THE VALIDITY AND RELIABILITY OF RATINGS OF PERCEIVED EXERTION (RPE) IN ISOMETRIC EXERCISE TRAINING FOR THE REDUCTION OF ARTERIAL BLOOD PRESSURE

by

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Abstract

Hypertension (HTN), characterised by a sustained elevation in arterial blood pressure (≥140 mmHg systolic and/or ≥90 mmHg diastolic), is the leading global risk factor for disease, ahead of tobacco smoking, household air pollution, dietary factors, and physical inactivity. In addition, HTN is the primary modifiable risk factor for the development of cardiovascular disease (CVD), the largest preventable cause of morbidity and mortality worldwide. Reductions of ≥5 mmHg in systolic and/or diastolic blood pressure (BP) result in a significant reduction in the risk of CVD, myocardial infarction, stroke, and mortality. Pharmacological treatment requires lifelong adherence to daily medication to successfully control BP to within clinical target ranges, which comes at a considerable economic, personal, and social cost, including undesirable side effects. As a result of this, the adherence to and effectiveness of medical interventions for high BP is low. Exercise has been recommended as a non-pharmacological lifestyle modification for the treatment of HTN, with isometric exercise (IE), including isometric wall squat (IWS) exercise, proving to be an effective and time efficient means of reducing resting and ambulatory BP. However, the previous methods used to prescribe and implement IE interventions have mostly required expensive and/or specialised equipment, laboratory visits, and maximal exercise testing, which may reduce uptake and adherence to these programmes. The use of ratings of perceived exertion (RPE) to prescribe and control IE training intensity could potentially overcome a number of these barriers. Therefore, the aims of this thesis were to (1). validate RPE for use during IWS exercise, and (2). implement a home-based exercise intervention using RPE as a more accessible means of prescribing and controlling IWS exercise intensity. The initial studies in this thesis demonstrated the validity and reliability of RPE during the IWS protocols currently used in interventions for BP reduction. Then, a 4-week home-based IWS intervention was implemented, in a mixed group of normotensive and pre-hypertensive males and females, using a novel RPE method to prescribe and monitor exercise intensity. Following the intervention, 100% of the participants successfully achieved a clinically important reduction in BP. This included significant reductions in resting systolic, diastolic, and mean arterial BP, and ambulatory systolic BP, when compared to a control group. This novel prescription method may make IE more accessible by removing proven barriers to participation. This may in turn increase the uptake, adherence to, and overall effectiveness of IWS interventions for the reduction of resting BP.

Publications and Conferences

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Abbreviations

1RM	One-Repetition Maximum
AMBP	Ambulatory Blood Pressure
ANOVA	Analysis of Variance
BLa	Blood Lactate
BMI	Body Mass Index
BP	Blood Pressure
BRS	Baroreceptor Reflex Sensitivity
CAD	Coronary Artery Disease
CI	Confidence Intervals
CoV	Coefficient of Variation
CR-10	Borg's Category-Ration Scale
CVD	Cardiovascular Disease
DBP	Diastolic Blood Pressure
EI	Exercise Intensity
ECG	Electrocardiogram
EMG	Electromyography
EMGpeak	Peak Electromyography Result during Maximal Voluntary Contraction
ERF	Estimated Repetitions to Failure
HR	Heart Rate
HRpeak	Peak HR achieved during the Incremental Isometric Wall Squat Test
HTN	Hypertension
HRV	Heart Rate Variability
HTV	Hypertensive
IE	Isometric Exercise
IES	Isometric Exercise Scale
IHD	Ischaemic Heart Disease
IHG	Isometric Handgrip
ILE	Isometric Leg Extension
IWS	Isometric Wall Squat
IIWST	Incremental Isometric Wall Squat Test
LV	Left Ventricle/Ventricular
MAP	Mean Arterial Pressure
MCID	Minimum Clinically Important Difference
MI	Myocardial Infarction
MVC	Maximal Voluntary Contraction
NTN	Normotension
NTV	Normotensive
NRS	Numerical Rating Scale

NO	Nitric Oxide
NOS	Nitric Oxide Synthase
OMNI-RES	OMNI Resistance Exercise Scale
PAD	Peripheral Artery Disease
PEH	Post-Exercise Hypotension
PP	Pulse Pressure
Pre-HTN	Pre-hypertension
Pre-HTV	Pre-hypertensive
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PTD	Perceived Task Duration
Q	Cardiac Output
RES	Resistance Exercise Specific RPE
RIR	Repetitions in Reserve
RPD	Ratings of Perceived Discomfort or Pain
RPE	Ratings of Perceived Exertion
RPE-AM	Ratings of Perceived Exertion for the Active Muscle(s)
RPE-O	Overall Ratings of Perceived Exertion
RPP	Rate Pressure Product
SD	Standard Deviation
SV	Stroke Volume
S-RPE	Sessional Ratings of Perceived Exertion
SBP	Systolic Blood Pressure
TFM	Task Force Monitor
THRR	Target Heart Rate Range
TPR	Total Peripheral Resistance
TPRI	Total Peripheral Resistance Index
VO_2	Oxygen Consumption
WHO	World Health Organisation

CHAPTER 1:

Introduction and Literature review

1.1 Introduction

1.1.1 Hypertension

Hypertension (HTN), or high blood pressure (BP), defined as a systolic BP (SBP) ≥140 mmHg and/or a diastolic BP (DBP) ≥90 mmHg (Public Health England, 2014), is considered a global epidemic (Pescatello et al., 2004) responsible for approximately 10 million deaths each year (WHO, 2013). In 2010, HTN was the leading global risk factor for disease, ahead of tobacco smoking, household air pollution, dietary factors and physical inactivity (Lim et al., 2012); although, some of these risk factors are associated with HTN. High BP is also the 3rd ranked cause of disability-adjusted life-years (Ezzati, 2002), making it a substantial contributor to the global burden of chronic disease (Lim et al., 2012; WHO, 2013). In the year 2000, 26.4% of the global adult population had HTN (26.6% of men and 26.1% of women), with predictions that by 2025 this number would rise to 29% (Kearney et al., 2005). However, by 2013, approximately 35-40% of the adult European population were diagnosed as hypertensive (Mancia et al., 2013), with over 50% of the UK over 60-year-old population affected (NICE, 2011).

Long-term and potentially fatal blood pressure-related complications include coronary artery disease (CAD), kidney disease (Kearney et al., 2005), congestive heart failure, stroke, cognitive decline (Taylor et al., 2003), and overall reduced quality of life (Battersby et al., 1995). At 40–69 years of age, each 20 mmHg increase in SBP (or 10 mmHg increase DBP) is associated with a greater than twofold increase in mortality from stroke, ischaemic heart disease (IHD), and from other vascular causes (Prospective Studies Collaboration, 2002). Indeed, approximately 54% of strokes, 47% of IHD, and 25% of other cardiovascular disease (CVD) worldwide is directly attributable to high BP (Lawes et al., 2008).

Cardiovascular disease, including IHD, CAD, congestive heart failure, myocardial infarction (MI), peripheral artery disease (PAD), and cerebrovascular accidents, is the leading preventable cause of morbidity and mortality worldwide; with 31% of all deaths purportedly resulting from CVD (WHO, 2013). Hypertension is the most powerful predictor of the development of CVD (Mancia et al., 2013), with an elevation in SBP being strongly associated with the frequency of cardiovascular events (Weber et al., 2013). The disease burden of CVD worldwide is great, with low-income and middle-income countries bearing 80% of the total burden, half of which occurs in people of working age (MacMahon et al., 2008), further increasing the economic load of the disease.

1.1.2 Isometric exercise as an intervention for hypertension

Physical activity and cardiorespiratory fitness levels are recognised as predictors of CVD risk (Kodama et al., 2009; Prasad & Das., 2009), with inverse relationships with the development of HTN (Carnethon et al., 2010). Consequently, current guidelines recommend at least 30 minutes of moderate intensity physical activity, 5 days per week (WHO, 2010; ACSM, 2013). The most commonly recommended

form of exercise is aerobic exercise, which has been shown to effectively reduce BP (Cornelissen & Fagard, 2005a; Cornelissen & Smart, 2013), but resistance exercise is also widely recommended for its range of health benefits including BP reduction (Cornelissen & Fagard, 2005b; Cornelissen et al., 2011; Cornelissen & Smart, 2013).

As with medical interventions, exercise interventions suffer with poor adherence caused by low activity uptake and high drop-out rates (Zunft et al., 1999). The most commonly reported barrier to uptake and adherence to an exercise intervention is a perceived lack of time (Zunft et al., 1999). Further reported barriers include cost (expensive equipment, gym memberships, and travel expenses) and self-esteem issues, as some individuals wish to avoid the judgement of others in a fitness setting (Salmon, 2001). As such, a developing area of research and interest is isometric exercise (IE), which has been shown to be a more time efficient means of effectively reducing resting BP (Wiles et al., 2010; Cornelissen & Smart, 2013; Devereux et al., 2015). Indeed, the majority of IE protocols consist of 4 contractions held for approximately 2-minutes and are conducted just 3 times per week (Inder et al., 2016; Lawrence et al., 2015), substantially less than the 150-minutes per week currently recommended (WHO, 2013). In addition, some isometric methodologies have effectively used a combination of laboratory and home-based IE (McGowan et al., 2007; Millar et al., 2009a, 2009b; Stiller-Moldovan et al., 2012), thus limiting the travel and exposure to perceived judgement in an exercise setting. Despite the reduction in training time, mean reductions of 5.2 mmHg SBP and 3.9 mmHg diastolic BP (DBP) have been demonstrated following IE interventions, in a mix of normotensive (NTV) and HTV individuals (Inder et al., 2016).

While these IE protocols undoubtedly have the potential to reduce barriers to exercise participation, the current methods used to prescribe and control exercise intensity (EI) have tended to require specialist equipment that requires expertise to use, and is often prohibitively expensive; for example, isokinetic dynamometers (Devereux et al., 2010; Wiles et al., 2010; Baross et al., 2012), handgrip dynamometers (McGowan et al., 2007) and electromyography (EMG; Devereux et al., 2015). Additionally, these prescription methods involve laboratory-based maximal testing to quantify relative training loads, further increasing the barriers to participation. Therefore, if a means of prescribing and monitoring IE intensity could be developed that did not require expensive equipment and laboratory testing, these potential barriers could be removed, allowing the benefits of short duration IE to be utilised by a wider audience. Consequently, the overall effectiveness of these exercise interventions could be increased dramatically.

1.1.3 Ratings of perceived exertion as a measure of exercise intensity

Ratings of perceived exertion (RPE) could provide an easy to use and accessible alternative means of assessing, monitoring and prescribing EI (Colado et al., 2014). Indeed, it has long been established that RPE provides an accurate measurement of EI and physiological exertion during cardiovascular exercise

(Chen et al., 2002). In addition, there is now a growing body of evidence that indicates that various RPE scales provide a valid measure of EI during resistance exercise, including the Borg 6-20 (Lagally & Costigan, 2004), OMNI-RES (Aniceto et al., 2015), and the Borg CR-10 (Buckley & Borg, 2011) scales. During IE specifically, RPE has demonstrated strong relationships with both workload (Li & Yu, 2011; Rudroff et al., 2011; Lampropoulou & Nowicky, 2012) and EMG (Hummel et al., 2005; Troiano et al., 2008; Lampropoulou & Nowicky, 2012), the variables most commonly used to quantify IE intensity. If RPE can be shown to be a sufficiently accurate and reliable measure of EI, it is possible that it could be used to prescribe IE interventions to produce participant specific intensities sufficient to reduce arterial BP without the need for expensive equipment or exercise testing.

1.1.4 Chapter overview

This chapter will critically analyse the relevant research findings in the following areas: Categorisation and diagnosis of hypertension, medical treatment of hypertension, exercise interventions for BP reduction, the development of the home-based isometric wall squat intervention, current limitations to these interventions, and the validity of RPE as a measure of EI. This critical review was conducted over a 3-mointh period, from October 2015 to January 2016 inclusive, to inform the data collection and study design of the current research project. The literature search was focused on research articles within a 15-year period, with the inclusion of seminal and often cited work from outside this time-period.

1.2 Arterial blood pressure

Blood pressure is the hydrostatic pressure exerted by the blood on the walls of the vasculature (Booth, 1977). Systolic BP is the maximum pressure exerted by the blood during left ventricular (LV) contraction and DBP is the minimum arterial pressure occurring during myocardial relaxation and LV filling (Brzenzinski, 1990). As such, so called 'pulse pressure' (PP) is the difference between SBP and DBP and represents the force exerted by the LV contraction. Elevated PP is a marker of increased arterial stiffness (Franklin et al., 1997b) and consequently is a predictor of future cardiac events (Millar et al., 1999; Verdecchia et al., 1998). The average arterial pressure throughout a full cardiac cycle is referred to as mean arterial pressure (MAP), which can be estimated using the following equation: MAP = [SBP + (2 x DBP)]/3. Mean arterial pressure is the product of cardiac output (Q) and total peripheral resistance (TPR), giving the equation: MAP = Q x TPR (Pescatello et al., 2004; Millar et al., 2014). Additionally, as Q is determined by HR multiplied by stroke volume (SV), MAP is affected by any changes in HR, SV and/or TPR (Lund-Johansen, 1980).

Blood pressure status is categorised in several groups, hypotension, normotension (NTN), pre-hypertension (Pre-HTN) and hypertension (HTN), as shown in Table 1.1. Typically, normal or optimal BP (NTN), is classified as an SBP <120 mmHg and a DBP < 80 mmHg (WHO, 2007; Mancia et al., 2013; Public Health England, 2014). While HTN, a disease characterised by chronically elevated BP levels (Leung et al., 2017), is defined as an SBP of ≥140 mmHg and/or DBP of ≥90 mmHg (Carretero & Oparil, 2000). A diagnosis of HTN requires 2 clinical measurements where SBP or DBP are above the aforementioned levels (Pickering et al., 2005). As previously stated, HTN is now considered a global pandemic, is associated with increased risk of CVD, MI, kidney disease, and is responsible for approximately 10-million deaths each year (WHO, 2013).

Table 1.1: Blood pressure classification and categories

BP Classification*	SBP (mmHg)	DBP (mmHg)
Normotension	<120	<80
Pre-hypertension	120-139	80-89
Stage-1 Hypertension	140-159	90-99
Stage-2 Hypertension	≥160	≥100

*BP classification determined by the highest result. Adapted from Pickering et al. (2005)

It has been suggested that the current BP classifications are too conservative and that people with BP values considerably below what is considered HTV are also at increased health risk (Vasan et al., 2001a). Indeed, it has been suggested that a mean SBP over 115 mmHg should be considered high or elevated (Lawes et al., 2008), as the risk of cardiovascular events doubles for every 20 mmHg (SBP) and 10 mmHg (DBP) increase in BP >115 mmHg and >70 mmHg in SBP and DBP respectively

(Prospective Studies Collaboration, 2002). Consequently, the pre-hypertensive (Pre-HTV) population, with an SBP between 120-139 mmHg and a DBP between 80-89 mmHg (Chobanian et al., 2003), has been highlighted as a group of interest for research and health intervention (Public Health England, 2014).

At present, approximately 30% of the population are Pre-HTV (Gupta et al., 2010), and as such are at increased risk of developing HTN in the future, when compared to those with optimal BP (Vasan et al., 2001a). Moreover, patients with a BP in the upper range of Pre-HTN (SBP: 130- 139 mmHg and/or DBP: 85-89 mmHg) are twice as likely as those in the lower Pre-HTN range (SBP: 120-129 mmHg and/or DBP: 80-84 mmHg) to develop HTN (Vasan et al., 2001b). In addition to the increased risk of HTN, 93% of Pre-HTVs present with at least one additional CVD risk factor (Liszka et al., 2005), associated with a considerably increased risk of MI, CAD and CVD (Qureshi et al., 2005; Guo et al., 2013; Huang et al., 2013). As a result, Pre-HTN has been implicated in 9.1% of all deaths (Liszka et al., 2005).

Reform with clinical practice towards prevention rather than treatment, has resulted in a greater emphasis on identify groups that are at increased risk of developing HTN (Naylor et al., 2015). As such, the Pre-HTV population has been highlighted as a target for BP reduction to reduce the incidence of HTN and associated CVD morbidity and mortality. As a result, there is now growing evidence that this population can drastically benefit from interventions with the aim of reducing BP towards optimal levels (Chobanian et al., 2003).

1.3 Medical Treatment of Hypertension

Hypertension is now the most frequently encountered and most diagnosed condition by general practitioners (Hemmelgram et al., 2008; Sharman & Stowasser, 2009; James et al., 2014). Despite this, it has been suggested that HTN remains under-recognised and under-controlled (Joffres et al., 2013), with up to 60% of hypertensive (HTV) individuals unaware of their condition and are therefore failing to manage their BP to within optimal levels (Public Health England, 2014). In those that are aware of their condition, medical treatment is effective at rapidly reducing the risk of CVD, stroke, and mortality (Wright et al., 2015). There are various pharmacological treatments that have been shown to successfully combat HTN; however, these treatments often have side effects, require lifelong adherence, and have a high socio-economic cost (Heidenreich et al., 2011). As a result of this, adherence to BP medication treatment is poor (Caro et al., 1999), further lowering the rates of successful BP control (Fitz-Simon et al., 2005). Indeed, it is estimated that between 50 and 70% of diagnosed patients are not controlled to within clinical target ranges (Chobanian et al., 2003; Sarafidis, 2011; Mills et al., 2015). If the above estimates are correct, only between 12 and 20% of hypertensives are receiving effective medical treatment.

