INVESTIGATION INTO INTRA-ABDOMINAL PRESSURE AND NEUROMUSCULAR ACTIVATION TO INCREASE FORCE PRODUCTION IN TRADITIONAL MARTIAL ARTS PRACTITIONERS.

A Thesis submitted by

Sherrilyn Walters, GradCert, BappSc

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Abstract

Introduction: The extent to which martial arts practitioners utilise respiratory pressures and neuromuscular activation during force production is not well known. This study investigated whether Chinese wushu (kung fu) practitioners utilise a greater proportion of intra-abdominal pressure (IAP) and neuromuscular activation of the respiratory and pelvic floor muscles to increase their force production compared to healthy control participants.

Methods: Nine trained wushu practitioners and nine healthy untrained control participants were instrumented with skin-surface electromyography (EMG) electrodes on the sternocleidomastoid (EMG_{scm}), rectus abdominis (EMG_{ra}) and the group formed by the transverse abdominal and internal oblique muscles ($EMG_{tra/io}$). A multipair oesophageal EMG electrode catheter measured EMG of the crural diaphragm (EMG_{di}) along with gastric (P_g: a surrogate measure of IAP), transdiaphragmatic (P_{di}), and oesophageal (P_e) pressures. Participants performed two tasks to measure force production: Standing Isometric Push and Standing Isometric Resistance. Participants were familiarised with the tasks and performed a minimum of three efforts for each task. Within-day, between-trial reproducibility intraclass correlation coefficients (ICC) for pressure, force and EMG were > 0.67 for trained and > 0.53 for control participants in the Standing Isometric Push task. ICC were also > 0.86 for trained and > 0.71 for control participants in the Standing Isometric Resistance task.

Results: Compared to the control group, the trained group produced higher levels of force, lower P_e, and higher P_{di} in both tasks ($P < 0.05$). The trained group produced higher P_g and higher $EMG_{tra/io}$ in the Standing Isometric Push task, and higher EMG_{di} in the Standing Isometric Resistance task ($P < 0.05$). The trained group had an earlier onset of P_g with respect to the onset of force production than the control group ($P < 0.05$). The relative contribution of P_g/P_e and P_{di}/P_e were higher for the trained group ($P < 0.05$). Significant positive correlations were found between P_g and absolute force production in both groups ($P < 0.05$).

Conclusions: Trained wushu practitioners appear to utilise IAP to a greater extent than untrained controls with similar physical activity levels to produce higher levels of force. These findings may have implications in a wide range of sports and activities, as these methods may be adapted and taught to individuals to improve performance, prevent injury or aid in rehabilitation.

Thesis Certification Page

This Thesis is entirely the work of Sherrilyn Walters except where otherwise acknowledged. The work is original and has not previously been submitted for any other award, except where acknowledged.

Principal Supervisor: Dr. Dean Mills

Associate Supervisor: Dr. Ben Hoffman

Student and supervisors signatures of endorsement are held at the University.

Dedication

This thesis is dedicated to the memory of Master Chen Qing Ho.

Generous teacher and visionary martial artist.

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Glossary of Abbreviations

IAP – intra-abdominal pressure

P_g – gastric pressure

P_{di} – transdiaphragmatic pressure

P_e – oesophageal pressure

EMG – electromyography

EMG_{scm} – EMG of the sternocleidomastoid

EMG_{ra} – EMG of the rectus abdominis

$EMG_{tra/io}$ – EMG of the group formed by the transverse abdominal and internal oblique

EMG_{di} – EMG of the crural diaphragm

BMI – body mass index

FVC – forced vital capacity

FEV_1 – forced expiratory volume in one second

$P_{e,max}$ – maximum oesophageal pressure

$P_{g,max}$ – maximum gastric pressure

$P_{di,max}$ – maximum transdiaphragmatic pressure

RMS – Root Mean Square

SD – Standard Deviation

Chapter 1: Introduction and Literature Review

1.1 Introduction to wushu

Traditional Chinese Martial Arts stem from a culture that is rich in philosophy and belief structures. Chinese Martial Arts are known in the West by a number of generic terms, with the most common being kung fu. The term kung fu comes from the Chinese characters 功夫, or gōngfu in Mandarin, which means effort, accomplishment, skill, art or workmanship, and can be used to refer to any skill learned through great effort. The term that is most commonly used in China to describe Chinese Martial Arts is wushu (武術／武术 (wǔshù)), which means martial art.

Wushu is a very popular physical activity both in China and world-wide, with over 70 million practitioners in China alone (Theeboom, Zhu, & Vertonghen, 2017). The number of affiliated member countries of the International Wushu Federation rose from 38 in 1991 to 147 in 2014 (Theeboom et al., 2017). The practice of martial arts is also a popular physical activity in Australia, with approximately 1.2% of the adult (15 years old and above) population participating in martial arts (SportAus, 2019). Wushu is widely practiced in Australia, with the Australian Kung Fu (Wushu) Federation Inc. having undertaken accreditation intakes for over 2000 kung fu instructors since 1986 (Kung-Fu-Wushu-Australia, 2020).

Wushu is a broad system of training with the primary aim of preparing the body and mind for combat and/or self-defence. In addition to theoretical and philosophical aspects which are integral to traditional wushu training, the major physical aspects of wushu include basic movement training, form routines, application training, potency training (physical conditioning), and qigong ("chee-gung"). Form routines are complex sequences of movement incorporating mobility, attack, and defence that are passed down from teacher to student and form the core of most traditional wushu systems. Emphasis is placed on practicing form routines in a relaxed manner, not using physical muscle strength alone, but also using “inner space” and “breathing vitality” as the central focus (Chen, 2011).

Qigong is a system of breath control and regulation that is integral to traditional wushu (Lin et al., 2018). The basic components of qigong consist of concentration, relaxation, breath control, breath regulation, body posture, and controlled movement (Lin et al., 2018). Various types of qigong have been developed and practiced in China for approximately 7000 years (Lin et al., 2018). Wushu has been practiced in China for over 1000 years and has been in development for many generations (Su, 2016).

There are many different styles of wushu that are practiced around the world. Chang Hong is a traditional school of wushu that was founded in Taiwan by Master Chen Qing Ho and which follows the historical tradition of teaching Northern and Southern styles of wushu concurrently. Master Chen Qing Ho instructed students to “inhale through the nose into the body, directly into the dantian” (the term dantian in this document refers to the lower dantian and describes the area of the pelvic cavity (Jiang & Zou, 2013)), “without stopping the flow of air in the chest” (Chen, 2005). He placed a strong emphasis on breathing as deeply into the body as possible and allowing the upper body to remain relaxed while “Qi” is allowed to enter the dantian and remain stable there (Chen, 2005). He described the “Qi” stopping in the chest area when the upper body was not relaxed, potentially causing internal injury. He described the breath being drawn along the inner side of the spine into the dantian while lightly raising the anus.

Qigong training is incorporated in wushu training to increase the practitioner's ability to control the breath and use "Qi" to aid in force production and stability. While the traditional concept of "Qi" has many varied interpretations and has not yet been defined in scientific literature (Yao, Yang, & Ding, 2013), "Qi" appears to be associated with internal fluid pressure (Lee, 2018; Yao et al., 2013). Thus, the instruction to allow "Qi" to enter the "dantian" corresponds with increasing pressure in the pelvic and abdominal cavities. The focus in traditional martial arts on keeping the chest area relaxed is in contrast with breathing techniques used in conventional activities such as the Valsalva Manoeuvre, which involves a forced exhalation against a closed glottis, resulting in increased intra-thoracic pressure (Hackett & Chow, 2013). The Valsalva manoeuvre is commonly used by strength athletes during lifting movements such as the deadlift to stabilise the trunk and improve muscle force production through increased intra-abdominal pressure (IAP) (Porth, Bamrah, Tristani, & Smith, 1984; Ikeda et al., 2009).

In wushu literature and instruction, descriptions of Qi, the dantian and other fundamental concepts are most often allegorical or functional in nature, describing what a student should feel or focus on mentally rather than a literal description of the physiological processes involved. For example, the dantian is often described as a "cauldron" producing steam. While these descriptions may be useful for some students, many students find these explanations confusing and difficult to understand. There is very little empirical evidence available to define these theoretical concepts, and the mechanisms behind the production of force and the stabilisation of the body used in wushu have not been adequately investigated.

Accordingly, the aim of this study was to investigate whether wushu practitioners utilise a greater proportion of IAP and neuromuscular activation of the respiratory and pelvic floor muscles to increase their force production compared to healthy control participants. This study represents an important insight into the use of respiratory pressures and associated muscular activity in traditional wushu which will bring increased understanding to this highly developed system of bodily movement and force production. The results of this study may have several applications in terms of improving force production performance in a wide range of sports and physical activities.

1.2 Characteristics of martial arts practitioners

Wushu is a physical activity that is of moderate to high aerobic intensity (depending on the particular style and the practitioner's experience level) and has been reported to have a variety of health benefits. Wushu practice is associated with improvements to strength, submaximal cardiovascular fitness, muscle endurance, bone mineral density, and movement speed (Donovan, Cheung, Catley, McGregor, & Strutton, 2006; Fong et al., 2017; Tsang, Kohn, Chow, & Fiatarone Singh, 2008; Tsang, Kohn, Chow, & Fiatarone Singh, 2010). In addition, wushu practice has been associated with lowered body fat in females and improvements to physical and mental stress responses (Gualdi Russo, Gruppioni, Gueresi, Belcastro, & Marchesini, 1992; Tsang et al., 2008).

1.3 Forces produced by martial arts practitioners

One mechanical component of wushu practice, which underpins some of the health benefits such as strength, movement speed, and bone mineral density, is the production of force in both striking and grappling. A number of research studies have been undertaken to quantify the forces involved in strikes by trained martial arts practitioners, with a few of these focusing on force production in wushu/kung fu practitioners. Direct comparisons between studies are difficult to undertake due to the differences in the types of forces measured and variations in the measurement methodology. Nevertheless, Table 1.1 provides a summary of the research studies that have investigated the forces produced by a range of martial arts practitioners and untrained participants. This table shows that the forces produced by martial arts practitioners can range from over 5000 N in elite boxing and mixed martial arts (MMA) athletes to less than 300 N in novice and inexperienced college-aged individuals (House & Cowan, 2015; Smith, Dyson, Hale, & Janaway, 2000).

Several studies have also directly compared the forces produced by novices or untrained individuals with those produced by experienced martial arts practitioners. For example, Neto, Magini, Saba, & Pacheco (2008) found that advanced wushu practitioners produced significantly higher impact forces than both intermediate and novice participants. Gulledge & Dapena (2008) also observed that professional boxers and MMA athletes produced more punching force than untrained participants. The primary factors leading to the increased ability to generate forces demonstrated by trained martial arts practitioners may include genetics and training history. However, another key factor may be an enhanced control of pressures within the body.

Table 1.1. Summary of forces produced by a range of martial arts practitioners.

Reference	Participant Characteristics (n)	Force produced (N)	Type of strike	Force measurement equipment
Joch, Fritsche, & Krause (1981)	Male boxers		Not reported	Not reported
	Elite (n = 24)	3453		
	National (n = 23)	3023		
	Intermediate (n = 23)	2932		
Wilk, McNair, & Feld (1983)	Male karateka	2400 - 2800	Various	Calculation based on acceleration and estimated mass of fist.
Smith, Dyson, Hale, & Janaway (2000)	Male boxers		Rear hand straight punch	Wall-mounted force plate (4 triaxial piezoelectric force transducers) with a boxing manikin cover.
	Elite (n = 7)	4800 ± 227		
	Intermediate (n = 8)	3722 ± 133		
	Novice (n = 8)	2381 ± 116		
Walilko, Viano, & Bir (2005)	Olympic boxers (n = 7)	3427 ± 811	Straight punch	Hybrid III boxing manikin equipped with a 6-axis load cell in the neck, a Tekscan pressure sensor in the dummy's face, and Endevco accelerometers on the boxer's hands.
Neto, Magini, Saba, & Pacheco (2008)	Male wushu (Yau-Man) practitioners		Palm strike	Participants struck a basketball of known weight and motion analysis was performed to record hand speed and acceleration. Force was calculated from these values and the estimated mass of the fist.
	Experienced (n = 7)	1256 ± 128		
	Novice (n = 6)	859 ± 137		
Gulledge & Dapena (2008)	Male elite boxing and MMA athletes (n = 13)	5000 - 5250	Rear hand punch	StrikeMate^{TM} accelerometer-based commercial force measurement device.
	Untrained punchers (n = 24).	3750 - 4000		
House & Cowan (2015)	Novice and inexperienced college-aged individuals (n = 22)	239 ± 111	Straight punch	F-Scan force sensory shoe sole attached to a punching bag.

1.4 Pressures in the body

The human body is largely made up of water, with the total body water comprising approximately 50-60% of adult body weight (Chumlea et al., 1999). Due to the near incompressible nature of water, forces exerted on compressible vessels containing water cause an increase in hydrostatic pressure throughout the fluid-filled vessel. In more complex hydrostatic or hydraulic systems, this concept can be used to communicate mechanical force from one point of the system to another through fluid-filled pipes or vessels, which is the basis of most hydraulic machinery (Akers et al., 2006). Fluid spaces exist throughout the body, including within and between cells, organs, and muscles. The interstitium is a term describing these fluid-filled spaces. Through the use of confocal laser endomicroscopy, Benias et al. (2018) reported that the interstitium comprises not only spaces between cells, but also visible fluid-filled spaces within tissues throughout the body, including the submucosa, dermis, and fascia, that are dynamically compressible and distensible and through which interstitial fluid flows. Figure 1.1 shows the locations where interstitial spaces have been found in the body.

Due to the relative size and structure of the trunk, the thoracic and abdominal cavities produce and contain large amounts of pressure. It has been observed that the contraction of the diaphragm and the passive or active contraction of the abdominal wall and pelvic floor muscles are the key factors involved in the determination of intra-abdominal pressure (Emerson, 1911). Respiratory pressures are of great importance in activities such as martial arts practice, which incorporates a highly developed system of breath control.

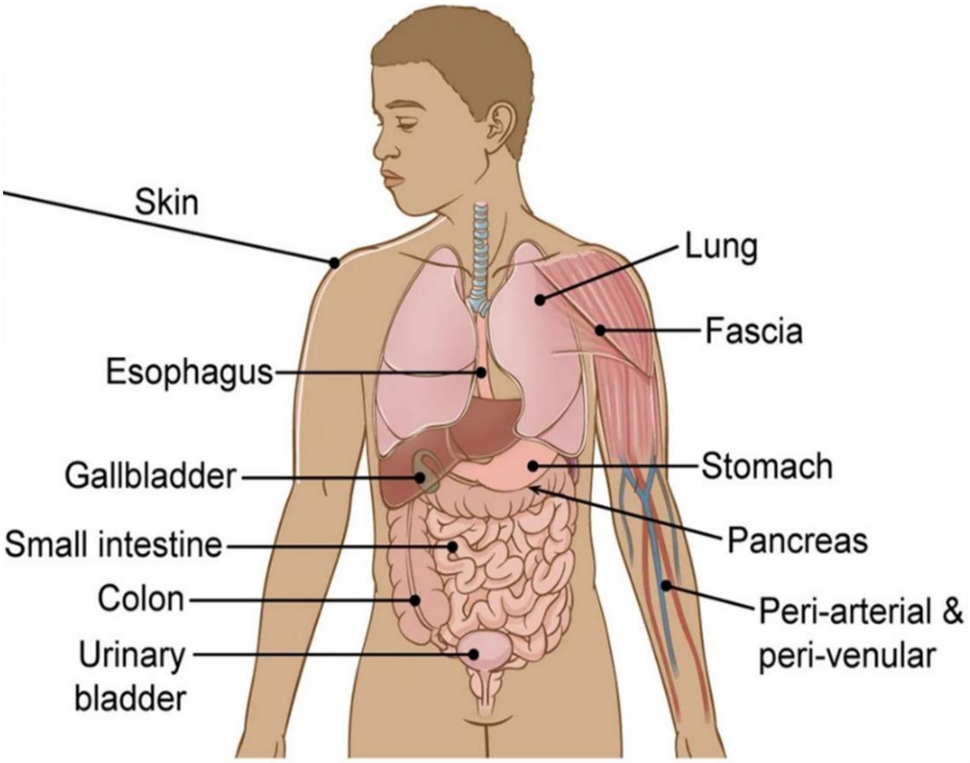

Figure 1.1. Schematic showing the locations of identical histologic structures (interstitial spaces) seen in fibroconnective tissues throughout the body. Reprinted from "Structure and Distribution of an Unrecognized Interstitium in Human Tissues," by Benias et al., 2018, Sci Rep 8, 4947 (2018). Illustration by Jill Gregory, licenced under CC-BY-ND. (https://creativecommons.org/licenses/by-nd/4.0/legalcode).

1.5 Control of intra-abdominal and fluid pressures in the body

The pressure generated within the abdominal cavity can be distributed among surrounding structures, and the effects of a raised IAP include increased arterial blood pressure and cerebrospinal fluid pressure (Narloch & Brandstater, 1995; Porth, Bamrah, Tristani, & Smith, 1984; Sale, Moroz, McKelvie, MacDougall, & McCartney, 1993). In addition, it has been found that pressures in the blood and lymph spaces are affected by intra-abdominal pressure (Emerson, 1911). Due to its near incompressible nature, fluid in the body has the potential to transmit or oppose forces. The distribution of IAP to surrounding structures may also have an effect on forces produced by muscle contractions in other areas of the body. Sleboda & Roberts (2019) tested a model of muscle structure, which was pressurised during the middle of an isometric contraction using a pneumatic cuff. The authors observed that pressurisation increased isometric force at long muscle lengths. These observations provide a sufficient foundation to posit that changes in IAP could affect internal fluid pressure in other parts of the body due to the interconnected whole of the interstitium. In turn, this fluid pressure could affect intramuscular fluid pressure which has been found to play a role in muscular force production (Sleboda & Roberts, 2019).

1.6 Intra-abdominal pressure and the control of force production

IAP is the pressure created within the abdominal cavity and it is considered to play an important role in supporting and stabilising the trunk (Aspden, 1987; Cholewicki, Juluru, & McGill, 1999; Cresswell, Oddsson, & Thorstensson, 1994; McGill & Sharratt, 1990; Stokes, Gardner-Morse, & Henry, 2010). IAP has also been found to be associated with improved performance in a range of sports including weight lifting (Cresswell et al., 1994; Kawabata, Shima, & Nishizono, 2014; Tayashiki, Kanehisa, & Miyamoto, 2018; Tayashiki, Mizuno, Kanehisa, & Miyamoto, 2017), swimming (Moriyama et al., 2013; Ogawa, Shima, Ohta, Kawabata, & Zushi, 2012), rowing (Manning, Plowman, Drake, Looney, & Ball, 2000), and running (Grillner, Nilsson, & Thorstensson, 1978). In addition, IAP is believed to aid in heavy load carrying by stiffening and stabilising the spine and pelvis (Brown & McConnell, 2012), and functional respiratory muscle training has been found to improve load carriage performance (Faghy & Brown, 2019).

