The Effects of Nasal Breathing on Aspects of Athletic Performance

A thesis

submitted in partial fulfilment

of the requirements for the degree

of

Master of Health, Sport and Human Performance

at

The University of Waikato

by

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2023

Abstract

Breathing and respiration are a fundamental and vital processes for our survival. Breathing or pulmonary ventilation can be defined as the biological process of inhaling oxygen (O_2) and exhaling carbon dioxide (CO_2), while respiration can be defined as the chemical process that occurs within the cells following the gas exchange occurring in the lungs. Given its importance, it seems logical to find the most efficient breathing mode during exercise and should be a focus for many athletes, coaches, and practitioners when seeking to improve aspects of athletic performance. Chapter One of this thesis provides a basic introduction with a definition and description of the physiology (cellular respiration) and mechanics of breathing. The importance of oxygen, specifically during exercise is discussed, followed by some of the limitations of the respiratory system when fatigued. Different breathing methods that have been previously used are introduced such as reduced breathing frequency and nasal-only breathing and their potential for improving aspects of athletic performance.

Chapter Two reports on the current literature regarding the use of different breathing modes (nasal, oronasal, and oral) during training. Recently, research has been conducted regarding the use of various breathing modes, alongside respiratory muscle training (RMT) devices and their effects on aspects of athletic performance. Previous studies have observed the acute effects of these breathing modes on athletic performance. Current evidence suggests that nasal-only breathing has the largest acute effect on aspects of athletic performance such as VO_2 max, heart rate, and minute ventilation (VE) and shows the greatest potential for performance adaptation. In terms of longitudinal research, there is limited evidence on the effects of a long-term breathing interventions such as nasal breathing. Therefore, the work of this thesis aimed to add to the current literature and further investigate the relationship between breathing and athletic performance, in particular the effects of nasal-only breathing.

Chapter Three contains a pilot study that aimed to determine the effects of a 4-week nasal breathing intervention on aspects of athletic performance. As part of the study (n= 10) participants (28 ± 10.12) years were divided into an experimental (n=7) and control (n=3) group. All participants underwent pre and post testing consisting of a maximal ramp test. The 4-week training intervention consisted of three training sessions per week over the 4-weeks, totalling 12 training sessions. Both the experimental and

control groups for Weeks-1&2 performed 10-rounds of 10-seconds maximum effort, interspersed with 30-seconds of active recovery. In Weeks-3&4 the number of rounds increased to 15 but the rest intervals remained the same. All sessions were performed on an Airdyne air resisted bike. The experimental group performed all 12-sessions with mouth tape to ensure nasal-only breathing occurred during training, while the control group performed the training with no taping or instructions regarding breathing technique.

Analysis revealed no significant effects were observed on maximal ramp test performance, *i.e.*, change in maximum power or $VO_{2\ peak}$ in either the control or experimental group. *Large* but non-significant between-group differences were observed for VE, tidal volume, respiratory compensation point and alveolar ventilation (p-values 0.22 to 0.06). Interestingly, there were notable decreases in breathing frequency and minute ventilation at all submaximal intensities (50-80% $VO_{2\ peak}$; ES: 0.15 to 0.89), with a significant difference in minute ventilation at of 60% $VO_{2\ peak}$, suggesting potential improvements in breathing economy and gas exchange at submaximal intensities. Overall, it was concluded that nasal-only breathing has the potential to improve aspects of athletic performance via training adaptations, specifically during submaximal intensities; however, further research is needed with longer intervention durations and greater participant numbers.

Acknowledgements

Finishing this thesis has been the culmination of my interests in exercise science and physiology, many years of learning and practicing different types of breath-work and the trial and era of both in my various sporting codes. It has been a big goal of mine to conduct research in a topic that has fascinated me for many years now and I would like to express my appreciation for the individuals who have helped me throughout the duration of this thesis.

I would like to thank my supervisor Dr Marty Beaven for helping me finalise and complete this thesis. A huge thank you to the Sport & Recreation staff at Toi Ohomai for allowing me to use your sports laboratory and gym to conduct my training study and testing. Specifically, I would like to thank Ruth Naidoo, Paul Winwood and Tracey Clissold for your knowledge, guidance and continuous support over the years. I have always appreciated the time you have given me throughout my study journey.

To my friend Brock van Leeuwen, you have helped me to expand my perspective on the human body and mind. You are continuously pushing me to see beyond the surface and always there to deep dive into an idea and how it can be practically applied.

A big thank you to my whanau, I have been beyond blessed to have parents and brothers who would drop anything to help me. You have always supported my ambitions to learn, even if that has meant added financial strain. No matter what, you have all been there to pick me up when things have been tough and congratulate me when the mahi has been done. I will never be able to repay you for what you have given me but, I hope I can make you proud with the work I have produced.

Last but certainly not least my biggest thank you goes to my partner Chloe Ryan. This thesis would not have been possible to complete without your unwavering support and patience. You have taught me so much over this process, your academic knowledge and skills are unmatched, and it is clear you are going to excel in the career you have chosen. It is hard to put into words my appreciation for the time you have given me and my mahi, from the long nights collecting data, the big shifts at Percy Rd proofing draft after draft and the continuous moral support you have given when things seemed to be hitting a brick wall. Thank you, you are the rock behind this thesis, and I am very lucky to have you by my side.

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List of Abbreviations

AT – Anaerobic threshold

ATP – Adenosine triphosphate

AV – Alveolar ventilation

BF – Breathing frequency

BL – Blood Lactate

BM – Body mass

CI – Confidence interval

CO_2 – Carbon dioxide

CON – Control

EPO – Erythropoietin

ES – Effect size

EXP – Experimental

FEO_2 – Forced expiratory oxygen

Hb – Haemoglobin

HR – Heart rate

L/min – Litres per minute

LT – Lactate Threshold

MET – Metabolic Equivalent of Task

NB – Nasal Breathing

NO – Nitric oxide

OB – Oral Breathing

ON – Oronasal Breathing

O_2 – Oxygen

PCO_2 – Partial pressure of carbon dioxide

$PETCO_2$ – End Tidal Carbon Dioxide Pressure

$PETO_2$ – End Tidal Oxygen Pressure

$Power_{max}$ – Maximum Power

PO_2 – Partial pressure of oxygen

Q – Perfusion

RBF – Reduced breathing frequency

RCP – Respiratory compensation point

RER – Respiratory exchange ratio

RPE – Rate of perceived exertion

RR – Respiration rate

SD – Standard deviation

V – Ventilation

VE – Minute ventilation

VE/VCO_2 – Ratio of Minute Ventilation to Carbon Dioxide Production

VE/VO_2 – Ratio of Minute Ventilation to Oxygen Consumption

VCO_2 – Carbon Dioxide Production

VO_2 – Oxygen Consumption

VO_2 max – Maximal oxygen consumption

V/Q – Ventilation/ Perfusion

VT – Tidal volume

VT^1 – Ventilatory Threshold One

VT^2 – Ventilatory Threshold Two

W – Watts

Chapter One - Introduction

Background

Breathing and respiration are a fundamental and vital processes for our survival. Breathing or pulmonary ventilation can be defined as the biological process of inhaling oxygen (O_2) and exhaling carbon dioxide (CO_2), while respiration can be defined as the chemical process that occurs within the cells following the gas exchange occurring in the lungs (Powers & Dhamoon, 2019). Given its importance, it makes sense that finding the most efficient breathing mode during exercise should be a focus for many athletes, as well as coaches and practitioners. There are many different breathing patterns that occur amongst individuals; however, in healthy individuals, breathing will predominantly occur through the nasal cavity at rest, and a combination of mouth and nose (oronasal) breathing during exercise (Camner & Bakke, 1980). Intuitively many individuals believe the oral breathing during exercise may be the most effective, as a greater volume of air can enter the lungs; however, there is no current evidence to suggest that this is optimal for athletes.

Energy demands of sport require the development of both the aerobic and anaerobic energy systems (Sözen, 2018). Traditionally, many coaches and athletes have approached training to improve athletic performance through methods such as resistance training, speed and power training, and aerobic training with a focus on increasing volume and intensity over a period of time (Gronek et al., 2014). Athletes require high levels of aerobic fitness in order to generate and maintain power output during repeated high-intensity efforts and recover efficiently between those efforts (Stone & Kilding, 2009). In terms of improving an athlete's aerobic performance, coaches have utilised methods such as interval training, tempo training, and fartlek training (Howley & Thompson, 2022), which look to improve cardiorespiratory endurance by improving cardiac function and peripheral blood flow and prompting more efficient utilisation of oxygen and fuel substrates within the muscle to generate greater amounts of adenosine triphosphate (ATP) (Kenney et al., 2021). Given the importance of aerobic performance for athletes, it would seem important to focus on the fundamental aspects, such as breathing mechanics and respiratory efficiency.

As previously mentioned, breathing mechanisms involve two aspects: 1) Inspiration, and 2) Expiration. Inspiration is the active process of the diaphragm and intercostal muscles contracting, increasing the volume of the thoracic cavity and decreasing the pressure within the lungs, resulting in a pressure difference between the lungs and atmosphere (Macklem, 1998). These pressure differences cause air to flow into the lungs *i.e.*, bulk flow (Muir, 1966). Expiration is a passive process that occurs after the gaseous exchange has occurred in the lungs. This process involves the exhalation of CO_2, which is the by-product of cellular respiration (Patel et al., 2018). The diaphragm and intercostal muscles relax, causing a decrease in thoracic cavity volume and increase in thoracic pressure, resulting in airflow out of the lungs (O'Halloran, 2018). Respiration is the gas exchange process that occurs between inspiration and expiration, where O_2 diffuses from the alveoli in the lungs to the bloodstream and CO_2 from the bloodstream to alveoli (Boudin et al., 2023). Respiratory efficiency *i.e.*, greater O_2 into the bloodstream and therefore working muscles, is highly related to breathing mechanics. If an individual has functional breathing mechanics, they will be able to create greater pressure differences, allowing for higher concentrations of O_2 into the alveoli, which in turn creates for efficient respiration via increased alveoli surface area and larger concentration gradients, ultimately improving the diffusion of O_2 into the bloodstream and CO_2 into the lungs (Petersson & Glenny, 2014).

There is clear evidence that fatigue of the respiratory system hinders exercise performance, but the role of respiratory musculature and methods of breathing is an understudied aspect of exercise science (Mador & Acevedo, 1991; Verges et al., 2007). Respiratory muscles such as the diaphragm, intercostals, and abdominal muscles can account for up to 11% of total O_2 consumption during heavy exercise and can receive up to 15% of the cardiac output (Kenney et al., 2021). Fatigue of the diaphragm triggers the body's metaboreflex, resulting in arterial blood being diverted from limb muscles back to the diaphragm and causing limb fatigue (Harms et al., 1997; Hill, 2000; Jammes & Balzamo, 1992; Romer & Polkey, 2008). Respiratory limitations to performance can occur when the pulmonary-cardiovascular systems are not specifically trained (Kenney et al., 2021). Exercise induced arterial hypoxemia can occur during exercise approaching exhaustion where there is a discrepancy between ventilation (V) and perfusion (Q) or flow of blood to alveolar capillaries, resulting in an increase in partial pressure of O_2 (PO_2) and decrease in partial pressure of CO_2 (PCO_2) (Powers & Dhamoon, 2019). This increase in PO_2 and decrease in PCO_2 results in vasoconstriction of capillaries and reduced oxygen delivery to working muscles (Harms et al., 1997; Hill, 2000; Jammes & Balzamo, 1992; Romer & Polkey, 2008). Therefore, performance limitations reside primarily in the respiratory muscles ability to promote efficient breathing mechanics which links the relationship between ventilation and perfusion, or the V/Q ratio, which dictates the gas exchange process and ultimately the efficiency of arterial blood delivery to the working muscles (Dempsey, 1985; Dempsey et al., 2006; Powers & Dhamoon, 2019). Fortunately, functional capacity of the respiratory musculature is trainable. Intentionally restricting airflow during inhalation, exhalation, or both, forces the respiratory muscles to increase work output to adequately support airflow and gas exchange needs (Thurston et al., 2015).

One method that has already been investigated is reducing breathing frequency. Previous research in cycling performance, demonstrated that a reduced breathing frequency (RBF) protocol induced cardiorepiratory adaptions. Specifically, RBF showed an 19% increase in tidal volume, an 11% increase in peak power (W), and an increased CO_2 tolerance (hypercapnic training effect) (Kapus et al., 2013). Improvements in cycling performance were also reported by Romer *et al*. (2002), showing significant improvements in 20 km and 40 km time trial performance by 3% and 5% respectively. Breath holding interventions, also known as apnea, have showed increases in hematocrit, erythropoietin (EPO) concentration, hemoglobin (Hb) mass, lung volume, and reduced blood acidosis and oxidative stress, which can contribute to an increase in sporting performance (Baković et al., 2005; Lemaître et al., 2010). Though these studies provide evidence for breathing training to be integrated into athletic training, there is still a lack of robust data across the many types of breathing protocols that could be used to increase athletic performance.

Another method to restrict airflow during exercise is nasal-only breathing. The beneficial functions of the nose in relation to breathing have been well-documented, including the filtering, warming, and humidifying of inspired air before inhalation into the lungs (Sahin-Yilmaz & Naclerio, 2011). Nasal breathing provides a resistance to breathing that is twice that of oral breathing and this increase in resistance increases total lung volume and improves PO_2 in the alveoli (Swift et al., 1988). During exercise, nasal breathing has shown to reduce forced expiratory oxygen (FEO_2) indicating an increased O_2 uptake in working cells (Morton et al., 1995). It has also been reported that nasal breathing increases the time of the expiratory phase of the respiratory cycle (Ayoub et al., 1997), which has been linked to increased parasympathetic activation or the body's relaxation response (Cappo & Holmes, 1984). Additionally, nasal breathing promotes the production of nitric oxide (NO) in the paranasal sinuses. NO has been shown to be a potent vasodilator, increasing arterial oxygenation and reducing pulmonary vascular resistance (Settergren et al., 1998). Given the functional benefits of nasal breathing, combined with the limitations that the respiratory system can place on athletic performance, there is need for further investigation into the effects of nasal breathing training protocols on aspects of athletic performance.

This chapter outlines the background (Section 1.1) and context (Section 1.2) of the research, and its purpose (Section 1.3). Section 1.4 describes the significance and scope of the research. Finally, Section 1.5 outlines the structure of this thesis.

Context

There is limited evidence regarding the use of a nasal breathing pattern during training; however, given the benefits mentioned above, nasal-only breathing may be a beneficial breathing method during training. The focus of this thesis is to determine the effects of nasal breathing training on physiological aspects that contribute to athletic performance, including maximal oxygen uptake (VO_2 max), minute ventilation (VE), and heart rate (HR).

Purpose

The aim of this thesis is to: 1) Report on the current literature regarding the use of nasal breathing during training, and 2) Complete a pilot study, investigating the use of a four-week nasal breathing intervention and its effects on aspects of athletic performance. Key objectives within the study design look to see whether a four-week intervention elicits positive physiological adaptation on the respiratory system and whether these adaptations prompt increases in performance measures.