Despite the poor adherence and effectiveness of medical treatment, it comes at a high economic and social cost (Chockalingam et al., 2006). It is estimated that 'greater than optimal' BP accounts for over 10% of the world's healthcare expenditure and up to 25% of European healthcare costs (Gaziano et al., 2009). Between 2000 and 2004, the NHS funded 90 million prescriptions for anti-hypertensive medication annually; these prescriptions equated to approximately 15% of the total annual NHS budget for primary care drugs (North of England Hypertension Guideline Development Group, 2004). By 2006, approximately £1 billion was spent on anti-hypertensive drug therapies in the UK annually (NICE, 2011). In contrast, in the United States, the cost of anti-hypertensive drugs reached $46.4 billion in 2010 (Go et al., 2014). As previously mentioned, low and middle-income countries are often the hardest hit by the effect of HTN. It has been proposed that a 10-year multi-drug intervention in low and middle-income countries, using two BP lowering medications could avert an estimated 17.9 million CVD related deaths; however, this multi-drug intervention would have an estimated annual cost of between 33 and 61 billion USD (Lim et al., 2007), making it prohibitively expensive for these countries to get the medication to all that need it.

1.4 Non-medical interventions for blood pressure reduction

1.4.1 Lifestyle modifications for blood pressure reduction

As previously stated, pharmacological interventions to control BP are expensive and relatively ineffective, with only 30-50% of diagnosed patients successfully controlled to within clinical BP target ranges (Chobanian et al., 2003; Sarafidis, 2011; Mills et al., 2015). With greatest levels of CVD and

HTN in developing and lower-income countries (WHO, 2002), the need for cheap or free, readily accessible interventions is even greater than in more developed countries.

The current European recommendations for the treatment of hypertension suggest that following confirmation of BP status, patients with an SBP ≥140 mmHg or DBP ≥90 mmHg should receive antihypertensive medications alongside lifestyle interventions (Williams et al., 2018). Conversely, it is recommended that patients with high normal BP (SBP 130-139 mmHg and/or DBP 85-89 mmHg) should be offered lifestyle advice and should not be offered drug treatment, until they are nearing the hypertension diagnosis threshold (140/90 mmHg) despite a prolonged attempt at lifestyle modification (Williams et al., 2018).

It is well known that several key factors increase the risk of HTN and CVD; some risk factors are non-modifiable such as family history, ethnicity, sex, and age (Sharman & Stowasser, 2009), while others are modifiable including smoking, excessive alcohol consumption, high cholesterol levels, obesity, and physical inactivity (Wong et al., 2001). As such, there have been several lifestyle modifications targeted at increasing healthy eating, lowering sodium and alcohol intake, reducing obesity, increasing physical activity, and exercise (Touyz et al., 2004) that attempt to tackle HTN before the need for medication (Chockalingam et al., 2006).

Physical inactivity is currently estimated to be the fourth leading cause of mortality worldwide (WHO, 2010), therefore, reducing sedentary behaviour and increasing exercise participation has become a priority for increasing population health and specifically in the treatment of HTN (Brook et al., 2015). Encouragingly, the efficacy of physical activity interventions to produce a range of health benefits, including reduction in the risk of all-cause mortality, has been demonstrated repeatedly (Kokkinos & Myers, 2010; Woodcock et al., 2011). Moreover, the positive effects of exercise on BP have been verified in NTV, Pre-HTV and HTV individuals (Cornelissen & Smart, 2013).

1.4.2 Exercise as a non-pharmacological blood pressure intervention

Dynamic aerobic endurance exercise is currently recommended as a primary BP treatment option (Chobanian et al., 2003; Pescatello et al., 2004), and in patients undergoing pharmacological treatment, with 150-minutes of weekly physical activity deemed an effective adjunct to anti-hypertensive medication (Mosca et al., 2011). Indeed, various meta-analyses have confirmed the effectiveness of aerobic interventions with mean reductions ranging from 3.5 – 4.7 mmHg and 1.6 – 3.1 mmHg in resting SBP and DBP respectively (Halbert et al., 1997; Whelton et al., 2002; Cornelissen & Smart, 2013). Moreover, reductions have been demonstrated in NTV, Pre-HTV and HTV populations, with the largest reduction seen in Pre-HTV and HTV populations (Whelton et al., 2002; Cornelissen & Smart, 2013). The aerobic interventions in these studies used exercise including, walking (Murphy et al., 2006), jogging (Tsuda et al., 2003), cycling (Finucane et al., 2010), and swimming (Tanaka et al., 1997). Exercise intensities ranged from 35%-95% of peak oxygen consumption (VO_2), with frequencies

ranging from 1–7 times per week, and intervention durations from 4 to 52-weeks (Halbert et al., 1997; Kelley et al., 2001; Whelton et al., 2002; Cornelissen & Smart, 2013).

In addition to long-standing aerobic training recommendations, resistance training has been endorsed as a physical activity option to improve health and cardiovascular fitness (Pescatello et al., 2004; Cornelissen et al., 2011). Typically, resistance exercise programmes have lasted from 6-weeks to 6-months, with exercise intensities ranging from 30-100% of 1-repetition maximum (1RM) and reported training frequencies of 2-3 sessions per week (Kelley & Kelley, 2000; Cornelissen et al., 2011; Cornelissen & Smart, 2013). Reductions in resting SBP and DBP ranging from 3 - 3.9 mmHg, have been shown in previous meta-analyses examining these dynamic resistance exercise studies (Kelley & Kelley, 2000; Cornelissen et al., 2011). In addition to the BP benefits, improvements in VO_2, body fat percentage, and plasma triglycerides have been demonstrated (Cornelissen et al., 2011). A recent meta-analysis analysing 93 exercise trials, including 29 randomised controlled dynamic resistance studies, suggested that the mean reduction in BP were more modest than previously suggested (SBP: -1.8 mmHg and DBP: -3.2) (Cornelissen & Smart, 2013), supporting previous findings that the effects of dynamic resistance training programmes are often less pronounced than those of an aerobic/endurance type (Fagard, 2001; Fagard & Cornelissen, 2007). However, as demonstrated previously in aerobic exercise, considerably greater training-induced reductions were demonstrated in Pre-HTV individuals (SBP: -4.0 mmHg and DBP: -3.8 mmHg) when compared to both NTV and HTV individuals (Cornelissen & Smart, 2013), further emphasising the importance of targeting exercise interventions at this demographic.

Despite the well-known and frequently advertised healthy benefits of exercise, worldwide participation in regular physical activity is worryingly low. It has been estimated that approximately 50% of adults embarking on a new exercise programme will drop out within the first 6 months, and only 20% will continue to exercise for more than 24 months (Dishman, 1988). As a result, analysis of more than 12,500 adults in the USA, UK, and Canada, countries that have invested significant time and money to disseminate the recommended physical activity guidelines, demonstrated that only 10–15% of adults achieved the recommended 150-minutes of moderate intensity aerobic or resistance exercise per week (Tucker et al., 2011; Garriguet & Colley, 2014). To exacerbate the situation further, it has been suggested that when using solely aerobic exercise, more that 3-hours per week (>180-minutes) may be required for effective BP reduction (Pescatello et al., 2004). Interestingly, the most commonly cited reason for this low uptake and adherence is a perceived lack of time (Chao et al., 2000; Kraft et al., 2014a), suggesting that many adults may view the current recommendations as inaccessible, leading them to eventually reject the guidelines (Brawley & Latimer, 2007) or discouraging them from trying in the first place (Bethancourt et al., 2014; Sparling et al., 2015).

1.4.3 Isometric exercise

Traditional resistance exercise consisting of cyclical dynamic concentric and eccentric contractions, is widely recommended as part of a healthy lifestyle (WHO, 2010). In addition, there is now growing interest surrounding the use of isometric resistance exercise in the fight against HTN (Carlson et al., 2014; Inder et al., 2016). Isometric exercise is a type of resistance exercise involving a static muscle contraction against an immovable load; as such, muscle length remains constant during the contractions despite any changes in load (Fadel et al., 2004; Lind, 2011).

Isometric exercise interventions are a more time efficient means of effectively reducing resting BP (Wiles et al., 2010; Cornelissen & Smart, 2013; Devereux et al., 2015). Indeed, the majority of IE sessions follow the protocol originally presented by Wiley et al. (1992) consisting of 4 contractions held for approximately 2-minutes, separated by a rest period, ranging from 1-4 min (Millar et al., 2014). These interventions typically require just 3 sessions per week (Millar et al., 2013; Lawrence et al., 2015; Inder et al., 2016), leading to considerably less training time (a total of 24-minutes) than the 150-minutes per week currently recommended (WHO, 2013), and substantially less than has been suggested to elicit the greatest BP reduction with aerobic exercise, 40–60 min/session with a frequency of at least three times/week (Borjesson et al., 2016).

In addition to the reduced time burden during each training session, IE interventions are also relatively short-term; with interventions ranging from 3-10 weeks in duration, eliciting similar reductions in BP to aerobic training intervention averaging approximately 16-weeks in duration (ranging from 4 – 37 weeks) (Borjesson et al., 2016). Thus, it has been suggested that IE interventions are the most effective and time efficient type of exercise intervention to achieve clinically important BP reductions (Millar et al., 2013; Carlson et al., 2014) and as such may present a more accessible means of undertaking exercise for health and BP management.

1.4.4 Acute effects of isometric exercise

1.4.4.1 During an isometric contraction

At the onset of an IE contraction, sharp increases in Q and BP are reported (Araujo et al., 2011; Iellamo et al., 1997, 1999b; Fisher & White, 1999; Fisher et al., 2007). Stroke volume does not increase markedly, so increases in Q are predominantly caused by increases in HR (Donald, 1967), although these HR increases are still more modest than those seen during dynamic forms of exercise (Lind & McNicol, 1967). Conversely, the rapid ‘pressor response’, characterised by increases in SBP, DBP, and MAP, is more pronounced than during dynamic exercise (Lind, 1970).

Baroreceptors are specialised sensors, found in the aortic arch and carotid sinus, that respond to stretching of the arterial walls. At rest, when BP rises, the expansion of the arterial walls increases the rate of firing of the baroreceptors, termed the baroreflex, to the cardiovascular and vasomotor control

centres of the central nervous system (Tschakovsky & Pyke, 2008; Mooren, 2012). This inhibits sympathetic drive and increases parasympathetic stimulation to the heart and blood vessels, thereby decreasing HR, TPR, and ultimately BP.

During exercise, initial increases in HR and BP are mediated by a reduction in parasympathetic activity caused by withdrawal of vagal tone, as a result of reduced baroreceptor reflex sensitivity (BRS), or the so called 'upward resetting' to a higher point of baroreceptor activation (Iellamo et al., 1999; Fisher et al., 2006), by central command (Alexander et al., 1994; Ogoh et al., 2002; Chrysant, 2010; Kaur & Mann, 2016) and the exercise pressor reflex (Gallagher et al., 2001; Smith et al., 2006). It has been demonstrated that central command and the pressor reflex act simultaneously and seemingly in equal measures to reduce BRS (Gallagher et al., 2006). The parasympathetic meditation of the first cardiovascular responses was confirmed, following administration of a parasympathetic blockade, atropine, which blunted the HR response in the first 30-seconds of IHG exercise (Martin et al., 1974).

The term 'pressor reflex' describes the mechanical and metabolic activation of afferent nerves in a contracting muscle, which stimulates the cardiovascular control centre within the medulla oblongata (Tschakovsky & Pyke, 2008). Following withdrawal of parasympathetic regulation, the pressor reflex acts to stimulate sympathetic nervous activity, further increasing HR and consequently Q (Alexander et al., 1994; Chrysant, 2010; Martin et al., 1974). Mechanical stimulation of the pressor reflex is caused by increased firing of afferent mechanoreceptors, as motor unit recruitment and firing rates increase to maintain tension (Vaz et al., 1996). Metabolic activation of peripheral chemoreceptors (metaboreflex) is caused by increases in metabolites, including hydrogen ions (H^+) and lactate, due to occlusion of the vascular beds of the exercising muscles (Edwards et al., 1972; Karlsson et al., 1975; Tesch & Karlsson, 1977; Rotto & Kaufman, 1988; Mostoufi-Moab et al., 1998; Iellamo et al., 1999b; Ichinose et al., 2006). Increased sympathetic activation has been demonstrated during isometric leg contractions, with increases in the low frequency component of HR variability, a measure of sympathetic activation and vagal withdrawal (Iellamo et al., 1999a).

Total peripheral resistance increases during isometric exercise (Kivowitz et al., 1971) due to the physical occlusion of blood flow to exercising muscles and increases in vasoconstriction mediated by sympathetic activity (Barcroft & Millen, 1939; Mark et al., 1985). As a result, the increases in Q lead to further elevations in BP (Lind & McNicol, 1967; Lind, 1970).

Heart rate and BP responses are proportional to the IE load, contraction time (Franke et al., 2000), and exercising muscle mass (Freund et al., 1978). As such, linear increases in HR and BP have been seen with contraction time, where the gradient of the increases are dependent on the workload and muscle mass (Fisher et al., 2007; Wiles et al., 2008; Devereux et al., 2011; Goldring et al., 2014; Carlson et al., 2017). It has been suggested that greater intensities, muscle mass and duration of contraction will result in a wider activation of muscle fibres, causing increased afferent mechanoreceptor activation (Vaz et

al., 1996) and greater occlusion of resistance vessel blood flow (MacDougall et al., 1985; Williams et al., 2007). Moreover, increases in contraction time and muscle mass cause greater accumulation of metabolites, chemoreceptor stimulation, and therefore sympathetic activation (Gandevia & Hobbs, 1990).

1.4.4.2 Acute post-exercise responses

A single bout of aerobic, dynamic resistance or isometric exercise can lead to a transient post-exercise drop in BP, below resting measures; a phenomenon referred to as post-exercise hypotension (PEH) (MacDonald, 2002; Millar et al., 2009a; Araujo et al., 2011; Moraes et al., 2012). The onset of PEH occurs in as little as 5 minutes post-exercise (MacDonald et al., 2000), with the peak decrements occurring most often by 30 or 45-min post-exercise (Kenney & Seals, 1993; MacDonald, 2002). Several studies have demonstrated statistically significant PEH following isometric exercise (Stewart et al., 2007; Millar et al., 2009a), with more exaggerated responses notable in Pre-HTV and HTV individuals compared with NTV exercisers (MacDonald, 2002; Cardoso et al., 2010; Carpio-Rivera, 2016). Peak decreases in BP have been reported of 18-20 mmHg and 7-9 mmHg in HTVs, 10 mmHg and 16 mmHg in Pre-HTVs, and 8-10 mmHg and 3-5 mmHg in NTVs, SBP and DBP respectively (Kenney & Seals, 1993). In addition to greater decrements, PEH appears to be more prolonged in HTV (Pescatello et al., 1991; Brownley et al., 1996; Wallace et al., 1999; Quinn, 2000) and Pre-HTV subjects (Ash et al., 2017), when compared to NTVs.

The magnitude of PEH response also appears to be related to the muscle mass involved in the contraction. For example, single-quadricep protocols have failed to elicit PEH (Barrett-O'Keefe et al., 2013; Devereux et al., 2015); yet, a number of resistance exercise studies have demonstrated PEH when using multiple muscle groups (Brown et al., 1994; MacDonald et al., 1999a; Simão et al., 2005; Mohebbi et al., 2009; Duncan et al., 2014; Mohebbi et al., 2016).

As suggested during exercise, autonomic control of BP is mediated by the arterial baroreflex, central command, and the exercise pressor reflex (Smith et al., 2006). During recovery from IE, BRS is thought to increase following exercise to a level above that seen at baseline (Halliwill et al., 1996b; 2013); leading to increased parasympathetic modulation coupled with withdrawal of sympathetic activity (Millar et al., 2009b), which contribute to PEH. Likewise, upon cessation of an IE contraction there is a sudden removal of mechanical resistance and reperfusion of blood to previously occluded muscle mass (Halliwill et al., 2013), this acts to lower TPR and redistribute blood volume to an increased vasculature. This reperfusion is associated with a local persistent vasodilation, causing a period of post exercise hyperaemia in the vascular beds of previously active muscle (Halliwill et al., 2001; 2013); this post-exercise vasodilation can last for up to 1-2 hours after exercise (Cléroux et al., 1992; Isea et al., 1994; Halliwill et al., 1996a).

It has been postulated that sheer stress (frictional force exerted by the blood on the endothelium) during exercise combined with increased post-exercise parasympathetic activity, cause an increase in the release of vasodilating agents, such as nitric oxide (NO) (Jungersten et al., 1997; Raitakari & Celermajer, 2000), prostaglandins and histamine (Tinken et al., 2010), in an attempt to improve endothelial function, reduce TPR and restore blood flow to the occluded muscle. As such, it is thought that these agents may contributed to the persistent peripheral vasodilation and PEH. However, there are some conflicting results regarding these vasodilating agents. For example, inhibition of NO failed to prevent a sustained vasodilatory response during exercise recovery in NTV individuals (Halliwill et al., 2000). Likewise, the inhibition of an important prostaglandin did not affect the magnitude of post-exercise vasodilation following an acute bout of dynamic aerobic exercise (Lockwood et al., 2005). Similarly, while the application of histamine receptor antagonists was shown to blunt the PEH response in one study (McCord & Halliwill, 2006), a more recent study was unable to show histamine activation during PEH and sustained vasodilation following resistance exercise (Barrett-O'Keefe et al., 2013). These findings may suggest that these mechanisms are population and/or exercise dependant. Additionally, PEH and persistent vasodilation may be the consequences of multiple signalling molecules and pathways such that blocking one does not reliably stop the responses.