The most notable observation of the use of IAP to control force production is the Valsalva manoeuvre. This is commonly employed by athletes to increase lumbar stability and force production by increasing IAP during resistance exercises (Hagins, Pietrek, Sheikhzadeh, &

Nordin, 2006; Kawabata, Shima, Hamada, Nakamura, & Nishizono, 2010; Tayashiki et al., 2018). The Valsalva manoeuvre involves a forced exhalation against a closed glottis to pressurise the trunk and intra-abdominal cavity (Hackett & Chow, 2013). The Valsalva manoeuvre is widely used and is thought to be unavoidable when maximal voluntary contraction exceeds 80% (MacDougall et al., 1992). In addition to providing lumbar stability, the use of the Valsalva manoeuvre has been found to increase maximal muscle strength (Ikeda et al., 2009). Ikeda et al. (2009) assessed the effect of voluntary breathing conditions on maximal isometric force during maximum voluntary isometric contractions of large muscle groups. The breathing conditions assessed were normal breathing, forced inhalation, forced exhalation and the Valsalva manoeuvre. The authors found that the Valsalva manoeuvre and forced exhalation resulted in significantly increased peak force during shoulder adduction, elbow extension and knee extension. However, IAP was not measured and therefore whether IAP was utilised to control force production is unknown. Other mechanisms that have been shown to contribute to increased muscle strength are the kiai, a vocalisation utilised in some systems of martial arts, and grunting (O'Connell, Hinman, Hearne, Michael, & Nixon, 2014; Sinnett, Maglinti, & Kingstone, 2018).

The measurement of IAP is invasive and thus only a few studies have investigated IAP and the control of force production. IAP can be measured directly via an abdominal trochar, but most commonly IAP is assessed using a surrogate measure. Surrogate measures used include intra-rectal pressure, measured using a rectal pressure catheter, and gastric pressure (P_g), measured using a pressure catheter positioned through a nare and into the stomach. P_g has been shown to have a close relationship to IAP measured directly via an abdominal trochar (Turnbull, Webber, Hamnegard, & Mills, 2007).

The association between IAP and force production is not well understood and current findings are summarised in Table 1.2. Hagins et al. (2006) reported that IAP appeared to be unrelated to force production during maximal isometric trunk exertion in a knee bent position, however, this study was not performed on trained individuals. In addition, the changes in IAP that occurred during the maximal isometric trunk exertion tasks were considerably lower than the changes observed in other studies that showed a positive correlation between IAP and force production (Tayashiki et al., 2018; Tayashiki et al., 2017), indicating that a sufficient level of IAP may be required in order to influence force production.

Some studies have found a delay between production of IAP and the onset of force or torque (Harman, Rosenstein, Frykman, & Nigro, 1989; Marras, Joynt, & King, 1985), indicating that IAP may not contribute substantially towards maximum force production. Harman et al. (1989) asked participants to perform a deadlift while standing on a force platform and IAP was measured using a gastric pressure catheter alongside ground reaction forces. The authors observed that the increase in IAP ended before peak ground reaction forces occurred. In addition, Marras et al. (1985) investigated IAP using a gastric pressure catheter whilst participants exerted force with their back against a dynamometer in various isometric and isokinetic lifting positions. The authors found that there was a delay between the onset of IAP and the onset of torque in higher velocity conditions. However, neither of these studies were performed on trained individuals. Trained individuals may learn how to increase IAP for longer periods of time than untrained individuals. This may allow the trained individuals to sustain high levels of IAP throughout the production of force or torque.

Table 1.2. Summary of research investigating intra-abdominal pressure (IAP) and force production.

Reference	Participant tasks	Participants	Pressure measure	Neuromuscular activation measure	Force measure	Findings
Kawabata et al. (2014)	Quick dynamic dead lifts at various % isometric maximal lifting effort.	11 healthy men.	Intrarectal pressure transducer.	N/A	Dynamic lifting was performed on a force plate.	Preparative pre-lifting behaviours alter IAP and breathing and appear to be functionally important for dynamic lifting. Both the peak rate of IAP development and peak IAP increased with an increase in lifting load.
Tayashiki et al. (2018)	Hip extension during breath-hold at full inspiration, expiration or during normal breath-hold.	18 healthy men.	Intrarectal pressure transducer.	EMG of gluteus maximus, rectus femoris, vastus lateralis, biceps femoris and semitendinosis.	Hip extension maximal voluntary isometric contraction torque measured by dynanometer.	Suggests that a sufficient increase in IAP has a causal effect to improve the muscle strength of hip extensor.
Tayashiki et al. (2017)	Hip extension during breath-hold at full inspiration, expiration or during normal breath-hold.	12 active healthy men.	Intrarectal pressure transducer.	EMG of rectus abdominis, oblique external, oblique internal and erector spinae.	Hip extension maximal voluntary isometric contraction torque measured by dynanometer.	Study suggests that IAP has a positive causal effect on hip extension maximal voluntary isometric contraction torque. A sufficient IAP increase directly led to enhanced hip extension torque.
Essendrop, Hye-Knudsen, Skotte, Hansen, & Schibye (2004)	Heavy and sudden trunk loads.	10 well-trained judo and jujitsu fighters - 5 men and 5 women.	Gastric catheter.	N/A	Exposed to heavy sudden loads through imitated patient handling situations involving holding a falling patient.	IAP increased when trunk was loaded, and high IAP developed sufficiently fast to be present when the low-back structures had to cope with the large torques released from the sudden trunk loading.
Harman et al. (1989)	Deadlift with and without a lifting belt at 90% of 1-repitition maximum.	1 healthy woman and 8 healthy men.	Gastric catheter.	N/A	Ground reaction force was measured with a force platform.	IAP increased during deadlifting tasks. IAP was found to rise significantly earlier with than without the belt. Peak IAP and average IAP were also found to be significantly greater with than without the belt.

Table 1.2 Continued.

Reference	Participant tasks	Participants	Pressure measure	Neuromuscular activation measure	Force measure	Findings
Cresswell et al. (1994)	Maximal and sub-maximal lifting and lowering tasks.	7 healthy men.	Gastric catheter.	EMG of transversus abdominis, obliquus internus, obliquus externus, rectus abdominis.	Isokinetic dynamometer.	IAP increased linearly with increasing force in sub-maximal efforts, and IAP was highest during the fastest lifts. A strong correlation between IAP and transversus abdominis EMG was found.
Hagins et al. (2006)	Maximal trunk extension.	13 healthy men and healthy 20 women.	Gastric catheter.	N/A	Force transducer on a specially constructed weight-lifting device	No significant effects of breath control were found on maximal isometric trunk extension force. Breath control was correlated to changes in IAP. No correlation between force and IAP relative to breath control was found.
Cholewicki et al. (1999)	Isometric trunk flexion, extension and lateral bending exertions under various voluntary levels of IAP generation, trunk muscle contraction and breathing conditions.	9 healthy men and 1 healthy woman.	Gastric and oesophageal catheter.	EMG of latissimus dorsi, thoracic erector spinae, lumbar erector spinae, internal oblique, external oblique and rectus abdominus	N/A	IAP was associated with spine stability and compression force and co-contraction of 12 major trunk muscles. It was not possible to co-contract trunk muscles without generating IAP or generate IAP without trunk muscle co-contraction. IAP rose with isometric exertion, but force was not measured.

There are also a number of studies that indicate a positive relationship between IAP and external forces produced. Tayashiki et al. (2017; 2018) found that IAP was associated with hip extension maximum voluntary contraction torque and that this had positive causal effect on hip extensor muscle strength. In addition, Cresswell et al. (1994) found that IAP increased linearly with lifting and lowering force and concluded that an increase in IAP played a functional role in lifting and lowering activities. Finally, it has been observed that IAP plays an important role in preparative pre-lifting behaviour in dynamic deadlifting. Kawabata et al. (2014) found that the rate of IAP development and peak IAP (measured using an intrarectal pressure transducer while participants performed quick dynamic deadlifting tasks) increased with an increase in lifting load.

Figure 1.2 is a simplified diagram which demonstrates the working hypothesis of the mechanism by which we propose that IAP may be produced and utilised in the body to produce force. We propose that when producing force, a trained individual increases fluid pressure in the pelvic and abdominal cavities through the combined activation of the diaphragm, pelvic floor musculature and abdominal musculature. When an action is performed, such as a push with the arm, this pressure flows through the fluid filled spaces and tissue in the body and increases fluid pressure within relevant muscle groups, amplifying the force that can be produced.

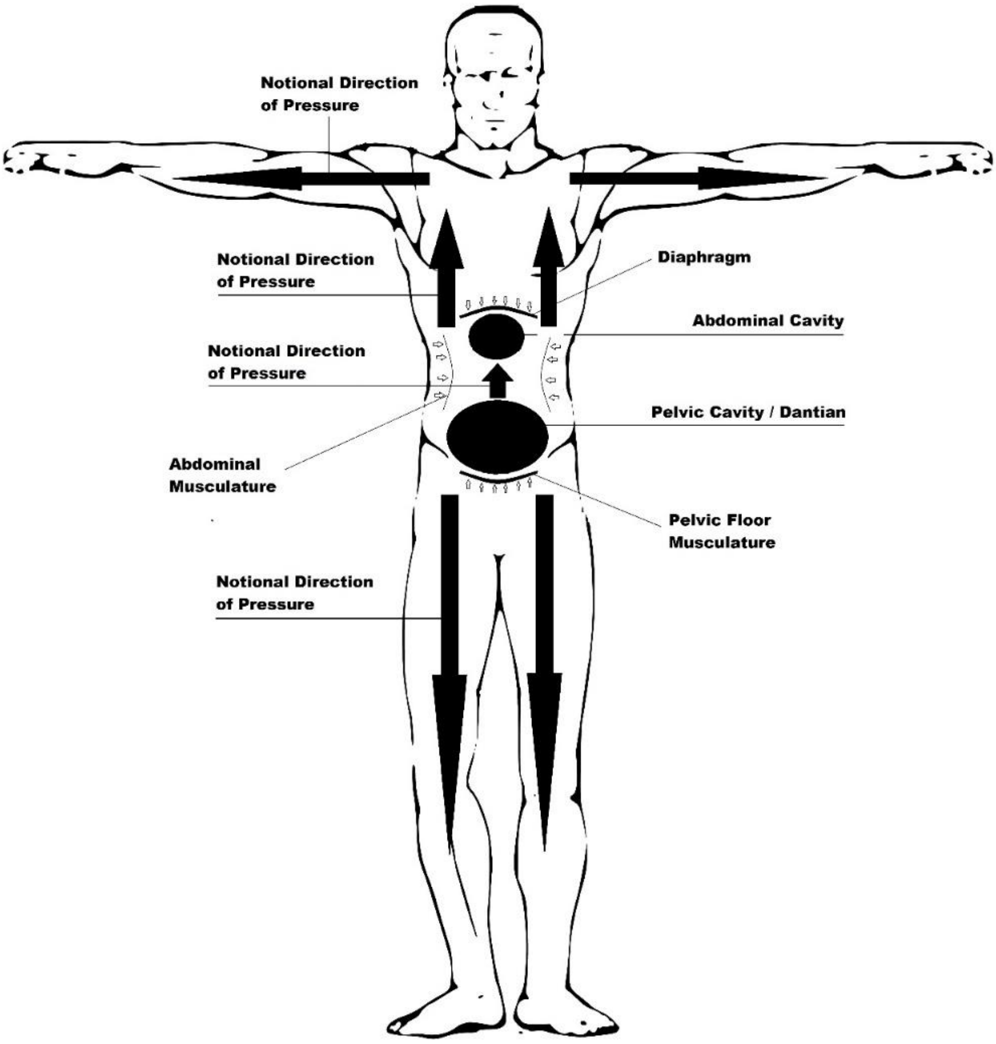

Figure 1.2. Simplified notional model of the pressure - force hypothesis. Illustrated by author.

1.7 Effect of exercise activities on respiratory musculature

A number of studies have shown training induced changes in respiratory musculature from exercise activities. Mandanmohan, Jatiya, Udupa, & Bhavanani (2003) reported that six months of yoga training increased maximum expiratory and inspiratory mouth pressures. In addition, a six week yoga training intervention also resulted in an increase in maximum expiratory and inspiratory mouth pressures and maximal breathing capacity in frail older adults (Cebrià i Iranzo, Arnall, Igual Camacho, & Tomás, 2014). In cadavers, it was reported that individuals who were muscular and physically active had larger diaphragm muscle mass than non-active individuals (Rochester, Arora, & Braun, 1982). Resistance exercise training has also been found to increase diaphragm recruitment (Al-Bilbeisi & McCool, 2000), and world class powerlifters were found to have greater maximum expiratory and inspiratory mouth pressures and diaphragm thickness than controls (Brown et al., 2013). Collectively, these studies suggest that training that includes breath control exercises such as yoga or resistance training leads to increased respiratory muscle size and function in participants.

1.8 Neuromuscular activation and intra-abdominal pressure

One component of force production that may underpin the relationship between IAP and force production is the level of neuromuscular activation of the diaphragm, abdominal musculature and pelvic floor musculature. Cresswell et al. (1994) found that the transversus abdominis muscles were strongly associated with IAP during lifting and lowering activities. In addition, Cholewicki et al. (1999) reported that IAP and trunk muscle co-contraction (measured with electromyography (EMG)) was tightly coupled when participants performed isometric trunk flexion, extension, and lateral bending exertions while generating 0%, 40% and 80% of their maximal IAP (measured with a gastric pressure catheter) or while co-contracting trunk muscles without consciously raising IAP. Hemborg, Moritz, & Löwing (1985) tested patients with lower back pain or weakness and weightlifters who undertook various breathing techniques during lifting tasks. The authors measured IAP and intrathoracic pressures (using gastric and oesophageal catheter pressure transducers), calculated transdiaphragmatic pressure, and measured EMG of the oblique abdominal, erector spinae, and puborectalis muscles (in some cases). A positive correlation between abdominal musculature and IAP was found and it was hypothesised that the diaphragm appeared to be the most important of the muscle groups for affecting IAP.

In contrast, McGill and Sharratt (1990) measured IAP (using a gastric pressure catheter) and muscle EMG of the rectus abdominis, external oblique, internal oblique, intercostal, and erector spinae during several tasks involving abdominal muscle activation. The authors did not find any consistent relationships between IAP and the muscle EMG of any particular muscle group when observed over the range of activities performed in the study, but found that the relationship between muscular activation and IAP generation appears to be task specific. In contrast to the other studies mentioned above, which generally measured EMG single peak amplitudes taken from a single point of time, McGill and Sharratt (1990) measured and observed EMG ‘time histories’. This may explain the difference in results.

Collectively, these studies suggest a link between IAP and neuromuscular activation of the diaphragm and the abdominal musculature. Any detailed study into IAP production should thus also include the monitoring of neuromuscular activation in order to more fully describe the contribution of key muscle groups.

1.9 Control of IAP and stability

The development of stability is one of the key goals of traditional martial arts training, as stability plays a role in the practitioner’s ability to generate and redirect forces, and in the prevention of injury. We propose that wushu practice may improve an individual’s lumbar stability and maintenance of posture and balance due to a greater control of IAP developed through training.

IAP has been reported to have a role in spinal stabilisation and spinal unloading and may help to prevent spinal injury during exercise (Arjmand & Shirazi-Adl, 2006; Aspden, 1987; Cholewicki et al., 1999; Cresswell et al., 1994; Stokes et al., 2010). Stokes et al. (2010) utilised a modified biomechanical model of the spine and associated musculature to test whether increased IAP was associated with reduced spinal compression forces. This model predicted that an increase in IAP would result in a reduction in spinal compressive force. In addition, Cresswell et al. (1994) concluded that an increase in IAP could have a dual function of stabilising the trunk and reducing compression forces on the lumber spine and that IAP may play a role in stabilising the trunk by stiffening the whole segment during sudden perturbations delivered to the trunk. Due to the roles that spinal and trunk stability play in the maintenance of balance (Anderson & Behm, 2005), IAP may play an important role in maintaining posture and in the prevention of falls.

1.10 Control of IAP in martial arts

There are a small number of studies that have attempted to determine the effect of other systems of martial arts training on the control of IAP. Kawabata et al. (2010) compared maximal isometric trunk flexor strength and IAP during isometric lifting tasks and found that trained judo practitioners had higher maximum IAP and stronger trunk flexor muscles than untrained controls. IAP was measured with an intra-rectal pressure transducer. However, this study did not measure muscular activation of the diaphragm and abdominal musculature or intra-thoracic pressure, which may be important to show the mechanisms involved in IAP generation and the differences between how trained and untrained individuals generate and utilise IAP. Essendrop et al. (2004) measured IAP using a gastric pressure catheter in well-trained judo and jujitsu fighters during a task involving sudden heavy trunk loading. This task required participants to support a person, who was simulating a fall at an unexpected time, and prevent the person from falling. It was found that the trained participants were able to develop high IAP at sufficient speed to be present when the lower-back structures had to cope with the large torques produced by the sudden trunk loading. However, this was not a comparative study involving trained and untrained participants.

Compared to other martial arts systems such as judo and jujitsu, traditional wushu has a significantly longer history of development (Henning, 1999). Wushu theory and practice contain a complex and developed body of knowledge surrounding breath control (qigong) and the control of internal pressures. As such, we propose that wushu practice may result in a greater level of control of internal pressures, including IAP, and an improved ability to utilise internal pressures to amplify force production by virtue of increasing the fluid pressure in muscle tissue. To our knowledge, no existing research has quantified the characteristics of force production and respiratory physiology that result from training in wushu and how these characteristics compare to untrained controls.

1.11 Summary

The martial art of traditional wushu contains the cumulative knowledge of centuries of in-depth practical and theoretical study into human movement and force production. One of the key areas of focus in traditional wushu relates to the control and development of internal pressures for use in combat applications involving producing and redirecting force which is a key component in both striking and grappling. The increased ability to generate forces demonstrated by martial arts practitioners may be due to enhanced control of pressures within the body, amongst other factors such as improved biomechanics and physiological conditioning. IAP is the pressure created within the abdominal cavity and its primary function is considered to be in supporting and stabilising the trunk. The relationship between IAP and force production is currently not well understood. Some studies report that IAP has a causal effect on hip flexor muscle strength and that it is correlated with lifting movements, but strong correlations between IAP and the strength of other muscle groups have not been shown. In addition, some studies have found that the timing of peak IAP and peak force or torque production do not align sufficiently for IAP to have a significant contribution to maximal force production. However, these studies did not include trained individuals, who may have a greater ability to generate and utilise IAP. Furthermore, some studies have found a link between martial arts training, higher levels of IAP and, potentially, improved control of IAP. However, this has yet to be observed in traditional wushu practitioners, who may display greater levels of control of IAP than some other systems of martial arts, due to the focus on generation and control of internal pressures that exists in wushu qigong training. Additionally, the role of neuromuscular activation of the diaphragm and abdominal musculature in IAP production in trained wushu practitioners should be compared to untrained controls.

1.12 Aims and Hypothesis

The aim of the study was to quantify and compare IAP and neuromuscular activation between trained wushu practitioners and untrained control participants during tasks requiring maximum isometric force production. We also investigated whether there was a relationship between IAP and absolute force production in these tasks. Our working hypothesis is that wushu-trained individuals have an increased ability to produce high IAP and utilise this pressure to augment force production and stabilise the body.

In this study, a multipair oesophageal EMG electrode catheter incorporating oesophageal and gastric pressure transducers was used to measure diaphragmatic EMG and transdiaphragmatic, oesophageal, and gastric pressures. Surface EMG measurements were also taken of the sternocleidomastoid, rectus abdominis and the group formed by the transverse abdominal and internal oblique muscles. A group of trained wushu practitioners and healthy, untrained controls performed isometric resistance tasks that involved the production of force or the resisting of force applied close to or against the trunk while maintaining a stable body position. These tasks were chosen because they were simple activities that were easy for both groups to perform without prior training but were also directly related to functional tasks performed in martial arts. The Standing Isometric Push task related directly to generating force in linear forward strikes or pushes, while the Standing Isometric Resistance task related directly to stabilising the body when dealing with incoming forces such as an impact or a push from an opponent. We hypothesised that wushu practitioners would produce higher IAP, utilise a greater percentage of EMG activity of key muscle groups, and be able to produce greater forces during isometric push and resistance tasks than untrained, healthy, active individuals.

