiale medier og på universitetets sosiale nettverk. Rekrutteringen skjer gjennom at deltaker tar kontakt med ansvarlige for prosjektet via email eller telefon, om de er interessert i å delta i studien.

2.4 Forskningsmetode

2.4.1 Metode for analysering av data

- [ ] Kvalitative analysemetoder
- [x] Kvantitative analysemetoder

2.4.2 Metode for innhenting av data

- [x] Fysiske tester (eks. opplæringsprogram, treningsprogram)
- [ ] Kliniske undersøkelser
- [ ] Andre intervensjoner over tid (eks. pre- post målinger)
- [x] Spørreskjema
- [ ] Intervju
- [ ] Observasjon
- [ ] Fotografi/film
- [ ] ANNET

* 2.5 Gi en begrunnelse for dine metodevalg

Vi har valgt et kvantitativt forskningsdesign som metode, med vekt på fysiske tester og spørreskjema for å på best mulig vis kunne gjennomføre hensikten med studien og sikre oss valide resultater. Ved å gjennomføre studien med et kvantitativt design vil vi kunne teste hypotesen vår om at den bærbare skjorten kan måle ventilasjonsvariabler i lagidrett.

Forskningsetikk

* 3.1 Samtykke

Lenker til maler for informasjonsskriv finner du på REK og SIKT sine hjemmesider. Det skal opplyses om at forskningsdata vil bli lagret i 5 år for etterprøvbarhet og kontroll

Samtykke vil bli innhentet

* 3.2 What risk factors can occur when implementing the project? Describe any measures.

Hver deltaker skriver under på samtykkeskjema før det blir gjort tester. Deltakere har til enhver tid rett til å trekke seg fra studien uten å oppgi grunn om hvorfor. Deltakere vil bli anonymisert med egen kode, og opplysninger innhentet er ikke mulig å identifisere for offentligheten. Det er et lite antall deltakere i studien, og alle opplysninger blir lagret på sikker måte og utilgjengelig for andre med passord. Personer i sårbare grupper og personer med sykdommer som fører til nedsatt fysisk kapasitet er ekskludert fra studien. Risikoen for selvtesting i denne studien er svært lav og testene er tilsvarende fysisk belastning som de utfører i idretten.

* 3.3 Forsvarlighet

Denne studien er forsvarlig å gjennomføre fordi den ikke inneholder noen identifiserbare og sårbare personopplysninger. Fordelen med denne studien er at dataene som innhentes kan
være med å videreutvikle den bærbare skjorta som måler ventilasjonsvariabler. Ulempen med studien er at det er et nytt forskningsområde for skjorta og den kan derfor gi oss ugyldige data i forhold til hypotese og problemstilling.

Vurdering av andre instanser og interesser

* 4.1 Er det sendt søknad til REK?

Vær obs på at: Skjemaet Framleggingsvurdering skal brukes når du er i tvil om et prosjekt må godkjennes av REK. Ikke søk FEK før svaret om framleggsvurdering fra REK foreligger. Mer info om REK kan finnes her.

Nei

* 4.2 Hvordan finansieres prosjektet?

Interne ressurser fra avdeling for idrettsvitenskap og kroppsøving.

* 4.3 Gis det kompensasjon eller økonomiske insentiver til forskningsdeltakere?

Nei

* 4.4 Eventuelle interessekonflikter for prosjektleder/-medarbeidere

Det er ingen interessekonflikter i denne studien, og det er heller ikke mulig at det vil oppstå i løpet av prosjektet

Vedlegg

Ansvarserklæring

- [x] Jeg erklærer at søknaden er gjennomgått og kvalitetssikret av veileder

Jeg erklærer at prosjektet vil bli gjennomført

- [x] I henhold til gjeldende lover, forskrifter og retningslinjer
- [x] I samsvar med opplysninger gitt i denne søknaden
- [x] I samsvar med eventuelle vilkår for godkjenning fra FEK

* Har du lastet opp alle nødvendige vedlegg?