Finally, it has been proposed that PEH could be associated with a reduction in blood volume during IE due to perspiration (Bush et al., 1999), and compartmental volume changes caused by; firstly, the accumulation of metabolites in the active muscle, which increase the osmotic gradient and pull water into the muscle from the blood, and secondly, increases in BP create a greater driving pressure that forces water out of the capillaries and in to the intracellular and interstitial spaces (Collins et al., 1989; Bush et al., 1999; Rezk et al., 2006).

1.4.5 Chronic effects of isometric exercise training

Multiple systematic reviews and meta-analyses have assessed the chronic effects of IE training interventions on resting BP; Cornelissen and Smart (2013) reported mean reductions 10.9 mmHg and 6.4 mmHg, in SBP and DBP respectively. Subsequently, Carlson et al. (2014) demonstrated mean reductions of 6.77 mmHg in SBP, 3.96 mmHg in DBP, and 3.94 in MAP, in a mix of NTV and HTV participants. Most recently, Inder et al. (2016) explored 11 randomised control trials implementing IE interventions and findings indicated significant, although more modest, mean reductions in SBP (5.2 mmHg), DBP (3.91 mmHg), and MAP (3.33 mmHg). Following sub-group analysis, Inder et al. (2016) suggested that the greatest reduction in MAP were seen in HTV (HTV: −5.91 mmHg vs NTV: −3.01 mmHg), older (>45 years: -5.51 mmHg vs <45 years: − 2.72 mmHg), male (males: -4.13 mmHg vs female: -2.29 mmHg) participants. It should be noted, that Inder et al. (2016) did not compare the NTV and HTV results with reductions found in Pre-HTVs. Cornelissen and Smart (2013) compared all three BP groups and suggested that Pre-HTV had the greatest reductions following resistance training.

Despite these proposed inter-group differences, clinically meaningful BP reductions of ≥ 5 mmHg in SBP or DBP (NICE, 2011), have been produced in NTV (Wiles et al., 2010), Pre-HTV (Baross et al., 2012), unmedicated HTV (Peters et al., 2006), and medicated HTV (McGowen et al., 2007b; Badrov et sl., 2013b) populations (Table 1.2). Similarly, clinically meaningful reductions have been shown in males (Wiles et al., 2010; Deveraux et al., 2010; Baross et al., 2012), females (Badrov et al., 2013a) and mixed groups (Garg et al., 2014); as well as, younger (Deveraux et al., 2010) and older (Badrov et al., 2013b) adults (Table 1.2).

While only a relatively small number of IE studies are available, results suggest that IE may induce the largest BP reductions, when compared to aerobic and dynamic resistance training, despite shorter training session and intervention durations (Carlson et al., 2014; Cornelissen et al., 2011; 2013).

1.4.5.1 Isometric exercise effectiveness

There are large methodological differences between IE intervention studies, with no agreed protocol for the most effective long-term BP reductions; these differences make between study comparisons difficult (Table 1.2). Training intensity, expressed as a percentage of maximal voluntary contraction (MVC) or as a percentage of peak EMG (Carlson et al., 2014), is most commonly performed at 30% of MVC or EMGpeak (Wiley et al., 1992); although lower intensities have been successfully used (Howden et al., 2002; Wiles et al., 2010; Baross et al., 2012). Exercise duration is relatively consistent, with the vast majority of studies using 4 x 2-minute contractions, separated by rest periods ranging from 1-minute (Taylor et al., 2003; Peters et al., 2006) to 4-minutes (Millar et al., 2013; Badrov et al., 2013a). The impact of these differences in rest period is currently unclear.

Different modes of IE and active muscle groups have been shown to be effective including IHG (Badrov et al., 2013b), ILE (Wiles et al., 2010), and arm flexion (Howden et al., 2002) exercise. As suggested previously for the acute IE response (Freund et al., 1978), a relationship between working muscle mass and physiological response has been proposed (Mitchell et al., 1980), suggesting that using larger muscle mass could elicit greater BP reductions. In support of this contention, Howden et al. (2002) demonstrated larger reduction in SBP, over the same time-period, following ILE at 20% MVC when compared to IHG exercise at 30% MVC. This may be caused by the recruitment of additional motor units in a larger muscle mass, increasing the sympathetic response to the working muscles (Mitchell et al., 1980). In addition, the larger muscle mass may allow greater metabolites build up and has a greater volume of blood vessels to benefit from persistent vasodilation, as was previously shown to elicit greater PEH following IE (Mohebbi et al., 2009; Duncan et al., 2014).

Intervention lengths are also changeable between studies. Most commonly, interventions have been conducted over a period of 8-weeks (Wiley et al., 1992; McGowan et al., 2007; Millar et al., 2007; Wiles et al., 2010); however, longer duration interventions up to 10-weeks (Taylor et al., 2003; Badrov

et al., 2013b; Garg et al., 2014) and shorter duration interventions of 3 – 4 weeks (Deveraux et al., 2010; Gill et al., 2015) have been implemented to successfully reduce BP.

Table 1.2: Isometric exercise training protocols utilised for the reduction of resting blood pressure

Reference	Participants n = (Sex)	BP Category	Mode	Training Intensity	Training Timings	Frequency	Duration	BP Change (mmHg)
Wiley et al. (1992)	8	Pre-HTN	Unilateral Handgrip	30% MVC	Exercise: 4 x 2 min Rest: 3 min	3 x/week	8 weeks	SBP: ↓ 13 DBP: ↓ 15
	10	Pre-HTN	Unilateral Handgrip	50% MVC	Exercise: 4 x 45 sec Rest: 1 min	5 x/week	5 weeks	SBP: ↓ 10 DBP: ↓ 9
Ray and Carrasco (2000)	9 (mixed)	NTN	Unilateral Handgrip	30% MVC	Exercise: 4 x 3 min Rest: 5 min	4 x/week	5 weeks	SBP: --- DBP: ↓ 5 MAP: ↓ 4
Howden et al. (2002)	8 (mixed)	NTN	Bilateral Arm Flexion	30% MVC	Exercise: 4 x 2 min Rest: 3 min	3 x/week	5 weeks	SBP: ↓ 10 DBP: ---
	9 (mixed)	NTN	Bilateral Leg Extension	20% MVC	Exercise: 4 x 2 min Rest: 3 min	3 x/week	5 weeks	SBP: ↓ 12 DBP: ---
Taylor et al. (2003)	9 (mixed)	HTN Medicated	Bilateral Handgrip	30% MVC	Exercise: 4 x 2 min Rest: 1 min	3 x/week	10 weeks	SBP: ↓ 19 DBP: --- MAP: ↓ 11
Peters et al. (2006)	10 (mixed)	HTN	Bilateral Handgrip	50% MVC	Exercise: 4 x 45 sec Rest: 1 min	3 x/week	6 weeks	SBP: ↓ 13 DBP: ---
McGowen et al. (2006)	17	HTN Medicated	Unilateral Handgrip	30% MVC	Exercise: 4 x 2 min Rest: 3 min	3 x/week	8 weeks	MAP: ---
McGowen et al. (2007a)	11 (mixed)	NTN	Unilateral Handgrip	30% MVC	Exercise: 4 x 2 min Rest: 3 min	3 x/week	8 weeks	SBP: ↓ 5 DBP: ---

Table 1.2: Continued - Isometric exercise training protocols utilised for the reduction of resting blood pressure

Reference	Participants	BP Category	Mode	Training Intensity	Training Timings		Frequency	Duration	BP Change (mmHg)
McGowen et al. (2007b)	7 (mixed)	HTN Medicated	Bilateral Handgrip	30% MVC	Exercise: Rest:	4 x 2 min 1 min	3 x/week	8 weeks	SBP: ↓ 15 DBP: ---
	9 (mixed)	HTN Medicated	Unilateral Handgrip	30% MVC	Exercise: Rest:	4 x 2 min 1 min	3 x/week	8 weeks	SBP: ↓ 9 DBP: ---
Millar et al. (2008)	25 (mixed)	NTN	Bilateral Handgrip	30-40% MVC	Exercise: Rest:	4 x 2 min 1 min	3 x/week	8 weeks	SBP: ↓ 10 DBP: ↓ 3
Wiles et al. (2010)	11 (males)	NTN	Bilateral Leg Extension	75% HRpeak (~10% EMG)	Exercise: Rest:	4 x 2 min 2 min	3 x/week	8 weeks	SBP: ↓ 4 DBP: ↓ 3 MAP: ↓ 3
	11 (males)	NTN	Bilateral Leg Extension	95% HRpeak (~21% EMG)	Exercise: Rest:	4 x 2 min 2 min	3 x/week	8 weeks	SBP: ↓ 5 DBP: ↓ 3 MAP: ↓ 3
Deveraux et al. (2010)	13 (males)	NTN	Bilateral Leg Extension	95% HRpeak (~24% EMG)	Exercise: Rest:	4 x 2 min 3 min	3 x/week	4 weeks	SBP: ↓ 5 DBP: ↓ 3 MAP: ↓ 3
Baross et al. (2012)	10 (males)	Pre-HTN	Bilateral Leg Extension	70% HRpeak (~8% EMG)	Exercise: Rest:	4 x 2 min 2 min	3 x/week	8 weeks	SBP: --- DBP: --- MAP: ---
	10 (males)	Pre-HTN	Bilateral Leg Extension	85% HRpeak (~14% EMG)	Exercise: Rest:	4 x 2 min 2 min	3 x/week	8 weeks	SBP: ↓ 11 DBP: --- MAP: ↓ 5
Stiller-Moldovan et al. (2012)	25 (mixed)	HTN Medicated	Bilateral Handgrip	30% MVC	Exercise: Rest:	4 x 2 min 1 min	3 x/week	8-10 weeks	SBP: --- DBP: --- MAP: ---
Millar et al. (2013)	13 (mixed)	HTN Medicated	Unilateral Handgrip	30% MVC	Exercise: Rest:	4 x 2 min 4 min	3 x/week	8 weeks	SBP: ↓ 5 DBP: --- MAP: ↓ 3

Table 1.2: Continued - Isometric exercise training protocols utilised for the reduction of resting blood pressure.

Reference	Participants	BP Category	Mode	Training Intensity	Training Timings	Frequency	Duration	BP Change (mmHg)
Badrov et al. (2013a)	12 (female)	NTN	Unilateral Handgrip	30% MVC	Exercise: 4 x 2 min Rest: 4 min	3 x/week	8 weeks	SBP: ↓ 6 DBP: --- MAP: ---
	11 (female)	NTN	Unilateral Handgrip	30% MVC	Exercise: 4 x 2 min Rest: 4 min	5 x/week	8 weeks	SBP: ↓ 6 DBP: --- MAP: ---
Badrov et al. (2013b)	12 (mixed)	HTN Medicated	Unilateral Handgrip	30% MVC	Exercise: 4 x 2 min Rest: 1 min	3 x/week	10 weeks	SBP: ↓ 8 DBP: ↓ 5 MAP: ↓ 6
Garg et al. (2014)	30 (mixed)	NTN	Bilateral Handgrip	30% MVC	Exercise: 5 x 3 min Rest: 5 min	3 x/week	10 weeks	SBP: ↓ 10 DBP: ↓ 3
Gill et al. (2015)	8 (mixed)	NTN	Bilateral Leg Extension	20% MVC	Exercise: 4 x 2 min Rest: 3 min	3 x/week	3 weeks	SBP: --- DBP: --- MAP: ---
	9 (mixed)	NTN	Bilateral Leg Extension	30% MVC	Exercise: 4 x 2 min Rest: 3 min	3 x/week	3 weeks	SBP: ↓ 3.6 DBP: ↓ 4 MAP: ↓ 3.9
Wiles et al. (2017)	28 (males)	NTN	Home-based Wall Squat	95% HRpeak	Exercise: 4 x 2 min Rest: 2 min	3 x/week	4 weeks	SBP: ↓ 4 DBP: ↓ 3 MAP: ↓ 3 HR: ↓ 5 TPR: --- SV: ---

↓ significant decrease, --- variable was measured and showed no significant differences.

1.4.5.2 Potential chronic mechanism of action

It has been suggested that repeated stimulation of the acute IE exercise and PEH responses may cause the chronic BP reductions seen after IE interventions, primarily through changes in autonomic regulation (Taylor et al., 2003; Millar et al., 2013) and improvements in vascular function (McGowan et al., 2007; Badrov et al., 2016); however, it should be noted that experimental findings supporting these chronic mechanisms are still limited and inconclusive.

Limited evidence for sustained changes in autonomic regulation, has been presented following a 10-week IHG training intervention, after which decreases in the LF/HF ratio component of heart rate variability (HRV) were shown, indicating a reduction in sympathetic and an increase in parasympathetic modulation at rest (Taylor et al., 2003). Likewise, increased resting vagal tone was detected following 8-weeks of IHG training, showing an increase in parasympathetic activation (Millar et al., 2013). In addition, Gandhi (2016) demonstrated that following a 5-week IE intervention that elicited significant resting BP reductions, the rate and magnitude of BP increase during an acute IE training session was significantly lower than pre-training. This result has been linked with previous findings that have suggested reduced sympathetic nerve activity responses during the first 2-minutes of IHG, following an IE intervention (Somers et al., 1992).

It has been suggested that the majority of the anti-hypertensive benefits of IE are due to reductions in TPR (Carlson et al., 2014). Previously it has been postulated that reductions in TPR following persistent exercise was, at least in part, due to baroreflex mediated reductions in sympathetic activation and consequently reductions in sympathetic vasoconstriction (Coats et al., 1992; Grassi et al., 1994). In addition, reductions in vasoconstrictor molecules (Maeda et al., 2001) and increases in vasodilators, such as NO (Jungersten et al., 1997) and histamine (Halliwill et al., 2013) are recognised adaptations to aerobic exercise programmes, which have favourable effects on TPR, and as such are of interest as potential mechanisms during IE. In support of this, McGowan et al. (2007) measured improvements in NO dependent vasodilation in the trained arm only following unilateral IHG in medicated HTVs, suggesting a localised response in trained muscles. Likewise, Peters et al. (2006) reported significant reductions in oxidative stress following 6-weeks of IHG in HTV participants. Oxidative stress negatively affects the delivery of vasoactive substances to blood vessels, thus reductions in oxidative stress may increase vasodilation and reduce TPR (Peters et al., 2006).

Finally, Badrov et al. (2013a) reported an increase in endothelial function following IHG training, which may explain improvements in arterial compliance, the elasticity of blood vessels, seen after exercise interventions (Cameron & Dart, 1994; Silva et al., 1997). Increased compliance in the aortic and carotid arterial vessels may in turn alter the discharge of the baroreceptor cells (Kingwell et al., 1997), contributing to increases in chronic BRS.

1.4.5.3 Limitations of the traditional isometric exercise interventions

While IE goes some way to reducing the time-burden barrier to exercise participation, further barriers that account for a large proportion of physical inactivity include cost (such as expensive equipment, gym memberships, and travel expenses) and self-esteem issues, such as a wish to avoid the judgement of others in a fitness setting (Salmon, 2001). As such, the majority of IE interventions are still potentially limited by these barriers. For example, most interventions require each training session to be conducted in a laboratory under the supervision of an exercise professional, thus incurring travel expenses and situations where participants may feel embarrassed and judged. In addition, the current methods used to prescribe and control EI have tended to require specialist equipment that is often prohibitively expensive; for example, isokinetic dynamometers (Devereux et al., 2010; Wiles et al., 2010; Baross et al., 2012), expensive digital handgrip dynamometers (McGowan et al., 2007; Millar et al., 2007) and electromyography (EMG; Devereux et al., 2015). This has raised concerns that the current IE methodologies are, in reality, neither cost nor time efficient (Millar et al., 2014), and still present unnecessary barriers that limit the overall effectiveness of these interventions (Kraft et al., 2014a; Millar et al., 2009b).

In response to this, some isometric methodologies have been explored that allow a combination of laboratory and home-based testing and training (McGowan et al., 2007; Millar et al., 2009a, 2009b; Stiller-Moldovan et al., 2012; Goldring et al., 2014); thus, making access to the exercise easier, while limiting the travel costs and exposure to perceived judgement (Ransdell et al., 2003; Goldring et al., 2014).