Significance

Specific respiratory interventions to aid athletic performance are a novel area of research. The present study is significant as it addresses an underdeveloped area of athletic training; however, improved breathing efficiency has the potential to provide systematic benefits for all areas of athletic performance and well-being.

The significance of focusing on nasal specific breathing allows the training of our very own breathing mechanisms and structures which includes the nose and its physiological functions. Progression within this area would provide athletes of all levels, ranging from recreational to elite, the ability to improve performance using their own innate tools without having to rely on external devices or resources.

Thesis Outline

The outline of this thesis can be seen in Figure 1. The remaining chapters of this thesis focus on the following: Chapter Two provides greater detail on the use of the nose for breathing compared to the mouth. Previous research on various breathing interventions during exercise and their effects on athletic performance are then explored in a systematic review of the literature. Presented in Chapter Three are the methods, results and discussion of a 4-week pilot study using a nasal-only breathing intervention during exercise. Lastly, Chapter Four presents the overall findings of the thesis, practical applications, strengths, limitations, and potential future research directions.

Chapter One: Introduction

Introduction to breathing in athletic performance and purpose of the thesis.

Chapter Two: Literature Review

Introduction to breathing methods and mechanics. Review of current literature on different breathing methods during exercise.

Chapter Three: Effects of a Nasal Breathing Intervention on Athletic Performance: A Pilot Study

A four-week nasal breathing intervention did not significantly improve aspects of athletic performance.

Chapter Four: Conclusion

Discussion, Limitations, Conclusions, and Future Research Directions.

Figure 1.: Thesis outline

Chapter Two - Literature Review

2.0 Prelude

Given the importance of efficient and effective breathing not only for sporting performance, but general health, it is important for research to assess different breathing methods to use during training sessions and how these may impact adaptations. Given the health benefits of nasal-only breathing as mentioned in the introductory chapter, this breathing mode may be beneficial to use during training. Therefore, the aim of this review is to determine the acute and longitudinal effects of different breathing methods (nasal, oronasal, and oral breathing) used during training on aspects of athletic performance such as VO_2 max, minute ventilation (VE), work output (W), and heart rate (HR). This chapter also identifies the gaps and limitations in the literature and provides justification for the research carried out in Chapter Three.

The Effects of Different Breathing Techniques and Dilators on Aspects of Athletic Performance

2.1 Introduction

The primary requirement for health, fitness and longevity is the body's ability to provide oxygen into the cells. During exercise, the heart and lungs can be thought of as two of the most important organs of the body (LeVert, 2002). The lungs bring in oxygen to the body, providing energy and removing carbon dioxide (CO2), while the heart pumps the oxygen to the working muscles. Given the importance of these organs and oxygen during exercise, it would seem that efficient breathing during exercise is vital. Appropriate breathing is believed to integrate mind and body, bringing a measurable experience of calm and rejuvenation when exercising (Travis et al., 1996). To facilitate appropriate breathing, breathing training has been suggested to modify breathing. The use of breathing modifications originates from practices such as meditation and yoga which was first introduced to Western culture in the late 1800s (Russo et al., 2017). The popularity of different breathing exercises and techniques such as the Wim Hof Method has increased over the years in spaces such as general population health, school, and work environments, due to the proposed benefits such as an increase in energy, mental focus, stress regulation, and decreased anxiety and chronic pain (Almahayni & Hammond, 2023). When it comes to high-performance sports, gaining the edge over your competitor can come down to as little as a 1% increase in performance. New Zealand integrated health specialist Dave Wood suggests on the 'Fight Dietitian Performance' podcast that when it comes to gaining peak performance the breath is the other 99% (Sullivan, 2021).

A recent systematic review and meta-analysis of breathing techniques on sport performance showed that slow-paced breathing and breath hold protocols over long-term interventions increased self-regulation ability, improved cardiovascular recovery, and enhanced parasympathetic activation for optimised recovery (Laborde et al., 2022). The authors of the meta-analysis defined long-term as 'studies involving multiple sessions (over several days, weeks, or months) with the same breathing technique intervention'. The review by Laborde and colleagues (2022) focused on interventions such as breath holds and slow-paced breathing which was not the focus of the current review. Additionally, many of these interventions were completed as individual breathing sessions and not during exercise training.

Currently there is a lack of information regarding the use of different breathing techniques and devices used during training to improve aspects of athletic performance, such as aerobic capacity which is commonly measured via a maximal oxygen uptake (VO_2 max) test (Shete et al., 2014). The VO_2 max is the highest rate of oxygen consumption attainable during maximal exercise and is commonly used to reflects the physical fitness of an individual (Bassett & Howley, 2000; Ranković et al., 2010) and this laboratory test is considered the 'gold standard' when evaluating aerobic capacity and endurance (Lee & Zhang, 2021). Other aerobic variables such as ventilatory thresholds (VT^1 and VT^2) have been analysed to determine physiological adaptation to breathing interventions during exercise. VT^1 is the point where ventilation (VE) begins to intensify (Mina-Paz et al., 2023), but oxygen uptake (VO_2) and carbon dioxide production (VCO_2) increase in proportion effectively buffering lactic acid in the blood (Parpa & Michaelides, 2022). The VT^2 is the point where lactic acid buffering is unable to keep pace with accumulation, resulting in a drop in blood pH and rapid elevation of lactate and hydrogen ions in the blood (Parpa & Michaelides, 2022). Previous research indicates that VT^1 and VT^2 can be effectively used to prescribe individual exercise intensities for endurance sports considering the individual metabolic response when switching from aerobic to anaerobic metabolism (Wolpern et al., 2015). Therefore, this review focuses on breathing interventions, both acute and longitudinal, and their effects on aspects of athletic performance, to identify relevant applications within sporting practice and consolidate the current state of research in this area. Specifically, the current review categorised three main breathing techniques into: 1) nasal; 2) oronasal; and 3) oral breathing, and their effects on aspects relevant to endurance performance. Firstly, a brief outline of breathing physiology and the primary breathing mechanics is discussed, with details on how each technique may influence sporting performance through physiological mechanisms. Secondly, the acute effects of different breathing training methods are discussed with reference to the current literature. Thirdly, the limited research on longitudinal of different breathing techniques will be presented and research questions defined based on identified gaps in the existing literature.

2.2 Methods

The systematic review was performed according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta Analyses) criteria (Clarke et al., 2015). Three databases (SPORTDiscus, SportsMedicine and Education, Google Scholar) were searched in March 2023 using the terms; “Nasal breathing” OR “Oral breathing“ OR “Oronasal” AND “Performance” OR “Exercise” OR “VO2 Max” OR “Aerobic fitness”. Once all databases had been searched, articles were filtered for relevance. Firstly, all duplicates and non-English translated articles were removed. Titles and abstracts were then screened but the author. If the author could clearly identify that the article was not related to breathing techniques *during training* and athletic performance in healthy individuals, the article was excluded. The remaining full text versions were obtained and read to identify whether the article was a scientific article that came from a peer-reviewed journal. Articles were only included if they met the following criteria; 1) Included an oral, oronasal, or nasal intervention, 2) Participants were considered healthy and injury free, 3) Interventions were carried out during exercise or training, and 4) Researchers measured and reported on physical performance variables such as VO_2 max and heart rate. Reference sections of the identified papers were also checked for other relevant articles. Once all articles had been identifed, information regarding the types of breathing interventions, performance tests, and outcome measures was extracted. Thirteen studies met the inclusion criteria and were included in this analysis (Figure 2).

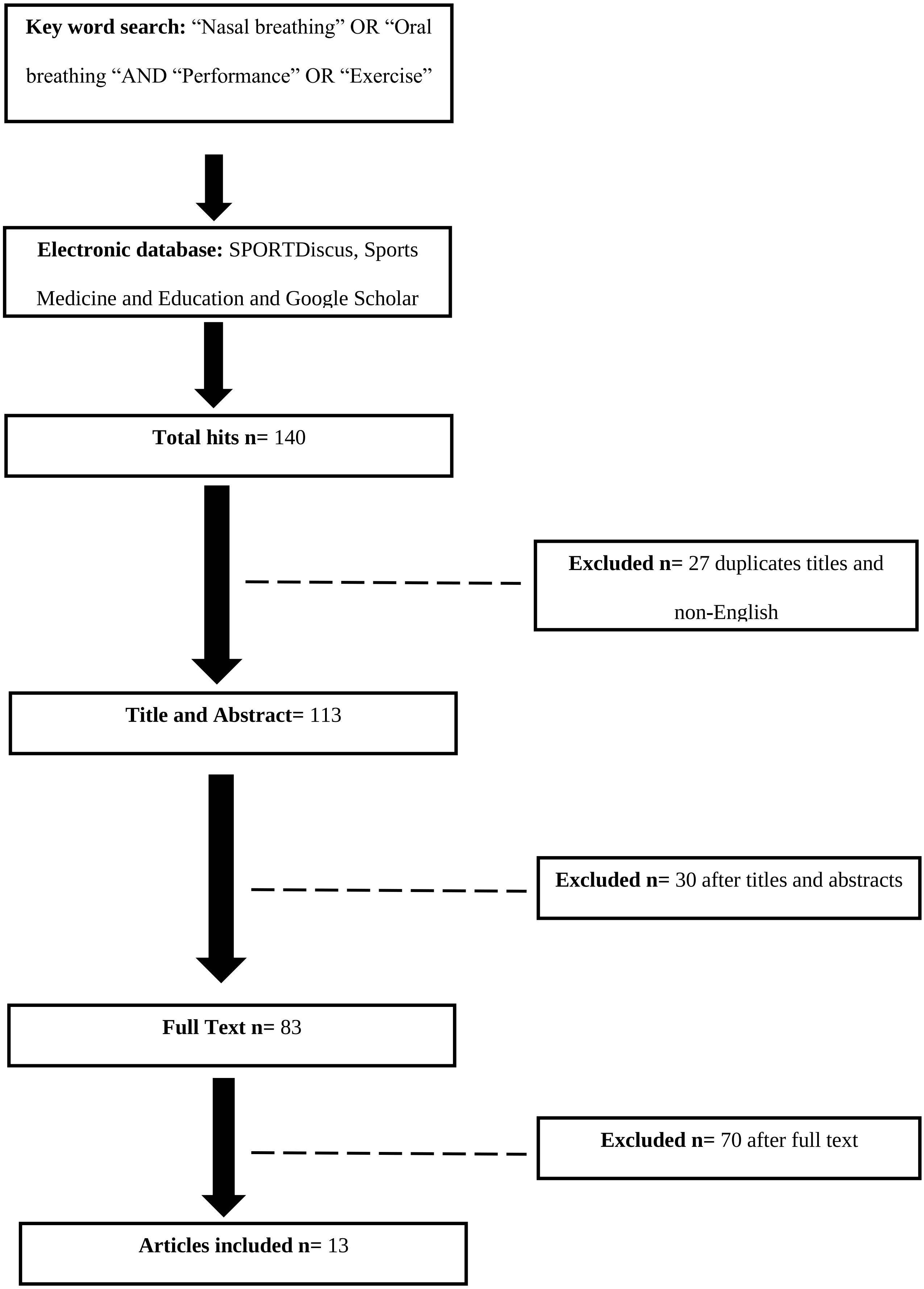

Figure 2. Flow diagram of the PRISMA search strategy and article selection process.

2.3. Breathing Mechanics and Types of Breathing Methods

The mechanics of breathing or pulmonary ventilation, occurs via a process known as bulk flow. This process refers to the movement of molecules along a passageway due to a pressure difference between the two ends of the passage (Howley & Powers, 2018). Bulk flow is achieved through specific respiratory muscles that assist in the inspiration and expiration of air. The primary muscles used during inspiration are the diaphragm and intercostal muscles. At rest, the diaphragm sits under the lungs in a domed shaped curve in the thoracic cavity. With inspiration the diaphragm contracts, flattening down towards the abdomen while the ribs and sternum are moved up and out by the external intercostal muscles. This three-dimensional expansion of the thoracic cage increases the volume inside the lungs and initiates the flow of air into the lungs (Costill et al., 2008). By contrast, expiration is a passive process (Beachy, 2018), involving the relaxation of the inspiratory muscles (diaphragm, intercostal muscles) and the natural elastic recoil of the lungs. This relaxation causes a decrease in thoracic cage volume, in turn increasing the pressure in the lungs relative to air pressure outside the body, and air is forced out of the lungs (Costill et al., 2008).

A key role of pulmonary ventilation is the provision of oxygen to the circulatory system. More than 99% of O_2 transported in the blood is chemically bound to haemoglobin found within red blood cells, which is then released to cells for metabolic oxidative phosphorylation and energy production, a process termed cellular respiration (Wilmore et al., 2004). By contrast, CO_2 is the product of oxidative phosphorylation and is transported in the blood as a bicarbonate (Bartholomew et al., 2017). With respect to exercise, the relationship between O_2 affinity to haemoglobin and the concentration of CO_2 in the blood determines how efficient haemoglobin is with releasing O_2 to the peripheral cells. The Bohr effect describes this phenomenon: as CO_2 concentration increases in the blood and pH levels decrease, haemoglobin releases up to 20% more O_2 into the peripheral tissues (Bartholomew et al., 2017).

2.3.1 Nasal Breathing

The nose has two basic functions: olfaction and respiration (Capão-Filipe et al., 2006)**,** with previous researchers suggesting that during rest, 80% of healthy individuals breathe exclusively through the nose (Chinevere et al., 1998). The nasal passage is an important structure, which serves a number of functional purposes (Hanstock et al., 2020). Firstly, the passage warms, humidifies and filters the air to prepare it for delivery to the lungs at near alveolar conditions (Martel et al., 2020). The structures within the nose and nasal passageway also regulate the direction and velocity of the air stream to maximise exposure to a network of fine arteries, veins, lymphatics, and nerves, in addition to the mucous blanket.

Of note, air passing through the nasal airway is slowed down by shelf-like bony structures in the nose called turbinates which impose approximately 50 percent more resistance to the air stream as compared to mouth breathing, resulting in 10 to 20 percent more oxygen uptake (Allen, 2017). This resistance during inhalation maintains elasticity of the lungs and aids filtration of the air as well as the mixing of air with the gas nitric oxide (NO), increases circulating blood oxygen and carbon dioxide levels, slows the breathing rate, and improves overall lung volume (Allen, 2017; Ruth, 2020).

The NO produced during nasal breathing by epithelial cells in the paranasal sinuses results in high levels of NO in sinus and nasal air (Alberti et al., 2015). Nitric oxide is involved in important physiological functions in the nasal cavity and paranasal sinuses, including antibacterial and antiviral activity, promotion of nasal mucosal gland secretions, maintenance of mucociliary transport, and regulation of nasal mucosal vascular tension (Guo et al., 2023). More importantly in relation to performance, NO improves arterial oxygenation and reduces the pulmonary vascular resistance (Angdin et al., 1998).

Another key aspect is that the nasal route of respiration offers an entry point into limbic brain areas for modulating cognitive function. Interestingly, research has found that nasal breathing significantly enhanced cognitive performance compared to oral breathing (Zelano et al., 2016). Cognitive performance can be defined as the efficient fulfilment of mental processes such as perception, learning, understanding, reasoning, intuition and awareness (Demir & Kiyici, 2023). Pfurtscheller and colleagues (2023) also suggest that nasal breathing at a rate of 6-seconds induces brain-body oscillations at a frequency of 0.16 Hz which has shown to have a significant effect on decreasing anxiety within participantss who suffered from high anxiety.