1.13 Significance

This study will for the first time provide a comprehensive understanding of IAP, intra-thoracic pressure, and neuromuscular activation of the diaphragm and key muscle groups in trained wushu practitioners compared to untrained controls during force production in isometric resistance tasks. This study will contribute to the development of the emerging understanding of the importance of fluid pressure in the human body and how this contributes to human movement and force production. Furthermore, we propose that the practice of wushu offers a method for increasing an individual’s control of IAP, their ability to generate high levels of IAP and their ability to utilise IAP to increase force production and stabilise the body. It is proposed that these methods could be adapted and taught to individuals in a wide range of sports and activities to improve performance and prevent injury. These methods may also have importance in rehabilitation from injury and in exercise programs for older populations focused on improving muscular strength and stability in a safe and sustainable manner.

Chapter 2: Methods

2.1 Participants

Nine trained martial arts practitioners and nine age-, sex-, height-, and weight-matched controls that were free from respiratory disease participated in the study (Table 2.1). A self-reporting medical history questionnaire (Appendix 1) confirmed that participants met the inclusion criteria (Appendix 2 and 3) and a Lifetime Physical Activity Questionnaire (Appendix 4) confirmed that control participants did not have significant prior martial arts experience. The trained martial arts participants had undergone training in the Chang Hong system of kung fu for at least one year (7.3 ± 7.2 years), including an intensive twelve-month qigong training program. This training program included daily practice of qigong breathing exercises and some basic potency training exercises that had been adapted from the traditional Chang Hong wushu system. The qigong exercises consisted of slow, controlled breathing combined with various arm movements and concentration on the sensation of the movement of "qi" during the exercises. The potency exercises consisted of performing various isometric movements while focusing on building and maintaining a feeling of connection from the dantian to the relevant limbs. All study procedures were approved by the University of Southern Queensland Research Ethics Committee, which adheres to the Declaration of Helsinki (Appendix 5). All participants provided written, informed consent prior to participation in the study (Appendix 6).

2.2 Experimental design

The study utilised a case controlled cross-sectional design. Participants attended the laboratory on one occasion 4 h postprandially. During the visit, height, body mass, and pulmonary function were initially assessed. Subsequently, participants were familiarised with all other measurements. Participants were then instrumented with skin surface EMG and an oesophageal

EMG catheter. Participants then repeated the pulmonary function measurements and undertook maximal respiratory pressure measurements before performing two tasks: the Standing Isometric Push task and the Standing Isometric Resistance task. These two tasks involved the participant producing (Standing Isometric Push) or resisting (Standing Isometric Resistance) force close to or against the trunk while maintaining a stable body position. The Standing Isometric Push task was performed first, in which the participant was required to push against a load cell fixed to a wall with maximum force while maintaining an isometric position. The Standing Isometric Resistance task was subsequently performed, in which the researcher applied a pushing force against the participant's sternum and the participant was required to resist this force while maintaining an isometric position. While either task could have been performed first, the Standing Isometric Push was performed first to ensure that the participants were fresh for this task, which required the participants to play a more active role. These tasks were chosen because they were simple tasks which could be performed easily by both the trained and control groups. Further, both tasks were structured in a way that would reduce the ability of the participant to use their body weight to produce or resist force by leaning due to the strict constraints applied to the posture of the participant during the testing.

2.3 Pulmonary function and maximal respiratory measurements

Pulmonary function was assessed according to published guidelines (Miller et al., 2005) using a spirometer (JAEGER® Vyntus; CareFusion, San Diego, CA, USA). Maximal gastric ($P_{g,max}$), oesophageal ($P_{e,max}$), and transdiaphragmatic ($P_{di,max}$) pressures were assessed according to published statements (ATS/ERS, 2002; Laveneziana et al., 2019). The distal end of a calibrated pneumotachograph (Model 3813; Hans Rudolph, Shawnee Mission, KS, USA) was closed and incorporated a 1 mm orifice to prevent glottic closure during efforts which were initiated from residual volume ($P_{e,max}$ and $P_{di,max}$) or total lung capacity ($P_{g,max}$). Mouth pressure was measured using a calibrated transducer (MLT844; AD Instruments, Bella Vista, Australia) inserted into the mouth port of the pneumotachograph. All respiratory function manoeuvres were performed whilst standing and sustained for at least 3 s. Repeat efforts separated by 30 s were performed until three serial measures differed by no more than 10% or 10 cmH_2O, whichever was smallest (Mills et al., 2014). The highest value recorded was used for subsequent analysis. These maximal pressure manoeuvres were used to determine maximal pressure and EMG responses.

Table 2.1. Participant anthropometrics and respiratory function. Values are mean ± Standard Deviation (SD).

Variable	Trained (n = 9)	Control (n = 9)	P Value
Age, years	37 ± 12	36 ± 11	0.84
Male / Female	6 / 3	6 / 3	
Height, m	1.76 ± 0.07	1.76 ± 0.09	0.88
Body mass, kg	78.2 ± 18.5	81.6 ± 14.6	0.68
BMI, $kg \cdot m^{-2}$	25.1 ± 5.0	26.3 ± 3.6	0.56
Self-reported physical activity, $MET \cdot min \cdot wk^{-1}$	639 ± 476	324 ± 247	0.10
FVC, L (%predicted)	4.47 ± 0.70 (93 ± 13)	5.09 ± 1.19 (104 ± 13)	0.08
FEV_1, L (%predicted)	3.76 ± 0.63 (95 ± 11)	4.10 ± 0.80 (103 ± 13)	0.16
$P_{e,max}$, cmH_2O	95.5 ± 40	94.8 ± 31.8	0.96
$P_{g,max}$, cmH_2O	173 ± 74.1	153 ± 58.1	0.53
$P_{g,max}$, cmH_2O / BMI	6.94 ± 2.67	5.83 ± 2.11	0.34
$P_{di,max}$, cmH_2O	140 ± 48	122 ± 60	0.48

Abbreviations = BMI, body mass index; FVC, forced vital capacity; FEV_1, forced expiratory volume in one second; $P_{e,max}$, maximum oesophageal pressure; $P_{g,max}$, maximum gastric pressure; $P_{di,max}$, maximum transdiaphragmatic pressure. Predicted values for pulmonary volumes and capacities are from Quanjer et al., (2012).

2.4 Standing Isometric Push Task

A load cell (Boxing Training Kit, Loadstar Sensors, Fremont, CA, USA) sampling at 1 kHz, was calibrated before testing across the physiological range and used to collect force data. The output from the load cell was recorded with software (LoadVUE for Boxer Training, Loadstar Sensors, Fremont CA, USA) for live viewing of the force trace and for offline processing. The load cell was affixed to the wall at a height of 1.12 m above the floor of the laboratory and the load cell plate had dimensions of 37 × 45 cm. The participant was positioned in front of the load cell at a distance that ensured their right palm was in contact with the load cell while their elbow maintained ~110° of flexion. This angle was confirmed using a standard goniometer aligned to the lateral epicondyle of the elbow, the acromion process in the centre of the humerus, and the ulnar styloid. The participant was free to place their arm at a position on the load cell plate that was most comfortable for them, providing they maintained ~110° of elbow flexion. To ensure the participant was not leaning into the load cell, a video camera was positioned perpendicular to the participant to record their head and upper torso movement. Using movement analysis software (Kinovea, version 0.8.15, www.kinovea.org) a vertical line was drawn on either side of the participant's head on the live video output. The live video output was displayed on a screen in front of the participant. If the participant was found to be leaning during a task, the task was repeated.

To perform the Standing Isometric Push task, the participant was instructed to apply as much sustained force as possible in a push against the load cell for 10 s without leaning forward, making any rapid 'jerking' movements, and/or pushing themselves away from the load cell (i.e. they were instructed to apply force in a steady and sustained fashion). If a change in position occurred, or if force was not applied steadily, participants were provided with feedback and the task was repeated. No instructions were given to the participant on how to breathe or produce force during the task. Repeat efforts were separated by 30 s and were performed until three measurements differed by no more than 10%. This process was repeated again with the left arm. Most participants only required 3-4 repetitions with each arm to achieve consistent results, while some participants improved after the first few repetitions, in which case the measurements were repeated until consistent results were achieved. The values obtained from three tasks on each arm were used for subsequent analysis.

The data from the load cell was time-aligned with the pressure and EMG data recorded using the data acquisition system (PowerLab 16/35, AD Instruments, Bella Vista, Australia) using a simultaneous signal on both platforms. To achieve this, electrocardiograph electrodes were attached to the plate of the load cell, and prior to each push task the load cell was tapped creating simultaneous responses in both software packages. The coordination of the pressure and EMG data and the load cell data output allowed for time-alignment in subsequent data analysis. A schematic representation of the Standing Isometric Push task experimental setup is shown in Figure 2.1.

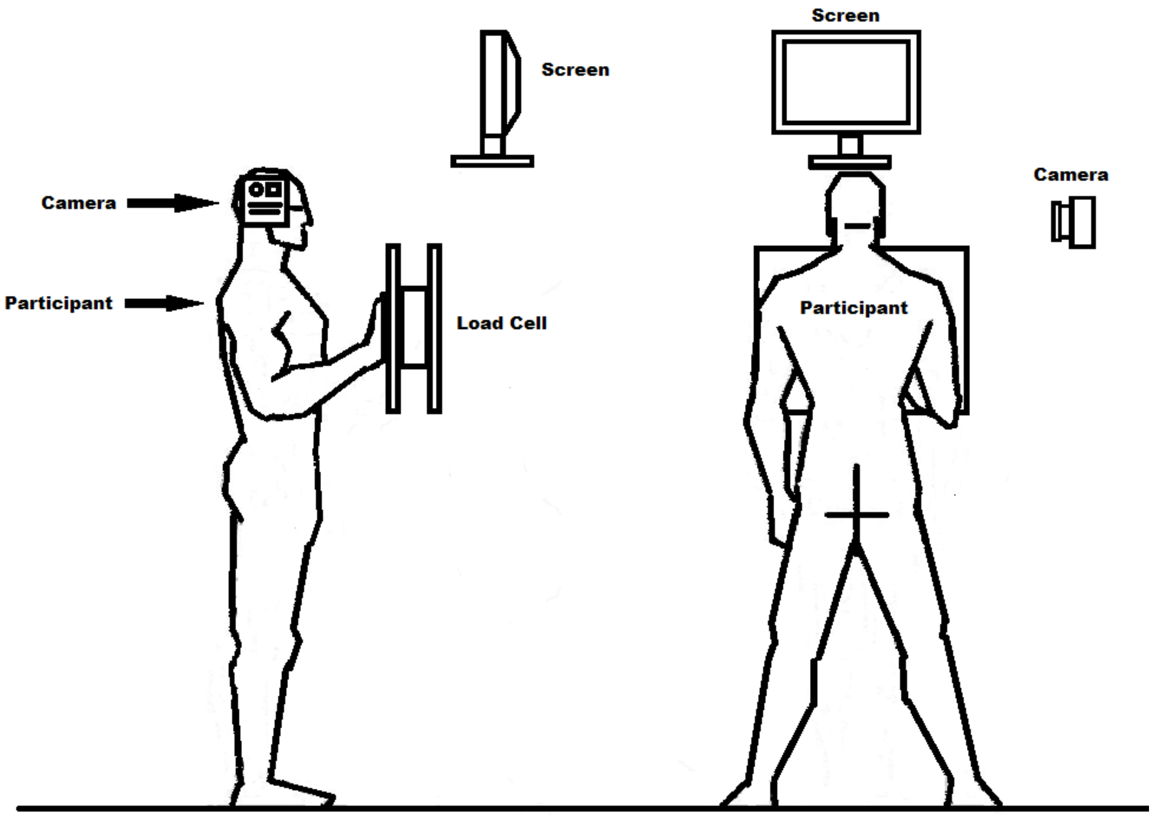

Figure 2.1. Schematic representation of the Standing Isometric Push task experimental setup.

2.5 Standing Isometric Resistance Task

The participants were instructed to stand fully upright with their feet in line, approximately shoulder width apart. A calibrated handheld grip strength dynamometer (MLT004/ST Grip Force Dynamometer, AD Instruments, Bella Vista, Australia) was placed by the researcher on the participant's chest at the centre of the participant's sternum. A padded block was attached to the dynamometer to avoid discomfort to the participant. From this position, the researcher applied force slowly and steadily against the participant's sternum at rate of approximately 7 N/s. This rate of force application was monitored by the researcher via visual inspection of the force output on LabChart Pro software (AD Instruments, Bella Vista, Australia). Kinovea movement analysis software was used to ensure the participants did not lean during the task. If the researcher noted a participant leaning forwards, the task was stopped and repeated after a 30 s pause. The researcher applied steady pressure via the dynamometer until the participant stepped backwards. The dynamometer was then immediately removed from the participant's chest. No instructions were given to the participant on how to breathe or produce force during the task. The task was repeated with 30 s breaks between tasks until three measurements differing by no more than 10% were collected. Most participants only required 3-4 repetitions to achieve consistent results, while some participants improved after the first few repetitions, in which case the measurements were repeated until consistent results were achieved. A schematic representation of the Standing Isometric Resistance task experimental setup is shown in Figure 2.2.

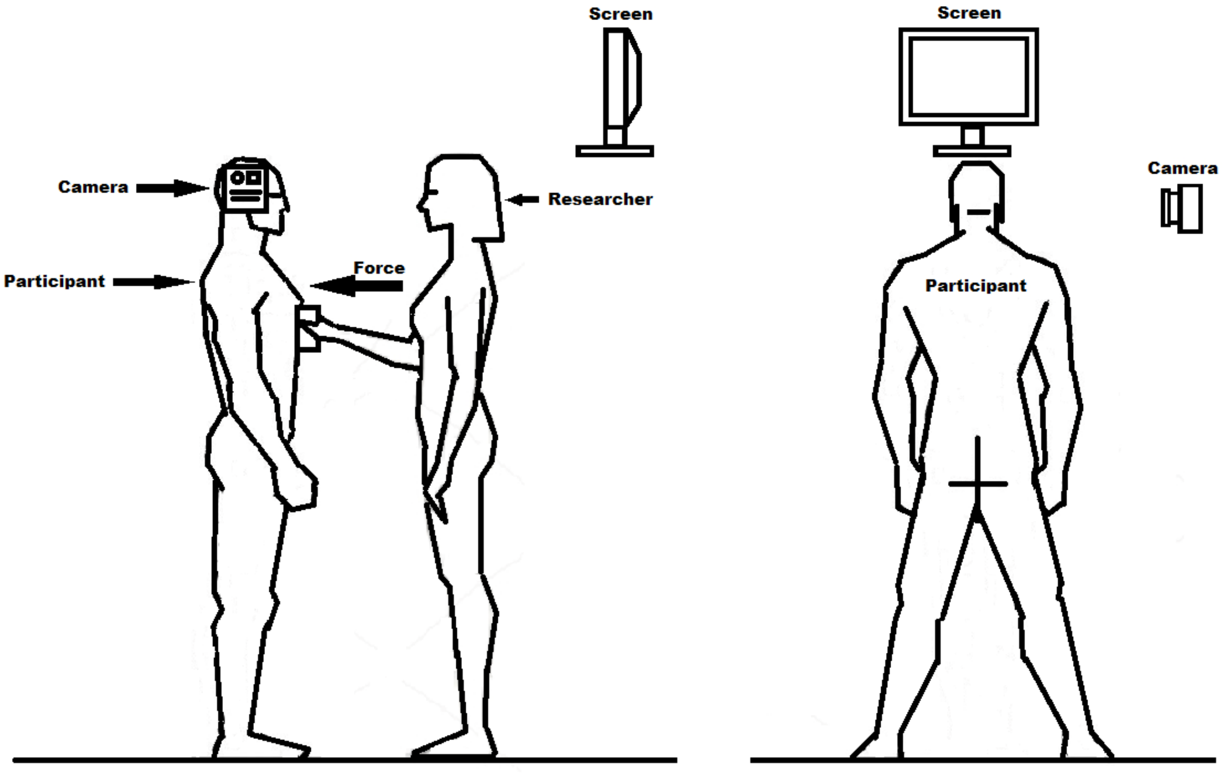

Figure 2.2. Schematic representation of the Standing Isometric Resistance task experimental setup.

2.6 Respiratory neuromuscular responses: Pressures and EMG

Neuromuscular activation of the crural diaphragm (EMG_{di}) was assessed using a bespoke multipair oesophageal electrode catheter (Gaeltec Devices Ltd., Dunvegan, Isle of Sky, UK). The catheter comprised a 100 cm silicon shaft (2.7 mm diameter) containing nine silver electrodes spaced 1 mm apart. Oesophageal pressure (P_e) and P_g were measured using two independent pressure transducers integrated within the catheter and positioned proximally and distally to the electrodes. The transducers were calibrated over the physiological range by placing the catheter within a sealed, air-filled tube to which positive and negative pressures were applied using a glass syringe filled with 2 ml of air. The calibration tube was connected to an electromanometer (MicroRPM, Care Fusion, Basingstoke, UK) and the voltage outputs of each pressure transducer were calibrated against reference pressures.

The catheter was positioned using the method described by (Luo et al., 2001). Following local anaesthesia with Co-Phenylcaine Forte Spray (ENT Technologies Pty Ltd., Hawthorne, Australia) the catheter was passed peri-nasally into the stomach until the diaphragm produced a positive pressure deflection on inspiration. The catheter was then repositioned based on the strength of EMG_{di} recorded simultaneously from different pairs of electrodes and was then secured in place. Neuromuscular activation of the sternocleidomastoid (EMG_{scm}), rectus abdominis (EMG_{ra}), and the group formed by the transverse abdominal and internal oblique ($EMG_{tra/io}$) muscles were assessed with pairs of bipolar skin surface electrodes (Ambu WhiteSensor 40713, Ambu Australia, Warriewood, Australia) after carefully cleaning and abrading the skin. The electrodes were 2 cm in diameter and the inter-electrode distance was 2 cm. The $EMG_{tra/io}$ site was chosen as an indication of pelvic floor activity due to the relatively invasive nature of direct measurement of pelvic floor activity. The transverse abdominal and internal oblique muscles have been shown to co-contract with pelvic floor contraction (Arab & Chehrehrazi, 2011). The positions of the surface electrodes were as follows: EMG_{scm}, placed at the midpoint along the longitudinal axis of the sternocleidomastoid muscle between the mastoid process and the medial clavicle; EMG_{ra}, 2 cm superior and 2-4 cm lateral to the umbilicus on the left-hand side of the torso; and for $EMG_{tra/io}$, 2 cm proximal to the midpoint on the line between the anterior superior iliac spine and the pubic symphysis on the left hand side of the torso.

2.7 Data capture and analysis

Raw data for flow, EMG, pressure, and force were sampled continuously at 200-2000 Hz using a 16-channel analog-to-digital data acquisition system (PowerLab 16/35; AD Instruments, Bella Vista, Australia). Data were recorded and analysed using LabChart Pro software package (AD Instruments, Bella Vista, Australia).