1.4.6 Development of the home-based isometric wall squat

Wiles et al. (2005) explored the use of a modified bathroom scale as a novel home-based method of conducting elbow flexor exercise. This study aimed to remove the need for expensive force transducers traditionally necessary to conduct constant force exercise. They showed significant increases in HR and BP in bouts 3 and 4 of the exercise, demonstrating the relationships between home-based constant force IE, HR and BP. Additionally, while this methodology required a specifically designed metal bracket to allow the bathroom scale to be fixed to the floor, making it impractical for a wide-scale implementation, they were the first to demonstrate that an improvised technique, using house-hold items, could be used to provide IE in the home. Following this, Wiles et al. (2008) explore the relationships between percentage of EMGpeak (EMG activation at MVC), HR and SBP, during an incremental test to exhaustion. It was hoped that HR and SBP could be used to prescribe and monitor EI, possibly optimising the effects of the exercise by measuring the actual stimulus being exerted on the relevant system (i.e., the cardiovascular system). EMG was used to allow the participant to adjust the force output to keep the relative EI constant during each 2-minute stage. Linear relationships were found between EI (%EMG), HR and SBP; thus, it was proposed that the incremental test and the relationships

between variables could be used to prescribe isometric EI. Wiles et al. (2010) then used this methodology during an 8-week intervention of bilateral ILE exercise in NTV participants. Each participant completed an incremental test, following which EI and HR were plotted to calculate the EMG required to elicit either a 75% or 95% HRpeak response (where HRpeak in the maximum HR achieved during the incremental test). The 75% HRpeak intensity was chosen as the lowest % HRpeak that could reliably be elicited with constant EMG exercise (based on pilot work) and 95% HRpeak was chosen to give the greatest separation possible between the two intensities, without making the exercise maximal. Following the 8-week intervention, significant reductions in SBP, DBP and MAP were shown in both the 75% and 95% groups, when compared to a control group. No differences in TPR, Q or SV were seen in either group. In the 95% group most of the BP reduction were seen in the first 4-weeks, although not significant until 8-weeks, while the 75% group showed more steady decreases up to 8-weeks. Based on these finding, a second intervention study was conducted using 4-weeks of bilateral ILE set at an EI corresponding to 95% HRpeak (Deveraux et al., 2010). Unlike Wiles et al. (2010), Deveraux et al. (2010) showed significant SBP, DBP and MAP reductions in just 4-weeks, while similarly no differences were found in TPR, Q or SV. The faster BP reductions may have been due to the cross-over design used by Deveraux et al. (2010), thus reducing the inter-participant variance when compared to a randomised control study, as was used by Wiles et al. (2010). A final bilateral ILE study was conducted, over 8-weeks, using EMG values corresponding to 70% HRpeak and 85% HRpeak (Baross et al., 2012). No significant differences in HR or BP were demonstrated in the 70% group after 8-weeks. Conversely, significant reductions in HR, SBP and MAP were shown in the 85% group, but no significant differences were shown in DBP. The reductions in SBP and MAP shown in the 85% group were greater than those previously shown by Wiles et al. (2010) and Deveraux et al. (2010) when prescribing at 95% HRpeak (Table 1.1), possibly due to the Pre-HTV older participants used by Baross et al. (2012). Despite this, the intensity was not sufficient to induce significant DBP reductions in that group.

The previous 3 studies reverted back to laboratory-based exercise using expensive EMG and isokinetic dynamometry equipment, in order to develop the HR prescription protocol; therefore, it was desirable to find an alternative exercise mode that could utilise the HR prescription method while being more suitable for home-based training. One such modality was the isometric wall squat (IWS) which utilised a constant position isometric contraction style (Hunter et al., 2002), with participants required to keep their knee joint at a prescribed angle while supporting an inertial load (body mass) using the quadriceps. This method removed the need for EMG and dynamometry, replacing them with the simpler and cheaper to measure knee joint angle and HR, while continuing to take advantage of the larger muscle mass used during ILE, which it is suggested may be able to produce a similar magnitude of resting BP reduction when conducted at a relatively lower exercise intensity (Howden et al., 2002) or over a shorter time frame (Gill et al., 2015) when compared to IHG exercise (Table 1.1).

Goldring et al. (2014) conducted a discontinuous isometric wall squat (IWS) test, where participants held one of 10 different knee joint angles from 135º to 95º, in 5º increments, for 2-minutes. Goldring et al. (2014) demonstrated the relationships between EI (knee joint angle), HR and BP. Additionally, they showed that HR increased significantly with each 10º increase in IWS intensity (decrease in knee angle) but not with 5º increases. Therefore, the 5 knee angles between 135º and 95º (inclusive) were used to develop a 5-stage incremental test, as used by Wiles et al. (2008), that could be used to predict the EI that corresponds to 95% HRpeak (Wiles et al., 2010). Work being conducted at Canterbury Christ Church University at the time of this review, and was later published (Wiles et al., 2017), implemented a 4-week home-based IWS intervention, in NTV participants, based on the work of Goldring et al. (2014). Exercise intensity was calculated, following an incremental isometric wall squat test (IIWST), at a knee joint angle corresponding to 95% HRpeak. Participants were given a device, the Bend and Squat, to control knee angle during the squat and a HR monitor to allow the researchers to monitor the exercise stimulus. Following 4-weeks of training, significant reductions in resting SBP (−4 ± 5 mmHg), DBP (−3 ± 3 mmHg), MAP (−3 ± 3 mmHg), Q (−0.54 ± 0.66 $L.min^{-1}$) and HR (−5 ± 7 $beats.min^{-1}$) were present. No significant changes in TPR or SV were shown. This study was the first to implement a full home-based IE intervention, using affordable equipment, to successfully reduce resting BP; thus, this was a large step forward in the accessibility of IE for the wider population.

1.4.6.1 Limitations of the current IWS protocols

The IWS reduces several of the previously mentioned barriers to IE, including the application of exercise to be completed at home, thus limiting the feeling of being watched and judged that is prevalent in an exercise setting and reducing travel costs (Salmon, 2001). Likewise, as suggested with previous IE interventions, IWS is a more time efficient means of eliciting a significant physiological effect. In addition, the tools used to monitor knee angle and HR are relatively inexpensive (approximately £10.00 per device), when compared to the previous equipment used.

Despite these benefits, there are still several barriers to participation created by the current IWS methods, including: 1. The need to attend a laboratory for IE/knee joint angle prescription; 2. maximal exercise testing; 3. the requirement for equipment that is not owned by most individuals (HR monitor) and that is not readily available to the public (Bend and Squat device). The need to attend a laboratory, although reduced significantly, will be a barrier to those individuals who try to avoid judgement and who see time as a limiting factor. Likewise, maximal exercise testing is time-consuming and may involve some health risks, especially in elderly participants (Desgorces et al., 2015) or in HTV individuals. Maximal testing is also impractical for larger groups (Eston & Evans, 2009) which requires these testing sessions to be one-to-one, which could again discourage participants who fear judgement. Finally, the need for equipment that is not already owned may present a financial barrier, especially in

low- and middle-income countries where elevated BP is having the greatest impact, and may make this form of intervention inaccessible to some people who cannot gain access to the Bend and Squat device.

These limitations come about primarily due to the need for accurate control of EI, and the inherent limitations within the currently validated methods of doing so. The control of EI is a key factor in ensuring the safety and efficacy of physical activity in a therapeutic setting (Robertson et al., 2004). Therefore, it is necessary to identify a safe, effective, and accessible means to establish and monitor appropriate training intensities (Gearhart et al., 2011), that can be conducted autonomously, and can limit or eliminate the need for maximal and/or laboratory-based testing and additional equipment not readily found within the home.

1.5 RPE as an alternative measure of exercise intensity

When quantifying physical work, Borg (1977) suggested that there are three main "effort continua" on which the physical work can be measured: the perceptual, the performance and the physiological. The perceptual continuum, or the so called 'perceived exertion', is "the feeling of how heavy and strenuous a physical task is" (Borg, 1998, pg. 8). Therefore, ratings of perceived exertion (RPE) are the quantification of this continuum, which encompasses the subjective intensity of the effort, strain, discomfort, and/or fatigue that are experienced during a physical task or exercise (Noble & Robertson, 1996). It has been suggested that the continuum of perceptual responses corresponds to the continuum of performance responses (e.g., changes in workload or power output) and the continuum of physiological responses (e.g., changes in HR or blood lactate) (Borg, 1998). As such, perceptual responses likely provide much the same information about exercise performance as the physiological responses do (Robertson & Noble, 1996). Indeed, the original perceived exertion scale designed by Borg (Borg's 6-20 scale), was based on the strong correlations demonstrated between its results and physiological variables such as HR, lactate level, respiration rate, and oxygen uptake (Coutts et al., 2009; Nakamura et al., 2010).

The perception of effort refers to the sum of all subjective sensations during an exercise performance (Berchicci et al., 2013), with numerous physical, physiological, and psychological factors playing a role in shaping the perceived exertion response during exercise (Pincivero et al., 2004b). As such, there is not a complete understanding of all the factors, processes, and mechanism that affect and form the perception of exertion. Indeed, it is possible that these mechanisms are changeable based on a number of factors, such as the environment, type of exercise, motivation and mood of the participant (Borg, 1998). Despite this incomplete knowledge, some of the underlying mechanisms have been outlined; for example, it has been demonstrated that a combination of localised sensation together with feedback from the circulatory and respiratory systems, metabolic system, skeletal muscles, and the peripheral nervous system all contribute to the level of perceived exertion (Pollock & Pels, 1984). During resistance exercise, it is suggested that an increase in workload or time-under-tension will cause an increase in muscular activity as a result of increased motor efferent commands, causing an increase in the number of corollary signals to the sensory cortex that may regulate the perception of exertion (Lagally et al., 2004). In addition, higher metabolic stress, as observed with shorter rest intervals (Kraemer et al., 1987; Abdessemed et al., 1999) or increased work done, leads to greater peripheral signals that mediate an increase in perceived exertion (Borg, 1970); this is supported by a demonstrated link between RPE and lactate concentration in the blood and muscles (Gearhart et al., 2009).

Findings of reliable relationships between RPE, performance variables and physiological measures (Gearhart et al., 2009), have made RPE an area of great interest for physiologists concerned with the control of EI during physical activity and sports (An et al., 2015). Borg (1998) originally suggested that

by correlating results from the three continua, it would be possible to identify and quantify important levels or zones of perceived exertion that could be used as adaptation or performance levels, training zones, or target stress levels. In this manner, RPE could be used to attain a target relative EI during training, even when the absolute amount of physical work may vary between participants or over time (Gearhart et al., 2008). Following this method, RPE has been extensively applied in various clinical, sport, and wellness settings to evaluate exercise tolerance and prescribe EI (Gearhart et al., 2008), predominantly during aerobic exercise (Glass & Chvala, 2001; Grego et al., 2004; Robertson et al., 2004). Chen et al. (2002) conducted an extensive meta-analysis on the use of RPE during aerobic exercise, concluding that RPE is a valid measure of EI ($r = 0.57 – 0.73$) with the highest validity coefficients achieved when using male participants, maximal exertion, and an unfamiliar exercise type. RPE has been widely accepted as a method of quantifying aerobic EI since Chen et al. (2002); however, its use has traditionally been less frequent during resistance exercise (Day et al., 2004). In more recent times, RPE has become a topic of interest in strength training research (Diniz et al., 2014) and has become more widely used to monitor multiple-set programmes (Gearhart et al., 2009; Lins-Filho et al., 2012) allowing the accurate and convenient tracking of exertion during exercise interspersed by rest periods (Gearhart et al., 2008; Kraft et al., 2014a), without the need for maximal or submaximal testing (Aniceto et al., 2015).

1.5.1 Measurement of perceived exertion

The measurement of perceived exertion has been conducted using a variety of different RPE scales, modes, and rating types. The two most widely used and validated RPE scales are the classical Borg 6-20 RPE scale (Borg 6-20) and the Borg Category-Ratio-10 scale (CR-10) (Borg, 1998; Noble & Robertson, 1996), each with various iterations and adaptations; for example, the use of only the verbal cues with no numerical ratings (Hampton et al., 2014), or vice versa, the 0-10 numerical scale with no additional words or images (Lampropoulou & Nowicky, 2012; 2014). Another scale that has grown in popularity is the OMNI-RES scale, especially for use during resistance exercise (Duncan et al., 2006; Farah et al., 2012; Bautista et al., 2014). The term OMNI is a contraction of the word omnibus and refers to the numerical category scale that employs interchangeable sets of exercise-specific pictorial descriptors positioned along a visually discernible exertional intensity gradient (Robertson et al., 2003). Subsequently, this scale design has led to the development of multiple exercise specific versions of the OMNI scale, including the OMNI-TheraBand (Colado et al., 2012; 2014) and the children's OMNI-STEP (Robertson et al., 2005). More recently, perceived task duration (PTD) (Shepherd et al., 2013) and the resistance exercise specific, estimated repetitions to failure (ERF) scales (Hackett et al., 2012) have been developed. These scales rather than asking the user to rate how hard they are finding the exercise, ask the user to estimated how much longer they can continue with the current exercise.

Regardless of the specific scale, there are two modes in which RPE can be used, estimation and production modes (Chen et al., 2002). Estimation, or response mode, is when the scale is used to estimate RPE while exercising at a pre-selected EI; whereas, production mode is where a user produces an appropriate EI in order to reach a pre-selected RPE level (Eston & Williams, 1988). Estimation mode is how most studies use and have used RPE to allow an adjunct measurement of exertion and intensity. In this mode, progress is demonstrated by a decrease in RPE at the same absolute workload (Robertson et al., 2004). Conversely, there is growing interest in RPE production mode, to allow prescription and tracking of strength training (Gearhart et al., 2008; 2009). In this mode, it is expected that as the user's specific strength or fitness increases, the absolute workload required to achieve the target RPE level will also increase, meaning that a consistence relative workload can be maintained without the need for repeat exercise testing (Robertson et al., 2004). This is thought to be particularly beneficial in vulnerable populations, such as older adults or HTV adults, because it could reduce or eliminate the need for 1RM testing (Gearhart et al., 2009).

There are several types of RPE rating that can be used regardless of the scale and mode in use. The most commonly used rating types are active muscle (localised), overall body (whole body or central), or session (whole session) RPE. Active muscle RPE (RPE-AM) is when the user is asked to differentiate the feeling of exertion in the active body region from any other feelings of exertion, and to give their rating only based on the exercising muscles (Robertson et al., 2003). Conversely, Overall body RPE (RPE-O), asks the user to account for all feelings off whole body exertion during the exercise (Gearhart et al., 2009). Both RPE-AM and RPE-O ratings, are typically given at the end of each set or repetition during the session, whereas session RPE (S-RPE), is collected at a pre-determined time-point once the exercise session is complete and asks the user to rate the entire session as a whole (Hiscock et al., 2015). It is generally accepted that the RPE-AM is the most intense, and therefore gives the highest RPE scores (Lagally et al., 2002a). A recent development is the calculation of 'RPE load', which multiplies the S-RPE by the session duration (training volume) to provide an overall training load value (Genner & Weston, 2014).

These differences in RPE scale, mode and type must be taken into consideration when comparing the results from individual studies.

1.6 Validity and reliability of RPE during resistance exercise

The validity of a measurement tool (e.g., RPE), is the extent to which that tool measures what it claims or was designed to measure, while reliability is the ability of that tool to measure the same result under the same conditions repeatedly (Field, 2014). It is suggested that for a measurement tool to be considered valid it must also be reliable (Field, 2014). Therefore, if RPE is to be used to prescribe and/or monitor IE interventions, then it is vital that it can accurately and reliably represent both the performance variables (EI) and the physiological exertion; as such, it is common to validate RPE scales using concurrent measures of both, i.e., does RPE change in a stepwise fashion with concurrent changes in physiological responses and EI increments (Gearhart et al., 2001; Robertson et al., 2005). If these relationships are shown, then RPE can be used as a useful and convenient single measure of all three EI response types (Lagally et al., 2002b; Kraft et al., 2014a), which may allow the optimal manipulation of training variables to achieve peak performance (Bautista et al., 2014).

1.6.1 Concurrent validity using measures of exercise intensity

The main variables traditionally used to define resistance training intensity are the number of exercise repetitions and sets, the workload, and the rest period (Garnacho-Catano et al., 2015). However, the manipulation of repetition duration, a variable that is under controlled and reported in strength training programmes, has been shown to produce different acute responses and chronic adaptations (Gillies et al., 2006; Tanimoto & Ishii, 2006; Goto et al., 2009). Additionally, longer repetition durations result in a smaller number of repetitions (Lachance & Hortobagyi, 1994; Hatfield et al., 2006; Sakamoto & Sinclair, 2006) and higher physiological responses (Mazzetti et al., 2007) at a given workload, which suggests that the manipulation of the repetition duration is an important factor in controlling EI. As such, in this thesis, EI is defined as the interaction of workload, number of sets, number of repetitions, repetition time and rest time (Figure 1.1); thus, EI can be modified by changing one or more of these variables for comparison with RPE during validation testing.

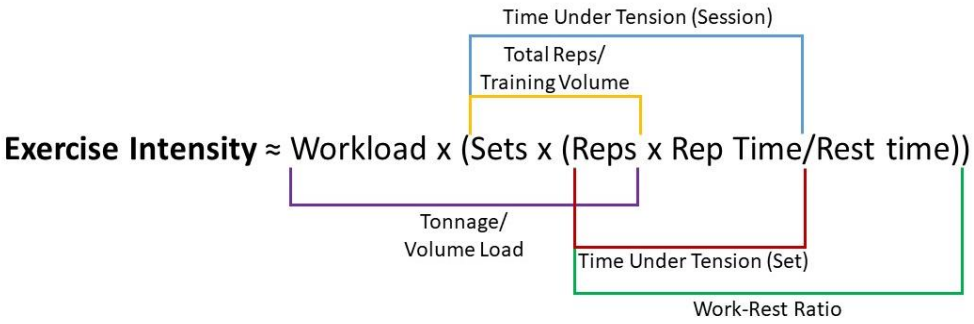


Figure 1.1: Exercise intensity variables and common terminology
Rep(s) = repetition(s), Workload could be substituted with force, torque or %MVC.