Ja

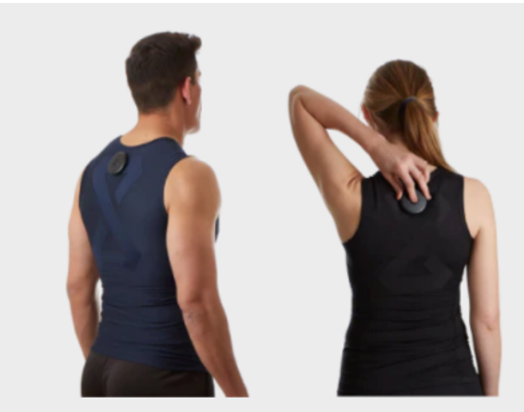
Attachment 3. Consent form

Vil du delta i forskningsprosjektet?

”Reliability and Validity of a wearable shirt for ventilation measurements in Team Sports”

Dette er en invitasjon til både kvinner og menn til å delta i et spennende forskningsprosjekt hvor formålet er å undersøke om Tyme Wear Smart Shirt er et troverdig måleinstrument når det kommer til lagsport. Dette med utgangspunkt i ventilasjon, pustefrekens og tidevolum.I dette skrivet gir vi deg informasjon om målene for prosjektet og hva deltakelse vil innebære for deg.

Formål



Dette er et masterprosjekt der målet er å undersøke om Tyme Wear Smart Shirt kan bli brukt ilagsport, så vel som i individuelle idretter. Problemstillingen for dette masterprosjektet er: “Can the Tyme Wear Shirt be a useful tool in collecting reliable and valid ventilatory data in team sports?”. Tyme Wear Smart Shirt er laget for å erstatte den tradisjonelle VO_2 max testen ved å måle både pustefrekvens, tidevolum og ventilasjons-volum under aktivt spill. Prosjektet startet i september i år og vil være ferdig i mai 2024. Opplysningene som vi får vil kun bli brukt til dette prosjektet

Hvem er ansvarlig for forskningsprosjektet?

Ansvarlig institusjon for masterprosjektet er instituttet for idrettsvitenskap og kroppsøving. Veileder for masterprosjektet er Stephen Seiler, professor ved institutt for idrettsvitenskap og kroppsøving.

Hvorfor får du spørsmål om å delta?

Vi ønsker nettopp deg til dette forskningsprosjektet fordi du driver med lagsport eller har en bakgrunn fra løpsbasert lagidrett.
Inklusjonskriteriene for prosjektet er at du er mellom 19-35 år, i en god fysisk form, samt at du driver eller har drevet med en lagsport som fotball, håndball, basketball, med mer.
Eksklusjonskriterier for prosjektet er blant annet astma, etter effekter fra covid eller andre lignende langvarige infeksjoner. Hvis du har andre sykdommer som fører til nedsatt fysisk kapasitet bør du ikke melde deg til studien.
Totalt vil det være 20 deltakere og du har til enhver tid rett til å trekke deg i løpet av prosjektet.

Hva innebærer det for deg å delta?
Deltakelse i prosjektet innebærer at du fyller ut et spørreskjema som tar ca. 15 minutt å fylle ut. Dette inneholder opplysninger om alder, kjønn, idrett du har drevet med, hvor mange dager i uken du trener, hva du har spist på testdagene og hvor lenge du har sovet påfølgende natten. Svarene fra spørreskjemaet vil bli lagt inn i en statistikk elektronisk.

I tillegg skal du gjennomføre en VO_2 max test på tredemølle, som varer i 4-8 minutter. Etter gjennomført VO_2 max test og en hvileperiode skal det gjennomføres en progessiv løpstest i gymsalen (Yo-Yo intermittent recovery test) som varer i ca 10 minutter. Testene skal gjennomføres to ganger, med noen dager mellomrom. VO_2 max testen gjennomføres med og uten maske, og du får ikke vite hvilken av dagene som skal gjennomføres med eller uten, før du kommer til labben der testen foregår.

Det er frivillig å delta
Det er frivillig å delta i prosjektet, og du kan til enhver tid trekke deg uten å måtte oppgi grunn om hvorfor. 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 forskningsresultatene til formålene vi har fortalt om i dette skrivet. Vi behandler opplysningene dine konfidensielt og i samsvar med personvernregelverket. Navn og kontaktopplysninger om deg vil bli anonymisert og kodet slik at dine data ikke er direkte knyttet til ditt navn. All data vil bli lagret på en sikker måte og utilgjengelig for andre enn de

som er involvert i prosjektet. Det innebærer at data oppbevares avidentifisert på instituttets passordbelagte PC. Anonymisert data vil kunne bli brukt i forbindelse med publisering av artikkel i tidsskrift eller i undervisning og kongresser.