Force data for the Standing Isometric Push task was analysed with Excel (Microsoft Office 365; Microsoft Corporation, Redmond, WA). Although participants had been instructed to apply as much sustained force as possible without leaning forward, making any rapid 'jerking' movements, and/or pushing themselves away from the load cell, some instances of these movements did still occur during the testing procedures. The force data was thus visually inspected for momentary data spikes associated with non-sustained force production and all of the spikes larger than 50% of the mean force produced by that participant in that particular task were removed. The onset of effort was determined automatically in Excel using the method described by (Chavda et al., 2020) which utilises a threshold for force onset based on 5 times the standard deviation of the baseline force measurement prior to the pushing onset. For the

Standing Isometric Resistance task, the rate of force development was calculated as the slope of the force-time graph from the time at which the push was applied by the researcher against the participant to the time when the maximum resistive force was identified. In addition, the total impulse for each Standing Isometric Resistance task was calculated as the integral of the force-time graph for the duration of each Standing Isometric Resistance task. Force was normalised to body mass (F_N) through the use of the equation [1] (Jaric, 2002):

$$F_N = \frac{F}{m^{\frac{2}{3}}} \qquad [1]$$

Where F is the absolute force produced by the participant and $m^{2/3}$ is the mass of the participant raised to the 2/3 power.

Raw EMG data was converted to root mean square (RMS) data using a time constant of 100 ms and a moving window. EMG data was high-pass filtered at 80 Hz, and notch-filtered at 50 Hz to suppress power line and harmonic interference. All EMG data were expressed as a percentage of the maximum EMG activity recorded during a maximal inspiratory or expiratory pressure manoeuvre (%max).

The onset of P_g was calculated automatically in LabChart Pro software (AD Instruments, Bella Vista, Australia) using a threshold value of 5 times the standard deviation of resting P_g. The onset time for P_g in relation to the onset time for force was compared between the two groups. Transdiaphragmatic pressure (P_{di}) was calculated online by subtracting P_e from P_g. In order to compare the two groups of participants in terms of the relative contribution of P_g/P_e (reflecting the pattern of abdominal to chest wall recruitment) and the relative contribution of P_{di}/P_e (pattern of diaphragm to chest wall recruitment), the differences between the pressures for each recruitment pattern type were determined. These differences were calculated as the percentage of the difference between the two pressures divided by the mean of the two pressure values, using equations [2] and [3] and based on previous work by (P. I. Brown, Johnson, & Sharpe, 2014; Nava, Ambrosino, Crotti, Fracchia, & Rampulla, 1993):

$$P_g/P_e\ (\%) = \frac{(P_g - P_e)}{\left(\frac{P_g + P_e}{2}\right)} * 100 \qquad [2]$$

$$P_{di}/P_e\ (\%) = \frac{(P_{di} - P_e)}{\left(\frac{P_{di} + P_e}{2}\right)} * 100 \qquad [3]$$

Maximum values were recorded for the force and pressure measurements along with the time at which the maximum values occurred for each Standing Isometric Push and Standing Isometric Resistance task. The mean values for the force and pressure measurements were also calculated during each task. In addition, to obtain the values "at peak force", the mean pressure and EMG measurements were calculated over a 1 s time period when peak force was achieved. Artefacts were visually inspected and manually removed from pressure and EMG values. For the Standing Isometric Push task, the data from the left and right hand efforts were combined when comparing values between groups.

2.8 Statistical analysis

Statistical analysis was performed using SPSS for Windows (IBM, Chicago, IL, USA) and Excel (Microsoft Office 365; Microsoft Corporation, Redmond, WA). The sample size was a convenience sample based on the availability of trained participants. All data sets were checked for normality using a Shapiro-Wilks test. Extreme outliers due to artefacts including breath holding or peristalsis, which were not representative of the results, were removed where data was found to be not normally distributed. Between-group data were analysed using independent t-tests. The relationship between P_g and forces produced were assessed using correlation coefficients for repeated observations. Statistical significance was set at $P < 0.05$. All values are presented as means ± SD. Within-day reliability of the repeated force and neuromuscular measurements for the Standing Isometric Push and Resistance tasks were assessed using the intraclass correlation coefficients (ICC).

Chapter 3: Results

3.1 Participant groups

There were no between-group differences in participant anthropometrics and respiratory function (Table 2.1), indicating that the groups were well matched prior to testing. Figures 3.1 and 3.2 show representative data sets from the Standing Isometric Push and Standing Isometric Resistance tasks for a trained and a control participant who were both male and aged 45 years with BMIs of 27 and 30 $kg \cdot m^{-2}$, respectively.

3.2 Reliability

There were no systematic differences in the repeated pressure, force and EMG measurements. Within-day, between-trial reproducibility coefficients in the Standing Isometric Push task for pressure, force and EMG were 0.68, 0.97, and 0.77 for trained, and 0.53, 0.94, and 0.78 for control participants, respectively. Within-day, between-trial reproducibility coefficients in the Standing Isometric Resistance task for pressure, force and EMG were 0.87, 0.95, 0.92 for trained and 0.72, 0.81, 0.82 for control participants, respectively. These values are indicative of moderate to excellent reliability.

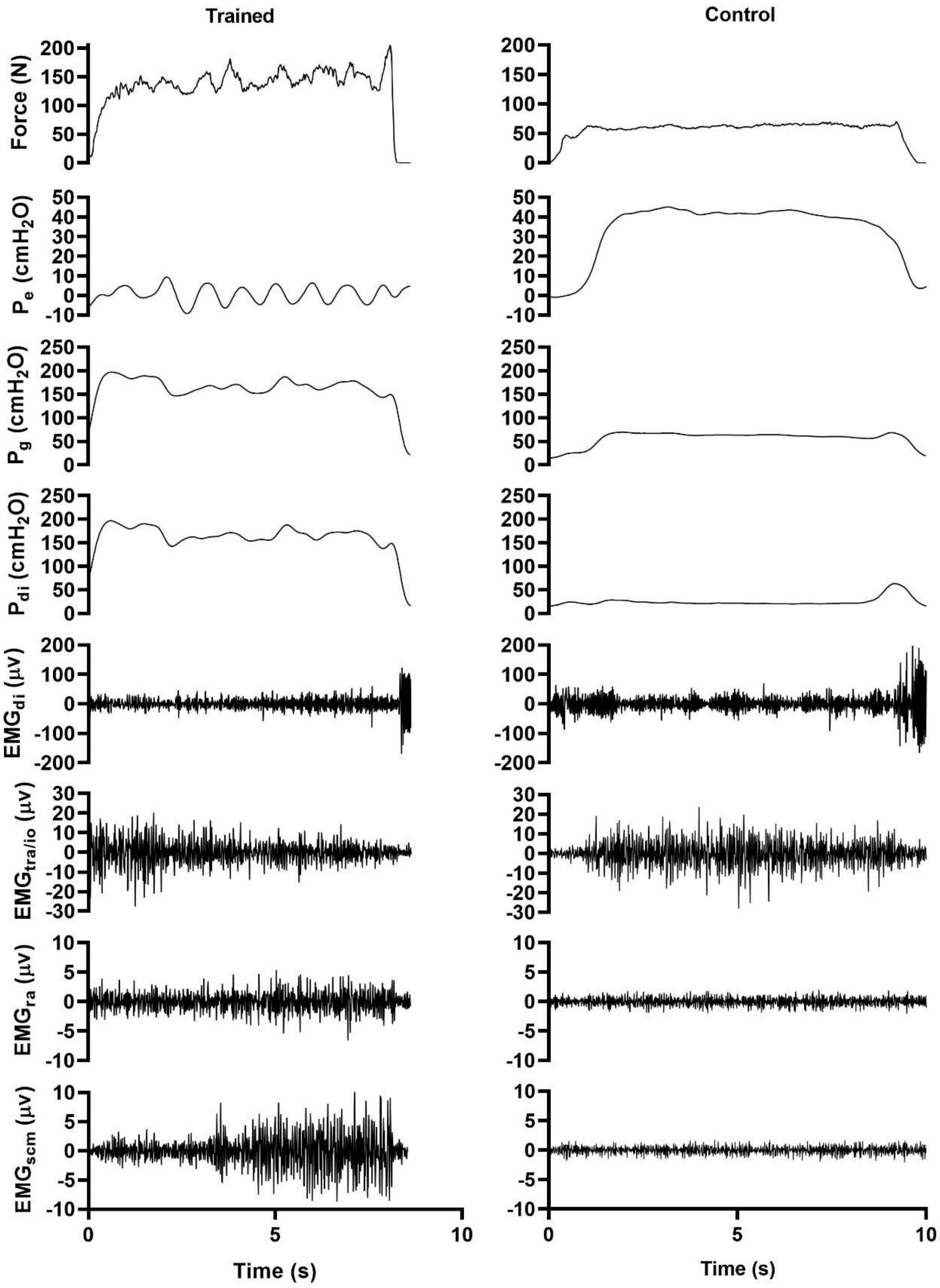

Figure 3.1. Representative set of data from the Standing Isometric Push task for a trained and control participant. *Abbreviations* = P_e, oesophageal pressure; P_g, gastric pressure; P_{di}, transdiaphragmatic pressure; EMG_{di}, crural diaphragm EMG; $EMG_{tra/io}$ transverse abdominis/internal oblique EMG; EMG_{ra}, rectus abdominis EMG; EMG_{scm}, sternocleidomastoid EMG.

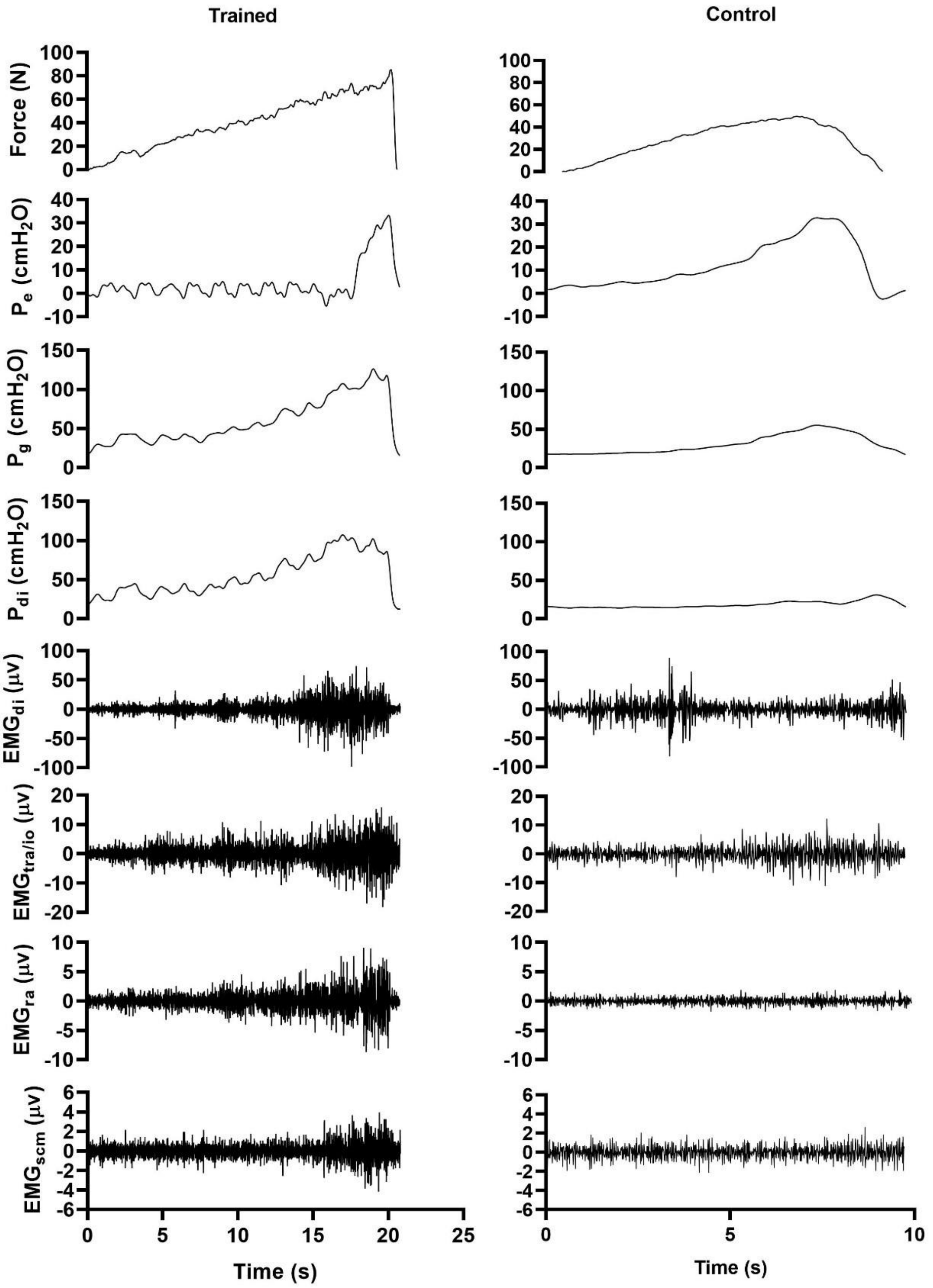

Figure 3.2. Representative set of data from the Standing Isometric Resistance task for a trained and control participant. *Abbreviations* = P_e, oesophageal pressure; P_g, gastric pressure; P_{di}, transdiaphragmatic pressure; EMG$_{di}$, crural diaphragm EMG; EMG$_{tra/io}$ transverse abdominis/internal oblique EMG; EMG$_{ra}$, rectus abdominis EMG; EMG$_{scm}$, sternocleidomastoid EMG.

3.3 Forces

For the Standing Isometric Push task, the absolute mean (66.5 ± 28.1 vs. 56.0 ± 17.1 N; P = 0.18) and peak forces produced (95.1 ± 41.9 vs. 76.5 ± 22.8 N; P = 0.11) were not different between the trained and control groups. However, when normalised for body mass, the normalised mean (P = 0.01) and peak forces produced (P = 0.006) were higher for the trained group than the control group (Figure 3.3).

To establish that the researcher pushed against participants in a similar manner for both groups during the Standing Isometric Resistance task, the rate of force development was compared between both groups. There were no differences in the rate of force development between the trained and control groups (7.24 ± 1.6 vs. 7.97 ± 1.55 N/s; P = 0.4). The absolute mean (39.9 ± 12.0 vs. 31.6 ± 9.06 N; P = 0.12) and peak forces applied (65.5 ± 22.1 vs. 53.6 ± 16.8 N; P = 0.21) were not different between the trained and control groups, but when normalised for body mass, the mean (P = 0.01) and peak (P = 0.02) forces were higher for the trained compared to the control group (Figure 3.3). The total impulse was higher in the trained group than in the control group (323 ± 37.5 vs. 265 ± 25.3 N/s; P = 0.04).

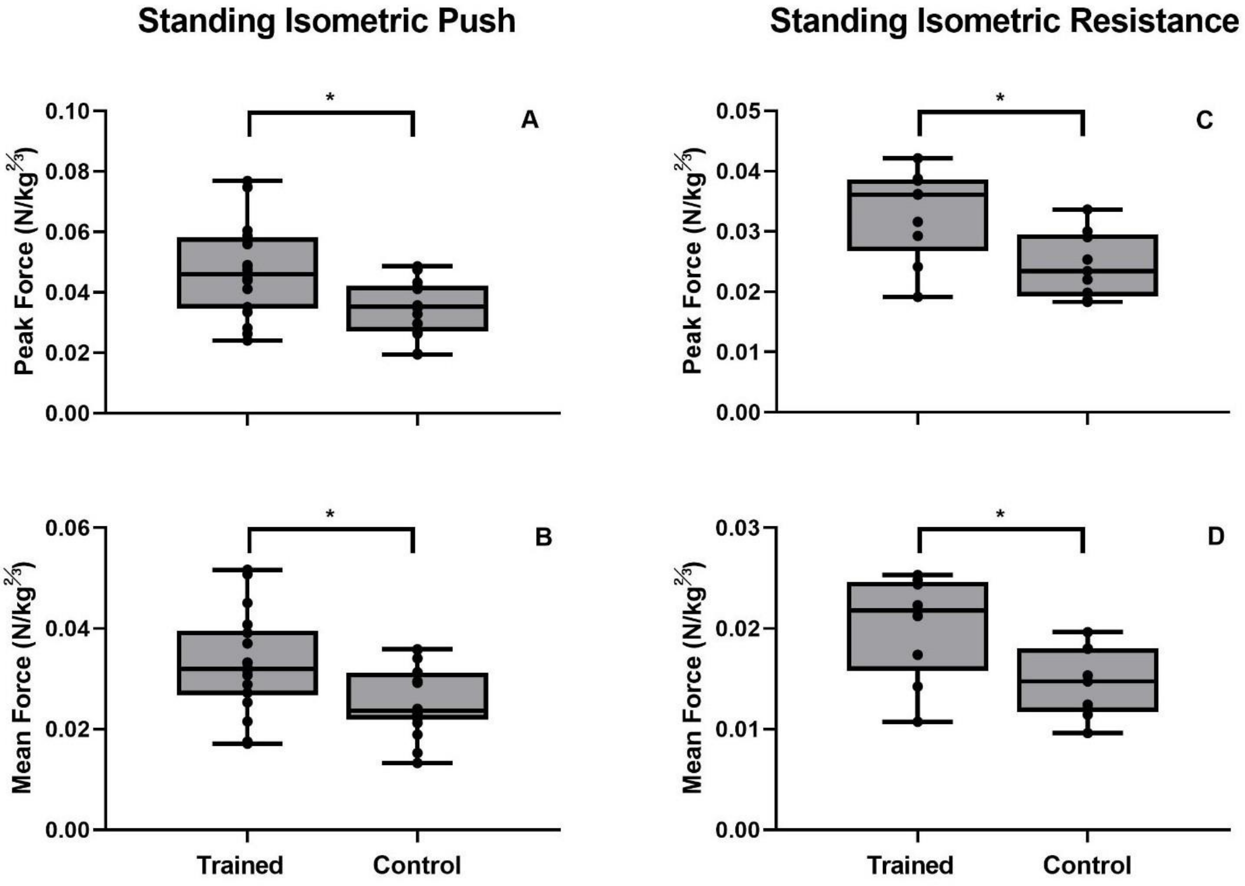

Figure 3.3. Peak (A and C top panel) and mean force (B and D bottom panel) normalised for body mass ($F_N = F/m^{2/3}$ (Jaric, 2002)) applied during the Standing Isometric Push and Standing Isometric Resistance tasks. *Significantly different from control group, $P < 0.05$.

3.4 Respiratory Pressures

Respiratory pressures during the Standing Isometric Push and Standing Isometric Resistance tasks for trained and control groups are shown in Table 3.1 and Figure 3.4. For the Standing Isometric Push task, all P_e values were lower for the trained group ($P < 0.05$) except for the change in P_e, which was not significantly different between the two groups ($P = 0.08$). All P_g and P_{di} values were higher for the trained group ($P < 0.05$). The relative contribution of P_g/P_e (reflecting the pattern of abdominal to chest wall recruitment) and the relative contribution of P_{di}/P_e (reflecting the pattern of diaphragm to chest wall recruitment) were higher for the trained group ($P < 0.05$; Figure 3.4). For the Standing Isometric Resistance task, mean P_e and the percentage maximum of mean P_e were lower in the trained group ($P < 0.05$). Except for P_{di} at peak force, all other P_{di} measures were higher in the trained group ($P < 0.05$). The onset of P_g with respect to the onset of force application was earlier for the trained group than for the control group in the Standing Isometric Push and the Standing Isometric Resistance tasks ($P < 0.05$, Figure 3.5).

Table 3.1. Respiratory pressures during Standing Isometric Resistance and Standing Isometric Push tasks for the trained and control groups. Values are mean ± SD.