Ratings of perceived exertion results have shown excellent concurrent validity with resistance exercise workload, eliciting validity coefficient of r = 0.83 (McGorry et al., 2010), r = 0.933 (Hackett et al., 2012), and r = 0.911 (Desgorces et al., 2015); although, it has been suggested that RPE usually underestimates workload, during submaximal isokinetic and isometric exercise (Pincivero et al., 2001). Similarly, significant differences in RPE have been shown with concurrent changes in the number of repetitions completed at a given workload (O'Connor et al., 2002, Woods et al., 2004). Subsequently, Genner and Weston (2014) suggested that volume load (workload x total repetitions) may provide stronger correlations with RPE than workload or repetitions alone. In addition, significant increases in RPE were demonstrated when repetition time was increased from 4-seconds to 6-seconds (Diniz et al., 2014), and RPE ratings were significantly increased with shorter recovery intervals between sets, during single and multi-joint exercises (Senna et al., 2011). Furthermore, the RPE was able to reflect the level of fatigue in power output (Hardee et al., 2012) and movement velocity (Mayo et al., 2014). These results suggest that RPE can accurately represent changes in EI caused by manipulation of any of the aforementioned variables.

Interestingly, RPE results used to extrapolate and predict 1RM have shown excellent relationships with measured values in young children (10-14 years) during bicep curls (r = 0.87 males, r = 0.89 females) and knee extensions (r = 0.89 males, r = 0.87 females) (Robertson et al., 2008) and in adults (r = 0.97 and r = 0.92), during the same exercises respectively (Eston & Evans, 2009). Likewise, Buckley and Borg (2011) concluded that RPE extrapolation used to predict 1RM was sufficiently accurate for health promotion and rehab settings in addition to being far less time consuming and more amenable than traditional 1RM testing. Moreover, Buckley and Borg (2011) showed that RPE was able to set appropriate loads and repetitions for strength training, in line with the current weight training guidelines.

1.6.2 Validity using measures of physiological exertion

It is widely acknowledged that the amount of physiological responses and stress caused by exercise, is the determining factor of whether an individual's adaptations are positive or negative and whether the outcome is performance enhancement, overtraining, illness, or injury (Genner & Weston, 2014). This makes the quantification and monitoring of physiological exertion vital for ensuring appropriate manipulation of training to induce desirable responses and adaptations, and may be more important than measuring absolute external performance (An et al., 2015).

The validity of RPE using HR as a concurrent measure of physiological exertion, has been demonstrated during various dynamic weightlifting exercises, r = 0.76 (Hollander et al., 2003) and during body weight resistance exercise, r = 0.71 (Giancotti et al., 2015). Likewise, strong validity coefficients (r = 0.605) were shown between RPE and blood lactate during circuit weight training in trained men (Aniceto et al., 2015). Additionally, strong positive correlations have been shown between RPE and muscle activation (EMG) during isometric upper trapezius exercise, r = 0.76 (Hummel et al., 2005), isometric

elbow flexion, r = 0.995 (Lampropoulou & Nowicky, 2012), and dynamic weighted squats, r = 0.97 (Marin et al., 2011). These results indicate that, as with EI, RPE provides an accurate measure of physiological exertion during resistance exercise.

1.6.3 Validity of RPE in production mode

Studies exploring the use of RPE in production mode are less common; however, there is growing evidence for the accuracy of production RPE ratings. Pincivero et al. (2002) showed significant increases in isometric knee flexion torque (%MVC) at each level from 0-9 on the CR-10 scale. Likewise, during isometric elbow flexion and extensions tasks, the increasing forces produced at 3, 5, 7, and 9 on the CR-10 scale were significantly distinct from each other (John et al., 2009). In addition, John et al. (2009) showed that older adults produced significantly greater force to elicit the same RPE rating as younger adults. Subsequently, Tiggemann et al. (2010) demonstrated excellent validity coefficients between RPE and the produced workload in untrained (r = 0.864), novice (r = 0.922) and advance lifters (r = 0.866). Most recently, Hampton et al. (2014) demonstrated that 5 different RPE wording levels (very light, light, somewhat hard, hard, and very hard), in the absence of any numerical or visual cues, were able to produce distinct levels of isometric finger flexion force. When implemented as a training intervention, ratings of 3, 6, and 9 on the OMNI-RES scale, were used to accurately and reliably select EI that were appropriate for improving muscular fitness (Lagally et al., 2009). Likewise, a 12-week training intervention, using an OMNI-RES rating of 4, was sufficient to produce significant post-training increases in 1RM, in 7 different resistance exercises (Gearhart et al., 2011). Whilst these findings only represent a limited number of studies, they provide preliminary evidence that RPE in production mode is valid and sufficiently accurate to induce training adaptations.

1.6.4 RPE reliability

The majority of studies that have tested the validity of RPE, have done so during a single exercise session (Gearhart et al., 2008) or a single exercise bout at each tested EI. If RPE is to be used to control and monitor EI across the duration of a training interventions, it is vital that the stability of its measurements is demonstrated between multiple time-points and training sessions (Colado et al., 2014). In estimation mode, intraclass correlation coefficient results demonstrated good between session reliability for both RPE-AM (0.72; SEM = 1.37) and RPE-O (0.76; SEM = 1.12) ratings (Colado et al., 2012). Similarly, 2-years later Colado et al. (2014) demonstrated good between session reliability for a TheraBand specific scale, with both RPE-AM (0.67; SEM = 0.62) and RPE-O (0.58; SEM = 0.65) rating types. During isometric elbow flexion, excellent test-retest reliability was demonstrated at workloads from 10% - 100% of MVC, with ICC results ranging from 0.96 to 0.99.

In production mode, weight lifted at RPE ratings of 3, 6, and 9, showed good to excellent reliability between sessions, ranging from ICCs of 0.69 to 0.95 (Lagally et al., 2009). Likewise, high ICC results ranging from 0.92 to 1.00, were shown during bench press and weight squat exercise (Hackett et al.,

2012). Moreover, during explosive leg press exercise, RPE-AM demonstrated ICC results of 0.729, in-between the first and second exposure to the exercise (Row et al., 2012). It should be noted that all the included reliability results were measured across 2 exercise sessions. As such, more reliability data is required for longer time-periods and across a greater number of sessions, to demonstrate reliability sufficient for training interventions. Despite this, the reliability data available suggests that RPE shows good between session reliability.

1.6.5 The importance of validating a specific scale for a specific use.

There is high variance in the validity, r = 0.549 (Duncan et al., 2006) to r = 0.995 (Lampropoulou & Nowicky, 2012), and reliability, ICC = 0.58 (Colado et al., 2014) to 1.00 (Hackett et al., 2012) coefficients within the current literature for RPE. Therefore, while it is probable based on previous findings that RPE will be a valid and reliable measure, it is difficult to accurately predict how valid and reliable it will be when used in a new form of exercise, such as IWS training. In addition, there are many conflicting results within the literature about the effect of participant characteristics on RPE results and validity. As previously stated, Chen et al. (2002) concluded that for aerobic training, higher validity coefficients were seen in males when compared to females, although this finding was not consistent across all outcome measures. Similarly, in the resistance exercise literature there are contrary findings (Pincivero et al., 2004b). It has been suggested that females report significantly lower RPE ratings than men at the same relative intensities (O'Connor et al., 2002; Troiano et al., 2008). While others have demonstrated no sex differences (Pincivero et al., 2010a; Springer & Pincivero, 2010; Buckley & Borg, 2011).

As with participant sex, there are contradictory finding relating to the effect of participant age. Several studies suggest that during submaximal exercise RPE ratings differ based on age, when used in estimation mode (Allman & Rice, 2003; Pincivero, 2011) and production mode (John et al., 2009). Conversely, conflicting results have shown RPE to be independent of participant age during both dynamic (Robertson et al., 2005; Pincivero et al., 2010a) and isometric exercise (Champagne et al., 2009; Pincivero et al., 2010b).

These conflicting results, possibly caused by the large number of RPE scales used, rating modes, rating types, participant characteristics, exercise modalities, testing environments and validation constructs, make it difficult to draw conclusions and make comparisons between studies. As such, Borg (1998) suggested that depending on the situation, exercise, and perceptual scale being used, the relationships between the perceptual, performance and physiological responses may not always be simple and linear. Therefore, it was recommended that each relationship is studied specifically in the situation in which it will be used, and then this data should be integrated into the models used. For this reason, it has been suggested that caution should be taken when using RPE scales with modalities, materials, populations,

or exercise types other than those they have been specifically validated for (Robertson et al., 2003; Colado et al., 2014).

As no RPE scale has previously been validated for use during IWS exercise, before any exploration of prescription using RPE can be undertaken, and before the previous findings on the use of RPE and the possible influences of moderating variables can be considered, RPE from a specific scale must be validated during the current IWS protocols to ensure it is accurate during this type of testing and training. If RPE can show concurrent validity with both EI and physiological variables, and reliability during this mode of exercise, then prescription and control of IWS exercise can be explored; which may allow IE interventions to be carried out in the home without the need for laboratory visits, maximal exercise testing or specialist equipment, further reducing potential barriers to IE participation.

1.7 Research aims

1.7.1 Thesis aims

The aims of this thesis were:

1) To assess the usefulness of RPE as an alternative method of monitoring isometric exercise intensity during the protocols currently implemented in isometric wall squat interventions for the reduction of blood pressure.
2) To modify the current isometric wall squat prescription methods, using RPE, to create a more accessible home-based IE training intervention, using only items commonly found in the home and not requiring laboratory visits or invasive testing.

These thesis aims will be achieved through the completion of sequential and rigorous experimental studies. The primary aims for each study are outlined below.

1.7.2 Study aims

Study 1) To collate the current research findings on RPE to assess the validity of RPE during resistance exercise and to expose any confounding variables during its use.

Study 2) To assess the efficacy of RPE during the incremental isometric wall squat test.

Study 3) To explore the ability of RPE to accurately represent changes in discontinuous isometric wall squat intensity.

Study 4) To investigate the effectiveness of RPE during the current home-based isometric wall squat training intervention protocol.

Study 5) To implement the findings of the previous 4 studies, to examine the effectiveness of a 4-week home-based isometric wall squat training intervention, using RPE to prescribe and monitor exercise intensity, as a means of reducing arterial blood pressure.

CHAPTER 2:

Study 1

Criterion-Related Validity of Ratings of Perceived Exertion during Resistance Exercise in Healthy Participants: A Systematic Review and Meta-Analysis

Work from this chapter was presented at the European College of Sport Science Annual Congress (Lea, O'Driscoll, Hulbert, Scales & Wiles, 2018) and is currently under review for publication in Sports Medicine.

2.1 Introduction

While reviewing the relevant literature to inform this thesis (Chapter 1), many equivocal and contradictory findings were identified in the growing body of evidence investigating the use of RPE during resistance exercise. Additionally, due to inherent differences in study design and the unavoidable limitations in every study, validity results from individual studies cannot be taken as a true representation of the validity of RPE as a whole (Chen et al., 2002). This particular shortcoming is highlighted by the wide range of reported validity coefficients within the current literature, with correlation magnitudes ranging from r = 0.518 (Rudroff et al., 2011) to r = 0.995 (Lampropoulou & Nowicky, 2012) during isometric elbow flexion alone. These wide differences in the suggested validity of RPE, make it difficult to quantify the actual validity of RPE during resistance exercise. Consequently, as was previously shown for aerobic exercise (Chen et al., 2002), the validity of RPE may not be as high as previously suggested by individual, often cited, studies.

Previous studies have suggested that there are many factors that could affect the validity of RPE during exercise, and therefore could explain some of the heterogeneity in the results from individual studies. During cardiovascular exercise, Chen et al. (2002) assessed the effect of several study and RPE characteristics on the strength of the RPE and exercise intensity relationship, including: participant sex, fitness/activity level, RPE scale used, type of exercise (e.g. running, swimming), exercise protocol (e.g. continuous, discontinuous or maximal, submaximal), and RPE mode (i.e. production mode, where the participants are required to manipulate the exercise intensity to achieve a specific RPE score; or estimation mode, where the participant is required to estimate their RPE while working at a predetermined exercise intensity). The findings of the Chen et al. (2002) meta-analysis suggested that the highest validity coefficients were achieved when highly fit, male participants, were maximally exerted, during an unusual task, and when a 15-point Borg scale was used (rather than 21-point, 9-point or Category-Ratio Borg scales). These authors (Chen et al., 2002) reported mean validity coefficients of between r = 0.57 and 0.72 depending on the outcome measure used; and while outcome measure did not have a significant effect on the validity coefficients, there were contradictory findings regarding the effects of moderators depending upon which outcome measures were used. For example, this particular study (Chen et al., 2002) showed that when heart rate (HR), blood lactate (BLa) and VO_2 were used as outcome measures, RPE in production mode produced significantly higher validity coefficients; however, when ventilation rate was used as the outcome measure, estimation mode produced significantly higher correlations. Likewise, while the highest validity coefficients were obtained from male participants, when BLa was used as the outcome measure, female participants produced significantly higher validity coefficients.

Different experimental designs have also produced ambiguous findings when using RPE in a resistance exercise setting. Research examining the effect of age on RPE response, has suggested that older people

require a higher torque to elicit the same RPE score as younger individuals in production mode (John et al., 2009). Likewise, it has been shown that younger individuals may produce higher RPE scores than older individuals, for the same intensities, during estimation mode tasks (Pincivero, 2011). While conversely, other studies have suggested that there is no difference in RPE score due to age (Robertson et al., 2005; Pincivero, 2011). Similar contradictory results are found for the effect of sex, with some studies showing no differences in RPE based on sex (Eston & Evans, 2009; Gearhart et al., 2011), while others show females report higher RPE scores during upper and lower body exercise (Buckley & Borg, 2011).

Ratings of perceived exertion can be accurate in both estimation (Lampropoulou & Nowicky, 2014; Zourdos et al., 2016; Morrin et al., 2018), and production mode (Pincivero, 2011; Morrin et al., 2018; Tiggemann et al., 2010) during resistance exercise, but it is not currently clear whether one produces greater validity coefficients than the other. Additionally, to confound matters further, evidence also suggests that upper body exercises may produce higher RPE results than lower limb exercises (Buckley & Borg, 2011), and that RPE ratings that focus on the specific active muscle group produce higher RPE results than those that take into account overall or whole-body exertion (Lagally & Robertson, 2006).

These large differences in validity coefficients, contradictory findings relating to moderator variables, and the results from previous studies using other forms of exercise (e.g., cardiovascular) highlight the absence of, and confirm the need for, collation of the current research results, quantification of the validity of RPE during resistance exercise, and a greater understanding of which factors, if any, affect the validity of RPE during this type of exercise.

This information and clarity would inform the implementation of the final study in this current research, to allow the most affective application of an RPE prescribed IWS intervention. Additionally, these findings could allow future studies and exercise interventions to use appropriate RPE scales and adapt their protocols to best utilise RPE depending on the exercise type and participants being used. Therefore, the aims of this study were to:

(1) Conduct a systematic review and meta-analysis to collate the current findings and assess the validity of RPE during resistance exercise.

(2) Perform moderator analysis to examine which participant, exercise, RPE scale and study design characteristics may affect the validity of RPE during resistance exercise.

2.2 Methods

2.1.1 Search strategy

This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. A systematic computer-based literature search, ending 28/02/2020, was conducted using the following databases and websites: PubMed, Web of Science, SPORT Discus and Research Gate. Three levels of search terms were used; Level 1: RPE **OR** perceived **OR** 'perceived exertion' **OR '**perceived effort' **OR** exertion **OR** effort **OR** perception; Level 2: intensity **OR** 'exercise intensity' **OR** 'heart rate' **OR** HR **OR** 'blood pressure' **OR** BP **OR** EMG **OR** lactate **OR** workload **OR** work **OR** load; and level 3: concentric **OR** eccentric **OR** isometric **OR** resistance **OR** resistive **OR** 'resistance exercise' **OR** 'concentric exercise' **OR** 'eccentric exercise' **OR** 'isometric exercise'. Searches were conducted for level 1 **AND** level 2 **AND/OR** 3.

The reference lists of original studies and reviews were also examined to identify any additional articles of interest. Where the researchers were unable to gain access to the full research article, corresponding authors were contacted to ask for a copy of the paper; two full texts were received for evaluation (Bertucci et al., 2015; Martin et al., 2014). Where possible, key authors in this field were contacted, to ask for relevant unpublished or in-press data. Additionally, a call for unpublished or in-press data was also placed on Research Gate, which yielded one response (Chapman et al., 2017). Finally, studies that failed to present the data required for the quantitative analysis, but otherwise met the eligibility criteria (section 2.2.2), were sent a request for the missing data; one author replied to this call (Millar et al., 2009).

Retrieved studies were downloaded to EndNote X8 (Thomson, Reuters, Carlsbad, California, USA) and duplicates were removed. The titles and abstracts of the retrieved studies were screened against the eligibility criteria. After this initial assessment, the full texts of papers deemed to meet the eligibility criteria were then assessed using the same criteria.