Hva skjer med personopplysningene dine når forskningsprosjektet avsluttes?

Prosjektet vil etter planen avsluttes i mai 2024, og all materiell som spørreskjema og datamateriell vil slettes etter avsluttet prosjekt.

Hva gir oss rett til å behandle personopplysninger om deg?

Vi behandler opplysninger om deg basert på ditt samtykke.

På oppdrag fra Institusjon for idrettsvitenskap og kroppsøving har Sikt – Kunnskapssektorens tjenesteleverandør vurdert at behandlingen av personopplysninger i dette prosjektet er i samsvar med personvernregelverket.

Dine rettigheter

- Innsyn i hvilke personopplysninger som er registrert om deg
- Få rettet personopplysninger om deg
- Få slettet personopplysninger om deg
- Få utlevert en kopi av dine personopplysninger (dataportabilitet)
- Kunne sende klage til personvernombudet eller Datatilsynet om behandlingen av dine personopplysninger
- Du, som deltaker, er ellers også forsikret av UiAs egen forsikringsordning for forskningsprosjekter.

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

- Tone Haga (tlf: 46825430/ email: tonebrit@lyse.net), Ester Moen (tlf: 41284255/ email: estermoen@hotmail.com), Stephen Seiler (tlf: +4738141347/ email: stephen.seiler@uia.no) Eller Matthew Spencer (tlf: +4798404378 / email: matthew.spencer@uia.no)
- Vårt personvernombud: Ina Danielsen, tlf: 452 54 401, email: personvernombud@uia.no

Hvis du har spørsmål knyttet til vurderingen som er gjort av personverntjenestene fra Sikt, kan du ta kontakt via:

- Epost: personverntjenester@sikt.no eller telefon: 73 98 40 40.

Med vennlig hilsen

Stephen Seiler og Matthew Spencer	Tone Haga og Ester Moen
veileder	Student

Samtykkeerklæring

Jeg har mottatt og forstått informasjon om prosjektet "Reliability and Validity of the Tyme Wear Shirt in Team Sports?" og har fått anledning til å stille spørsmål. Jeg samtykker til:

- ☐ å delta i Vo2 max test og Yo-Yo test over to omganger.
- ☐ å delta i spørreskjema.
- ☐ At ansvarlig for prosjektet kan bruke opplysninger om meg fra spørreskjema og datainnsamling i prosjektet.

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

----

(Signert av prosjektdeltaker, dato)

Attachment 4. Readiness for testing questionnaire

Date and time for testing:

Sport and training background: Project ID-number:

Height and weight:

Age:

Sex:

Male Female

Sports background:

- ♦ Handball
- ♦ Football
- ♦ Basketball
- ♦ Other: __________________

How often do you work out per week (training sessions per week)?

Other

Date and time for testing:

Readiness for testing:

	5	4	3	2	1	Record Score
FATIGUE	Very fresh	Fresh	Normal	More tired than normal	Always tired	
SLEEP QUALITY	Very restful	Good	Difficulty falling asleep	Restless sleep	Insomnia	
GENERAL MUSCLE SORENESS	Feeling great	Feeling good	Normal	Increase in soreness/tightness	Very sore	
STRESS LEVELS	Very relaxed	Relaxed	Normal	Feeling stressed	Highly stressed	
MOOD	Very positive mood	A generally good mood	Less interested in others &/or activities than usual	Snappiness at team-mates, family and co-workers	Highly annoyed/ irritable/down	

Estimated hours of sleep last night:

Have you been sick in the last week?