	Standing Isometric Push		Standing Isometric Resistance	
	Trained	Control	Trained	Control
Mean P_e, cmH_2O	8.2 ± 7.03*	24.6 ± 11.8	0.58 ± 6.18*	10.7 ± 12.3
Mean P_e, %max	10.1 ± 8.48*	26.5 ± 12.6	-0.51 ± 7.28*	7.22 ± 4.82
Peak P_e, cmH_2O	31.4 ± 14.1*	45.4 ± 16.1	11.3 ± 7.74	19.1 ± 6.46
Peak P_e, %max	39.2 ± 20.7*	54.6 ± 19.8	22.7 ± 21.8	32.3 ± 25.9
P_e at Peak Force, cmH_2O	12.7 ± 12.0*	26.9 ± 15.7	4.02 ± 10.0	15.0 ± 10.5
P_e at Peak Force, %max	16.3 ± 14.6*	29.0 ± 12.4	5.43 ± 13.2	16.1 ± 8.37
ΔP_e, cmH_2O	39.1 ± 14.5	48.4 ± 16.2	15.8 ± 7.8	17.3 ± 5.38
Mean P_g, cmH_2O	72.7 ± 41.8*	48.7 ± 19.1	48.6 ± 23.6	34.2 ± 20.5
Mean P_g, %max	39.6 ± 11.8*	31.2 ± 5.12	27.9 ± 6.35	21.9 ± 8.79
Peak P_g, cmH_2O	112 ± 58.4*	72.4 ± 34.2	105 ± 64.7	69.0 ± 42.8
Peak P_g, %max	66.2 ± 14.4*	47.8 ± 11.4	58.7 ± 20.2	44.2 ± 18.5
P_g at Peak Force, cmH_2O	84.7 ± 45.2*	49.8 ± 19.4	79.1 ± 49.5	58.1 ± 38.7
P_g Peak Force, %max	48.3 ± 15.4*	33.0 ± 6.76	43.7 ± 13.8	36.2 ± 16.3
ΔP_g, cmH_2O	92.1 ± 50.0*	59.1 ± 32.8	55.6 ± 34.2	43.2 ± 33.2
Mean P_{di}, cmH_2O	62.7 ± 43.2*	22.9 ± 10.5	48.0 ± 22.7*	25.8 ± 14.1
Mean P_{di}, %max	40.9 ± 18.9*	21.1 ± 10.1	32.9 ± 6.98*	20.3 ± 6.65
Peak P_{di}, cmH_2O	100 ± 50.0*	47.9 ± 18.1	87.2 ± 40.8*	39.3 ± 21.2
Peak P_{di}, %max	71.7 ± 17.8*	47.8 ± 20.4	67.7 ± 18.7*	37.2 ± 16.0
P_{di} at Peak Force, cmH_2O	72.1 ± 49.2*	22.4 ± 11.5	71.8 ± 45.0	36.9 ± 27.1
P_{di} at Peak Force, % max	47.5 ± 24.0*	19.9 ± 13.7	47.7 ± 18.0*	30.9 ± 12.7
ΔP_{di}, cmH_2O	94.3 ± 41.1*	47.3 ± 23.0	45.7 ± 20.8*	21.4 ± 10.6

Abbreviations = P_e, oesophageal pressure; P_g, gastric pressure; P_{di}, transdiaphragmatic pressure. *Significantly different from the control group, $P < 0.05$.

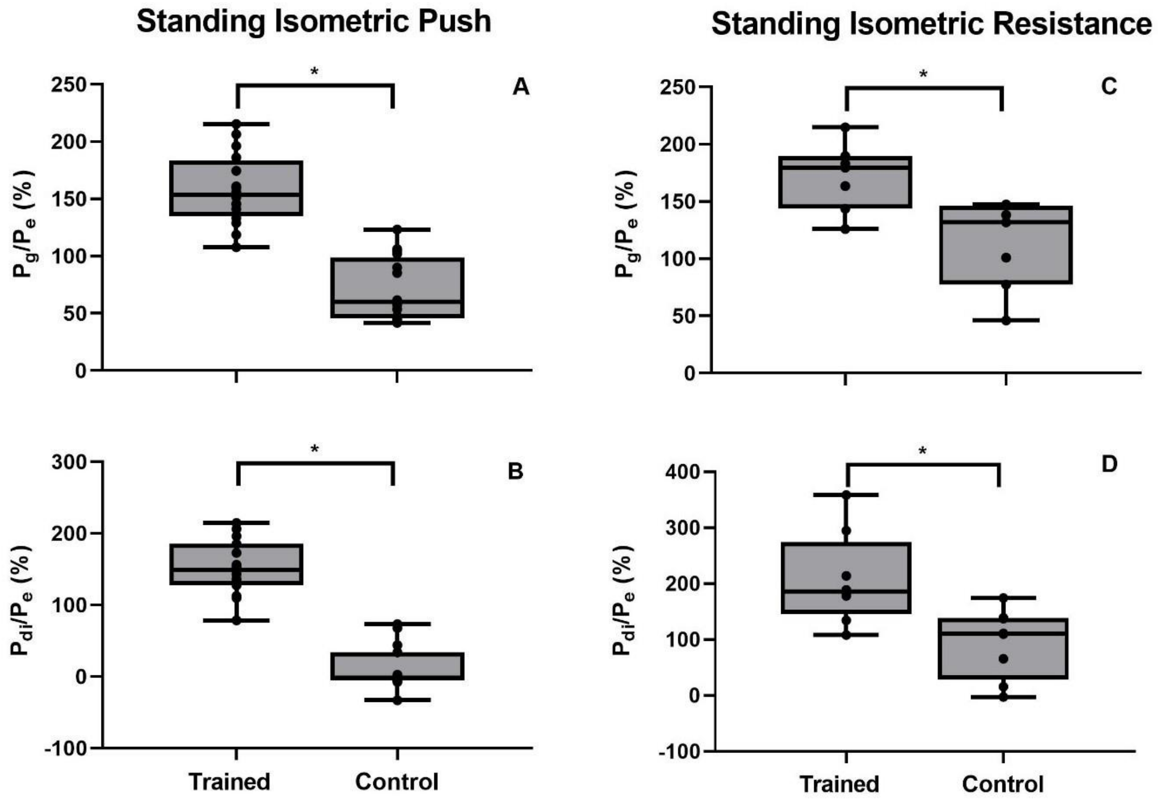

Figure 3.4. Relative contribution of gastric/oesophageal pressure (P_g/P_e; A and C) and the relative contribution of transdiaphragmatic/oesophageal pressure (P_{di}/P_e; B and D) during the Standing Isometric Push and Standing Isometric Resistance tasks. *Significantly different from the control group, $P < 0.05$.

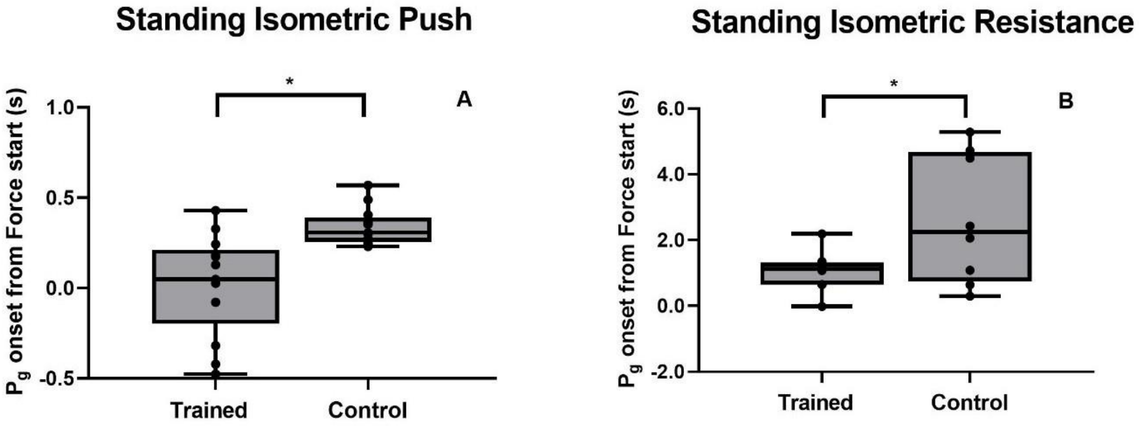

Figure 3.5. Time of gastric pressure (P_g) onset from Force Start (onset of force production) in the Standing Isometric Push (A) and Resistance (B) tasks. *Significantly different from the control group, $P < 0.05$.

3.5 Neuromuscular activation

Neuromuscular activation during the Standing Isometric Push and Standing Isometric Resistance tasks for the trained and control groups are shown in Table 3.2. Mean EMG_{di} RMS and EMG_{di} RMS at peak force for the trained group were higher during the Standing Isometric Push and Standing Isometric Resistance tasks than those obtained from the maximal inspiratory pressure manoeuvres and, therefore, these values exceeded 100% of maximum. Furthermore, EMG_{ra} RMS at peak force for the trained group during the Standing Isometric Push tasks exceeded the values obtained during the maximal expiratory manoeuvres. In the Standing Isometric Push task, the trained group utilised a higher percentage of $EMG_{tra/io}$ at peak force than the control group ($P = 0.01$). There were no differences between the groups for EMG_{di}, EMG_{ra}, and EMG_{scm} in the Standing Isometric Push task.

Table 3.2. Neuromuscular activation during the Standing Isometric Push and Standing Isometric Resistance tasks for the trained and control groups. Values are mean ± SD.

	Standing Isometric Push		Standing Isometric Resistance	
	Trained	Control	Trained	Control
Mean EMG_{di} RMS, %max	121 ± 43.0	98.2 ± 37.8	103 ± 42.8*	65.8 ± 21.6
EMG_{di} RMS at peak force, %max	113 ± 46.9	91.8 ± 28.3	129 ± 67.2*	64.7 ± 19.8
Mean $EMG_{tra/io}$, %max	89.2 ± 48.6	69.5 ± 28.7	62.5 ± 34.0	44.7 ± 18.7
$EMG_{tra/io}$ RMS at peak force, %max	93.5 ± 33.5*	64.5 ± 20.5	78.7 ± 38.0	62.1 ± 33.8
Mean EMG_{ra} RMS, %max	86.9 ± 27.3	81.3 ± 14.4	76.1 ± 21.8	75.5 ± 12.8
EMG_{ra} RMS at peak force, %max	114 ± 84.0	84.4 ± 16.1	93.9 ± 31.0	90.6 ± 22.7
Mean EMG_{scm} RMS, %max	39.8 ± 30.2	51.1 ± 44.3	30.0 ± 23.8	34.7 ± 26.3
EMG_{scm} RMS at peak force, %max	46.5 ± 38.2	50.7 ± 41.6	32.8 ± 26.0	35.3 ± 26.5

Abbreviations = EMG_{di}, crural diaphragm EMG; $EMG_{tra/io}$ transverse abdominis/internal oblique EMG; EMG_{ra}, rectus abdominis EMG; EMG_{scm}, sternocleidomastoid EMG; RMS, root mean square. *Significantly different from the control group, $P < 0.05$.

In the Standing Isometric Resistance task, the trained group utilised a higher percentage of EMG_{di} than the control group, both throughout the movement ($P = 0.048$) and at peak force ($P = 0.02$). There were no differences between the groups for $EMG_{tra/io}$, EMG_{ra}, and EMG_{scm} in the Standing Isometric Resistance task.

3.6 Correlations

Table 3.3 shows the correlations between force and P_g during the Standing Isometric Push task. Strong positive correlations were found between P_g and force in both the trained and control groups during the Standing Isometric Push Task ($P < 0.05$; Table 3.3).

Table 3.3. Correlations between peak/mean force and respiratory pressures and EMG during the Standing Isometric Push task.

	Peak Force (N)		Mean Force (N)	
	Trained	Control	Trained	Control
Mean P_g (cmH2O)	$r = 0.700$*	$r = 0.620$*	$r = 0.753$*	$r = 0.635$*
Peak P_g (cmH_2O)	$r = 0.582$*	$r = 0.642$*	$r = 0.651$*	$r = 0.614$*
P_g at Peak Force (cmH_2O)	$r = 0.684$*	$r = 0.635$*	$r = 0.739$*	$r = 0.654$*

Abbreviations = P_g, gastric pressure *Significantly correlated, $P < 0.05$.

Chapter 4: Discussion

4.1 Main findings

The aim of the study was to quantify and compare IAP and neuromuscular activation between trained wushu practitioners and untrained control participants during tasks requiring maximum isometric force production. We also aimed to determine the relationship between IAP (determined by the surrogate measure of P_g) and absolute force production in these tasks. We hypothesised that trained wushu practitioners would produce higher IAP, utilise a greater percentage of EMG activity of key muscle groups, and be able to produce greater forces during isometric resistance tasks than untrained, healthy, active individuals. Our results supported our hypothesis.

4.2 Force

Our findings demonstrate that during tasks requiring maximum isometric force production trained wushu practitioners can produce significantly higher levels of isometric force than untrained controls. These results are in agreement with previous studies that have also demonstrated that trained martial arts practitioners can produce greater forces than untrained individuals (Gulledge & Dapena, 2008; House & Cowan, 2015; Joch et al., 1981; Neto et al., 2008; Smith et al., 2000). The forces produced in the present study are lower than others reported for trained martial arts practitioners. This may be explained by the type of task undertaken as previous studies have utilised striking (Gulledge & Dapena, 2008; House & Cowan, 2015; Joch et al., 1981; Neto et al., 2008; Smith et al., 2000) rather than the isometric force application used in the present study. The observed differences in respiratory pressures and neuromuscular activation between the trained wushu practitioners and untrained controls may be a major contributing factor towards the differences in force production.

4.3 Respiratory pressures

We observed that the trained group were able to generate large P_g while keeping P_e very low in comparison to the control group, resulting in a higher P_{di}. In addition, the relative contribution of both P_g and P_{di} with respect to P_e were higher for the trained group than for the control group. These findings may demonstrate that the control group had a much higher level of chest wall recruitment resulting in higher P_e in both tasks than the trained group, while the trained group showed more recruitment of the diaphragm and abdomen. The results of this study indicate that increased recruitment of the diaphragm and abdominal musculature resulting in high P_{di} and P_g may be advantageous to core stability. This was particularly demonstrated in the Standing Isometric Resistance task, in which the amount of force that the participant was able to resist was an indication of their core stability. The findings of this study may also indicate that higher chest wall recruitment with respect to abdominal and diaphragm recruitment may be detrimental to core stability. To our knowledge, this is first report that martial arts training can lead to a greater recruitment of the diaphragm and abdominal musculature during tasks requiring maximum isometric force production. In support of this finding, Brown et al. (2014) observed that there was an increase in P_{di}, in the absence of a change in P_g, during a Müeller manoeuvre after 4 weeks of inspiratory muscle training.

These results support the notional model of pressure and force production found in wushu practice as pictured in Figure 1.2. In this model, pressure is produced in the pelvic and abdominal cavities by the combined action of pelvic musculature, abdominal musculature, and the diaphragm, with the thoracic cavity remaining neutral. Due to the higher levels of force produced or resisted by the trained group, it is hypothesised that this may be a more effective and efficient method of generating internal pressure to augment force production than that utilised by untrained individuals.

MacDougall et al. (1992) observed that a brief Valsalva manoeuvre was unavoidable when force production exceeded approximately 80% of maximum voluntary contraction. The Valsalva manoeuvre is characterised by an increase in intra-thoracic pressure (inferred from an increase in P_e) in addition to an increase in IAP (Porth et al., 1984). The higher P_e observed in the control group is co-linear with the characteristics of the Valsalva manoeuvre, and it appears that they control group may have generally utilised the Valsalva manoeuvre to increase pressure when attempting to achieve maximal isometric forces. In addition, Cholewicki et al. (2002) found that it was generally not possible to generate IAP without increasing P_e, but they did theorise that with training, individuals may be able to recruit trunk musculature in different ways.

Our study reports that trained martial arts practitioners were able to produce maximal isometric forces without pressurising the thoracic cavity. This indicates that through training, wushu practitioners gain superior control over internal pressures, allowing them to pressurise the abdominal cavity independently of the thoracic cavity. This finding is supported by the findings of Zhang, Guo, Jing, & Liu (1992), who utilised an alternative manoeuvre based on qigong exercises to address some of the drawbacks of the Anti-G straining manoeuvre which is taught to fighter piolets as a means of counteracting the fall in head-level blood pressure caused by high G-forces. The Anti-G straining manoeuvre involves pressurising the abdominal and thoracic cavities in a similar manner to the Valsalva manoeuvre and has a number of drawbacks, including a risk of visual disorder or loss of consciousness. The authors observed that, in contrast to the Anti-G Straining manoeuvre, when pilots utilised the qigong manoeuvre their P_e remained negative or at low pressures while P_g were remarkably raised.

4.4 Coordination of pressure and force

The role of IAP in force production has been questioned in the literature due to an observed delay between the production of IAP and the onset of force or torque (Harman et al., 1989; Marras et al., 1985). We observed that the onset of P_g with respect to the onset of force production occurred sooner in the trained group than in the control group for both tasks and that the trained group was able to sustain high levels of IAP throughout the tasks. This supports the findings of Essendrop et al. (2004), who found that trained martial arts practitioners were able to generate IAP with enough speed to support the lower back during sudden trunk loading. Our findings also indicate that a trained individual can generate IAP with enough speed to assist in the rapid production of force. It may be possible for IAP to be controlled and utilised rapidly enough by a trained individual to contribute to force produced in striking movements or other rapid movements.

Previous studies have found strong correlations between IAP and hip extensor muscle strength (Tayashiki et al., 2018; Tayashiki et al., 2017). However, other studies have failed to find correlations between IAP and muscular strength in other areas of the body (Hagins et al., 2006; McGill & Sharratt, 1990). In addition, studies have found significant recruitment of the diaphragm and abdominal muscles during non-respiratory manoeuvres such as weight training and lifting tasks, and it has been shown that non-respiratory manoeuvres can strengthen the diaphragm (DePalo, Parker, Al-Bilbeisi, & McCool, 2004).

We observed a strong positive correlation between P_g and force produced by the hand in a push (Standing Isometric Push), and between IAP and resisted force applied against the trunk (Standing Isometric Resistance) for both trained and untrained individuals, but the correlations were stronger for the trained group. This may indicate that pressure produced in the abdominal cavity can have an effect on both body stabilisation and on the force produced by the limbs.

4.5 Neuromuscular activation

We observed that EMG_{di} (in the Standing Isometric Resistance task) and $EMG_{tra/io}$ (in the Standing Isometric Push task) were higher in the trained group than in the control group. These results show that the trained group was capable of a higher recruitment of the diaphragm, transverse abdominis, and internal oblique musculature. The higher level of recruitment of the transverse abdominis and internal oblique musculature also indirectly showed a higher level of pelvic floor activation. These findings corresponded with other research that has shown that IAP is strongly associated with the transversus abdominis, internal oblique, and pelvic floor muscles, and that the diaphragm has a causal effect on IAP (Cresswell et al., 1994; Hemborg et al., 1985; Hodges, 1999; Neumann & Gill, 2002).

4.6 Methodological limitations

Due to the limited number of trained wushu practitioners that we were able to recruit for this study, the sample size was limited to a convenience sample, and there were within-group variations in age, height, weight and sex. These limitations were addressed by selecting controls who were matched to the trained group and as such there were no between-group differences in these variables. There was also a considerable variation in length of training in the trained group, ranging from 1 year to 22 years of training in the Chang Hong system of wushu.

The force tasks were chosen because they were simple activities that were easy for both groups to perform without prior training. These tasks were found to have good internal validity demonstrated by the reported repeatability data. In addition, the tasks had good external validity as both tasks related directly to functional tasks performed in martial arts (either generating force in linear forward strikes and pushes or dealing with incoming forces such as an impact or a push from an opponent). A limitation of the tasks chosen for this study was the difficulty in entirely preventing participants from leaning into the force transducers with their body weight, thus affecting their force production results. The tasks were designed to minimise this by various means, including the positioning of the participant close to the force transducer in the push task through setting the angle of the elbow, and the use of the video camera and monitor to prevent movement of the participant’s head. This may still have impacted the accuracy of the results as some leaning may have still occurred in some participants. In addition, no instructions on breathing technique were given to participants and there was considerable variation between individuals in terms of patterns of breathing which may have impacted the results. The Standing Isometric Push task was performed before the Standing Isometric Resistance task in all tests. This may have had an impact on the participants’ levels of recruitment during the second task. However, as all participants performed the tasks in the same order, this did not affect the interpretation of the results.