2.3.2 Oronasal Breathing

When healthy individuals reach high ventilatory rates during exercise, a switch from predominately nasal breathing to oronasal breathing occurs (Becquemin et al., 1999) and nasal airflow resistance decreases because of a combination of sympathetic nervous system mucosal vasoconstriction and *alae nasi* muscle recruitment which lowers vestibule resistance (Passali et al., 2015). The turning point from nasal breathing to oronasal has been reported at 38 ± 12% of the predicted maximum physical working capacity for men, and at 55 ± 13% for women in moderately trained young adults (Niinimaa et al., 1980). Oronasal breathing is the ability to breathe through the mouth and nose, but being able to breathe through the nose without showing signs of fatigue or dyspnoea (Mattos et al., 2017). This switch occurs because the mouth offers much lower resistance to airflow (Becquemin et al., 1998). During oronasal breathing, the soft palate lies in between the tongue and the posterior pharyngeal wall, this means when both the mouth and nose are open, the soft palate is responsible for the partitioning of oronasal flow with inspiration through the nose and expiration out the mouth (Rodenstein & Stanescu, 1984). It is calculated that oronasal breathing occurs at a ventilation of in excess of approximately 30 $L \cdot min^{-1}$. This increase in ventilation is typically sensed as discomfort and can trigger a physiological response (switch point) to predominantly oral breathing; however, this switch point can be very different from participant to participant (Lafortuna et al., 1978; Williams et al., 2000).

2.3.3 Oral Breathing

Oral (or mouth-only) breathing is considered an abnormal breathing pattern either during wakefulness or during rest, except while exercising. In about 85% of cases, oral breathing represents an involuntary, subconscious adaptation to reduced patency of the nasal airway and mouth breathing is required simply to obtain sufficient ventilation (Foster et al., 2022). Mouth breathing syndrome is a dysfunctional pattern that constitutes a chain reaction of body adaptation to abnormal breathing patterns. Of note, breathing through the mouth facilitates forward head posture, a low and forward tongue position, and increased activity of the accessory muscles of respiration, sternocleidomastoid, scalene and pectorals (Berzin & Correa, 2008). Previous research that evaluated oral breathing patterns, such as a diaphragmatic mode of inhalation with under-expansion of the thoracic cavity and reduced mobility of the nostrils, suggested a reduced patency of the upper-airways (Cuccia et al., 2008).

As noted above, at rest and during low levels of exercise, nasal breathing is dominant, whilst at higher levels of intensities, oral breathing is used due to the volume of air needed to reach the lungs (LaComb et al., 2015). Nasal breathing during exercise has been observed in humans at ventilation rates of up to 60 L/min; however, the switch from nasal to oral breathing usually occurs above 30 $L \cdot min^{-1}$ (Bennet et al., 2006). The switch from nasal breathing to primarily oral breathing during heavier workloads does not significantly affect pulmonary function, and may therefore be appealing to athletes when metabolic demand increases (Adams et al., 1989); however, this does not necessarily mean this breathing pattern is best suited for athletic performance. As mentioned previously there are multiple functions the nose performs when used in respiration; thus, breathing orally bypasses the added benefits the nose provides such as the humidification of air and release of NO into the bloodstream. Unlike nasal breathing, oral breathing does not facilitate the function of the Bohr effect, as the slower exhale of nasal breathing when compared to oral breathing allows for the accumulation of CO_2, lowering the pH level of the blood and increasing the release of oxygen molecules from haemoglobin into working muscle cells (Boudin et al., 2023). Overall, it is feasible to suggest that there may be benefits to nasal breathing during exercise (Recinto et al., 2017).

2.4. Acute effects of different breathing techniques on performance

Both acute (n = 12) and longitudinal (n = 1) studies were included in this review and are analysed and discussed in individual sub-sections. Results are discussed in relation to the type of breathing intervention, performance test used, and its outcome measures. With regards to the acute studies, the authors excluded nasal dilator placebo studies, if they did not report comparisons to other breathing techniques or protocols. Of note, many of the acute studies did not use a true control group, *i.e.*, groups that performed the test with no instruction regarding breathing technique, with most studies comparing two different breathing techniques.

2.4.1 Acute effects of oronasal breathing vs oral breathing on performance

In terms of oronasal breathing, there was a total of two studies (Al-Hazzaa, 1987; Meir et al., 2014), which compared the acute effects of oronasal breathing to strictly oral breathing. Nasal clips were used for both studies to ensure oral only breathing conditions during testing. However, several differences occurred between studies, such as the exercise test performed, cohorts tested, and performance variables quantified (see Table 1).

Both research groups measured heart rate (HR) as a performance variable, which is a key indicator of cardiovascular fitness, representing the efficacy of the heart, lungs, and vascular system to deliver oxygen to working muscles so that prolonged physical activity can be maintained (Dimkpa, 2009). Additionally, HR has previously been shown to correspond with several physiological markers of performance such as lactate threshold (LT), ventilatory thresholds, and the respiratory compensation point (RCP) (Lucía et al., 2000). Ventilatory threshold (VT_1) is commonly described as the point at which pulmonary ventilation and carbon dioxide (CO_2) output begin to increase exponentially (Kim et al., 2021). The respiratory compensation point (RCP) marks the onset of hyperventilation, due to failure of the body's buffering mechanisms which leads to metabolic (lactic) acidosis (Meyer et al., 2004). Contrasting results were found in HR values between the two studies. Al-Hazza (1987) reported a significant decrease in HR during the oronasal breathing condition (ES = 2.54; Table 1) compared to oral only; whilst Meir *et al.* (2014) recorded no significant differences between conditions. Different testing protocols may have played a role in the contrasting HR results, as one study allowed for a steady state of exercise to be achieved with incremental increases to exhaustion allowing time for participants to adapt to the breathing condition (Al-Hazzaa, 1987). The second study was performed at maximum effort for time, which may have made it harder for participants to adapt to each breathing condition and explain the increase in blood lactate (Meir *et al*., 2014).

Table 1. Acute Effects of Oronasal Breathing on Aspects of Athletic Performance

Study Characteristics			Participant Characteristics					Results		
Author	Groups	Equipment	*n* (age [y])	Sex	Sport (Level)	Performance Test	Outcome measures	Results (mean ± SD)	**% Difference**	**ES**
Al-Hazza, 1987	**ON** **OB**	Nose clip	5 (N/R)	M = 5	NR	Maximal Graded Exercise Test (cycle ergometer)	HR (bpm)	**ON**: 172 ± 1.7 **OB**: 176 ± 1.6	-2.27	2.42
Meir et al., 2014	**ON** **OB**	Nose clip	10 (21.7 ± 2.4)	M = 10	Rugby/ rugby league (Amateur)	400 m Shuttle	Time (s)	**ON**: 96.80 ± 3.28 **OB**: 95.83 ± 4.05	1.01	0.26
							RPE	**ON**: 17.9 ± 0.9 **OB**: 16.9 ± 1.6	5.74	0.77
							HR (bpm)	**ON**: 187.3 ± 8.5 **OB**: 187.3 ± 7.9	0	0
							BL ($mmol \cdot L^{-1}$)	**ON**: 15.78 ± 3.23 **OB**: 14.61 ± 1.58	7.7	0.46

Key: BL = blood lactate, bpm = beats per minute, ES = effect size, HR = heart rate, OB = oral breathing group, ON = oronasal breathing group, *n* = number of participants, NR = not reported, RPE = rate of perceived exertion, s = seconds, SD = standard deviation

Meir and colleagues (2014) also measured shuttle time (in seconds), blood lactate, and rate of perceived exertion (RPE). All three variables had a slight increase during the oronasal breathing condition, indicating that participants found this condition harder compared to strictly oral breathing. These observations could be due to a number of factors, such as familiarisation with the breathing technique *i.e.*, participants generally default to oral breathing during exercise, therefore may have struggled to adjust to the oronasal breathing technique. Additionally, it was noted that participants were not instructed to refrain from physical activity 24 hours and were engaged in team trainings leading up to the testing session. Thus, any carry-over fatigue from previous trainings may have also influenced results.

2.4.2 Acute effects of nasal breathing on performance

Of the ten acute studies reviewed in Table 2, nasal breathing and nasal dilators were the most common techniques used with half of these studies (n=5) using an external or internal nasal dilator (Dinardi et al., 2021; Case et al., 1998; Macfarlane & Fong, 2004; O'Kroy, 2000; Tong et al., 2001). The remaining five studies used athletic tape across the mouth to ensure nasal only breathing during the intervention (Boas et al., 2013; Dallam et al., 2018; LaComb et al., 2017; Rappelt et al., 2023; Recinto et al., 2017). It is important to note that those studies using nasal dilators did not instruct their participants to breathe purely through their nose.

2.4.2.1 Nasal dilators

External and internal nasal dilators are designed to increase or maintain nasal patency. Nasal dilators have been thought to reduce nasal resistance and consequently reduce the nasal breathing effort and increase nasal ventilation (Krakow et al., 2006; Vermoen et al., 1998). Additionally, a delay in oral breathing onset has been hypothesized (Gelardi et al., 2019).

Based on the current evidence, it appears that nasal dilators had minimal, non-significant acute effects on VO_2 max, with results ranging from 0.42 to 1.72% (Table 2) (Dinardi et al., 2021; Case et al., 1998; Tong et al., 2001). Two studies (Case et al., 1998; Dinardi et al., 2017) reported an acute increase in workload (distance run or level reached) when using nasal dilators with improvements ranging from 10.5 to 16.2% compared to no dilator (Table 2); however, these differences were not significant.

External dilators appear to be the most common, with four of the five studies using this equipment (Case et al., 1998; Macfarlane & Fong, 2004; O'Kroy, 2000; Tong et al., 2001); however, the largest increases in overall performance appeared to be with the internal nasal dilator (Dinardi et al., 2017) which showed a significant increase of 16.2% in performance measured by metres covered during a Yo-Yo intermittent test. Based on current research, it appears that external nasal dilators do not have a significant effect on physiological or performance function. In contrast, the limited available evidence has demonstrated that internal nasal dilators have the potential to induce a desirable effect on endurance performance in healthy male team sport athletes; however, more evidence is required.

Table 2. Acute Effects of Nasal Breathing and Nasal Dilators on Aspects of Performance

Study Characteristics			Participant Characteristics			Results				
Author	**Groups**	**Equipment**	*n* (Age [y])	**Sex**	**Sport (Level)**	**Performance Test**	**Outcome measures**	**Results (mean ± SD)**	**% Difference**	**ES**
Boas et al., 2013	**NB** **OB**	N/A	104 (7-11)	M = 44 F = 60	NA (Recreational)	6-minute walking test	Walking distance (m)	**NB**: 667.13 ± 90.68 m **OB**: 543.40 ± 79.41 m	20.4	1.45
Case et al., 1998	**NB** **CON**	External nasal dilator	9 (20.8 ± 2.20)	M = 9	NA (Recreational)	Max Interval Running test	VO_2max (mL·kg^{-1}.min^{-1})	**NB**: 48.2 ± 6.1 **CON**: 48.0 ± 4.4	0.42	0.04
							HR (bpm)	**NB**: 187 ± 11 **CON**: 185 ± 12	1.08	0.17
							Level reached	**NB**: 10 ± 5 **CON**: 9 ± 3	10.53	0.24
Dallam et al., 2018	**NB** **OB**	Mouth tape	10 (29 ± 9.45)	M = 5 F = 5	Running (Recreational)	Running graded exercise test (GXT)	Time to Exhaustion (s)	**NB**: 428 ± 24 **OB**: 421 ± 18	1.65	0.11
							VO_2 Max (L·min^{-1})	**NB**: 2.55 ± 0.24 **OB**: 2.75 ± 0.25	-7.55	0.60
							VCO_2 Max (L·min^{-1})	**NB**: 3.19 ± 0.36 **OB**: 3.55 ± 0.33	-10.68	0.93
							VE (L·min^{-1})	**NB**: 90.50 ± 9.92 **OB**: 117.76 ± 12.73	-26.18	2.38
							HR (bpm)	**NB**: 180.50 ± 3.92 **OB**: 185.40 ± 3.57	-2.68	0.48
							RR (breaths·min^{-1})	**NB**: 39.20 ± 2.13 **OB**: 49.40 ± 2.53	-23.02	1.06

							$PETO_2$ (mmHg)	**NB**: 85.60 ± 1.11 **OB**: 89.70 ± 1.21	-4.67	1.07
							$PETCO_2$ (mmHg)	**NB**: 44.70 ± 1.55 **OB**: 40.20 ± 1.46	10.60	0.78
Dinardi et al., 2017	**NB** **CON**	Internal nasal dilator	15 (26.5 ± 4.7)	M = 15	Rugby (Amateur)	Yo-yo test	VO_2max ($mL·kg^{-1}·min^{-1}$)	**NB**: 41.5 ± 2.5 **CON**: 40.8 ± 1.3	1.72	0.35
							Distance (m)	**NB**: 613.3 ± 295.70 **CON**: 528 ± 159.40	16.20	0.36
							RPE	**NB**: 8.30 ± 1.10 **CON**: 8.9 ± 0.80	6.70	0.62
LaComb et al., 2017	**NB**	Athletic tape	19 (24.5 ± 5.0)	M = 9 F = 10	NR	Running graded exercise test at 80% of VO_2 Max	VO_2 Max ($L·min^{-1}$)	**NB**: 3.11 ± 0.70 **OB**: 3.37 ± 0.62	-8.00	0.39
	OB	Nose clip					VCO_2 Max ($L·min^{-1}$)	**NB**: 2.98 ± 0.81 **OB**: 3.29 ± 0.61	9.62	0.44
							HR (bpm)	**NB**: 166 ± 19.8 **OB**: 175 ± 10	-5.14	0.50
							RER	**NB**: 0.95 ± 0.08 **OB**: 0.98 ± 0.04	-3.1	0.47
Macfarlane and Fong 2004	**NB** **CON**	External nasal dilator	30 (12-18)	M = 30	NR	40 m sprint Shuttle sprint 20 m shuttle sprint	Horizontal Power ($kg·m^{-1}·s^{-1}$)	**NB**: 375 **CON**: 375	0	NA
							Average Speed ($m·s^{-1}$)	**NB**: 4.55 **CON**: 4.55		
							Peak Running Speed ($km·h^{-1}$)	**NB**: 9.50 **CON**: 9.50		