Attachment 5. Recruitment poster

Forskningsprosjekt

"Reliability and Validity of a wearable shirt for ventilation measurements in Team Sports"

Inklusjonskriterier

VI SØKER DELTAKERE

Vil du være en del av et forskningsprosjekt der formålet er å måle ventilasjon, pustefrekvens og tidevolum, ved hjelp av ny teknologi? I vår master skal det undersøkes om Tyme Wear Smartskjorte kan bli brukt i løpsbasert lagsport, så vel som i individuelle idretter. Du skal på to testdager utføre en VO2 max test på tredemølle, en 10 minutters rolig jogg og en Yo-Yo test i hallen på Spicheren. VO2 max testen vil utføres på tredemølle i labben og utføres en gang med maske og en gang uten, i tilfeldig rekkefølge.

Du er mellom 19-35 år.
Du har en bakgrunn fra løpsbasert lagidrett (f.eks. fotball, håndball, basketball).
Du er fysisk aktiv.
Du er komfortabel med utstyret som brukes under en VO_2 max test og med å løpe det du klarer på slutten av en maks test som varer noen minutter.
Du er komfortabel med stikk i fingen (for å måle blodlaktat).

Eksklusjonskriterier

Du har astma, etter-effekter fra Covid eller andre lignende langvarige infeksjoner. Du er gravid.
Du har en skade eller sykdom som fører til nedsatt fysisk kapasitet.

Hva kreves av deg som deltaker?

For å delta i dette forskningsprosjektet må du innfri inklusjonskriteriene, og du må ha mulighet til å stille til **2 ulike testdager** på ca samme tid på dagen. Det skal utføres to tester på en testdag, samt et spørreskjema med informasjon om alder, treningsvaner og idrettsbakgrunn. Vekt og høyde vil registreres da dette er nødvendig for oppstart av VO_2 max test.
Du må komme uthvilt til testdagene og skal ikke spille kamp eller trene tungt innen to dager før testdagene. I tillegg skal du informere om dagsform på testdagen og hvordan du har sovet. Du kan ikke spise **innen 2 timer** før testene eller innta kaffein.

Når gjennomføres testene?

Testene gjennomføres i perioden uke 45-49 og/eller uke 1-3, og du må være tilgjengelig i opptil 2 timer på hver testdag. Det vil være mulig å gjennomføre test i helgen!

Meld deg på prosjektet på mail til ansvarlige studenter for prosjektet: Tone Haga - tbhaga18@uia.no - 46825430
Ester Moen - estera18@uia.no - 41284255

Attachment 6. Protocol lab-testing

Protocol lab- testing

Before the participants enter:

1. System warm-up.
2. Check filter before calibration and open gas.
3. Start calibration of lactate-machine and Vo_2 max machine.
4. Ready the masks, and the antibacterial washing water.
5. Prepare material for lactate-testing.

When the participants have entered:

1. Take measurements of the participant (height, weight).
2. The participant fills out the questionnaire.
3. Enter measurements in the system.
4. Turn on treadmill.
5. Connect participant with the Tyme Wear Smart Shirt, and pulse belt.
6. The participant does a 10-minute warm up with the Tyme Wear Smart Shirt and the mask.
7. The participant performs the Vo_2 max test with the Tyme Wear Smart Shirt and mask, make sure the treadmill has an incline of 3 degrees.
8. The participant takes off the mask and rests one minute before lactate-test.
9. While waiting, put the mask in the antibacterial water and connect a new mask to the Vo_2 max- machine.
10. Lactate-test of the participant → all needles, blood samples etc. is being thrown in the yellow trash cans.
11. The participant rests for 10-20 minutes before the next test.

Preparing for the next test:

1. New calibration of the Vo_2 max machine.
2. Clean the surfaces of the treadmill.
3. Repeat 1-10 as described above!

When finished in the lab:

1. Disconnect the mask and put it in the antibacterial water.
2. Make sure results from all tests are saved and printed.

3. Throw all needles, blood samples etc. from the lactate tests.
4. Make sure the gas is closed and put the Vo_2 max machine and lactate machine on standby.
5. Clean all surfaces and put everything in place.
6. Hang up the pipe with paper at both ends.
7. Set the masks to dry.

Attachment 7. Google questionnaire

https://docs.google.com/forms/d/e/1FAIpQLSf_TzCosIYTjzuUOLoLND65M-NdEEYlm0qm93sul9vpkWttvw/viewform?fbclid=IwAR3iugB2YFbBAGnh4stVgMevHrHtesDGQNUc2EQOiWK9RJ6PVJhV6MoTYs8