During this study, the computer monitor showing pressure and EMG was visible to the participants. It was observed that most of the participants achieved higher P_g in subsequent attempts of each task, and it is believed that this may be evidence of the participants rapidly learning improved control of IAP through the use of biofeedback. We repeated trials until these measurements began to plateau.

In this study, we chose to utilise maximal inspiratory and expiratory manoeuvres to obtain maximum EMG values. Subsequently, for some participants, we found that maximum measured EMG values occurred during the Standing Isometric Resistance or Standing Isometric Push tasks rather than during the maximal respiratory manoeuvres. This resulted in some %max EMG values being reported as greater than 100%. We chose to retain the maximum EMG values obtained during the maximal respiratory manoeuvres as a standardised means of calculating %max EMG values because the respiratory manoeuvres were more repeatable with less variability in terms of respiration and muscle recruitment between individuals and between the two groups than the Standing Isometric Resistance or Standing Isometric Push tasks.

4.7 Applications and future directions

This research has provided important insights into how trained wushu practitioners are able to use optimised internal mechanics including the control of IAP and associated musculature to produce greater forces than untrained participants. The results of this study indicate that martial arts training may result in a greater ability to control internal pressures and utilise these pressures to increase force production than conventional sport and exercise. Breath control is used in many sports to increase force production, including weightlifting. However, the conventional methods used, such as the Valsalva manoeuvre, have significant limitations and are impossible to apply over extended periods of time. The ability to produce and sustain high levels of IAP for extended periods of time while breathing may be unique to traditional martial arts and would be of great benefit to sports and exercise disciplines involving the application of force over an extended time period, as well as to load carrying and manual tasks.

Future studies should be undertaken into the practicality and effectiveness of instruction in respiratory training based on wushu qigong to improve performance and prevent injury in other sports and exercise activities. Research should also be conducted into the potential benefits of incorporating training based on wushu in exercise programs aimed at improving muscular strength and stability during recovery from injury or in older populations who have reduced muscular strength.

Chapter 5: Conclusion

The aim of the study was to quantify and compare IAP and neuromuscular activation between trained wushu practitioners and untrained control participants during tasks requiring maximum isometric force production. We also aimed to determine the relationship between IAP and absolute force production in these tasks. In conclusion, we observed that trained wushu practitioners were able to produce and resist more force than untrained controls, recruit a greater percentage of muscular activity of the diaphragm, transverse abdominis, and internal oblique musculature, and produce significantly higher levels of IAP with respect to intra-thoracic pressure than untrained controls. It was also found that IAP had a strong positive correlation with force produced and resisted in both groups. The higher levels of force production and resistance of force in the trained group may be due to the different patterns of pressurisation and muscle use observed between the two groups. These findings may have implications in a wide range of sports and physical activities, as these methods may be adapted and taught to individuals to improve performance and to aid in injury prevention and rehabilitation.

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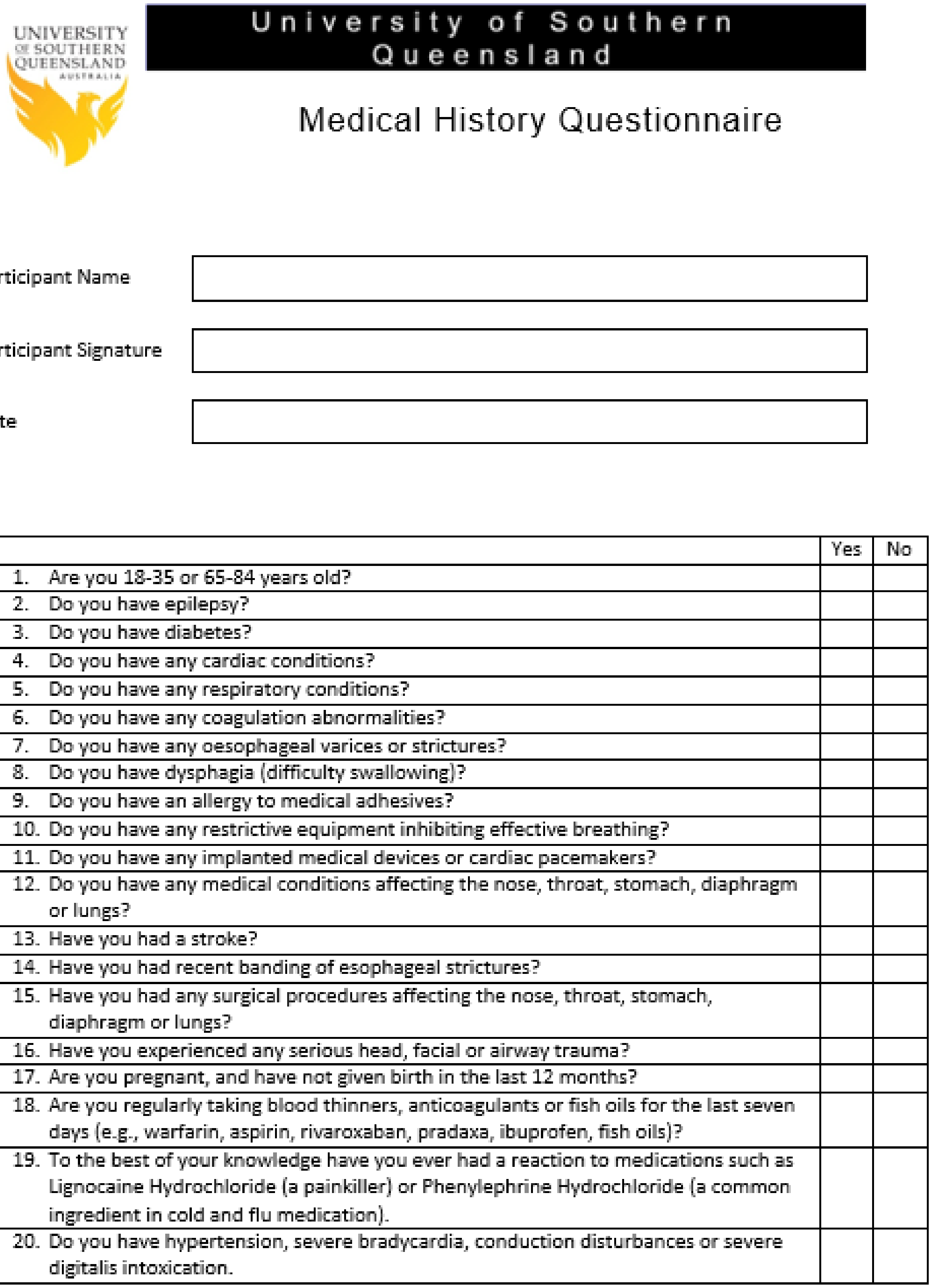
Appendix 1. Medical History Questionnaire



UNIVERSITY OF SOUTHERN QUEENSLAND AUSTRALIA

University of Southern Queensland

Medical History Questionnaire

Participant Name

Participant Signature

Date

	Yes	No
1. Are you 18-35 or 65-84 years old?		
2. Do you have epilepsy?		
3. Do you have diabetes?		
4. Do you have any cardiac conditions?		
5. Do you have any respiratory conditions?		
6. Do you have any coagulation abnormalities?		
7. Do you have any oesophageal varices or strictures?		
8. Do you have dysphagia (difficulty swallowing)?		
9. Do you have an allergy to medical adhesives?		
10. Do you have any restrictive equipment inhibiting effective breathing?		
11. Do you have any implanted medical devices or cardiac pacemakers?		
12. Do you have any medical conditions affecting the nose, throat, stomach, diaphragm or lungs?		
13. Have you had a stroke?		
14. Have you had recent banding of esophageal strictures?		
15. Have you had any surgical procedures affecting the nose, throat, stomach, diaphragm or lungs?		
16. Have you experienced any serious head, facial or airway trauma?		
17. Are you pregnant, and have not given birth in the last 12 months?		
18. Are you regularly taking blood thinners, anticoagulants or fish oils for the last seven days (e.g., warfarin, aspirin, rivaroxaban, pradaxa, ibuprofen, fish oils)?		
19. To the best of your knowledge have you ever had a reaction to medications such as Lignocaine Hydrochloride (a painkiller) or Phenylephrine Hydrochloride (a common ingredient in cold and flu medication).		
20. Do you have hypertension, severe bradycardia, conduction disturbances or severe digitalis intoxication.		

21. Are you taking medications which may affect your heart, lungs or ability to participate in exercise? If yes, please list the relevant medications and/or conditions below		
22. Do you have any cultural requirements / needs (i.e., particular needs or sensitivities) that we should be aware of? If yes, please provide details below		

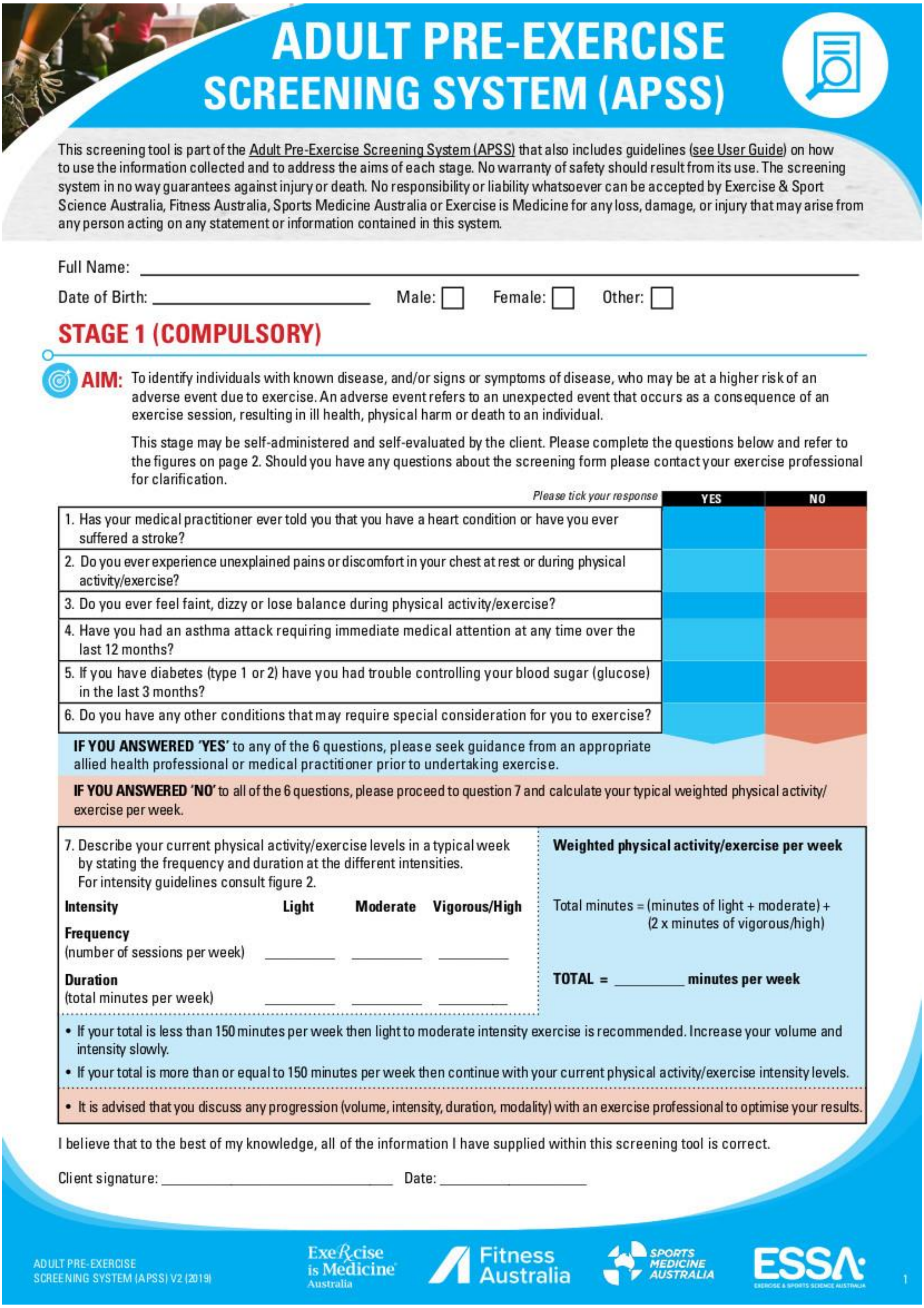
Please return this sheet to a Research Team member.

Appendix 2. Study exclusion criteria and rationale for exclusions.

Exclusion Criteria	Rationale
1. Aged under 18 years; Aged 60 years and older	Adults outside of these ages are either too young to have a fully developed respiratory system; or are of too high of a risk of adverse medical outcomes from the testing.
2. Diabetes	Participants with diabetes may experience adverse blood sugar concentrations as a result of fasting coupled with the inspiratory threshold loading.
3. Cardiac conditions	Participants with cardiac conditions may be at risk of exacerbations if they were to participate in the testing.
4. Respiratory conditions	Participants with respiratory conditions may be at risk of exacerbations if they were to participate in the testing.
5. Coagulation abnormalities	Participants with coagulation abnormalities are at increased risk of excessive bleeding as a result of cannula insertion.
6. Oesophageal varices or strictures	Participants with oesophageal varices or strictures are at greater risk of damage to the oesophagus during catheter placement.
7. Dysphagia (difficulty swallowing)	Participants may experience greater discomfort during catheter placement with increased risk of being unable to place the catheter.
8. Reactions to medical adhesives	Participant may experience discomfort as a result of the medical adhesive used to attach EMG electrodes.
9. Restrictive equipment inhibiting effective breathing	May present challenges in administering tests and intubating the participant if other instruments are obstructing access to their face, head and chest.
10. Medical condition or surgical procedure involving the nose, throat, diaphragm, lungs or stomach	Surgical procedures relating to the nose, throat, diaphragm and lungs may present a risk of difficult intubation and increased risk of internal damage to the participant. Any alterations to the stomach may interfere with gastric pressure measurements.

11. Recent banding of oesophageal strictures	Participants with recent banding of oesophageal strictures are at greater risk of damage to the oesophagus during catheter placement.
12. Surgical procedures affecting the nose, throat, stomach, diaphragm or lungs	Surgical procedures relating to the nose, throat, diaphragm and lungs may present a risk of difficult intubation and increased risk of internal damage to the participant. Any alterations to the stomach may interfere with gastric pressure measurements.
13. History of head, facial or airway trauma	Presents a risk of difficult intubation and increased risk of internal damage to the participant.
14. Currently pregnant or having given birth in the previous 12 months	Pregnancy interferes with the internal placement of organs and their ability to function at optimal levels. Further, stress and the procedures undertaken may harm the unborn child.
15. Blood thinners, anticoagulants or fish oils	Participants with coagulation abnormalities are at increased risk of excessive bleeding as a result of difficult catheter placement.
16. Known reactions to medications	This question aims to limit the chance of an allergic reaction to the local anaesthetic Co-Phenylcaine Forte Spray
17. Currently taking medications which affect the heart, lungs or ability to participate in exercise	Medications could affect a variety of factors leading to complications in participant safety or could introduce additional variables into the data collected.
18. Hypertension, severe bradycardia, conduction disturbances or severe digitalis intoxication	These conditions increase the risk of complications with the Co-Phenylcaine Forte.

Appendix 3. Study exclusion criteria – Pre-Exercise Screening System



ADULT PRE-EXERCISE SCREENING SYSTEM (APSS)

This screening tool is part of the Adult Pre-Exercise Screening System (APSS) that also includes guidelines (see User Guide) on how to use the information collected and to address the aims of each stage. No warranty of safety should result from its use. The screening system in no way guarantees against injury or death. No responsibility or liability whatsoever can be accepted by Exercise & Sport Science Australia, Fitness Australia, Sports Medicine Australia or Exercise is Medicine for any loss, damage, or injury that may arise from any person acting on any statement or information contained in this system.

Full Name: ______________________________

Date of Birth: ______________ Male: ☐ Female: ☐ Other: ☐

STAGE 1 (COMPULSORY)

AIM: To identify individuals with known disease, and/or signs or symptoms of disease, who may be at a higher risk of an adverse event due to exercise. An adverse event refers to an unexpected event that occurs as a consequence of an exercise session, resulting in ill health, physical harm or death to an individual.

This stage may be self-administered and self-evaluated by the client. Please complete the questions below and refer to the figures on page 2. Should you have any questions about the screening form please contact your exercise professional for clarification.

Please tick your response	YES	NO
1. Has your medical practitioner ever told you that you have a heart condition or have you ever suffered a stroke?		
2. Do you ever experience unexplained pains or discomfort in your chest at rest or during physical activity/exercise?		
3. Do you ever feel faint, dizzy or lose balance during physical activity/exercise?		
4. Have you had an asthma attack requiring immediate medical attention at any time over the last 12 months?		
5. If you have diabetes (type 1 or 2) have you had trouble controlling your blood sugar (glucose) in the last 3 months?		
6. Do you have any other conditions that may require special consideration for you to exercise?		

IF YOU ANSWERED 'YES' to any of the 6 questions, please seek guidance from an appropriate allied health professional or medical practitioner prior to undertaking exercise.

IF YOU ANSWERED 'NO' to all of the 6 questions, please proceed to question 7 and calculate your typical weighted physical activity/exercise per week.

7. Describe your current physical activity/exercise levels in a typical week by stating the frequency and duration at the different intensities. For intensity guidelines consult figure 2.

Intensity	**Light**	**Moderate**	**Vigorous/High**
Frequency (number of sessions per week)	________	________	________
Duration (total minutes per week)	________	________	________

Weighted physical activity/exercise per week

Total minutes = (minutes of light + moderate) + (2 x minutes of vigorous/high)

TOTAL = ________ **minutes per week**

- If your total is less than 150 minutes per week then light to moderate intensity exercise is recommended. Increase your volume and intensity slowly.
- If your total is more than or equal to 150 minutes per week then continue with your current physical activity/exercise intensity levels.

- It is advised that you discuss any progression (volume, intensity, duration, modality) with an exercise professional to optimise your results.

I believe that to the best of my knowledge, all of the information I have supplied within this screening tool is correct.