O'Kroy, 2000	**NB** **OB**	External nasal dilator	15 (20 ± 1.4)	M = 5 F = 10	NR	Cycle erg incremental test	Exercise time (s)	**NB**: 635 ± 128 **OB**: 630 ± 120	0.79	0.04
							Work rate (W)	**NB**: 257 ± 74 **OB**: 255 ± 70	0.78	0.03
							Breathing frequency (breaths·min^{-1})	**NB**: 55.3 ± 9.4 **OB**: 52.8 ± 6.3	4.62	0.31
Rappelt et al., 2023	**NB** **OB**	Athletic tape, nasal dilator strip	19 (26.5 ± 5.1)	M= 16 F= 3	Endurance sport (Amateur)	Cycle erg incremental test	Power (W)	**NB**: 139.2 ± 53.7 **OB**: 142.3 ± 51.1	-2.20	0.05
							VO_2 (L·min^{-1})	**NB**: 2.44 ± 0.77 **OB**: 2.61 ± 0.74	-6.73	0.22
							VE (mL·kg^{-1}·min^{-1})	**NB**: 53.0 ± 16.1 **OB**: 60.0 ± 18.3	-12.38	0.40
							HR (bpm)	**NB**: 139.3 ± 20.7 **OB**: 138.7 ± 18.5	0.43	0.03
							VT (L)	**NB**: 1.97 ± 0.61 **OB**: 1.95 ± 0.49	1.02	0.03
							Breathing frequency (breaths·min^{-1})	**NB**: 27.3 ± 4.9 **OB**: 30.7 ± 5.3	-11.72	0.66
							$PETO_2$ (mmHg)	**NB**: 98.17 ± 3.59 **OB**: 100.85 ± 3.14	-2.69	0.79
							$PETCO_2$ (mmHg)	**NB**: 41.38 ± 2.83 **OB**: 39.11 ± 2.36	5.64	0.87

Recinto et al., 2017	**NB**	Athletic tape	9 (24.44 ± 7.60)	M = 7 F = 2	NR	Wingate cycle test	Peak power (W)	**NB**: 734.7± 172.1 **OB**: 694.9±176.8	5.56	0.25
	OB	Nose clip					Mean power (W)	**NB**: 513.6± 112.6 **OB**: 503.1±125.1	2.06	0.08
							Mean speed ($km{\cdot}h^{-1}$)	**NB**: 51.7 ± 4.8 **OB**: 51.4 ± 5.1	0.58	0.06
Tong et al., 2001	**NB** **CON**	External nasal dilator	8 (NR)	M = 8	NR	Prolonged Intermittent cycle exercise test	Ratings of perceived magnitude of breathing effort	**NB**: 7.4 ± 1.0 **CON**: 8.1 ± 0.6	8.6	0.84
							VO_2max ($mL{\cdot}kg^{-1}{\cdot}min^{-1}$)	**NB**: 38.9 ± 3.1 **CON**: 38.5 ± 2.6	1.04	0.14

Key: bpm = beats per minute, CON = control group, ES = effect size, GXT = graded exercise test, HR = heart rate, *n* = number of participants, NB = nasal breathing group, NR = not reported, OB = oral breathing group, PETCO2 = end tidal carbon dioxide pressure, PETO2 = end tidal oxygen pressure, RPE = rate of perceived exertion, RR = respiratory rate, s = seconds, SD = standard deviation, VCO2 = volume of carbon dioxide produced, VE = minute ventilation, VO_2 Max = maximal oxygen consumption, VT = tidal volume

2.4.2.2 Strictly nasal breathing

Research by Rappelt *et al*., (2023) required participants to use mouth tape to ensure nasal-only breathing; however, no device was used to guarantee oral breathing only, with just verbal instructions given to breath orally. The authors reported a small significant decrease in VO_2 max (6.73%, ES = 0.22), along with a decrease in minute ventilation (12.4%, ES = 0.40) and breathing frequency (11.7%, ES = 0.66) in the nasal-only condition. In turn, there was a significant increase in end tidal partial pressure of CO_2 ($PETCO_2$: 5.6%, ES = 0.87) and a significant decrease in end tidal partial pressure of oxygen ($PETO_2$: 2.7%, ES = 0.79) which represent the concentration of CO_2 and O_2 in the blood at the end of an exhalation (Richardson et al., 2016). The authors interpreted these partial pressure results as an increased pulmonary diffusion time in the nasal-only breathing condition (Hostetter et al., 2016; LaComb et al., 2017), which may suggest an increase in oxygen diffusion to the blood and consequently, improved breathing economy (Dallam et al., 2018; Hostetter et al., 2016). Of specific interest to endurance sports, breathing economy plays a major role in performance (Marko et al., 2022) resulting in a more controlled breathing pattern at high intensities, which has shown to improve 20 km cycling performance time and power output in trained cyclists (Vickery, 2008).

Similar results were also reported by Dallam *et al*., (2018) and LaComb *et al*., (2017) in terms of deceases in VO_2 max performance (7.5 – 8.0%, ES = 0.39 – 0.60); however, only the decrease reported by LaComb and colleagues was significant (Table 2). Of note, the participants in the study conducted by Dallam and colleagues (2018) had 6 months experience with nasal breathing during trainings prior to data collection. This prior experience may explain the similar work outputs achieved *i.e.,* time to exhaustion during both conditions and the non-significant difference in VO_2 max. Additionally, Dallam and colleagues also reported similar increases to Rappelt et al., (2023) in $PETCO_2$ (10.6%, ES = 0.78) and a significant decrease in $PETO_2$ (4. 7%, ES = 1.07), again suggestive of greater breathing economy compared to the oral breathing condition.

In terms of HR, researchers have reported decreases ranging from 2.7 to 5.1% as a result of nasal-only breathing. This decreased cardiovascular loading is to be expected as authors also reported significantly lower minute ventilation (VE) values during nasal breathing conditions (Dallam et al., 2018; LaComb et al., 2017; Rappelt et al., 2023). LaComb *et al*., (2017) concluded that nasal-only breathing was effective at submaximal intensities but significantly reduced VO_2 max at higher exertions.

The results of these acute studies show that strictly nasal breathing typically causes a slight decrease in VO_2 max performance; however, this breathing technique shows superior breathing economy and may therefore provide a potential stimulus for adaptation over an extended period of time. With a sufficient adaptation period, nasal breathing during exercise may reduce breathing frequency, hypocapnia, and increase NO production (Dallam et al., 2018). Though one obvious limitation to nasal-only breathing during high exercise intensities is smaller airways, it does appear to increase diaphragmatic function, as evidenced by Trevisan and colleagues (2015), who demonstrated that nasal-only breathing increased recruitment of the accessory inspiratory muscles and lower diaphragmatic amplitude, compared to oral-only breathing. This improved diaphragmatic function has been correlated with positive health benefits such as reduced resting heart rate, post-exercise oxidative stress and metaboreflex sensitivity; however, further research is needed into the benefits of diaphragmatic breathing during exercise.

2.4.3 Acute of effects of oral breathing on performance

With regards to strictly oral breathing, the current search did not find any studies that measured the effects of strictly oral breathing against a group with no instruction (control group). Lack of information is likely due to the fact that oral breathing is the default breathing technique that most athletes will default to as exercise intensity increases (Saibene et al., 1978). Six previously discussed studies compared oronasal and nasal breathing protocols against strictly oral breathing (Al-Hazzaa, 1987; Dallam et al., 2018; LaComb et al., 2017; Meir et al., 2014; O'Kroy, 2000; Recinto et al., 2017). All of these studies used a nose clip to ensure strict oral breathing during performance tests.

2.4.4 Summary of acute results

It appears that strictly nasal breathing (athletic tape placed over mouth) has the greatest acute effect on physiological metrics (VO_2 max: -7.6 to -8.0%, HR: -2.7 to -5.1%, VE: -26.2%) that contribute to athletic performance compared to oronasal breathing (HR: -2.3 to 0%, performance: 1.0%). Currently, it is hard to make clear comparisons, as different tests, protocols, participants, and variables of interest have been used and reported. Further research is needed to determine the acute effects of strictly nasal breathing versus oronasal breathing on athletic performance measures and determinants of aerobic capacity such as VO_2 max. Based off the existing literature, it seems evident that nasal breathing has the largest acute effect on performance compared to oral breathing which is likely the default breathing for most individuals, and has the potential to be used as a training stimulus to elicit beneficial adaptations over a long period of time. This comment is supported by desirable performance adaptations such as increased aerobic capacity and breathing economy.

2.5. Longitudinal effects of different breathing techniques on performance

The following section details the longitudinal effects of different breathing techniques used during training on aspects of athletic performance. The authors did not identify any research that has used strictly nasal or oronasal breathing over an extended period of time during exercise. Only one study using a respiratory muscle device during exercise was found and included in the current review (Gonzalez-Montesinos et al., 2021). Study characteristics, performance tests, and outcome measures are presented in Table 3 and are discussed in relation to the type of breathing intervention used.

2.5.1 Longitudinal effects of respiratory muscle device on performance

Gonzalez-Montesinos and colleagues (2021), investigated the effects of a endurance-training device called FeelBreathe® on performance in elite male cycling athletes. Endurance-training devices require muscles to work for prolonged periods and the only load imposed on muscles is that of the inherent flow resistance (McConnell, 2013). This specific device restricted the amount of airflow by covering a portion of the nostril. Over a 9-week period the width of each strip increased from 4 mm (2-weeks) to 5 mm (4-weeks), to 6 mm (3-weeks) during 144-hours of cycle training. The participants were not instructed to breathe purely through the nose; however, the authors did report that the Feelbreathe® device did promote nasal inspirations and mouth exhalations during training sessions.

Table 3. Longitudinal Effects of Respiratory Muscle Training Devices Used During Training on Aspects of Athletic Performance

Study Characteristics			**Participant Characteristics**			**Results**				
Author	**Groups**	**Intervention/ (Duration)**	*n* **(Age [y]))**	**Sex**	**Sport (Level)**	**Performance Test**	**Outcome measures**	**Results (mean ± SD)**	**% Difference**	**ES**
Gonzalez-Montesinos et al., 2021	**EXP**	FeelBreathe nasal restrictive device (9-week, 144 hours cycle training with device)	10 (35.3 ± 9.4)	M= 10	Cycling (Elite)	Incremental cycle ergometer (30 W increases/ min)	Power (W)	Pre **EXP**: 4.9 ± 0.3 **CON** 4.6 ± 0.3 Post **EXP**: 5.6 ± 0.4 **CON**: 4.8 ± 0.3	**EXP**:15.38 **CON**: 4.25	**EXP**: 1.97 **CON**: 0.66
	CON	No device – 144 hours of training	8 (38.1 ± 11.7)	M= 8			VO_2 Max ($mL \cdot kg^{-1} \cdot min^{-1}$)	Pre **EXP**: 55.8 ± 4.7 **CON**: 51.1 ± 5.4 Post **EXP**: 56.8 ± 6.6 **CON**: 50.9 ± 4.0	**EXP**: 1.77 **CON**:-0.39	**EXP**: 0.17 **CON**: 0.04
							VE ($L \cdot min^{-1}$)	Pre **EXP**: 149.1 ± 24 **CON**: 141.9 ± 17.4 Post **EXP**: 126.6 ± 21.4 **CON**: 139.6 ± 17.9	**EXP**: -16.32 **CON**: -1.63	**EXP**: 0.98 **CON**: 0.13
							VT^1 ($L \cdot min^{-1}$)	Pre		

								EXP: 1.9 ± 0.4 **CON**: 1.7 ± 0.4 Post **EXP**: 2.1 ± 0.5 **CON**: 1.9 ± 0.4	**EXP**: 10.00 **CON**: 11.11	**EXP**: 0.44 **CON**: 0.50
							VT^1 (W)	Pre **EXP**: 159.0 ± 28.5 **CON**: 144.4 ± 28.8 Post **EXP**: 180 ± 33.9 **CON**: 150.6 ± 27.8	**EXP**: 12.38 **CON**: 4.20	**EXP**: 0.67 **CON**: 0.21
							VT^2 ($L \cdot min^{-1}$)	Pre **EXP**: 3.4 ± 0.4 **CON**: 2.8 ± 0.6 Post **EXP**: 3.3 ± 0.6 **CON**: 3.2 ± 0.6	**EXP**: -2.98 **CON**: 13.33	**EXP**: 0.19 **CON**: 0.66
							VT^2 (W)	Pre **EXP**: 288 ± 28.1 **CON**: 253.8 ± 52.7 Post **EXP**: 306 ± 30.2 **CON**: 286.3 ± 38.1	**EXP**: 6.00 **CON**: 12.03	**EXP**: 0.61 **CON**: 0.71
							BF (breaths$\cdot min^{-1}$)	Pre **EXP**: 49.4 ± 10.5 **CON**: 53.3 ± 8.7	**EXP**: -13.00 **CON**: -2.80	**EXP**: 0.58 **CON**: 0.16

								Post EXP: 43.4 ± 10 CON: 54.8 ± 9.3		
							PETO$_2$ (mmHg)	Pre EXP:16.0 ± 0.4 CON: 16.1 ± 0.3 Post EXP: 15.4 ± 0.7 CON: 16.1 ± 0.3	**EXP**: -3.8.0 **CON**: 0 .00	**EXP**:1.05 **CON**: 0.00
							PETCO$_2$ (mmHg)	Pre EXP: 4.8 ± 0.4 CON: 4.7 ± 0.4 Post EXP: 5.2 ± 0.5 CON: 4.6 ± 0.1	**EXP**: 8.30 **CON**:- 2.10	**EXP**: 0.88 **CON**: 0.34

Key: BF = breathing frequency, PETCO2 = end tidal carbon dioxide pressure, PETO2 = end tidal oxygen pressure, VE = minute ventilation, VO$_2$ Max = maximal oxygen consumption, VT^1 = ventilatory threshold one, VT^2 = ventilatory threshold two, W = watts

Positive performance increases were reported when comparing experimental and control group results, such as increases in power output and power output at VT^1 and VT^2. One proposed explanation for an increase in power output at VT^1 and VT^2 could be the increase in the experimental groups VT^1 point. Improvements in VT thresholds are relevant factors for performance and metabolic flexibility during exercise, meaning a better use of fat as an energy source, saving energy from muscle glycogen, preventing fatigue, and improving the peak power developed (Gonzalez-Montesinos et al., 2021).

Reductions in minute ventilation (VE) were also reported in the experimental group compared to the control group, which represents a reduction of the physiological demand of exercise. Additionally, decreases in breath frequency and end tidal partial pressure of oxygen ($PETO_2$), and increases in inspiration time and end tidal partial pressure of CO_2 ($PETCO_2$) were reported for the experimental group, indicating improvement in breathing economy. These physiological outcomes are suggestive of improved cardiovascular performance, a lower of cardiac output, and increased energy efficiency and resulted in an increase in performance during an incremental cycle ergometer test. It should be noted that these participants were elite level cyclists and greater performance enhancements may be observed in amateur and sub-elite athletes. Previous systematic reviews and meta-analysis of the effect of respiratory muscles devices on athletic performance (Fernández-Lázaro et al., 2021; Illi et al., 2012; Karsten et al., 2018) report similar results suggesting respiratory muscle training devices can improve endurance exercise performance and are suited for athletes participating in endurance or intermittent sports. These reviews primarily focused on devices used outside of training and therefore were not included in this review.