2.2.2 Eligibility criteria

The eligibility criteria for inclusion in qualitative synthesis were: (1) only original research articles were included. (2) studies must use at least one group of healthy participants. 'Healthy' was defined as having no injury or illness that could affect the participant's performance, having no clinical diagnosis of any condition or dysfunction, and were not taking any medication that could affect exercise performance or cardiovascular function; there were no age restrictions on the participants used. (3) studies must have used a resistance exercise modality, defined as a systematic series of exercises that cause muscles to work or hold against an applied force or weight (ACSM, 2009); dynamic, eccentric only, concentric only, isometric, and isokinetic exercises were all acceptable. (4) data must be presented for at least one group that did not receive any confounding interventions e.g., supplementation. (5) a rating scale must

have been used to measure perceived exercise intensity, exertion, or discomfort. (6) only studies written in English could be accepted. There were no restrictions on publication date, and un-published or 'grey' literature, for example theses and conference proceedings were accepted.

For inclusion in the quantitative (meta) analysis, all the qualitative synthesis criteria must have been met and then additionally: (7) Studies must have presented one of the following outcome measures: exercise intensity (EI), HR, BP, EMG or BLa. For the purposes of this study, EI is defined as the interaction of workload, number of sets, number of repetitions, repetition time, and rest time (Figure 1.1, Section 1.6.1, Page 26). Thus, EI can be modified by changing one or more of these variables. (8) if using exercise intensity as the criterion measure, there must have been an objective change between trials/conditions; for example, studies that increased load and decreased repetitions to match tonnage/volume load between conditions, were not included in the quantitative analysis. (9) Data must have been presented in one of the following forms for RPE and at least one of the physiological exertion measures and/or EI: correlation or linear regression (r or r^2 values) or means and standard deviation from two or more trials/conditions (e.g., time points or workloads).

2.2.3 Data extraction and coding

All data were extracted and coded onto a custom Excel spreadsheet. Studies in the meta-analysis were coded for participant, exercise, RPE scale and study features (Table 2.1) to allow for meta-regression analysis of possible moderators. The 'muscle action' used in each study was coded for studies using dynamic (i.e., a concentric followed by an eccentric contraction), concentric only, eccentric only or isometric. The part of the body used in the exercise, or 'body segment' was also coded, i.e. an upper body, lower body or whole-body exercise. Continuous and intermittent exercise 'protocols' were included and coded (e.g. an incremental test vs. a traditional weight training session respectively). Where a study actively adjusted workload between trials or conditions, the workload range (maximum workload – minimum workload) was also coded as percentage of one-repetition maximum (%1RM) or percentage of maximal voluntary contraction (MVC). Ratings of perceived exertion scale properties were recorded including: scale used, number of points on scale (e.g., the Borg 6-20 scale is a 15-point scale); fixed maximum, whether the scale has a fixed or open maximum (e.g. maximum = 10 or an open ended scale like the CR-10); rating mode (estimation or production); rating type, i.e. rating exertion in the active muscles only (RPE-AM), overall body (RPE-O), or whole session (S-RPE). Finally, if EI was manipulated, the variables used to do so were coded.

If a study did not report a variable or their result did not fit into one of the pre-defined categories, a code of '99' was given and the study was excluded from the meta-regression analysis for that variable. Negative correlation r-values for repetition velocity and RPE or knee joint angle and RPE, that represent increases in time under tension and workload respectively, were included as positive values.

Information from studies fulfilling the qualitative inclusion criteria, but not the quantitative, were synthesised using a narrative/thematic summary method.

Table 2.1: Participant and study features and coding

Type	Feature	Categories	Coding
Participant	Age of Participants (years)	Mean Years	No.
	Sex of Participants	Male Female Both	1 2 3
	Resistance Training Level	Sedentary <6 month >6 month >1 Year Elite Level	1 2 3 4 5
Exercise	Muscle Action	Dynamic Concentric Eccentric Isometric	1 2 3 4
	Body Segment	Upper Lower Whole	1 2 3
	Protocol	Continuous Intermittent	1 2
	Workload Range	(% 1RM)	No.
RPE Scale	Scale Used	Borg 6-20 CR-10 OMNI-RES ERF Borg Words IES NRS PTD RES + RIR	1 2 3 4 5 6 7 8 9
	Number of Points	--	No.
	Fixed Maximum	Yes No	1 2
	Rating Mode	Estimation Production	1 2
	Rating Type	Active Muscle Overall Sessional	1 2 3
Study	Outcome Measure	EI HR EMG BLa	1 2 3 4
	EI Variable Manipulated	Workload No. Reps Rep Time Rest Time	1 2 3 4

Coding nominal coding used to allow analyse as a categorical variable. *ERF* Estimated Repetitions to Failure, *Borg Words* Borg CR-10 verbal cues with no numerical cues. *IES* Isometric Exercise Scale, *NRS* Numerical Rating Scale, *PTD* Perceived Task Duration, *RES + RIR* Resistance Exercise Specific RPE with Repetitions in Reserve.

2.2.4 Risk of bias in individual studies

The risk of individual study bias in methodology or reporting was assessed, independently by authors 1 and 4, using a 9-point scale designed in-house for RPE validity studies (Appendix 6). The 9 criteria assessed were: (1) participant eligibility criteria specified and fulfilled, (2) participant information given (must include: age, sex and training status), (3) a priori power analysis/sample size calculation completed, (4) exercise type (dynamic, isometric etc.) and movement (squat, bench press etc.) specified, (5) exercise intensity specified (including load, number of sets, number of repetitions, repetition time and rest interval time), (6) exact RPE scale used (including any modifications), (7) RPE instructions are specified, (8) anchoring procedures are specified, (9) a measure of repeatability/reliability was reported. Each criterion was given a score of 0 (indicating the criteria was not fulfilled or was not reported) or 1 (indicating the criteria was fulfilled and reported). A score of 0-3 was considered 'high risk', 4-6 was considered 'moderate risk', and 7-9 was considered to have a 'low risk' of bias.

2.2.5 Data analysis

2.2.5.1 Publication bias

To examine the possibility of publication bias in this body of evidence, funnel plots of individual Fisher z values versus their corresponding standard errors were manually examined for signs of asymmetry. Duval and Tweedie's trim and fill method was then used to look for missing studies and adjust the point estimate accordingly. Following this, the Classic fail-safe N was calculated to elucidate the number of unpublished non-significant studies that would be needed to make the result of this analysis non-statistically significant ($p < 0.05$). Finally, Orwin's fail-safe N was calculated to examine how many unpublished studies would be required to reduce the calculated point estimate to a 'medium' or 'low' effect size ($r < 0.5$ and $r < 0.3$ respectively).

2.2.5.2 Synthesis of results

All analyses were conducted using Comprehensive Meta-Analysis software (version 3, Biostat Inc., Englewood, NJ, USA). Some of the eligible studies reported multiple outcome variables for the same participants. Therefore, 2 separate random-effects meta-analyses were conducted; the first, 'all measures', included any outcome variable, while the second, 'EMG only', included EMG as the only outcome measure. All studies/cohorts reporting EI as the outcome measure were included in the primary 'all measures' analysis therefore a separate analysis was not required. There were insufficient studies to conduct separate analyses for HR, BP or BLa, thus studies reporting these variables were only included in the 'all measures' analysis. For each analysis the mean sample size weighted correlation coefficient (r), 95% confidence intervals (CIs), and significance level (p) were calculated. Between-study heterogeneity was assessed using standard Chi Squared test (Cochran's test), τ^2 and I^2 statistics.

2.2.5.3 Sensitivity analysis

Sensitivity analysis was conducted on each meta-analysis by systematically removing each study, one at a time, from the analysis to assess the effect on the point estimate. As no single study significantly affected the point estimate, all the studies eligible for each analysis were included.

2.2.5.4 Moderator analysis

Where statistically significant between-estimate heterogeneity was shown by the Chi Squared test ($p < 0.01$), meta-regression analysis was conducted to determine the effect of participant and study characteristics on the effect sizes reported. All moderators were assessed separately, using univariate regression analysis, and then used in combination to find the most effective multivariate regression model. Individual moderators and models were assessed using the τ^2 (unadjusted τ^2 vs adjusted τ^2) and R^2 statistics.

2.3 Results

2.3.1 Literature search

As seen in Figure 2.1, the primary searches revealed 3268 potentially relevant studies. After removing 2051 duplicates, the titles and abstracts of 1217 studies were examined against the inclusion criteria. Of the 1217 studies, 131 appeared to adhere to the inclusion criteria and as such the full texts were then reviewed. During full text review the reference lists of each article were examined for additional articles; 36 additional articles were identified, and these full texts were also examined. Of the 167 reviewed full texts, 118 studies were eligible for inclusion on the qualitative analysis (49 excluded), with 75 studies included (43 excluded) in the final quantitative analysis (Figure 2.1).

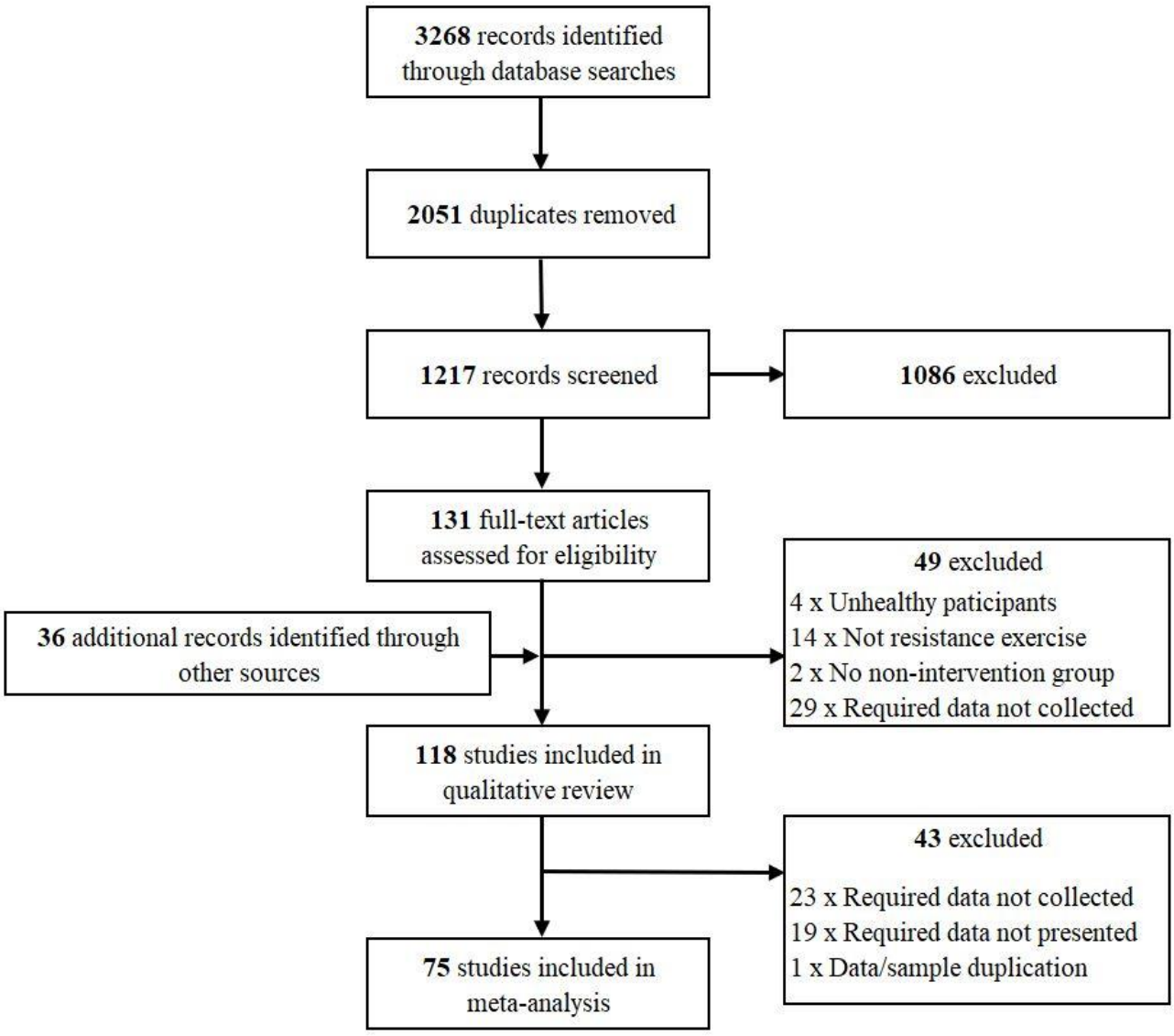


Figure 2.1: PRISMA flowchart illustrating the phases of the search and study selection

2.3.1.1 Study characteristics

Of the 75 studies eligible for the quantitative analysis, the overall risk of bias was 'low' in 44 studies and 'medium' in 31 studies. No studies included showed a 'high' risk of bias. Only 13 studies included/reported a measure of inter-session reliability. The primary analysis (All Measures) included 75 studies (Figure 2.3), with 99 unique cohorts (criterion measures: EI = 89, HR = 2, EMG = 6, BLa = 2). These 99 cohorts contained a total of 2231 participants. The secondary analysis (EMG only) used 7 studies (Figure 2.4), containing 8 unique cohorts with a total of 340 participants.

2.3.2 Publication bias

There was some evidence of asymmetry in the funnel plot for the primary analysis (Figure 2.2); however, Duval and Tweedie's trim and fill method did not add or remove any studies and made no adjustment to the point estimate. Additionally, the Classic fail-safe N revealed that 158597 non-significant studies would be required to render the analysis non-significant ($p > 0.05$). Likewise, the Orwin's Fail-safe N analysis showed that 108 and 268 studies, each with a correlation of $r = 0.00$, would be required to reduce the weighted mean effect size to medium ($r < 0.5$) and small ($r < 0.3$) respectively.

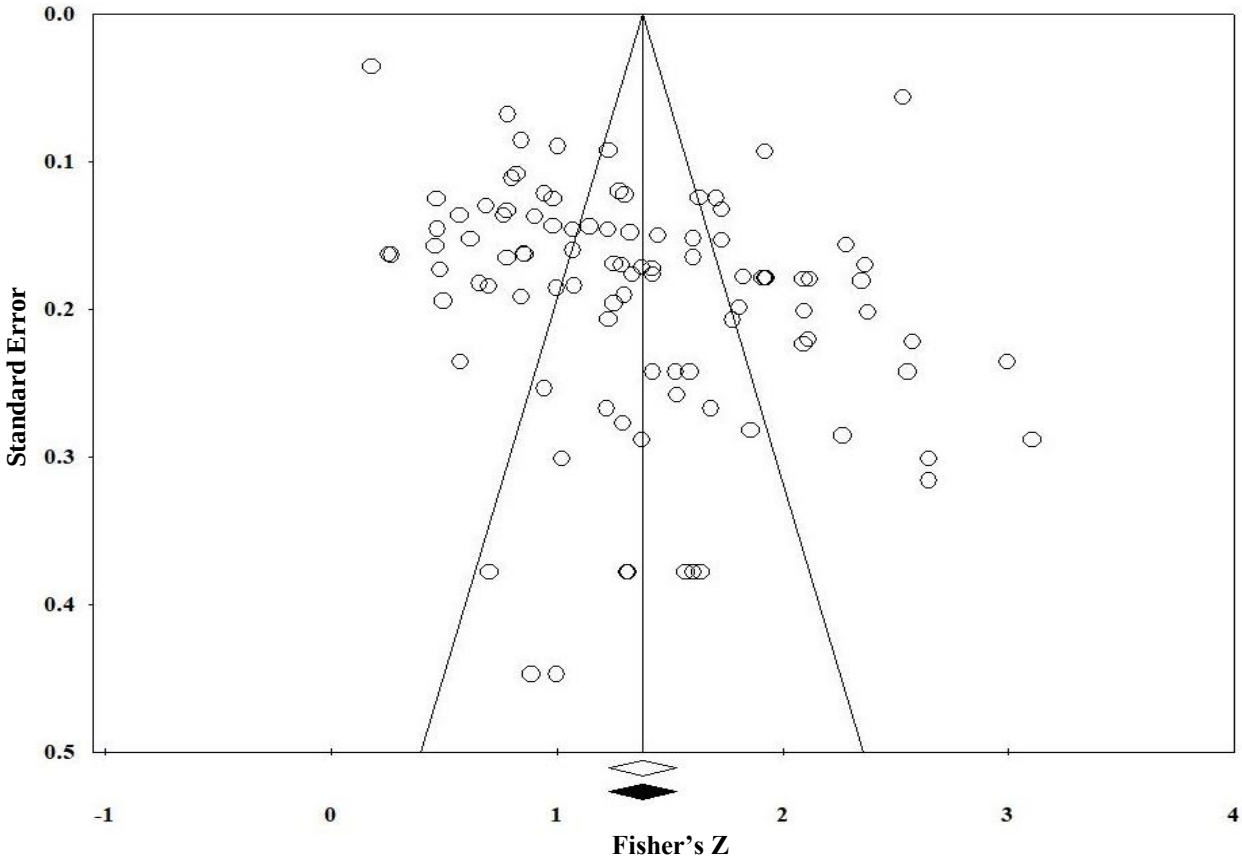


Figure 2.2: Funnel Plot of Standard Error by Fisher's Z. *Clear diamond is the point estimate prior to any attempted corrections. Black diamond is the point estimate following Duval and Tweedie's random-effects Trim and Fill adjustment*

2.3.3 Primary analysis: validity of RPE using all outcome measures

Figure 2.3 shows the validity coefficients and 95% confidence intervals for each of the studies, and the weighted mean effect size for the relationship between RPE and the measures of EI and physiological exertion. The overall weighted mean validity coefficient was very large, r = 0.880 (95% CI: 0.842 to 0.910; $p < 0.001$). There was significant between study heterogeneity ($p < 0.001$); total between study variance was $\tau^2 = 0.526$, with a high level of true/explainable between study heterogeneity ($I^2 = 96.1\%$).