Client signature: ______________________ Date: ______________

ADULT PRE-EXERCISE SCREENING SYSTEM (APSS) V2 (2019)

Exercise is Medicine Australia
Fitness Australia
SPORTS MEDICINE AUSTRALIA
ESSA EXERCISE & SPORTS SCIENCE AUSTRALIA

1

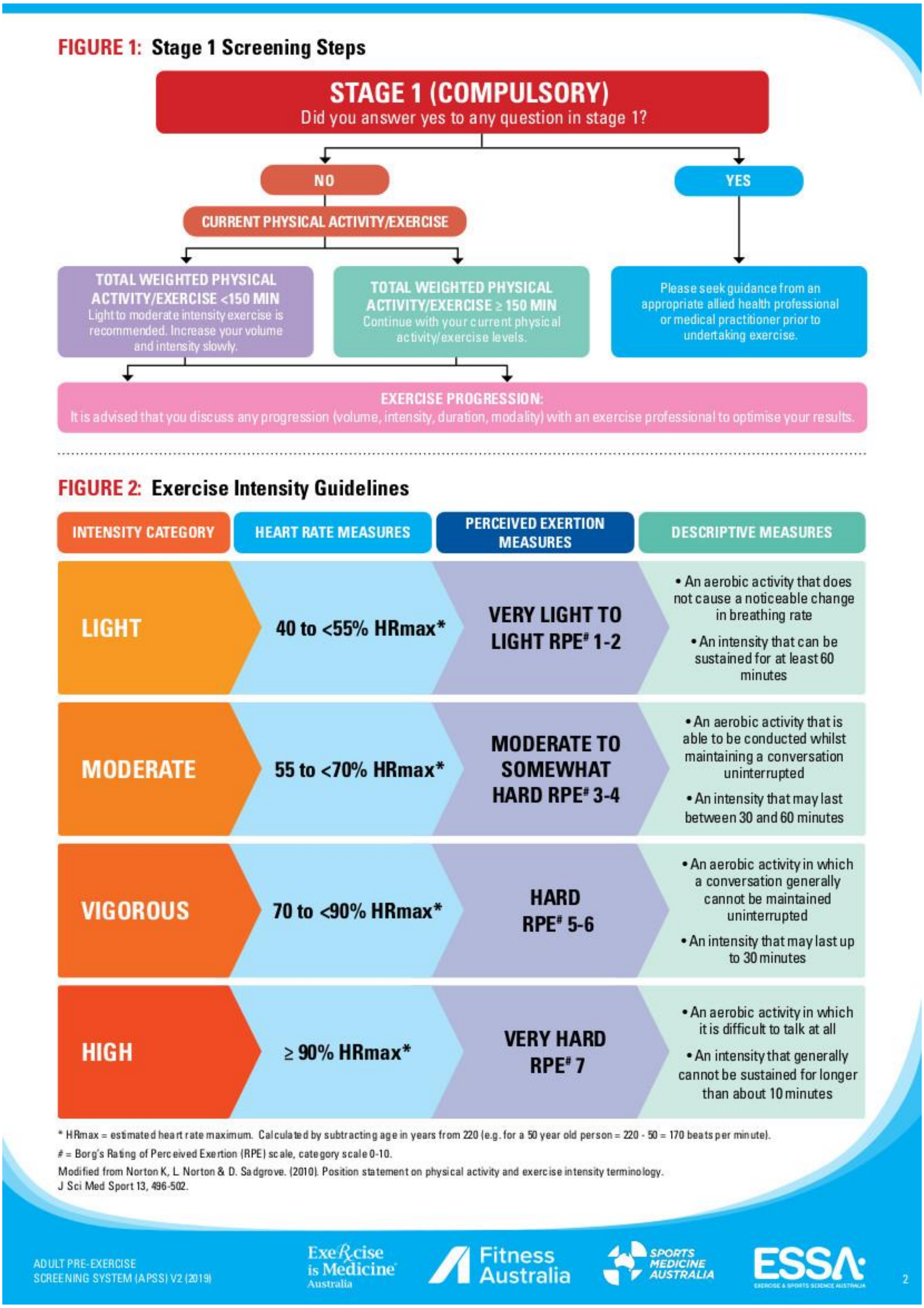


FIGURE 1: Stage 1 Screening Steps

STAGE 1 (COMPULSORY)
Did you answer yes to any question in stage 1?

NO

CURRENT PHYSICAL ACTIVITY/EXERCISE

TOTAL WEIGHTED PHYSICAL ACTIVITY/EXERCISE <150 MIN
Light to moderate intensity exercise is recommended. Increase your volume and intensity slowly.

TOTAL WEIGHTED PHYSICAL ACTIVITY/EXERCISE ≥ 150 MIN
Continue with your current physical activity/exercise levels.

YES

Please seek guidance from an appropriate allied health professional or medical practitioner prior to undertaking exercise.

EXERCISE PROGRESSION:
It is advised that you discuss any progression (volume, intensity, duration, modality) with an exercise professional to optimise your results.

FIGURE 2: Exercise Intensity Guidelines

INTENSITY CATEGORY	HEART RATE MEASURES	PERCEIVED EXERTION MEASURES	DESCRIPTIVE MEASURES
LIGHT	**40 to <55% HRmax***	**VERY LIGHT TO LIGHT RPE# 1-2**	• An aerobic activity that does not cause a noticeable change in breathing rate • An intensity that can be sustained for at least 60 minutes
MODERATE	**55 to <70% HRmax***	**MODERATE TO SOMEWHAT HARD RPE# 3-4**	• An aerobic activity that is able to be conducted whilst maintaining a conversation uninterrupted • An intensity that may last between 30 and 60 minutes
VIGOROUS	**70 to <90% HRmax***	**HARD RPE# 5-6**	• An aerobic activity in which a conversation generally cannot be maintained uninterrupted • An intensity that may last up to 30 minutes
HIGH	**≥ 90% HRmax***	**VERY HARD RPE# 7**	• An aerobic activity in which it is difficult to talk at all • An intensity that generally cannot be sustained for longer than about 10 minutes

* HRmax = estimated heart rate maximum. Calculated by subtracting age in years from 220 (e.g. for a 50 year old person = 220 - 50 = 170 beats per minute).

= Borg's Rating of Perceived Exertion (RPE) scale, category scale 0-10.

Modified from Norton K, L Norton & D. Sadgrove. (2010). Position statement on physical activity and exercise intensity terminology. J Sci Med Sport 13, 496-502.

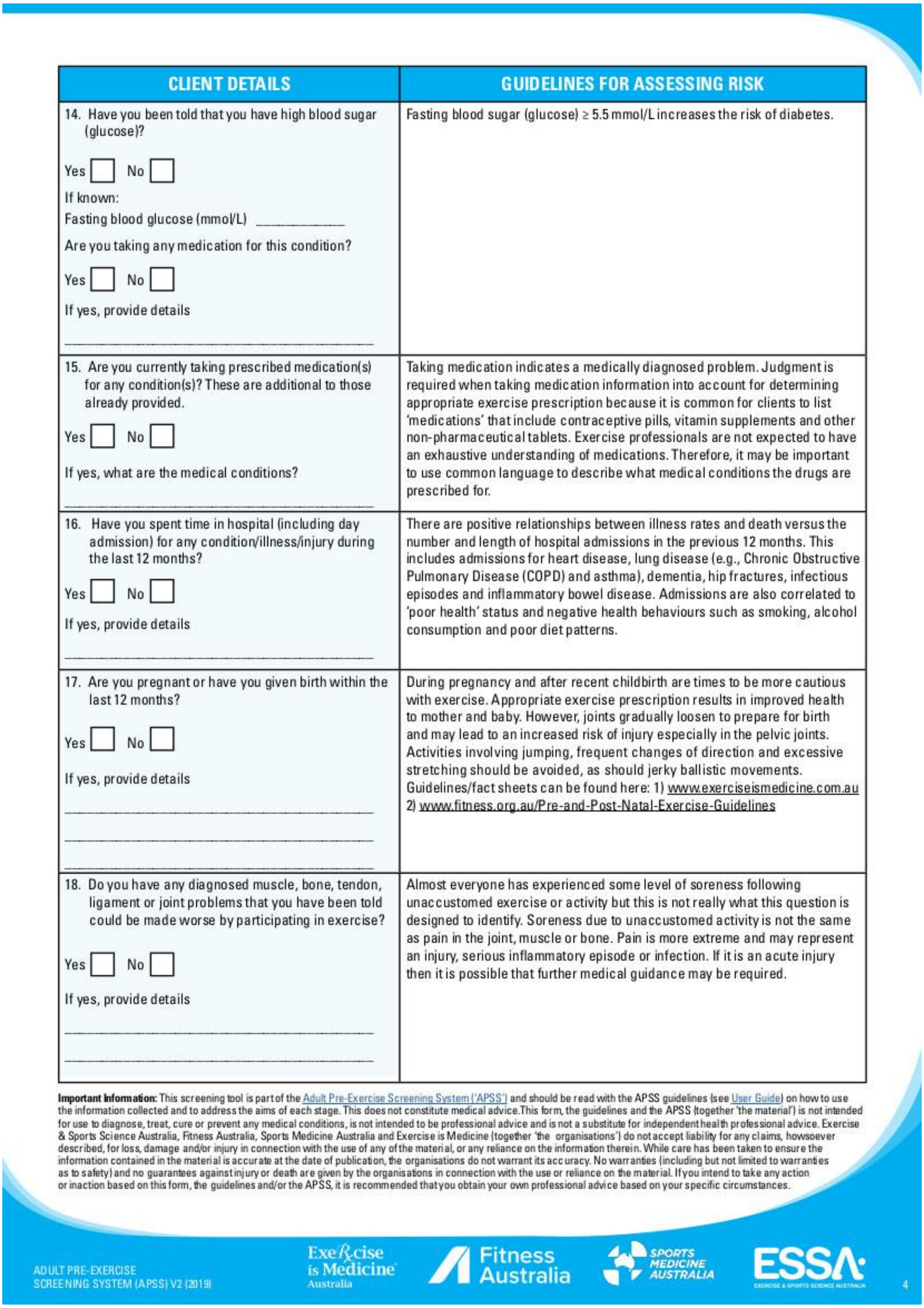
ADULT PRE-EXERCISE
SCREENING SYSTEM (APSS) V2 (2019)

2

STAGE 2 (RECOMMENDED)

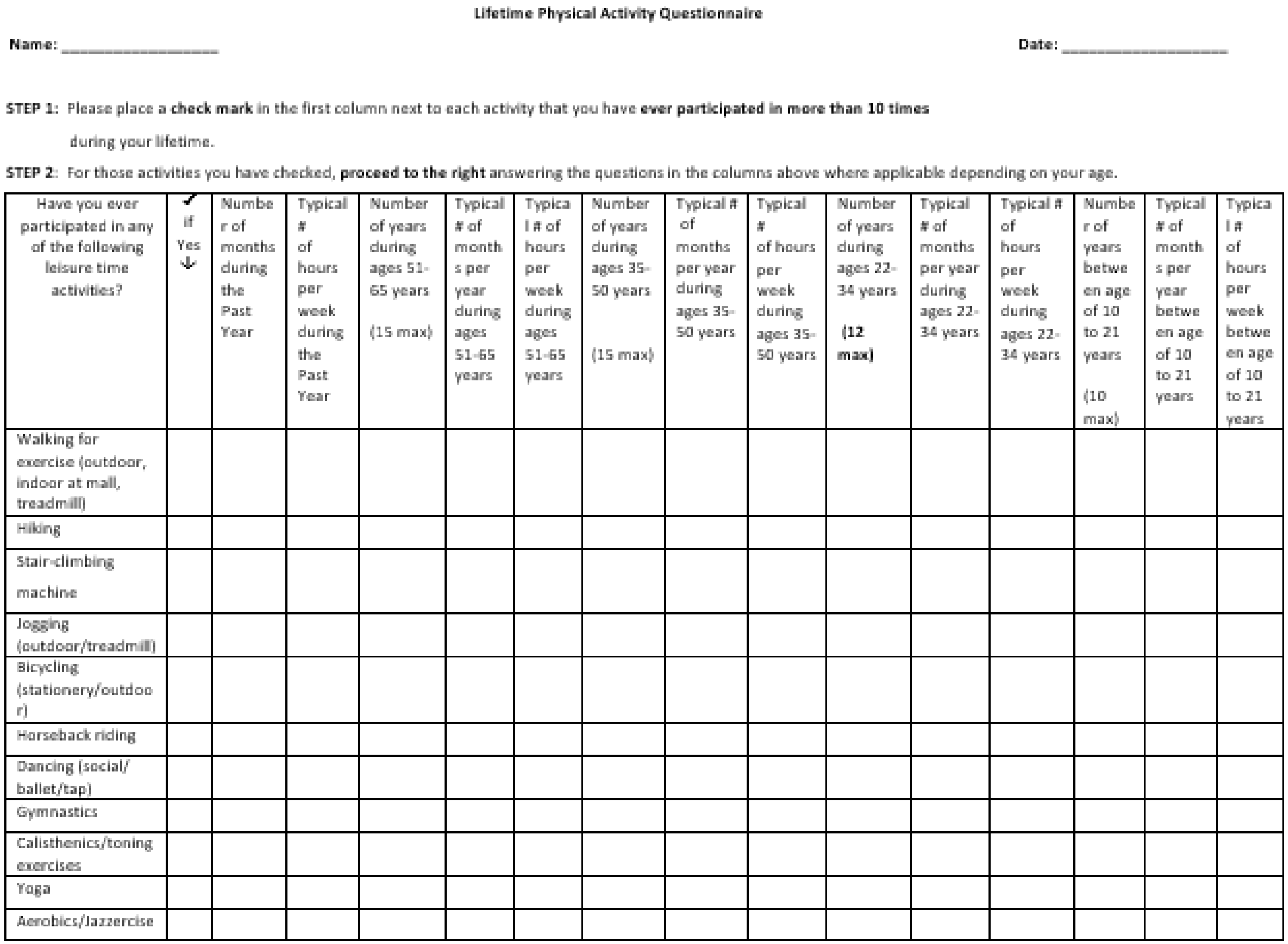
AIM: This stage is to be completed with an exercise professional to determine appropriate exercise prescription based on established risk factors.

CLIENT DETAILS	GUIDELINES FOR ASSESSING RISK
8. Demographics Age: ____________ Male ☐ Female ☐ Other ☐	Risk of an adverse event increases with age, particularly males ≥ 45 yr and females ≥ 55 yr.
9. Family history of heart disease (e.g. stroke, heart attack)? Relationship (e.g. father) Age at heart disease event ________________ __________ ________________ __________ ________________ __________	A family history of heart disease refers to an event that occurs in relatives including parents, grandparents, uncles and/or aunts before the age of 55 years.
10. Do you smoke cigarettes on a daily or weekly basis or have you quit smoking in the last 6 months? Yes ☐ No ☐ If currently smoking, how many per day or week? ______________________________	Smoking, even on a weekly basis, substantially increases risk for premature death and disability. The negative effects are still present up to at least 6 months post quitting.
11. Body composition Weight (kg) ________ Height (cm) ________ Body Mass Index (kg/m²) ________ Waist circumference (cm) ________	Any of the below increases the risk of chronic diseases: BMI ≥ 30 kg/m² Waist > 94 cm male or > 80 cm female
12. Have you been told that you have high blood pressure? Yes ☐ No ☐ If known, systolic/diastolic (mmHg) ______________________________ Are you taking any medication for this condition? Yes ☐ No ☐ If yes, provide details ______________________________	Either of the below increases the risk of heart disease: Systolic blood pressure ≥ 140 mmHg Diastolic blood pressure ≥ 90 mmHg
13. Have you been told that you have high cholesterol/ blood lipids? Yes ☐ No ☐ If known: Total cholesterol (mmol/L) __________ HDL (mmol/L) __________ LDL (mmol/L) __________ Triglycerides (mmol/L) __________ Are you taking any medication for this condition? Yes ☐ No ☐ If yes, provide details ____________________	Any of the below increases the risk of heart disease: Total cholesterol ≥ 5.2 mmol/L HDL < 1.0 mmol/L LDL ≥ 3.4 mmol/L Triglycerides ≥ 1.7 mmol/L



CLIENT DETAILS	GUIDELINES FOR ASSESSING RISK
14. Have you been told that you have high blood sugar (glucose)? Yes ☐ No ☐ If known: Fasting blood glucose (mmol/L) ____________ Are you taking any medication for this condition? Yes ☐ No ☐ If yes, provide details ____________________	Fasting blood sugar (glucose) ≥ 5.5 mmol/L increases the risk of diabetes.
15. Are you currently taking prescribed medication(s) for any condition(s)? These are additional to those already provided. Yes ☐ No ☐ If yes, what are the medical conditions? ____________________	Taking medication indicates a medically diagnosed problem. Judgment is required when taking medication information into account for determining appropriate exercise prescription because it is common for clients to list 'medications' that include contraceptive pills, vitamin supplements and other non-pharmaceutical tablets. Exercise professionals are not expected to have an exhaustive understanding of medications. Therefore, it may be important to use common language to describe what medical conditions the drugs are prescribed for.
16. Have you spent time in hospital (including day admission) for any condition/illness/injury during the last 12 months? Yes ☐ No ☐ If yes, provide details ____________________	There are positive relationships between illness rates and death versus the number and length of hospital admissions in the previous 12 months. This includes admissions for heart disease, lung disease (e.g., Chronic Obstructive Pulmonary Disease (COPD) and asthma), dementia, hip fractures, infectious episodes and inflammatory bowel disease. Admissions are also correlated to 'poor health' status and negative health behaviours such as smoking, alcohol consumption and poor diet patterns.
17. Are you pregnant or have you given birth within the last 12 months? Yes ☐ No ☐ If yes, provide details ____________________ ____________________ ____________________	During pregnancy and after recent childbirth are times to be more cautious with exercise. Appropriate exercise prescription results in improved health to mother and baby. However, joints gradually loosen to prepare for birth and may lead to an increased risk of injury especially in the pelvic joints. Activities involving jumping, frequent changes of direction and excessive stretching should be avoided, as should jerky ballistic movements. Guidelines/fact sheets can be found here: 1) www.exerciseismedicine.com.au 2) www.fitness.org.au/Pre-and-Post-Natal-Exercise-Guidelines
18. Do you have any diagnosed muscle, bone, tendon, ligament or joint problems that you have been told could be made worse by participating in exercise? Yes ☐ No ☐ If yes, provide details ____________________ ____________________	Almost everyone has experienced some level of soreness following unaccustomed exercise or activity but this is not really what this question is designed to identify. Soreness due to unaccustomed activity is not the same as pain in the joint, muscle or bone. Pain is more extreme and may represent an injury, serious inflammatory episode or infection. If it is an acute injury then it is possible that further medical guidance may be required.

Appendix 4. Lifetime Physical Activity Questionnaire.