One key limitation to the study by Gonzalez-Montesinos and colleagues (2021), was the lack of information around the breathing patterns participants used. Though the authors stated the FeelBreathe® device promoted nasal inspirations and mouth exhalations during training sessions *i.e*, oronasal breathing pattern, it is unknown if this is the case. Previous research has shown performance improvements in athletes who performed Buteyko breathing techniques (BBT) which are exclusively nasal breathing, 5 times per week, for 6 weeks (Chaudhary et al., 2021). The authors reported a significant increase in VO_2 max estimated from a Yo-Yo test in the experimental group (15.5%, ES =

1.51) compared to the control group (1.7%, ES =0.18). Though this was a significant increase, VO_2 max was not measured using spirometry but instead estimated using the following formula: VO2 max ($mL \cdot min^{-1} \cdot kg^{-1}$) = distance (m) x 0.0084 + 36.4 (Chaudhary et al., 2021). This research was not included in the current review as breathing techniques were performed outside of trainings, but the results do suggest that potential adaptations in breathing economy and aerobic capacity can occur with nasal breathing. This provides further rationale into the investigation of nasal breathing patterns during training sessions to induce performance adaptations.

2.6 Conclusion and future research direction

Upon review of the current literature strict nasal-only breathing during exercise has a negative acute effect on physiological variables such as $VO_{2,}$ heart rate, and minute ventilation when compared to oronasal and oral breathing. Therefore, nasal-only breathing has the potential to be used as a training stimulus over a period of time to induce desirable adaptations such as increased aerobic capacity. Increased breathing economy due to changes in ventilatory measures such as end tidal partial pressures of oxygen and carbon dioxide seen in both acute and longitudinal studies are also of interest in relation to performance. Though the data is limited, the use of a flow restrictive device that encourages nasal breathing over a 9-week period during exercise, improved power output, breathing economy, and elicited increased ventilatory thresholds in elite cyclists. Future research direction should be focused on nasal-only breathing interventions during various sport training across different levels of athletes from elite to no-elite both male and female. Therefore, the aim of the following training study (Chapter 3) is to investigate the effect of a 4-week nasal breathing intervention performed during exercise on aspects of athletic performance.

Chapter Three - Effects of a Nasal Breathing Intervention on Aspects of Athletic Performance: A Pilot Study

3.0 Prelude

Chapter Two highlighted a body of evidence describing the unique characteristics of nasal breathing and the acute effects of this breathing method on aspects of athletic performance. Additionally, the current limitations in the literature were identified, namely the lack of information regarding the chronic effects of nasal breathing during training. Therefore, the purpose of this chapter is to determine the effects of a four-week nasal breathing intervention on physiological aspects of relevance to athletic performance at maximal and submaximal intensities. This study will provide coaches and practitioners with insight into the potential use of nasal breathing during training to enhancing the adaptive stimulus with the potential to impact performance, specifically at submaximal intensities.

3.1 Introduction:

The health benefits of nasal breathing has been widely documented (Ruth, 2020). Some of the reported health benefits include: 1) the warming and filtering of air; 2) facilitating the inhalation of NO, a vaso- and broncho-dilator that increases oxygen transport; 3) regulation of airflow; and 4) facilitating the physiologically appropriate action of the diaphragm (Graham, 2012). In addition to these positive effects, many negative effects have been reported with abnormal mouth breathing, such as: 1) unfiltered and poorly humidified air being introduced into the lungs; 2) upper chest breathing which is inefficient; and 3) chronic over-breathing (Graham, 2012; Ruth, 2020). Given these benefits of nasal breathing, and negative effects of mouth breathing, it seems logical that nasal breathing is adopted as an efficient way to introduce and utilise oxygen within the body. During exercise, especially as intensity increases, individuals tend to switch from nasal breathing to oral breathing (Niinimaa et al., 1980). However, by doing so, individuals may be missing out on the many benefits of nasal breathing that could potentially improve their performance during exercise or enhance training outcomes.

Currently there is no research reporting on the effects of a nasal breathing intervention on aspects of athletic performance such as maximum oxygen uptake (VO_2 max), heart rate (HR), respiratory thresholds, and overall breathing economy and efficiency. As previously discussed in Chapter Two, several acute studies have reported slight performance decreases in VO_2 max; however, improvements in breathing economy have been observed. Here, it was hypothesized that nasal breathing may provide a potential stimulus for adaptation by reducing breathing frequency, improving breathing economy, and improving VO_2 max. Therefore, the aim of this pilot study was to examine the effects of a four-week nasal-only breathing intervention on physiological aspects of ventilation of relevance to athletic performance in recreationally trained athletes.

3.2 Methodology

3.2.1 Experimental approach to the problem

The effects of a 4-week nasal breathing intervention on ventilatory measures were analysed using a matched pair randomised control design. Pre- and post-training performance was quantified to determine the effectiveness of a nasal-only breathing performed during an assault bike intervention on variables associated with athletic performance. Ten male and female recreational athletes were matched for relative VO_2 max and divided into an experimental (EXP) (n = 7) and a control group (CON) (n = 3). Both groups participated in the same training; however, the EXP group performed the session with strictly nasal breathing (athletic tape placed over the mouth). Weeks One and Two sessions consisted of 10 rounds of 10-sesonds max effort followed by 30-seconds active recovery. In Weeks Three and Four, the intervals remained the same, but the number of rounds increased from 10 to 15. Each group performed the session three times per week. Pre-training aerobic capacity was established using a graduated exercise test to exhaustion before the first week of training, and post-training performance was measured in Week 5. Inferential statistics were used to determine the practical meaning of any observed changes in the independent variables.

3.2.2 Participants

Fourteen participants were recruited from a local university to participate in this study. All participants had previous experience of resistance and aerobic training (2+ years). All participants were free of injury at the commencement of this research. Ethics was approved by the University of Waikato Human Research Ethics Review Board (HREC2022#37; (Appendix 3) and all procedures were performed in accordance with the Declaration of Helsinki. All participants were informed about the risks associated with testing and the four-week training intervention. Prior to pre-testing all participants gave their written informed consent in accordance with the University of Waikato ethic committee guidelines. Group allocation was determined based on sex and VO_2 max scores attained during the pre-testing session (EXP: n = 7; CON: n = 7). During the experimental period, two participants withdrew from the study due to a health condition preventing them to complete the 4-week trial. Another two participants sustained injuries unrelated to the intervention and therefore could not complete the post-test. Therefore, a total of 7 participants in the experimental group and 3 participants in the control group were included in the final analysis (Table 4).

Table 4. Participant characteristics (mean ± SD)

Variable	Control (n = 3)	Experimental (n = 7)
Age (y)	29 ± 4.0	29 ± 10
Height (cm)	173 ± 4.2	181 ± 7.6
Body mass (kg)	69.3 ± 0.58	90.7 ± 16.41

3.2.3 Equipment and measures

3.2.3.1 Cortex Metalyzer 3B-R3

A Metalyzer 3B-R3 (Cortex, Leipizig, Germany) was used during pre-and post-testing sessions to determine participants VO_2 max. (Guazzi et al., 2017). The Metalyzer 3B-R3 a spiroergometric device, and is considered reliable for exercise testing in sports, medical routine and research (Meyer et al., 2001). The Cortex Metalyzer uses a breath-by-breath system to directly measure an individual's concentration of inspired oxygen (VO_2) and expired carbon dioxide (CO_2) to calculate VO_2 max ($mL \cdot kg^{-1} \cdot min^{-1}$) and metabolic equivalent of task (METs) (O'Brien et al., 2020). Dedicated MetaSoft software was used to analyse and export breath-by-breath respiratory measures from the Metalyzer 3B-R3. Calibration of the gas analysis system was performed prior to all assessments according to the manufacturer's instructions.

3.2.3.2 Wattbike

The Wattbike (Wattbike, Nottingham, England) was used for the maximal ramp test during the pre- and post-testing sessions. The Wattbike is an air and magnetically braked cycle ergometer that was designed with British cycling for the training and performance assessment of cyclist (Wainwright et al., 2017). Cycle ergometers such as the Wattbike support a variety of exercise applications (Hopker et al., 2010) and sport science laboratories around the world see it as an accurate and reliable tool for training and performance assessment (Wainwright *et al*., 2017). Use of the Wattbike allowed for the incremental exercise test to exhaustion using the bikes in-built maximum ramp test.

3.2.3.3 Polar H10 Heart Rate (HR) Monitor

Polar H10 HR monitors (Polar, Kempele, Finland) was used to measure participants HR during the pre- and post-testing ramp tests. Multiple studies have measured the validity of the Polar H10 and consider it the gold standard of HR data collection (Schaffarczyk et al., 2022; Weaver et al., 2019). The Polar H10 heart rate monitor is a heart rate variability sensor that comes with a wearable chest belt and has a high precision and accuracy capturing HR in real-time (Chattopadhyay & Das, 2021). The Polar H10 was connected to the Cortex Metalyzer, providing HR data in real-time during the maximal ramp test.

3.2.3.4 Borg Scale

Borg's rate of perceived exertion (RPE) 16-point scale was used during pre and post max ramp test. The Borg RPE scale is a tool to give a global measure of an individual's effort, exertion, breathlessness, and fatigue during physical work (Williams, 2017). Borg's scale is a categorical matrix of numbered intervals from 6-20 with equal distances between different individual perceptions of exertion that correlates cardiac frequency and intensity of exercise (Cabral et al., 2018). The RPE was recorded at the end of each stage during the ramp test.

3.2.3.5 AirDyne AD8

Ten participants completed the 4-week intervention on an AirDyne AD8 assault bike (Schwinn, Chicago, United States). An assault bike is an air resisted bike that required the participant to use both the upper and lower extremities simultaneously (Ponce-García et al., 2021). The machine cannot adjust the difficulty which increases as the speed increases, on the principle of an aerodynamic brake (resistance created by the flywheel), the load is therefore more complex with a likely overlap in the use of energy resources and physiological response (Schlegel & Křehký, 2020).

3.2.3.6 Mouth Tape

To ensure nasal-only breathing during the 4-week training, the experimental group applied mouth tape during each session. Strapping tape was used as the adhesive was strong enough to stick during intense exercises. Taping of the mouth has been used in previous acute nasal breathing studies to ensure strict nasal-only breathing during exercise (Dallam et al., 2018; LaComb et al., 2017).

3.2.4 Procedures

Testing was conducted at baseline (Week 0) and after 4 weeks of training. Testing was conducted at the same time of day, at Toi Ohomai Institute of Technology sport science laboratory. Participants were required to attend one familiarisation session prior to the pre-testing session. The familiarisation session was divided into two parts: the first part was the laboratory induction, and the second was the gym induction. In Part One, participants were shown the laboratory and fitted with the correct gas analysing mask of the Cortex Metalyzer and the test administrator adjusted the Wattbike to fit the participant. The mask size and Wattbike adjustments were noted down and replicated during the testing sessions. In Part Two of the familiarisation session, participants were taken into the gym and shown the Airdyne assault bike they would be using for the 4-week training intervention. Participants were shown how to adjust the bike to their specific measurements and how to set the interval times and number of rounds for each week of the training intervention. Once it was certain that the participants were confident in the use of the Airdyne assault bike, they were then shown how to apply the strapping tape to their mouth in accordance with the taping protocol within the ethics application for this research. The tape was stored at the gym so it would be easily accessible for each participant for each of their sessions. Participants were asked to refrain from any strenuous activity during the 12 hours before each testing session.

3.2.4.1 Spiroergometry (Maximal Ramp Test)

Participants were fitted with the correct gas mask and the Wattbike was adjusted according to the measurements recorded during the familiarisation session. Participants were provided with a 10-minute standardized warm up on the Wattbike before beginning the maximal ramp test. Participants completed this warm-up with the gas mask and Polar HR monitor on. The Polar H10 HR monitor was placed on the participant just below their sternum and the face mask was fitted firmly to ensure no air leaks. The maximal ramp test is an incremental exercise test to volitional exhaustion similar to testing protocols used by (Gonzalez-Montesinos et al., 2021; O'Kroy, 2000; Tong et al., 2001). The ramp test was performed using the in-built maximum ramp test on the Wattbike. A starting power output of 55 W was used for both sexes during pre and post testing. Power output was progressively increased at the end of each one-minute stage by either 19 W for males or 15 W for females until exhaustion. If participants could not reach or maintain the required Watts in the first 30-seconds of the minute stage, the test was terminated, and the power output for the final completed stage was recorded. Prior to commencement of the test participants were once again shown the Borg RPE scale and were provided with an additional explanation of how to use it. During the final 5-seconds of each stage the Borg scale was shown to participants by the primary investigator standing next to them, and participants indicated their RPE by pointing to the number that corresponded to their perceived effort. Two assessors (primary investigator and research assistant) were always present for each test and both assessors provided consistent feedback at the start and end of each stage. Verbal encouragement was given to participants by each assessor during the final stages of the ramp test. Upon cessation of the test, the mask was immediately removed and participants were encouraged to remain on the Wattbike to warm down for 2-5 minutes. There were no conflicts of interest between participants and both assessors to avoid an external motivating factor.

During the testing sessions, variables such as absolute ($L{\cdot}min^{-1}$) and relative ($mL{\cdot}min^{-1}{\cdot}kg^{-1}$) maximal oxygen uptake (VO_2 max), minute ventilation (VE), minute ventilation/oxygen uptake (VE/VO_2), minute ventilation/carbon dioxide production (VE/VCO_2), breathing frequency (BF), carbon dioxide production (VCO_2), respiratory exchange ratio (RER: VCO_2/VO_2), power output (W), and HR measures were determined and used for analysis.

3.2.4.2 Training Intervention

The nasal-only breathing training intervention was completed over a period of 4-weeks. Once participants had completed their familiarisation session and pre-test, they were instructed to complete a total of 12-sessions at the Toi Ohomai Aquatic Centre gym. Prior to each session, participants placed athletic tape over their mouths, to ensure nasal-only breathing pattern was used during the training. In Weeks 1 and 2 of the intervention, participants completed 10 rounds of 10-seconds maximum effort and 30-seconds of active recovery for a total effort time of 1:40 (min:s) and a total session time of 6:40. Active recovery was defined as a low intensity pace at the participant's choice; however, the participant had to remain moving at all times during the 10 rounds. In Weeks 3 and 4 participants completed the same intervals of 10-seconds max effort and 30-seconds active recovery but the number of rounds were increased to 15 for a total effort time of 2:30 and a total session time of 10:00. Participants performed the nasal-only breathing exercise sessions three times per week and it was up to the participants to decide the scheduling for sessions in the week *i.e*., perform session on consecutive days, one day rest between sessions *etc*. All training was performed on the AirDyne AD8 assault bike.

The control group performed the same 4-week training protocol as the EXP group, for a total of 12-sessions except there was no taping of the mouth to ensure nasal-only breathing, allowing participants to breath in their own natural pattern. No breathing instruction were given to control group participants throughout the entirety of the training study.

3.2.4 Outcome Measures

3.2.4.1 Maximum Power ($Power_{max}$)

As the stages of the maximal ramp test were one-minute, maximal power was measured as the last fully completed one minute stage. If the participant did not reach the target power output within the first thirty seconds of the one-minute stage, the test was terminated.