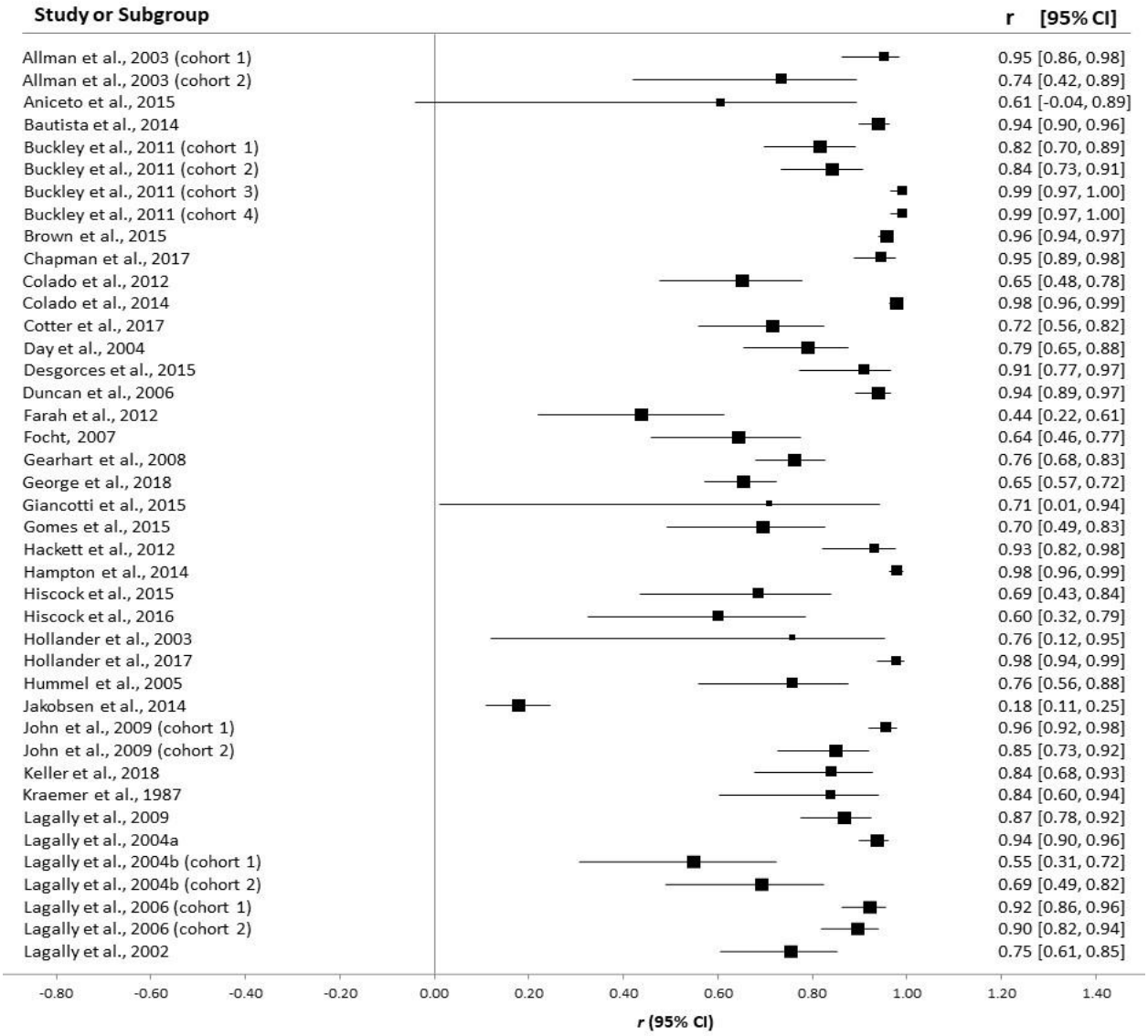


Figure 2.3: Forest plot showing the weighted validity coefficients (solid squares) and 95% confidence intervals (solid horizontal lines) for each study included in the 'all measures' analysis.

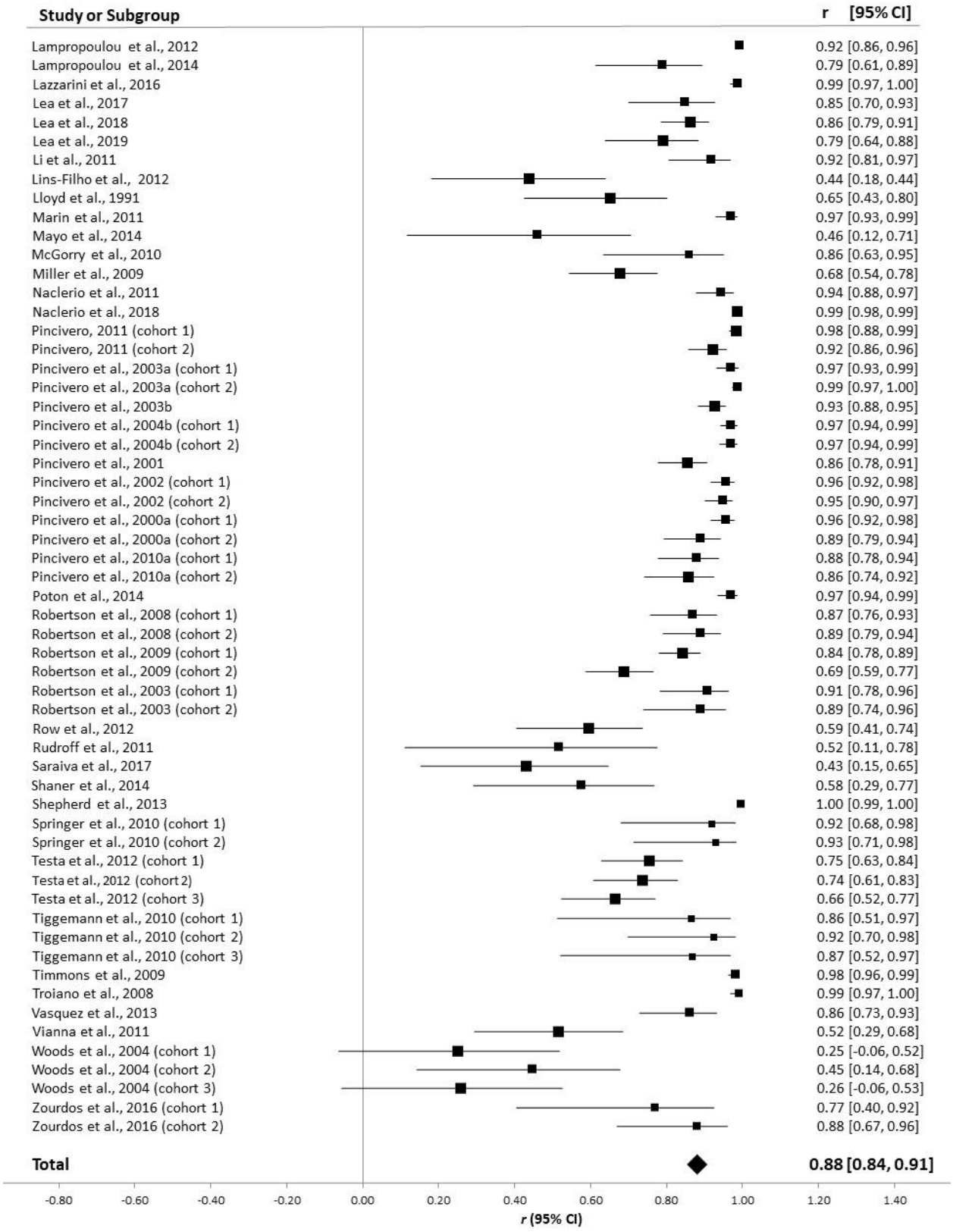


Figure 2.3 Cont.: Forest plot showing the weighted validity coefficients (solid squares) and 95% confidence intervals (solid horizontal lines) for each study included in the 'all measures' analysis. The bottom row indicates the overall random-effects validity coefficient (solid diamond).

2.3.4 Secondary analysis: validity of RPE with EMG as outcome measure.

As shown in Figure 2.4, the weighted mean effect size for the 8 cohorts reporting EMG as the outcome measures was also very large, r = 0.844 (95% CI: 0.585 to 0.947; p < 0.001). As with the primary analysis, there was significant between study heterogeneity (p < 0.001), between study variance was τ^2 = 0.624, and the level of true between study heterogeneity was high (I^2 = 97.3%).

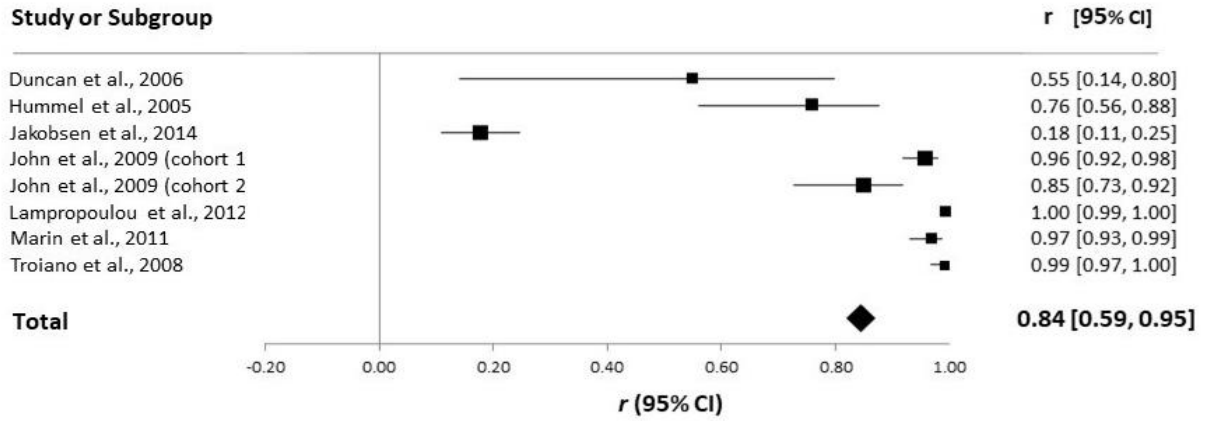


Figure 2.4: Forest plot showing the weighted validity coefficients (solid squares) and 95% confidence intervals (solid horizontal lines) for each study included in the 'EMG' analysis. The bottom row indicates the overall random-effects validity coefficient (solid diamond).

2.3.5 Moderator variables and meta-regression

As a significant level of explainable between study heterogeneity was present, meta-regression was used to examine which participant, exercise, scale, and study characteristics may affect the validity of RPE during resistance exercise. The secondary analysis contained data from 8 cohorts, 6 of which were included in the 'all measures' analysis. Additionally, the validity coefficients, variance and heterogeneity were comparable; therefore, moderator analysis was only conducted on the primary analysis (all measures).

Univariate regression analysis showed no moderating effect of the participant characteristics: age, sex or resistance training level (p < 0.05). Likewise, the exercise characteristics: body segment and protocol; scale characteristics: scale used, number of points, fixed maximum, rating mode and rating type; and the study characteristics: outcome measure and risk of bias, had no effect on the reported validity coefficients (p < 0.05). Conversely, univariate analysis of 98 cohorts showed that muscle action did significantly affect the validity coefficient, with isometric exercise giving significantly (p = 0.004) higher values than dynamic, concentric, or eccentric contractions (Figure 2.5a). Likewise, analysis of the 56 cohorts that reported a quantifiable change in workload, showed that the workload range significantly (p < 0.001) affected the validity coefficients with studies that used greater ranges showing larger effect sizes (Figure 2.5b). The EI and physiological exertion measure used had no effect on the validity of RPE; however, for the cohorts using EI as the criterion measure (n = 83), manipulation of

workload and repetition time showed significantly higher effect sizes ($p < 0.001$ and $p = 0.002$ respectively) than manipulation of the number of repetition or the rest interval time (Figure 2.5c).

Various multivariate regression models were built using the coded characteristics; workload range and EI variable showed collinearity and so could not be included in the same multiple regression models. The strongest model included: sex, rating type, rating mode and workload range. There were 50 unique cohorts that reported data for all 4 of these variables. This model explained 64% of the between study heterogeneity ($R^2 = 0.64$), reducing the total between study variance from $\tau^2 = 0.391$ to $\tau^2 = 0.142$. There was still a significant amount of variance not explained by the model ($p < 0.001$), and the amount of explainable variance was still high ($I^2 = 86.2\%$).

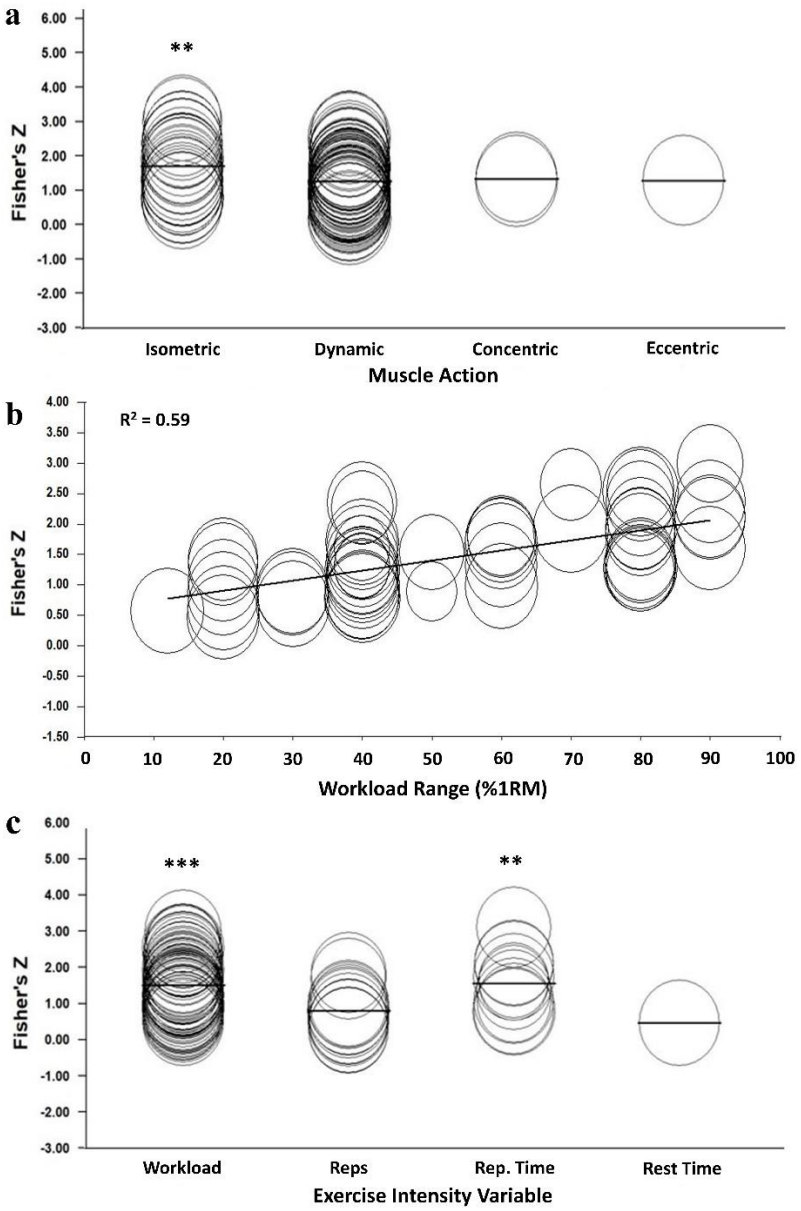


Figure 2.5: Significant results of the random-effects univariate meta-regression analyses. ***a*** *the effect of muscle action,* ***b*** *the effect of workload range, and* ***c*** *the effect of exercise intensity variable on Fisher's Z transformed validity coefficients. ** p < 0.01, *** p < 0.001.*

2.4 Discussion and qualitative analysis

2.4.1 RPE during resistance exercise

This is the first systematic review and meta-analysis to assess the validity of RPE as a measure of exercise intensity during resistance exercise modalities. The ultimate aim of this study was to inform researchers, athletes and coaches, so that RPE can be used more effectively in studies and interventions, by: 1. assessing the validity of RPE during resistance exercise, and 2. examining which participant, exercise, scale and study characteristics may affect the validity of RPE during this type of exercise. Additionally, these findings would be used to inform the final stage of this current research project, to allow RPE to be implemented in the most efficient way to prescribe an IWS intervention. The results of this meta-analysis demonstrate that RPE is a valid measure of resistance exercise intensity, with strong correlations to EI, HR, EMG, and BLa giving a weighted mean validity coefficient of r = 0.88; therefore, RPE validity may be higher during resistance exercise than was previous shown for aerobic exercise (Chen et al., 2002) and during team sports (McLaren et al., 2018). The use of RPE in aerobic exercise is widespread, adopted by exercise professionals and recreational athletes alike; however, the use of RPE, especially amongst recreational athletes, in resistance exercise is not yet as common. The meta-analysis results suggest that this is a tool that is both accurate and effective in the resistance exercise setting, and therefore could be of great benefit if used more widely to optimise exercise programming.