Lifetime Physical Activity Questionnaire

Name: ___________________ **Date:** ___________________

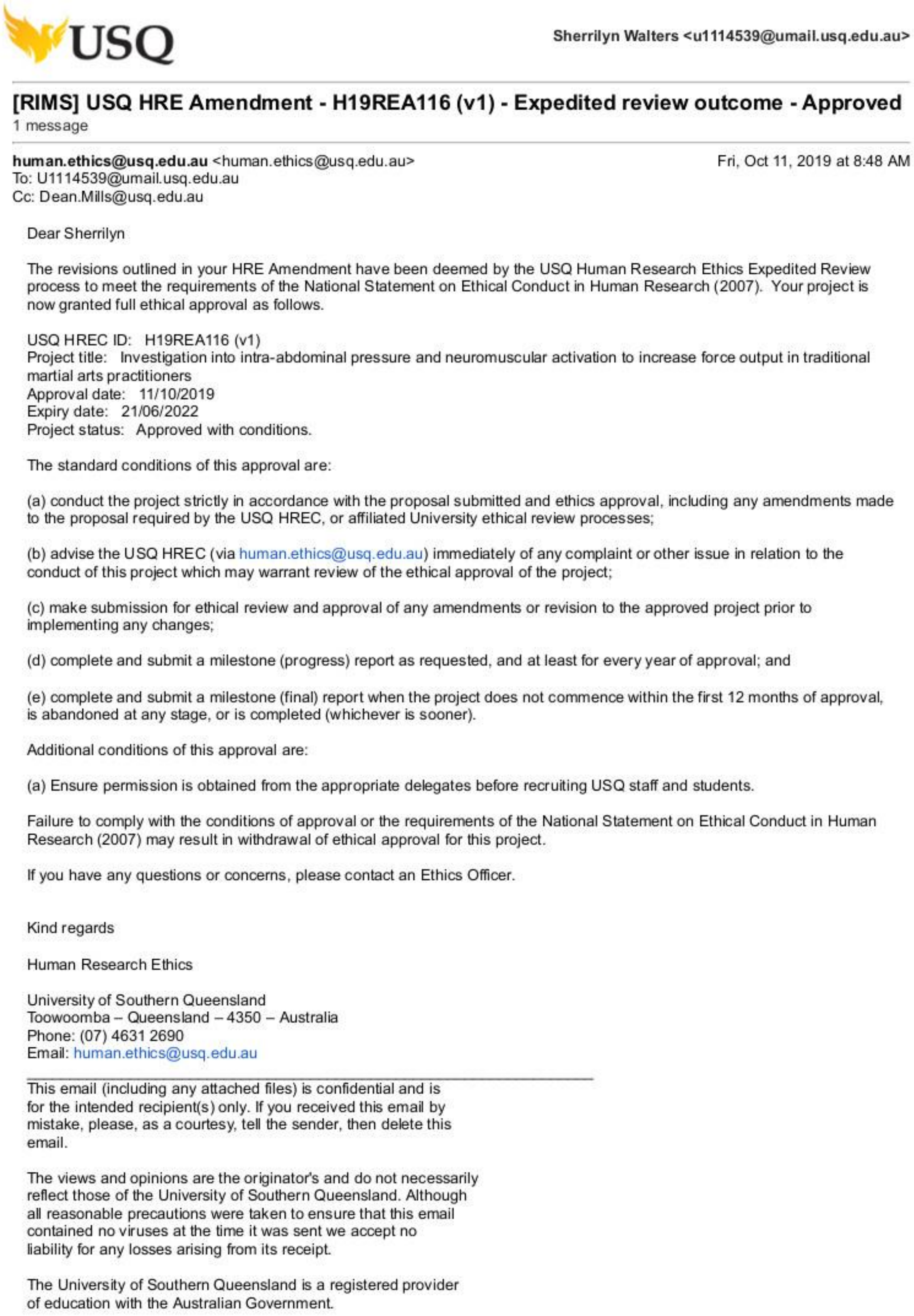
STEP 1: Please place a **check mark** in the first column next to each activity that you have **ever participated in more than 10 times** during your lifetime.

STEP 2: For those activities you have checked, **proceed to the right** answering the questions in the columns above where applicable depending on your age.

Have you ever participated in any of the following leisure time activities?	✓ if Yes ↓	Number of months during the Past Year	Typical # of hours per week during the Past Year	Number of years during ages 51-65 years (15 max)	Typical # of months per year during ages 51-65 years	Typical # of hours per week during ages 51-65 years	Number of years during ages 35-50 years (15 max)	Typical # of months per year during ages 35-50 years	Typical # of hours per week during ages 35-50 years	Number of years during ages 22-34 years **(12 max)**	Typical # of months per year during ages 22-34 years	Typical # of hours per week during ages 22-34 years	Number of years between age of 10 to 21 years (10 max)	Typical # of months per year between age of 10 to 21 years	Typical # of hours per week between age of 10 to 21 years
Walking for exercise (outdoor, indoor at mall, treadmill)															
Hiking															
Stair-climbing machine															
Jogging (outdoor/treadmill)															
Bicycling (stationery/outdoor)															
Horseback riding															
Dancing (social/ ballet/tap)															
Gymnastics															
Calisthenics/toning exercises															
Yoga															
Aerobics/Jazzercise															

Have you ever participated in any of the following leisure time activities?	✓ if Yes ↓	Number of months during the Past Year	Typical # of hours per week during the Past Year	Number of years during ages 51-65 years (15 max)	Typical # of months per year during ages 51-65 years	Typical # of hours per week during ages 51-65 years	Number of years during ages 35-50 years (15 max)	Typical # of months per year during ages 35-50 years	Typical # of hours per week during ages 35-50 years	Number of years during ages 22-34 years **(12 max)**	Typical # of months per year during ages 22-34 years	Typical # of hours per week during ages 22-34 years	Number of years between age of 10 to 21 years (10 max)	Typical # of months per year between age of 10 to 21 years	Typical # of hours per week between age of 10 to 21 years
Lifting weights															
Swimming for exercise (i.e. laps)															
Rowing/canoeing/ kayaking/rowing machine															
Water skiing															
Skiing/downhill															
X-country skiing/ski machine															
Skating (ice, roller, in-line)															
Tennis															
Other racquet sports															
Softball/baseball															
Golf (use golf cart)															
Golf (walking)															
Volleyball															
Basketball															
Martial Arts, specify system ________________															
Bowling															
Other: __________															

Appendix 5. Ethics Approval and Participant Information Sheet.



Sherrilyn Walters <u1114539@umail.usq.edu.au>

[RIMS] USQ HRE Amendment - H19REA116 (v1) - Expedited review outcome - Approved

1 message

human.ethics@usq.edu.au <human.ethics@usq.edu.au> Fri, Oct 11, 2019 at 8:48 AM
To: U1114539@umail.usq.edu.au
Cc: Dean.Mills@usq.edu.au

Dear Sherrilyn

The revisions outlined in your HRE Amendment have been deemed by the USQ Human Research Ethics Expedited Review process to meet the requirements of the National Statement on Ethical Conduct in Human Research (2007). Your project is now granted full ethical approval as follows.

USQ HREC ID: H19REA116 (v1)
Project title: Investigation into intra-abdominal pressure and neuromuscular activation to increase force output in traditional martial arts practitioners
Approval date: 11/10/2019
Expiry date: 21/06/2022
Project status: Approved with conditions.

The standard conditions of this approval are:

(a) conduct the project strictly in accordance with the proposal submitted and ethics approval, including any amendments made to the proposal required by the USQ HREC, or affiliated University ethical review processes;

(b) advise the USQ HREC (via human.ethics@usq.edu.au) immediately of any complaint or other issue in relation to the conduct of this project which may warrant review of the ethical approval of the project;

(c) make submission for ethical review and approval of any amendments or revision to the approved project prior to implementing any changes;

(d) complete and submit a milestone (progress) report as requested, and at least for every year of approval; and

(e) complete and submit a milestone (final) report when the project does not commence within the first 12 months of approval, is abandoned at any stage, or is completed (whichever is sooner).

Additional conditions of this approval are:

(a) Ensure permission is obtained from the appropriate delegates before recruiting USQ staff and students.

Failure to comply with the conditions of approval or the requirements of the National Statement on Ethical Conduct in Human Research (2007) may result in withdrawal of ethical approval for this project.

If you have any questions or concerns, please contact an Ethics Officer.

Kind regards

Human Research Ethics

University of Southern Queensland
Toowoomba – Queensland – 4350 – Australia
Phone: (07) 4631 2690
Email: human.ethics@usq.edu.au

University of Southern Queensland

Participant Information for USQ Research Project

Project Details

Title of Project:	Investigation into intra-abdominal pressure and neuromuscular activation to increase force output in traditional martial arts practitioners
Human Research Ethics Approval Number:	HXXREAXXX

Research Team Contact Details

Principal Investigator Details
Sherrilyn Walters
Email: u1114539@umail.usq.edu.au
Mobile: 0431012048

Supervisor Details
Dr. Dean Mills
Email: dean.mills@usq.edu.au
Telephone: (07) 3812 6147

Description

This project is being undertaken as part of a Masters Project.

Intra-abdominal pressure is the pressure created within the abdominal cavity and previous research has suggested that strength athletes and traditional martial arts practitioners utilise intra-abdominal pressure to aid in producing or resisting force. The purpose of this project is to determine whether, compared to control participants, trained Wushu (Chinese Kung Fu) martial arts practitioners can utilise a greater proportion of intra-abdominal pressure and neuromuscular activation to increase their force output.

While intra-abdominal pressure is used in various sports and disciplines, little is known about how a high level of control of intra-abdominal pressure can contribute to factors such as force production. This study will be investigating the use of intra-abdominal pressure during force production in trained martial arts practitioners and how this differs to untrained participants.

Participation

Your participation will involve attending the Sport and Exercise research laboratory at the USQ Ipswich campus on two separate visits separated by at least one week. Prior to the visits, you will be asked to complete a training history, pre-exercise screening and medical history questionnaire. On the first visit, your height, body mass, lung function and maximal inspiratory and expiratory mouth pressure will be measured. This involves you breathing into a hand held mouth pressure meter and pressures will be measured while breathing out as hard as possible, and while breathing in as strongly as possible after fully exhaling. This visit will last 30 minutes.

During visit 2, you will have a local anesthetic sprayed into your nose and an oesophageal electrode catheter inserted via your nose into your stomach. This catheter will detect intra-abdominal pressure, oesophogeal pressure and the muscular activation of your diaphragm. In addition, skin surface electrodes will be placed on your abdomen and chest to detect the muscular activity of key respiratory muscles, and you will wear a facemask which will measure airflow. You will then undertake lung function and maximal inspiratory and expiratory mouth pressure tests a second time. You will then perform the Push (Stability While Pushing) and Being Pushed (Stability Under Loading) procedures. The push test will be performed by standing close to a force plate on a wall and pushing with one hand as hard as you can. The being pushed test will be performed while standing with your chest and hips making contact with two wooden arms and a padded hand-held force gauge will be pressed against your chest. The pressure will be gradually increased at a steady rate until you are forced to take a step backwards. Muscular activity, airflow, force outputs from the force gauge and force plate and intra-abdominal and oesophogeal pressures will be measured during these tests. This visit will last 2 hours.

Your participation in this project is entirely voluntary. If you do not wish to take part you are not obliged to. If you decide to take part and later change your mind, you are free to withdraw from the project at any stage. You will be able to withdraw data collected about yourself after you have participated in these tests. If you do wish to withdraw from this project, please contact the Research Team (contact details at the top of this form).

Your decision whether you take part, do not take part, or to take part and then withdraw, will in no way impact your current or future relationship with the University of Southern Queensland, the Chinese Martial Arts and Health Centre Australia or the Martial Arts Research and Testing Laboratory.

Expected Benefits

Participants

You will gain information about your body mass, height, lung function and maximal inspiratory and expiratory mouth pressures which are a measure of respiratory muscle strength. You will also receive feedback about your ability to generate forces in the pushing test, and your ability to resist forces in the being pushed test. At the end of the research project you will be provided with a summary sheet of your test results compared to the average of all participants.

Benefits to the Community

This study will be of benefit to the community to assist in furthering understanding about the methods of force production. Intra-abdominal pressure is believed to assist with producing forces such as lifting heavy loads, impacting objects and contacting the body with others. Many other sports and exercise disciplines will benefit from an understanding of the control and use of intra-abdominal pressure and how this can be developed to improve performance. Intra-abdominal pressure is also believed to play an important role in spine stability and injury prevention of the lower back structures. This study will help to further the understanding of how IAP can be controlled and utilised to prevent injury.

Risks

There are minimal risks involved in participating in this research. These are outlined below.

Catheter Risks. The insertion of the catheter causes a very mild discomfort if any. You may feel mild discomfort or soreness in your nostrils and the back of your throat during the placement of the catheter into your oesophagus and stomach. You may also experience slight discomfort as a result of "gagging" while swallowing during catheter insertion and removal, but this occurs in less than 1% of people. There is also a risk of a nosebleed during the insertion or removal of the catheter which also occurs in less than 1% of people. These issues will resolve once the catheter is in position. There is also a small risk that the catheter may be placed in the wrong position and may need to be repositioned. In extremely rare cases (e.g., if a participant were to lose consciousness or if the catheter was forced) the catheter could enter the wind pipe. This happens in less than 0.5% of placements. If this occurs, you may experience mild discomfort in the back of your throat and may cough. A local anesthetic spray (Co-Phenylcaine Forte Spray) will be sprayed into the nostril receiving the catheter. The main risk associated with this substance is an allergic reaction.

Pushing and being pushed. There is a minor risk of falling over during the pushing and being pushed tests.

Travel time. If you are travelling from areas outside of Ipswich, you will need to factor in the travel time to the USQ Ipswich campus.

Privacy and Confidentiality

All data collected and responses to questionnaires will be treated confidentially unless required by law.

Your data will be made available for future research purposes where approved by the USQ Human Ethics Committee. This data will be stored and shared in a non-identifiable format and will only be provided upon request.

You will be provided with a summary sheet of your test results compared to the average of all participants at the end of this research project.

Any data collected as a part of this project will be stored securely as per University of Southern Queensland's Research Data Management policy.

Consent to Participate

Please complete the attached waiver form to give your consent to participate in this research and return this waiver form in person to the principle investigator.

Questions or Further Information about the Project

Please refer to the Research Team Contact Details at the top of the form to have any questions answered or to request further information about this project.

Concerns or Complaints Regarding the Conduct of the Project

If you have any concerns or complaints about the ethical conduct of the project you may contact the University of Southern Queensland Manager of Research Integrity and Ethics on +61 7 4631 2214 or email researchintegrity@usq.edu.au. The Manager of Research Integrity and Ethics is not connected with the research project and can facilitate a resolution to your concern in an unbiased manner.

Thank you for taking the time to help with this research project. Please keep this sheet for your information.

Appendix 6. Informed Consent Form.

University of Southern Queensland

Consent Form for USQ Research Project

Project Details

Title of Project:	Investigation into intra-abdominal pressure and neuromuscular activation to increase force output in traditional martial arts practitioners
Human Research Ethics Approval Number:	HXXREAXXX

Research Team Contact Details

Principal Investigator Details
Mrs. Sherrilyn Walters
Email: u1114539@umail.usq.edu.au
Mobile: 0431012048

Supervisor Details
Dr. Dean Mills
Email: dean.mills@usq.edu.au
Telephone: (07) 3812 6147

Participant Details

Name	
Date of Birth	
Address	
Contact number	

Emergency Contact Details

General Practitioner (GP) Contact Details

Name	
Address	
Contact	

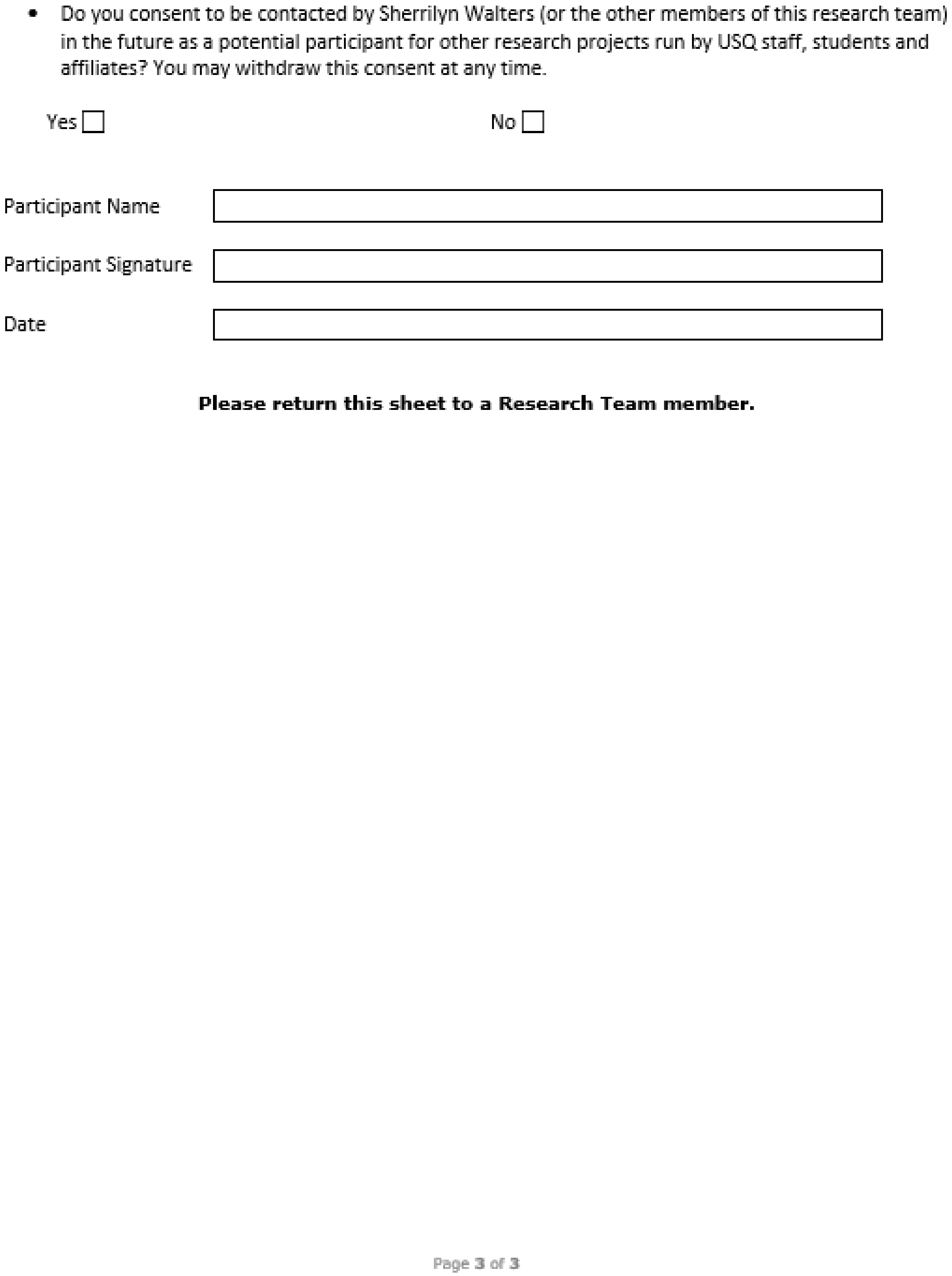
Next of Kin Contact Details

Name	
Address	
Contact	

Statement of Consent

By signing below, you are indicating that you:

- Have read and understood the information document regarding this project and understand the potential risks involved in participation in this research project.
- Have had any questions answered to your satisfaction.
- Are 18–57 years of age.
- Understand that if you have any additional questions you can contact the research team.
- Understand that you are free to withdraw at any time, without comment or penalty.
- Understand that you can contact the University of Southern Queensland Ethics Coordinator on (07) 4631 2690 or email ethics@usq.edu.au if you do have any concern or complaint about the ethical conduct of this project.
- Do not have diabetes.
- Do not have any cardiac (heart) or respiratory (lung) conditions.
- Do not have any coagulation abnormalities.
- Do not have any oesophageal varices or strictures.
- Do not have dysphagia (difficulty swallowing).
- Do not have an allergy to medical adhesives.
- Do not have any restrictive equipment inhibiting effective breathing.
- Do not have any medical conditions affecting the nose, throat, stomach, diaphragm or lungs.
- Have not had recent banding of esophageal strictures
- Have not had any surgical procedures affecting the nose, throat, stomach, diaphragm or lungs.
- Have not had any significant head, facial or airway trauma.
- Are not pregnant and have not given birth in the last 12 months.
- Are not regularly taking blood thinners, anticoagulants or fish oils for the last seven days (e.g., warfarin, aspirin, rivaroxaban, pradaxa, ibuprofen, fish oils)
- To the best of your knowledge have you ever had a reaction to medications such as Lignocaine Hydrochloride (a painkiller) or Phenylephrine Hydrochloride (a common ingredient in cold and flu medication).
- Are not currently taking medications which affect the heart, lungs or ability to participate in exercise.
- Do not have hypertension, severe bradycardia, conduction disturbances or severe digitalis intoxication.
- You agree to allow the re-use of your de-identified data in other research projects
- You agree to participate in the project.



- Do you consent to be contacted by Sherrilyn Walters (or the other members of this research team) in the future as a potential participant for other research projects run by USQ staff, students and affiliates? You may withdraw this consent at any time.

Yes ☐ No ☐

Participant Name

Participant Signature

Date

Please return this sheet to a Research Team member.