3.2.4.2 Maximal VO_2

VO_2 max refers to the highest rate of oxygen consumption attainable during maximal exercise and shows the maximum capacity of an individual to transport and utilise oxygen (Shete *et al*., 2014). The Cortex Metalyzer uses breath-by-breath technology to measure VO_2 data, and the in-built reporting system in Metasoft was used to smooth data and remove the noise. Classical methods for reaching VO_2 max criteria is the achievement of a plateau in VO_2 despite an increase in ventilation, RER values >1.10, blood lactate >8 mmol·L^{-1}, and >95% age predicted HRmax (Edvardsen et al., 2014). All participants achieved RER values over 1.10 and >95% of their age predicted HR max, but it was not clear for all participants if a plateau was achieved as mentioned by Doherty and colleagues (2003). For this reason, it is proposed for the purpose of this study that peak oxygen uptake ($VO_{2\ peak}$) is used as a more accurate variable rather than a definitive VO_2 max. Utility of $VO_{2\ peak}$ relates to its acceptance of as a criterion measurement of cardiorespiratory fitness and is the highest rate of O_2 uptake measured during a single maximum test (Green & Askew, 2018). Each participant's absolute and relative $VO_{2\ peak}$ was determined as the highest mean VO_2 value recorded during the last 30-seconds of each 1-minute stage before a participant's volitional termination of the test as described by O'Connor *et al*., (2015).

3.2.4.3 Minute Ventilation (VE)

Minute ventilation is the product of respiratory rate and tidal volume, and is a physiological indicator that has been shown to correlate with metabolic demand (Duru *et al*., 2000). Also known as total ventilation, VE represents the amount of air that enters the lungs per minute ($L \cdot min^{-1}$). The VE is calculated by tidal volume (VT) x respiration rate (RR) (Carroll, 2006) and was calculated through Metasoft Studio breath-by-breath analysis.

3.2.4.4 Tidal Volume (VT)

Tidal volume is typically described as the volume of gas that is being inspired and expired with each breath ($L \cdot min^{-1}$) (Koomen et al., 2021). Tidal volume needs to be sufficiently large to ventilate alveoli, deliver oxygen and eliminate carbon dioxide efficiently, but not be excessive that it damages alveoli due to large volumes and high pressures (Castle et al., 2002). Normal reported values of VT at rest in adults are 0.5 $L \cdot min^{-1}$ and 3 $L \cdot min^{-1}$ during exercise (Sterling, 1981).

3.2.4.5 Ventilatory Anaerobic Threshold (VAT) and Respiratory Compensation Point (RCP)

Traditionally, the anaerobic threshold (AT) can be identified through blood lactate concentration, termed the lactate threshold and is considered the gold standard (Campos et al., 2017). As this method is invasive and time consuming, for the current study a non-invasive approach was taken using the Ventilatory Anaerobic Threshold (VAT) and Respiratory Compensation Point (RCP) to determine the anaerobic threshold (AT). The VAT is the point at which CO_2 excretion increases in response to an increase in VO_2 to compensate for the rising blood lactate concentration (Kominami et al., 2022), and after this point the CO_2 exchange is equal to the production of lactate which results in a near constant blood lactate concentration (Visschers et al., 2015). The RCP is the point when lactate accumulation starts to exceed the CO_2 elimination and lactate levels in the blood will rise, such that hyperventilation is no longer be sufficient to maintain manageable pH levels in the blood (Visschers *et al.*, 2015). The phase between the VAT and the RCP is known as the isocapnic buffering (IB) phase (Hasanli et al., 2015). During this period, the maximal partial pressure of end tidal CO_2 ($PetCO_2$) remains stable and exercise induced lactate acidosis is buffered by circulating bicarbonate. When this process can no longer counteract metabolic acidosis due to rising lactate concentrations, RCP is reached and hyperventilation is initiated (Yen *et al*., 2018). Metasoft studio was used to automatically calculate the VAT and RCP threshold points.

3.2.4.6 Alveolar Ventilation (AV)

Alveolar ventilation (AV) can be defined as the volume of air that reaches the alveolar per minute ($L{\cdot}min^{-1}$), and takes into account tidal volume, respiratory rate, and dead space *(Ceylan et al*., 2022). Dead space can be separated into two divisions: anatomical (air in the conducting airways) and alveolar (alveoli that fill with air but do not participate in gas exchange). Together, anatomical and alveolar dead space form the physiological dead space which constitutes the total volume of air in the lungs that does not participate in gas exchange (Hallett et al., 2018). A normal values for physiological dead space has been reported as ~150 mL (Intagliata et al., 2018); therefore, alveolar ventilation was calculated using the following formula: alveolar ventilation = (tidal volume – dead space) x respiratory rate (Hallett *et al.*, 2018).

3.2.4.7 Breathing Frequency

Breathing frequency i.e. the number of breaths per minute is highly regulated to enable cells to produce the optimum amount of energy at any given occasion, a complex nervous system of nerve tissues regulates the rate of oxygen inflow and carbon dioxide outflow (Chourpiliadis & Bhardwaj, 2019). Breathing frequency has been shown to depend on metabolic demand (Loring et al., 1990), at rest BF in healthy adults is between 12-20 breaths per minute and 40-60 breaths per minute during exercise (Scott & Kaur, 2020).

3.2.4.8 Heart Rate

Heart rate is the speed of the heartbeat measured by the number of contractions per unit of time or beats per minute (bpm) (Dong, 2016). Percent of maximal heart rate has been a widely used tool to describe training intensities for athletes (Hofmann *et al*., 2001), while resting heart rate can be a key indicator of aerobic capacity (Rahnama et al., 2010).

3.2.4.9 Minute Ventilation, Tidal Volume and Breathing Frequency at Submaximal VO_{2peak}

Minute ventilation, tidal volume and breathing frequency were analysed at 50%, 60%, 70% and 80% of individual $VO_{2\ peak}$ values. Attaining values below $VO_{2\ peak}$ provide an insight into the respiratory system operating as close to a steady state as possible, as a consequence O_2 flow matches metabolic O_2 consumption, free from lactate accumulation influence (Ferretti et al., 2017).

3.2.5 Statistical Analysis

The statistical analysis was performed using Microsoft Excel (version 16.0; Microsoft, Seattle, WA) and SPSS 26.0 (SPSS, Inc., Chicago, IL). Data were presented as mean ± standard deviation (SD). Data was explored using histogram plots and distribution estimation. Normality of the data was tested using Shapiro-Wilk test. Homogeneity of variance was tested using the Levene's test. Paired T-tests were used to determine if any significant within-group differences were present (Ewens & Grant, 2005), and a customised spreadsheet designed by Hopkins (Hopkins, 2003) was used to determine the within- and between-group effects. The level of significance was set at $p \leq 0.05$. Mean difference, percentage change, and Hedge's *g* effect sizes (ES) were calculated with 95% confidence intervals (CI). Effect sizes were interpreted using the following criteria; trivial effect = ≤ 0.2, *small* effect = 0.21 – 0.49, *moderate* effect = 0.5-0.79, *large* effect = ≥ 0.8 (Cohen, 2013).

3.3 Results

Within- and between-group differences for the EXP and CON group are presented in Table 5. No significant differences ($p > 0.05$) were found for maximum power, with both groups having slight decreases over the 4 weeks. In terms of peak ventilatory variables, divergent results were reported between EXP and CON groups for $VO_{2\ Peak}$, VE, VT, and AV. Of note, the non-significant between-group effect size differences for VE, VT, RCP, and AV were all *large* (p-values 0.22 to 0.06: Table 5). The EXP group also experienced significant decreases in RCP (*ES: small)* and peak HR (*ES: moderate)*, but there were no significant between-group differences.

Table 5. Within- and between-group differences for peak values obtained during the maximal ramp test

Variable	Group	Pre-test Mean ± SD	Post-test Mean ± SD	Mean Difference (95% CI)	% change	Within-group ES	Within-group *p- value*	Between-group ES	Between-group *p-value*
Maximum Power (W)	CON	264 ± 58.0	259 ± 65.7	-5.0 (-16.5 – 26.5)	-1.9	0.08	0.42	0.13	0.85
	EXP	294 ± 58.4	286 ± 62.9	-7.6 (-22.5 – 37.6)	-2.6	0.12	0.56		
$VO_{2\ Peak}$ ($L{\cdot}min^{-1}$)	CON	4.0 ± 1.0	4.0 ± 0.9	-0.05 (-0.42 – 0.52)	-1.2	0.05	0.69	0.47	0.48
	EXP	4.0 ± 0.9	4.1 ± 0.8	+0.11 (- 0.55 – 0.34)	+2.5	0.12	0.58		
VE ($L{\cdot}min^{-1}$)	CON	182.6 ± 29.0	174.2 ± 33.7	-8.4 (-3.3 – 20.1)	-4.6	0.26	0.09	*0.92*	*0.22*
	EXP	168.0 ± 37.2	175.4 ± 24.2	+7.4 (-34.7 – 20.0)	+4.4	0.23	0.54		
VT ($L{\cdot}min^{-1}$)	CON	2.15 ± 0.19	2.02 ± 0.11	-0.13 (-0.18 – 0.43)	-6.2	*0.83*	*0.21*	*1.69*	*0.06*
	EXP	2.37 ± 0.47	2.46 ± 0.50	+0.09 (-0.22 – 0.03)	+3.7	0.18	0.12		
VT^1 ($L{\cdot}min^{-1}$)	CON	2.46 ± 0.12	2.20 ± 0.26	-0.26 (-0.34 – 0.88)	-10.6	*1.28*	*0.20*	0.02	0.97
	EXP	2.38 ± 0.60	2.12 ± 0.32	-0.26 (-028 – 0.80)	-10.9	0.54	0.28		
RCP ($L{\cdot}min^{-1}$)	CON	3.00 ± 0.77	2.92 ± 0.70	-0.07 (-0.18 – 0.34)	-2.7	0.10	0.34	*1.44*	*0.06*
	EXP	3.41 ± 0.63	3.13 ± 0.50	-0.28 (0.11 – 0.45)*****	-8.2	**0.49**	**0.004**		
AV ($L{\cdot}min^{-1}$)	CON	147.32 ± 22.85	140.48 ± 12.71	-6.8 (-20.00 – 33.68)	-4.6	0.36	0.38	*1.05*	*0.14*
	EXP	140.87 ± 35.20	153.67 ± 27.33	+12.79 (-37.44 – 11.85)	+9.1	0.41	0.25		
HR (bpm)	CON	187 ± 7.5	182 ± 3.5	-5.7 (-10.9 – 22.2)	-3.0	*0.96*	*0.27*	0.16	0.86
	EXP	186 ± 7.5	181 ± 9.0	-4.9 (1.6 – 8.1)*****	-2.6	**0.58**	**0.01**		
BF ($breaths{\cdot}min^{-1}$)	CON	71 ± 16.4	72 ± 8.2	+1.00 (-23.76 – 21.76)	+1.4	0.07	0.86	0.29	0.70
	EXP	64 ± 7.5	67 ± 8.9	+3.71 (-12.53 – 5.10)	+5.7	0.45	0.34		

Key: * = Significantly different ($p<0.05$) from pre-test, EXP = experimental group, CON = control group, CI = confidence interval, ES = effect size, W = watts, VO_{2peak} = maximal oxygen peak value, VE = minute ventilation, VT = tidal volume, VT^1 = ventilatory threshold, RCP = respiratory compensation point, AV = alveolar ventilation, HR = heart rate, BF = breathing frequency. Significant effects are highlighted in **bold**, and *large* effect sizes are *italicised.*

Ventilatory parameters (BF, VE, VT) at submaximal intensities (50%, 60%, 70% and 80% of $VO_{2\ peak}$) are presented in Figures 3-5. Breathing frequency decreased in the nasal-only breathing group at lower intensities from pre-post testing (-13.6 to -1.5%, ES: -0.39 to -0.89) compared to the control group which showed increases in breathing frequency (1.8 to 14.2%, ES: 0.41 to 1.30; Figure 3).

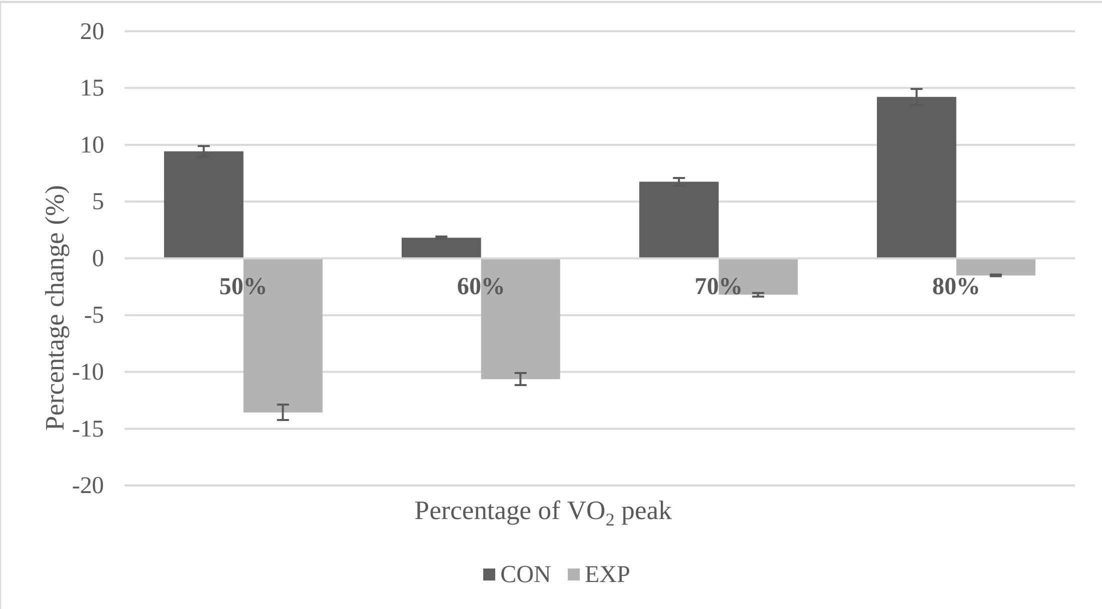

Figure 3. Pre-post changes in breathing frequency at submaximal intensities for the control and experimental group.

Lower VE was observed for the EXP group at all submaximal intensities (ES: 0.15 to 0.59). There was a significant within-group ($p < 0.05$) difference at 70% of $VO_{2\ peak}$ and a significant between-group difference observed at 60% of $VO_{2\ peak}$ (see Figure 4). No significant within-group differences were observed for the CON group (all $p > 0.05$). There were no clear trends in terms of VT (see Figure 5).

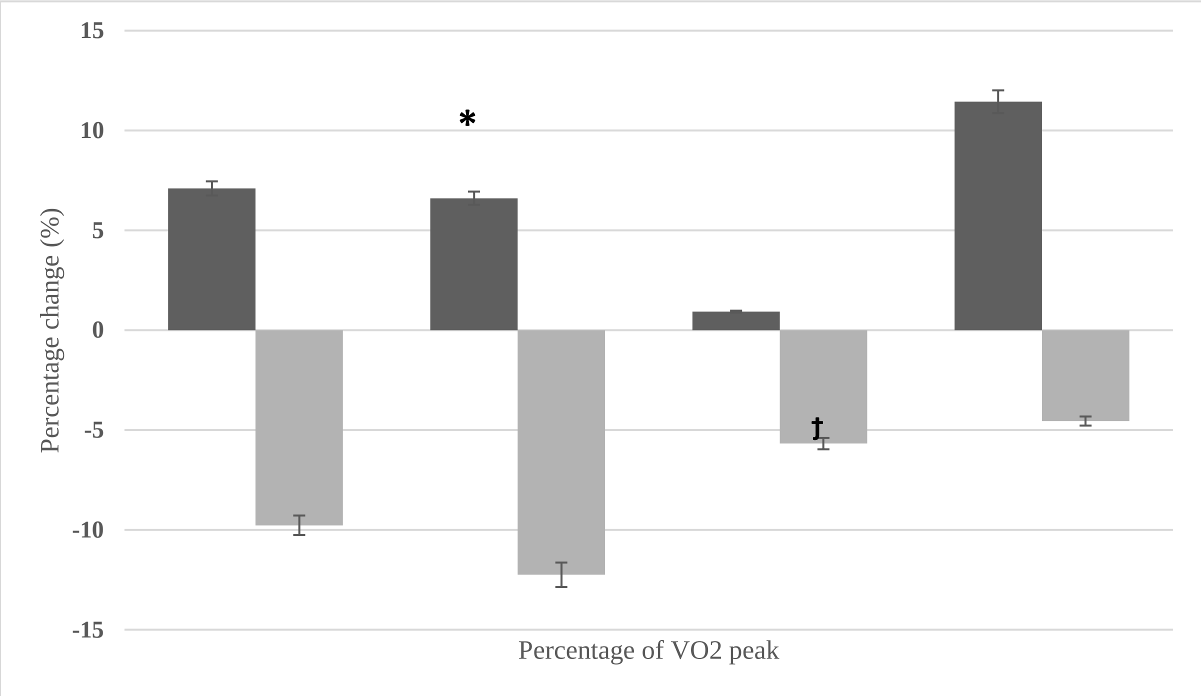

Figure 4. Pre-post changes in minute ventilation at submaximal intensities for the control and experimental group.

Key: * = significantly different from CON ($p < 0.05$), ƚ = significantly different from pre-test ($p < 0.05$)

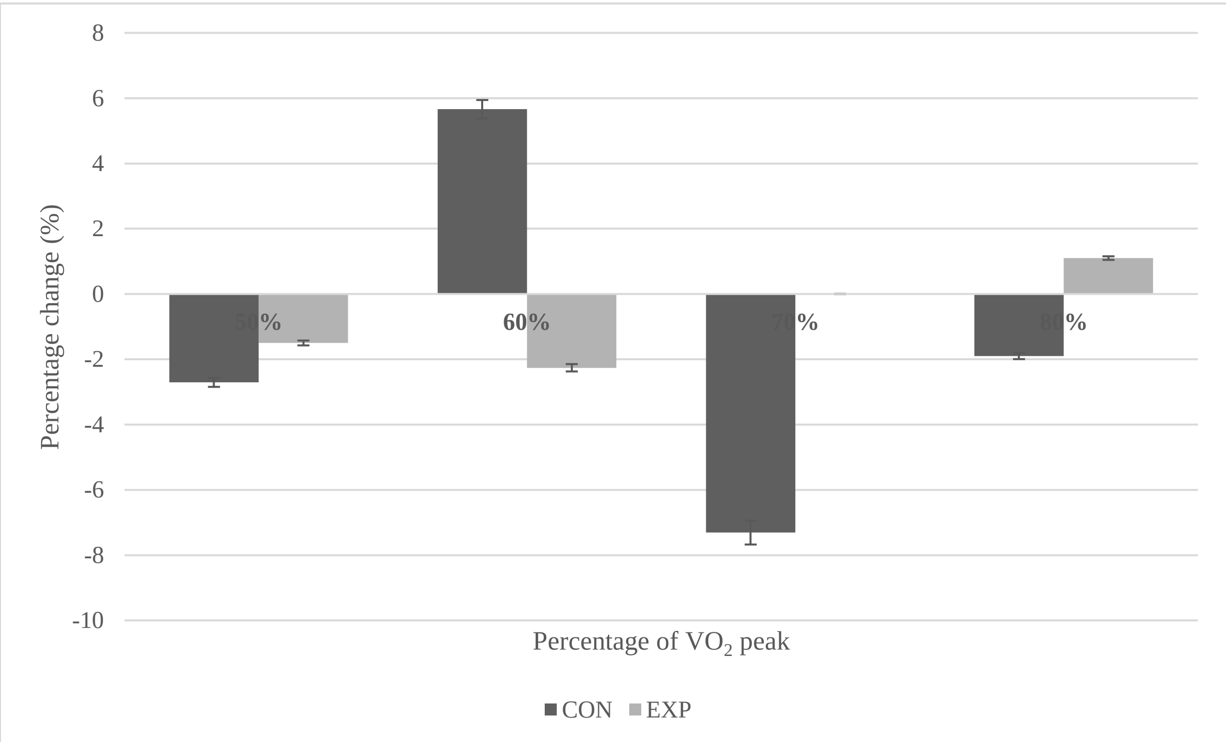

Figure 5. Pre-post changes in tidal volume at submaximal intensities for the control and experimental group

3.4 Discussion

The aim of this study was to determine the effects of a 4-week nasal breathing intervention on physiological aspects of ventilation relevant to athletic performance, measured via a maximal ramp test. It was hypothesised that nasal-only breathing would provide a potential stimulus for adaptation and reduce breathing frequency, improve breathing economy, and improve VO_2 max. The main findings were: 1) no significant change in maximum power ($Power_{max}$) reached (*i.e.*, level reached during the maximal ramp test), from pre- to post-testing for either group; 2) contrary to the initial hypothesis, there was no significant improvements in $VO_{2\ peak}$ for the experimental group; 3) significant decreases were seen in RCP and HR in the nasal-only breathing group; although there were no significant between-group differences; 4) *large* but non-significant between-group effect size differences were seen for VE, VT, RCP, and AV; and 5) decreases in breathing frequency and minute ventilation at submaximal intensities suggested improvements in breathing economy for the EXP group, which aligned with the original hypothesis. This seminal pilot study provides practitioners with insight into the potential use of nasal-only breathing within a sport performance environment.

There appeared to be no changes in maximal power output for either group after the 4-week training intervention. To the authors knowledge, there are no previous training studies that have determined the chronic effects of nasal breathing on power output. However, previous research by Recinto *et al.*, (2017) determined the acute effects of nasal breathing versus oral breathing during a standard Wingate anaerobic test. The authors reported that breathing mode did not affect power output or performance measures during high-intensity anaerobic exercise. Similar results were also reported by Rappelt and colleagues (2023), where they determined the acute effects of nasal-only breathing during low intensity training. After 60 minutes of cycling there was only a 2.2% difference in power output for restricted nasal-only breathing compared to oronasal breathing. Both research groups concluded that longitudinal studies were warranted to evaluate longitudinal responses of changes in breathing patterns. Based on the results of the current study, it can be concluded that a 4-week nasal breathing intervention does not significantly affect power output during a maximal ramp test; however, further research is needed to determine the effects of a longer nasal breathing training intervention (*i.e.*, 8-12 weeks), on cycling power output. A previous study by Gonzalez-Montesinos and colleagues (2021) reported a 14.3% increase in maximal power output after a 9-week cycle training using a nasal-restrictive device. Though the participants in this study were not instructed to perform strictly nasal breathing, it was noted that the device encouraged nasal breathing. Therefore, the current study may not have been of sufficient duration to elicit positive performance increases in power output.

In addition to observing no changes in power output, there were also no significant improvements in $VO_{2\ peak}$ for either the CON or EXP group. Maximal oxygen uptake during exercise is regarded by majority of researchers as the best indicator of aerobic capacity (*i.e.*, the functional capacities of cardiovascular and respiratory systems), as well as the capacity of tissues to utilise oxygen; at the same time, it is considered as the best indicator of an athlete's physical capacity (Ranković *et al.*, 2010). The current study demonstrated a small increase in $VO_{2\ peak}$ in the EXP group (2.50%) that contrasted a small decrease for the CON group (-1.24%); however, neither the within- nor between-group changes were significant. Gonzalez-Montesinos and colleagues (2021), reported similar findings after 9-weeks of nasal-restrictive breathing, as despite seeing improvements in power output, VO_2 max did not change. These authors speculated that this result may be attributed to an improvement in ventilation efficiency. An earlier study by LaComb and colleagues (2017), compared oral and nasal breathing at different intensities and reported that oral breathing provided greater respiratory and metabolic volumes (*i.e.*, VO_2 max) at higher intensities allowing for a steady state oxygen level to be achieved within recreationally trained male and female participants; however, they suggested that these results may not translate to greater respiratory efficiency, especially at lower intensities.

In terms of peak values obtained during the maximal ramp performance test, RCP and HR were the only variables to have significant within-group differences. The RCP is defined as the highest workload that can be sustained before marked hyperventilation occurs due to metabolic acidosis (Broxterman et al., 2018; Keir et al., 2018; Moral-González et al., 2020). The RCP has been reported to be a key indicator of for evaluating the limits of tolerable endurance exercise (Nakahara et al., 2020). Interestingly, in the present study, RCP had a significant decrease in the EXP group (-8.21%, ES: 0.49), however, no significant differences were observed in the CON group. Previous research has shown a

15% increase in RCP following low-frequency (1-day per week) severe-intensity interval cycle training for a duration of 3-months (Nakahara *et al*., 2020) and an 8.5% increase following 6-days per week interval running training for 6-months (Oshima *et al.*, 1998).

It is worth mentioning the between-group minute ventilation (VE), tidal volume (VT) and alveolar ventilation (AV) peak values presented *large* effect sizes and considerable increases for the EXP group (4.4 %), (3.7 %) and (9.1%) while the CON group showed contrasting decreases (-4.6 %), (-6.2 %) and (-4.6 %). The increase in VE and VT for the EXP group would explain the substantial increase in AV at peak values as an increase in VE would suggest an increase in BF at the same intensity, by increasing BF and VT, AV is improved (Walker et al., 1990). It should be noted that these effects were not *clear* in the *post-hoc* analysis as the confidence limits overlapped positive and negative values. There are several potential reasons to explain the discrepancy between previous studies and the current study. Firstly, the durations of the training interventions are largely different, with the current study only being 4-weeks in duration, compared to 12- 24 weeks long. It could be hypothesised that a duration longer than 4-weeks is needed for sufficient adaptation to a nasal-only breathing intervention. Secondly, differences in the testing protocols may explain some of the differences. Oshima and colleagues (1998), used a modified Bruce protocol, which increases the speed and incline every three minutes and the test terminates once you have hit 85% of your maximum heart rate. Conversely, the current study used a maximal ramp test that increased the workload by 15-20 W every minute. It has been previously speculated that tests with a high ramp rate, such as that applied in the present study, may hinder reaching a physiological steady state in such a short time (Stockhausen et al., 1997). Lastly, the most obvious difference is that the present study used a nasal-only specific breathing intervention; whereas, the aforementioned studies did not require participants to complete a specific breathing method.

As alluded to in previous paragraphs, and originally hypothesized, it is thought that nasal-only breathing may improve breathing economy, especially at submaximal intensities. Previous authors have used variables such as BF, VE, and VT to provide insight into ventilatory efficiency adaptations (Gonzalez-Montesinos et al., 2021; LaComb et al., 2017; Morton et al., 1995). The current study saw reductions in breathing frequency and VE at submaximal intensities (50-80% of $VO_{2\ peak}$), and as intensity increased, the difference between pre- and post-testing was attenuated. Though the researchers provided no instruction on how to breathe during the pre- and post-testing, it is likely that those in the EXP group would adopt a more nasal breathing mode in the post test, especially at lower intensities. This breathing technique could explain the reductions in BF and VE, as previous researchers have reported that nasal breathing reduces total VE at a given level of work (Dallam et al., 2018; LaComb et al., 2017). The VE is determined by breathing frequency and tidal volume, therefore a reduced VE logically reflects a reduced workload of breathing, which may indicate a reduced gross metabolic cost during exercise and therefore ventilatory economy (Hallett *et al*., 2018). Conversely, the CON group had substantial higher breathing frequencies than the EXP group across submaximal intensities at 50%, 70% and 80% of $VO_{2\ peak}$, as well as increases in VE. These results suggest that the individual's ventilation was not meeting the metabolic demand, and therefore represents a lesser breathing economy.

Additionally, as mentioned the EXP group had a considerable increase (9.11%, ES: 0.41) in alveolar ventilation (AV) at $VO_{2\ peak}$. Alveolar ventilation is a similar measurement to VE, which measures the amount of air that enters the lungs per minute, however, AV takes physiological dead space into account (Intagliata *et al*., 2018). Although speculative in the current study, an increase in AV can suggest several physiological adaptations such as an improvement in gas exchange via: 1) an increase surface area of alveoli membrane; 2) increases alveolar pressure difference; 3) increased solubility of O_2 and CO_2; and 4) a decrease in membrane thickness (Powers & Dhamoon, 2019). Improvements in gas exchange may indicate an improvement in V/Q (Ventilation/Perfusion) ratios during maximal intensity exercise. Conversely, the CON group reported a *small* decrease in AV at $VO_{2\ peak}$ (-4.64%, ES: 0.36), that resulted in a *large* effect size difference between groups (ES: 1.05). These results suggest that the CON group had a decreased breathing economy and gas exchange efficiency relative to the EXP group who showed improvements.

3.5 Conclusion

Based on the current study results, it appears that a nasal-only breathing intervention of 4 weeks has no significant effects on maximum power or $VO_{2\ peak}$ in a maximal ramp test. While no significant differences were observed for ventilatory parameters at peak values, there were a range of divergent results and significant effects in the HR and RCP that favoured the experimental group. Notably, there were *large* increases in VE and VT at peak values which translated to an improved alveolar ventilation. Increased AV along with decreases in BF and VE at submaximal intensities, was suggestive of improvements in breathing economy and gas exchange at submaximal intensities after a 4-week nasal-only breathing intervention. Further research is needed to quantify the use of a nasal-only breathing intervention longer than 4-weeks. The current study also had a small sample size and unbalanced groups; therefore, different results, interpretations, and conclusions may be reached with a larger sample size. Despite these limitations contrasting adaptations and *large* effect sizes favoured the nasal-only breathing group.

Chapter Four - Summary, Conclusions, Limitations, Practical Applications and Future Research Direction

This final chapter summarises the previous three chapters and draw conclusions based on the existing research and new research carried out in this thesis. The limitations of this research will be discussed and reflected on. Finally, key practical applications that may be useful for coaches and practitioners are stated and future research directions are discussed.

4.1 Summary and conclusions

Chapter One introduced the reader to breathing and the importance of correct breathing and respiratory efficiency during sporting activities. The benefits of nasal breathing at rest such as filtering, warming, and humidifying of air, resistance and production of NO were detailed; however, there is limited research and evidence regarding the use of nasal breathing patterns during training. Given the benefits of nasal breathing, it was hypothesized that utilising a nasal-only breathing pattern during training may result in favourable physiological adaptations. Thus, the aims of this thesis were to:

1) Report on the current literature regarding the use of nasal breathing during training.
2) Determine the effects of a 4-week nasal breathing intervention on physiological aspects relevant to athletic performance.

Chapter Two comprised a literature review exploring the use of different breathing modes on aspects of athletic performance. The review identified three different breathing methods: 1) nasal breathing; 2) oronasal breathing; and 3) oral breathing. The potential benefits and disadvantages of each of the breathing modes were briefly outlined. The PRISMA protocols were used to identify any articles that focused on the acute and longitudinal effects of different breathing methods on performance. It appeared that nasal breathing had the greatest acute effect on physiological metrics that can contribute to athletic performance; however, it was difficult to make clear comparisons between methods, as different tests, protocols, participants, and variables of interest were reported on. The review concluded that further research is needed to determine the acute effects of strictly nasal breathing compared to oronasal within the same study and training protocol. Furthermore, based on the limited existing literature, it seems evident that nasal breathing has the potential to acutely benefit performance when compared to oral breathing, which has been identified as the default breathing technique for most athletes at high intensities. Therefore, nasal breathing was identified as having the potential to be used as a training stimulus to induce desirable performance adaptations such as increased aerobic capacity and breathing economy. In terms of longitudinal studies, only one appropriate training study was identified. This single study reported improvements in power output, breathing economy, and ventilatory thresholds in elite cyclists; however, participants used a nasal restrictive device during trainings, which promoted nasal breathing, but still allowed for oral breathing. Given the lack of longitudinal research, it was apparent that research was required to determine the chronic effects of a nasal-only breathing intervention on aspects of athletic performance.

Chapter Three was a pilot study that aimed to determine the effects of a 4-week nasal breathing intervention on aspects of athletic performance. No significant effects were observed on maximal ramp test performance; however, positive differences in alveolar ventilation, the respiratory compensation point, and tidal volume were seen in the nasal-only experimental group. At submaximal intensities, notable increases in alveolar ventilation, coupled with a decrease in breathing frequency and minute ventilation, were suggestive of improvements in breathing economy. Overall, it was concluded that nasal-only breathing has the potential to improve aspects of athletic performance, specifically during submaximal intensities; however, further research is needed with longer intervention durations and a larger cohort.

4.2 Limitations

As with all research, there were several limitations that may have affected the strength and robustness of the study. While efforts were made to obtain reliable data and results, and using established testing methodologies, reflecting on the research and identifying limitations allows us to acknowledge what can be improved for future research.

Firstly, the sample size of this pilot study was relatively small (n = 10) for to a number of reasons. While not invasive, the study protocol required individuals to complete two maximum effort VO_2 max tests and commit to a 4-week training intervention performing three sessions per week, which affected participant recruitment Additionally, there was a large dropout rate of participants due to various reasons outside of the researcher's control. Coincidentally, and unfortunately for the research study, all the drop out participants were from the CON group, which resulted in unbalanced group sizes. As the participants were matched into groups based on VO_2 peak baseline data, it is unclear how much this imbalance affected the overall outcomes, although it is evident that small sample sizes often do not yield statistical significance (Goodhue et al., 2007). Therefore, having a larger sample size may have led to different results or interpretations. Another limitation related to the participants was that many participants reported being sick during the 4-week period, which may have significantly affected their post-testing results. With all that being said, the majority of these limitations were out of the researcher's control; however, in future larger sample sizes should be recruited to account for dropouts due to injuries, sickness, and other external compliance issues.

Another key limitation was the duration of the intervention due to time constraints and feasibility of the current study. Though there were some favourable adaptations observed in terms of breathing economy, greater adaptations may have been observed with a longer training period (*i.e*., 6-12 weeks). The 4-week duration may not have been enough time for the participants to adapt to the nasal breathing protocol, especially since the participants had no prior experience with nasal-only breathing; however, further research is needed to determine whether a longer duration intervention would yield different outcomes.

In terms of the testing protocol it has been previously speculated that tests with a high ramp rate, such as that applied in the Chapter Three training study, may hinder reaching a physiological steady state in such a short amount of time (Stockhausen *et al*., 1997). In future, it may be best to allow for longer times at each stage to allow the participants to adapt to the change in intensity and reach a steady state oxygen level. The protocol used in the current thesis has however, been shown to be reliable and time effective.

Lastly, as greater improvements were observed at submaximal intensities, it may be beneficial to provide a training intervention at lower intensity. The current study used a maximal effort intervention; however, a study with a 9-week training intervention at a range of lower intensities reported positive adaptations (Gonzalez-Montesinos *et al.*, 2021). Further research is needed to determine if this would be the case with strictly nasal-only breathing.

4.3 Practical Applications and Future Research Directions

Given the evidence from the literature review and the pilot study herein, it can be observed that nasal-only breathing during high-intensity interval training has a potential beneficial effect on breathing economy and gas exchange efficiency at submaximal intensities. Coaches or practitioners could apply this breathing method during training or sports to elicit potential performance benefits. As with all research, results need to be interpreted with caution, as the results are specific to the population, sport, training level, sex *et cetera*, and different results may be observed in other demographics.

Given the previously mentioned limitations, and the lack of current research, future research should focus long-term nasal-only breathing training interventions at different intensities, durations, demographics, and incorporated into sport-specific activities. A clear understanding of intensities, volume of training, durations is needed for coaches to confidently apply these training methods with their athletes.

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Appendices

Appendix 1. Participant Information Sheet

THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

Participant Information Sheet

Date Information Sheet Produced:

16/03/2023

Project Title: 'Effects of a Nasal Breathing Intervention on Athletic Performance'

You are invited to participate in a study looking at the physiological effects of a nasal breathing intervention on athletic performance. Whether or not you take part in this research is entirely your choice. If you want to take part now but change your mind later, you can withdraw from the study at any time.

This Participant Information Sheet will help you decide if you'd like to take part. It sets out why we are doing the study, what your participation would involve, the benefits and risks to you, and what would happen after the study ends. We will go through this information with you and answer any questions you may have. You do not have to decide today whether you will participate in this study.

Before you decide, you may want to talk about the study with other people, such as family, whānau, friends, or healthcare providers. Feel free to do this. If you agree to participate in this study, you will be asked to sign the Consent Form on the last page of this document.

Voluntary Participation and Withdrawal From this Study

Your participation in this research is voluntary. Before you choose whether to take part, it is important for you to understand why the research is being done and what it will involve for you. If you do not want to take part, you may contact the investigators to withdraw from the research at any time, without giving a reason.

What is the purpose of this research?

The purpose of this research is to investigate whether a 4-week nasal breathing intervention will elicit a physiological adaptation that will increase athletic performance. The adaptations which we are looking to see are:

An increase in nasal respiratory mechanics during high intensity exertion. Increased mechanical function would see a participant being able to maintain nasal only breathing effectively at moderate to high intensity without the need to revert to oronasal or mouth breathing.

An increase in carbon dioxide (CO_2) tolerance. Based on the Bohr Effect theory, by increasing ones CO_2 tolerance and increasing the amount of CO_2 present in the blood it lowers the pH level of the blood which allows haemoglobin to release oxygen more readily into peripheral cells.

An increase in nitric oxide released from the sinuses. This will allow for continuous vasodilation of the blood vessels, increasing blood flow and decreasing blood pressure. The release of nitric oxide combined with an increase in CO_2 in the blood will increase the amount of oxygenated blood released into the muscles therefore increasing work capacity.

An increase in respiratory muscle strength. Strengthening the diaphragm and intercostal muscles will delay respiratory muscle fatigue during exercise reducing the effect of the respiratory metaboreflex. When respiratory muscles fatigue the metaboreflex is activated, this mechanism restricts blood flow to the limbs and directs blood back to the diaphragm.

Performance measures:

- Maximal Oxygen uptake (VO_2max)
- Validation of Carbon Dioxide Production (VCO_2)
- Respiratory Exchange Ratio (RER)
- Heart Rate (HR)
- Maximal Inspiration Pressure (MIP)
- Maximal Expiration Pressure (MEP)
- Blood Oxygen Saturation (SPO_2)
- Work Rate (time)
- Power Output (W)
- Rate of Perceived Exertion (RPE)

The findings of this research will be used for the completion of a thesis within the Masters of Health, Sport and Human Performance.

How was I identified and why am I being invited to participate in this research?

An expression of interest email was sent to tutors within the Toi Ohomai Sport and Recreation faculty which could be forwarded on to students within their programmes. There was no exclusion criteria for this research, though it was beneficial if participants had previous experience in physical training, sports or interest in human physiology. Participants for this research were identified through voluntary expression of interest after an initial brief of the study from their tutor as well as a brief in person talk from the primary researcher. Participants were given the contact details of the primary researcher and expressed their interest to participate via email.

How do I agree to participate in this research?

Your participation in this research is voluntary (it is your choice) and whether or not you choose to participate will neither advantage nor disadvantage you. You are able to withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible.

If you wish to withdraw you can contact the primary researcher or alternatively the project supervisor at any time whose details have been listed in this information sheet.

What will happen in this research?

Research will take place over a 6-7week period:

Week 1-2: Familiarisation session/ pre-testing (Te Pare, Toi Ohomai)

Participants will attend a familiarisation session. In this session the primary researcher will go into detail of the research purpose and the performance measurements that will be recorded for testing. An explanation of the incremental exercise test will be given in this session. Participants will then be given a demonstration on how to perform the nasal breathing intervention, how to correctly apply tape over the mouth, what to expect and how to set the work: rest ratio on the assault bike for the correct exercise structure.

Pre-test: (Te Pare Sport Science Laboratory, Toi Ohomai)

Participants will be given the opportunity prior to undertaking the incremental exercise test to familiarise themselves with the mask of the and set the watt bike up to suit their height.

Prior to testing participants will be fitted with a heart rate monitor (Polar10) and a pulse oximeter. Upon commencement of the incremental exercise test participants will warm up for 1-minute at 0W, at the end of the 1-minute period resistance will be increased to 25W. Work rate will be increased by 25W every 2 minutes until voluntary exhaustion. Peak work rate is recorded at highest (W) that can be maintained for 30-seconds.

Week 3-6: Nasal intervention (4-weeks)

Participants will tape their mouth as shown in the familiarisation session for each of the 12 intervention sessions.

<u>Weeks 1 and 2 structure</u>: (assault bike)

10 rounds

10 seconds max effort: 30 seconds active recovery

Time total: 6.6 minutes

3 times per week

<u>Weeks 3 and 4 structure</u>: (assault bike)

15 rounds

10 seconds max effort: 30 seconds active recovery

3 times per week

Directly after completion of each session within the first 1minute of the last round participants will record their rate of perceived exertion (RPE).

Active recovery will be deemed as continuous arm and leg movement on assault bike at lowest desired intensity over the 30 second period.

Participants can stagger session throughout the week or complete their 3 sessions on continuous days as long as a total of 3 sessions per week are completed.

Each participant will be given their own google document that will only be accessible to the primary researcher and the participant to log each session and record RPE scores. Participants will be given a number which correlates to their name.

Week 7: Post Testing: (Te Pare Sport Science Laboratory Toi Ohomai)

Participants will repeat the incremental exercise test that was performed in the pre-test. Post testing will try and take place at the same time each participant performed their pre-test.

What are the discomforts and risks?

Participants might feel some discomforts when performing the incremental exercise test as they will be pushing themselves to their peak work capacity. Initial stages of the nasal intervention may elicit strong discomfort if participants are not use to breathing nasally during high intensity exercise or having higher levels of CO2. This discomfort should dissipate over time the more familiar participants become with the feeling. Taping of the mouth might also induce a state of discomfort and slight panic but the mouth will only be taped enough to provide the participant with a cue to keep the mouth shut during exercise. If at any time the participant felt they needed to breath orally the tape would be positioned to allow the participant to revert to mouth breathing. Risk of blackout though low is possible if participant is not adapted to the protocol and pushes past their limit.

How will these discomforts and risks be alleviated?

Discomforts will be spoken about during the familiarisation session so participants are aware of these prior to starting the intervention and have an understanding of why a particular discomfort might be happening during their intervention session. Participants will be shown clearly how to tape the mouth in a way that they can still open their lips or talk if they feel the need at any point. The tape's purpose is to cue the participant to keep their mouth shut but won't prevent them from opening their mouth.

What are the benefits?

Participants will gain experience of being part of a research project and how it is conducted. This experience may help them in the future if they were to pursue their own research within the sport and exercise environment.

Participants will get the opportunity to utilise state of the art physiological measuring devices that can provide insight into their personal physiology.

Learn how to implement a protocol that has the potential to improve their performance, which can be transferable into their own sports or training.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will my privacy be protected?

Participant's information and data collected over the 6–7-week period will remain confidential and only accessible to the primary researcher. Participants will have access to their own data but will not be able to see or identify other participants within the study. Any data published in the results of the thesis will maintain participant anonymity from other participants and any person who is to ready the results of this study.

What are the costs of participating in this research?

There are no financial costs involved with this research project. Participants will be giving up there personal time to participate in this training stiudy, which particpants should take into consideration before consenting to participate.

Will I receive feedback on the results of this research?

Once results have been analysed a summary of findings will be provided to each participant. Participants will also have a summary of their personal data sent to them via email.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Martyn Beaven, martyn.beaven@waikato.ac.nz, m: 022-5030577

Whom do I contact for further information about this research?

Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Researcher's Contact Details:

Nathan Stewart

nathan.stewart@toiohomai.ac.nz

027 502 4483

Project Supervisor's Contact Details:

Martyn Beaven

martyn..beaven@waikato.ac.nz

022 503 0577

Appendix 2: Participant Consent Form

Consent Form for Participants

Te Kāhui Manu Tāiko Private Bag 3105

Human Research Ethics Committee Hamilton 3240

Effects of a Nasal Breathing Intervention on Athletic Performance

Consent Form for Participants

I have read the **Participant Information Sheet** for this study and have had the details of the study explained to me. My questions about the study have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I also understand that I am free to withdraw from the study at any time, or to decline to answer any particular questions in the study. I agree to provide information to the researchers under the conditions of confidentiality set out on the **Participant Information Sheet**.

I agree to participate in this study under the conditions set out in the **Participant Information Sheet**.

I would like my information: (circle option)

a) returned to me
b) returned to my whānau
c) other (please specify) ____

I consent / do not consent to the information collected for the purposes of this research study to be used for any other research purposes. (Delete what does not apply)

Participant's Signature: ____

Participant's Name: ____

Date: ____

Researcher's Name and contact information:

____

____

Supervisor's Name and contact information: (if applicable)

____

____

Additional Consent as Required

Examples:

I agree / do not agree to my responses to be tape recorded.

I agree / do nor agree to my images being used

Signed: ____________________________________

Name: ____________________________________

Date: ____________________________________

Appendix 3: Ethics Approval

The University of Waikato
Private Bag 3105
Gate 1, Knighton Road
Hamilton, New Zealand

Human Research Ethics Committee
Roger Moltzen
Telephone: +64021658119
Email:humanethics@waikato.ac.nz

1 September 2022

Nathan Stewart
Te Huataki Waiora School of Health
DHECS
By email: nths1@students.waikato.ac.nz

Dear Nathan

HREC(Health)2022#37: The Effects of Nasal Breathing on Athletic Performance in Athletes

Thank you for your responses to the Committee feedback.

We are now pleased to provide formal approval for your project.

Please contact the Committee by email (humanethics@waikato.ac.nz) if you wish to make changes to your project as it unfolds, quoting your application number with your future correspondence. Any minor changes or additions to the approved research activities can be handled outside the monthly application cycle.

We wish you all the best with your research.

Regards,

Emeritus Professor Roger Moltzen, MNZM Chairperson, University of Waikato Human Research Ethics Committee