In support of this, several studies have compared predicted 1RM from submaximal RPE scores with measured 1RM. RPE extrapolated 1RM was shown to be sufficiently accurate for health promotion and rehabilitation settings, less time consuming, more amendable than traditional 1RM testing, and able to set appropriate loads and repetitions for strength training in line with current guidelines (Buckley & Borg, 2011). Likewise, in young active men and women, no significant differences were shown between predicted 1RM from RPE and measured 1RM during bicep curl and knee extension exercises (Eston & Evans, 2009). In young boys and girls (10 -14 years), predicted 1RM showed large effect sizes when correlated with actual 1RM, for both bicep curls (r = 0.87 males, r = 0.89 females) and knee extensions (r = 0.89 males, r = 0.87 females) (Robertson et al., 2008). These results suggest that flexible and safe protocols for predicting 1RM and prescribing exercise intensities can be developed using RPE, that may be more desirable than maximal testing in numerous settings and many populations, such as those suffering with hypertension. In addition, RPE may be an important tool in exercises where intensities and 1RM are harder or impossible to calculate; for example, TheraBand exercise (Colado et al., 2012; 2014), where it is impractical to measure accurate loads outside of the laboratory.

These findings further support the results of studies 2-4 (Chapters 4-6), in suggesting that RPE is a sufficiently accurate measure to be used to prescribe exercise interventions, including IWS training for the reduction of BP.

2.4.2 Participant characteristics

2.4.2.1 Age

The results of the meta-regression analysis showed that the age of participants did not statistically significantly affect the validity of RPE ($p < 0.05$). While results from different age groups may show statistically similar effect sizes (validity coefficients), this does not discount the possibility that there are consistent differences in the absolute magnitude of the responses, between age groups. There are conflicting results within the current literature around possible age differences in RPE responses. It has been suggested that at sub-maximal levels of exertion, older adults report lower RPE values than younger adults (Allman & Rice, 2003; Pincivero, 2011); with no difference shown at maximal fatigue (Allman & Rice, 2003). Likewise, in production mode, older participants have been shown to produce significantly higher %MVC contractions at set submaximal RPE levels (John et al., 2009; Pincivero, 2011). Conversely, no significant differences in RPE response were shown between young and older adults during maximal or submaximal isometric back extension (Champagne et al., 2009), submaximal isometric arm abduction (Pincivero et al., 2010b) or submaximal handgrip and leg extension exercises (Smolander et al., 1998). It should be noted that all the above studies used isometric exercise and, with the exception of back extension (Champagne et al., 2009), all used single joint exercises. One study (Buckley & Borg, 2011) that used a mixture of single and multi-joint, upper and lower body dynamic exercises, also showed conflicting results. Buckley and Borg (2011) concluded that, on the whole, results from the CR-10 scale showed no differences between age groups, especially during leg muscle training. However, age differences were seen during single-joint arm exercises and low-intensity leg extensions.

The results of this meta-analysis demonstrate that RPE provides a valid representation of EI irrespective of age. The mixed results in the literature make it unclear whether there is a reliable difference in RPE ratings caused by age. If there is an age dependant difference, it would seem likely that older participants give lower RPE ratings at the same submaximal relative workloads or older participants will produce higher relative loads at a set RPE, and this difference is likely to be more pronounced during single joint upper body exercise.

Based on these findings, as the IWS is a multi-joint lower body exercise, performed close to maximal exertion (95% peak), any potential age differences will be minimal. Therefore, currently, there is not sufficient evidence to warrant an age limit on the final RPE prescription study in this thesis. However, these finding warrant further investigation as it is possible that different RPE targets could be required based on age group during certain exercise types, especially for single joint upper body exercise such as IHG training.

2.4.2.2 Sex

Univariate moderator analysis showed that sex did not have a statistically significant effect on the validity of RPE results, and while the multivariate model explaining the largest amount of heterogeneity did contain sex as a variable, the amount of variance explained by sex was still not statistically significant ($p < 0.05$). These results suggest that there is no sex dependant difference in RPE validity. This result is contrary to the main findings of Chen et al. (2002), who showed higher validity coeffects in males, with all outcome variables except BLa where female validity was higher. It should be noted that in Chen's study, there were fewer females in the analysis of each outcome variable; and for BLa, females made up only approximately 25% of the total sample; this together with the conflicting results between outcome measures, highlights the need for further investigation with greater numbers of studies using female participants.

Two studies (O'Connor et al., 2002; Troiano et al., 2008) in the current analysis suggested that males give significantly higher RPE ratings, at the same relative exercise intensities than females. These studies used two novel exercise modalities, eccentric elbow flexor exercise (O'Connor et al., 2002) and upper Trapezius shoulder elevation exercise (Troiano et al., 2008), which raises the question as to whether certain types of resistance exercises do elicit a sex difference in RPE response. However, the vast majority of the current RPE research suggests there are no sex moderated difference; including during: 1RM prediction (Eston & Evans, 2009), concentric contractions (Pincivero et al., 2001; 2010a), eccentric contractions (Pincivero et al., 2010a), isometric contractions (Pincivero et al., 2002; 2003a), and dynamic resistance exercise (Glass & Stanton, 2004). Likewise, RPE ratings for active muscle and overall body (Lagally & Robertson, 2006), in estimation mode (Pincivero et al., 2003b; Springer & Pincivero, 2010; Buckley & Borg, 2011), in production mode (Pincivero et al., 2002), and in estimation mode in older adults (Gearhart et al., 2008; 2011) have all demonstrated no sex differences. Therefore, the weight of the available evidence suggests that there is no significant difference in mean RPE responses between males and females, and that individual differences are likely to have a far greater effect than any sex related differences. When combined with the results of the meta-regression analysis, it would seem that RPE can be used in males and females without equivocation and that the exclusion/underrepresentation of females in RPE studies is unwarranted.

2.4.2.3 Resistance training level

Moderator analysis showed that the resistance training level of the participants had no statistically significant effect on the validity of the RPE response given. There were a limited number of studies that directly compared groups with different resistance training experience. Comparisons of trained and untrained participants during back squat, bench press and arm curl exercises showed no differences in mean RPE rating (Shimano et al., 2006). Likewise, no differences were seen between novice and recreationally trained weightlifters during bench press exercises at the same relative intensities (Lagally

et al., 2004). Conversely, it has been suggested that, at low relative training volumes, novice athletes are less accurate at representing actual training load, giving lower RPE ratings than well-trained participants (Testa et al., 2012). Likewise, in estimation mode, novice squatters gave lower RPE scores than experiences squatters at maximal load (Zourdos et al., 2016). However, it was suggested that this could be due to the inability of novice squatters to perform a true 1RM test in dynamic squatting. In production mode, sedentary individuals produced significantly lower relative forces (% 1RM) than strength trained individuals, at both low and high submaximal RPE scores (Tiggemann et al., 2010). This result would seem to contradict the findings of the previous two studies, as this would suggest that novice athletes would perceive relative loads as harder than trained participants; but comparison of estimation and production mode in this way may not be valid.

Several studies have suggested that RPE ratings significantly decreased in participants following a training programme using the same exercise (Pierce et al., 1993; Pincivero et al., 2004a; Gearhart et al., 2008; Goncalves & Oliveira, 2013; Desgorces et al., 2015). However, all these studies compared RPE at set absolute loads or at relative loads based on 1RM tests performed before the training programme was completed. Additionally, these studies all showed an increase in 1RM following the training; therefore, the reductions in RPE are merely representative of an increase in strength and thus, the absolute loads becoming lower relative loads. Based on this, Gearhart et al. (2009) concluded that as relative load and RPE decrease concurrently, RPE can be used to track strength training in older individuals. One study was identified that compared RPE at relative workloads based on pre- and post-intervention 1RM (Gearhart et al., 2008). This study showed that in production mode, both the absolute and relative loads lifted increased following training, at RPE scores of 4, 6 and 8. This result would support the findings of Tiggemann et al. (2010), that trained individuals may produce higher relative forces at set RPE levels than novices.

Based on the available evidence, including the current meta-regression findings, there are no clear differences in RPE ratings caused by training level and experience. Additionally, RPE is equally valid across the difference experience levels. While it is possible that in production mode trained individuals will work at higher relative loads than novices. Therefore, when exploring the use of RPE to prescribe IWS training, care must be taken to ensure strength trained participants are not working at an increased relative workload (i.e., maximally). However, as the IWS exercise is performed close to maximal exertion and as IWS exercise is likely to be novel to most participants, even those who are strength trained, any training level differences should again be minimal, if indeed any difference do exist.

2.4.3 Exercise characteristics

2.4.3.1 Body segment

The body segment (i.e., upper, lower, or whole body) used had no statistically significant effect on the validity of the RPE responses given. As previously stated, some research has suggested that lower-body

exercises give more consistent inter- and intra-scale RPE results, than upper body exercises (Buckley & Borg, 2011). In estimation mode, it has been suggested that lower body exercise elicits higher RPE results than upper body, possibly due to the larger muscle mass involved (Mayo et al., 2014). Likewise, in production mode, at lower RPE values, higher relative loads were produced during bench pressing than during leg pressing; although, this difference was not present at higher sub-maximal RPE values (Tiggemann et al., 2010). In contrast to this, no significant differences where shown, between upper and lower body exercise, when using RPE to estimate number of repetitions until failure (Hackett et al., 2012) or to predicted maximal load (Eston & Evans, 2009). However, these two analyses are dealing with validity rather than differences in actual ratings given. Therefore, RPE is equally valid for upper, lower, or whole-body exercise; while there is limited evidence that the larger muscle mass of the lower body will give higher RPE estimations or lower relative loads in production mode.

This finding is in-line with previous findings that greater muscle mass also produces greater acute cardiovascular responses during and after IE; and may lead to greater chronic responses or similar responses when performed at a lower intensity (Howden et al., 2002). Therefore, these results support the use of RPE to prescribe and monitor IE conducted with the upper, lower, and whole-body.

2.4.3.2 Protocol

Chen et al. (2002) showed that during aerobic exercise, using HR as the outcome measure, random intermittent exercise protocols produced significantly lower validity coefficients than progressive continuous, progressive intermittent and submaximal protocols. While no individual study included in this review directly compared difference protocol types, moderator analysis of 92 cohorts, comparing continuous and discontinuous protocols, showed no statistically significant differences in RPE validity during resistance exercise. This would suggest that RPE can be equally valid when used to monitor EI during the IIWST and IWS training sessions. Additionally, any RPE prescription protocols developed for IWS interventions could equally use discontinuous or continuous exercise.

2.4.3.3 Workload range

Workload range was the biggest single predictor of between study variance, with univariate analysis showing that workload range explained 59% of the heterogeneity. Workload range was also the only significant variable in the multivariate model that explained 64% of the between study variation. The meta-regression showed that greater workload ranges led to significantly greater effect sizes ($p < 0.001$). This is to be expected, as a study that has compared RPE results at, for example, 40% and 50% of 1RM (a 10% range) will show a smaller effect size than one that has used 10% and 90% of 1RM (an 80% range). This variable could only be coded for in studies that actively manipulated workload; therefore, any studies that adjusted repetition time, number of repetitions or sets, or rest time could not be included. As a result, only 56 cohorts were included in the univariate analysis and 50 cohorts in the multivariate

analysis. It is likely that a far larger amount of the total between study variance would have been explained if exercise intensity, calculated using all 5 of the above variables, could have been quantified for each study.

2.4.3.4 Muscle action

There were no statistically significant differences in validity between dynamic, concentric or eccentric contractions ($p < 0.05$); whereas isometric contractions showed significantly ($p = 0.004$) higher validity coefficients than the other contraction types. It is possible that, due to the elongated nature of most isometric contractions, this increase in validity is linked in some way to the increased validity shown in studies that manipulated repetition time, when compared to number of repetitions or rest interval time (section 2.4.5.2). However, none of the included studies directly compared isometric contractions to any other type, so it is not possible to speculate why this is the case.

Previous research has demonstrated that both RPE and perceived pain values are significantly lower during eccentric contractions than during concentric (Hollander et al., 2003; Miller et al., 2009) and dynamic (Miller et al., 2009) contractions at the same absolute loads. This difference seems to be due to the increase 1RM capacity during eccentric contractions when compared to concentric. Indeed, RPE was consistent between eccentric and concentric contractions when each contraction was conducted at the same relative load, based on the 1RM for each contraction type (Hollander et al., 2017); with eccentric loads approximately 20% higher than concentric loads at the same RPE levels (Hollander et al., 2008).

While the cause of the increase in validity for isometric contractions is unclear, these results would suggest that the use of RPE during IE, such as during IWS interventions, will give a more accurate measurement of EI than dynamic resistance training, in addition to the improvements seen when compared to aerobic exercise.

2.4.4 Scale characteristics

2.4.4.1 Scale used, points and fixed maximum

Nine different RPE scales were used in the studies included in this review, including; Borg's 6-20, Borg's CR-10, the OMNI-RES, Estimated-Repetitions-to-Failure (ERF) (Hackett et al., 2012), Borg's scale verbal cues only (Hampton et al., 2014), Isometric Exercise Scale (IES) (Studies 2-4, Chapters 4-6), Numerical Rating Scale (Lampropoulou & Nowicky, 2012; 2014), Perceived Task Duration (PTD) (Shepherd et al., 2013), and Resistance Exercise Specific Scale with Repetitions in Reserve (Zourdos et al., 2016). Moderator analysis revealed that the specific RPE scale used did not influence the reported effect sizes. Likewise, differences in the RPE scale properties, number of points and fixed maximum, had no effect on the validity of RPE.

Ratings of perceived discomfort or pain (RPD) is often used as an analogue of RPE to monitor EI. Indeed, the CR-10 scale was designed for use as a muscular pain scale and later validated as an exertion scale (Borg, 1998). Comparison of perceived discomfort and perceived exertion has yielded similarly high correlation coefficients (r = 0.71-0.86) (Hollander et al., 2003), suggesting that both RPD and RPE are valid metrics that can be used to monitor EI. However, it has been suggested that RPE ratings are higher at a set intensity than RPD (Hollander et al., 2003; Fisher et al., 2017).

It is common within RPE research to use correlation with a previously validated RPE scale to show the validity of a new scale to measure the construct of perceived exertion; for example, Lagally and Robertson (2006) compared the OMNI-RES and Borg 6-20 scales (r = 0.94 to 0.97), Hackett et al. (2012) compared ERF and OMNI-RES (r = 0.96), Shepherd et al. (2013) compared the CR-10 and PTD (r = 99), and the current research (Study 2) compared the IES and CR-10 (r = 0.97). These results, in addition to providing the intended construct validity, further support the findings of this meta-analysis that many RPE scales, despite having different designs, properties, and intended uses can be used interchangeably without affecting the validity of the results.

2.4.4.2 Rating mode

The results of the meta-regression revealed that there were no statistically significant differences in validity coefficients between estimation and production modes ($p > 0.05$). During aerobic exercise, Chen et al. (2002) showed higher validity coefficients for production mode than estimation mode for all outcome measures except ventilation, which had a low number of production studies. This difference may be due to the higher validity coefficients seen in the current analysis for estimation mode during resistance exercise, and not due to a decrease in production mode validity.

Pincivero (2011) suggested that when compared to estimation mode, both older and younger adults significantly underproduce isometric leg extension torques at higher RPE levels. Whereas Morrin et al. (2018) showed no significant differences in the %MVC achieved between estimation and production trials, during isometric handgrip exercise. These conflicting results prompt further investigation to explore possible differences.

Hampton et al. (2014) showed that production mode could be used to produce distinct levels of force at 5 different RPE levels. Morrin et al. (2018) suggested that production RPE was sufficiently accurate to self-regulate isometric handgrip training for reducing BP. Likewise, OMNI-RES ratings of 3, 6 and 9 have been show to accurately and reliably produce intensities that are appropriate for improving muscular fitness (Lagally et al., 2009). A 12-week training intervention, at an RPE of 4 on the OMNI-RES scale, was sufficient to increase post-training 1RM in 7 different exercises (Gearhart et al., 2011). Similarly, a 12-week training intervention, prescribed at RPE ratings from 13-18 on the Borg 6-20 scale, produced increases in maximal leg press (58%), knee extension strength (20%), and knee extension

power (27%) (Tiggemann et al., 2016). These results suggest that RPE can be used in both estimation mode and production mode as a valid and accessible means of monitoring and prescribing EI respectively.

2.4.4.3 Rating type

This study demonstrated that differences in the rating type, i.e. RPE-AM (active muscles), RPE-O (overall body) or S-RPE (sessional), did not influence the strength of the validity coefficients obtained, suggesting that all three of these methods can be used to monitor EI with equal effectiveness. Results consistently show that RPE-AM ratings are higher than RPE-O ratings (Lagally et al., 2002a; Robertson et al., 2003; Lagally & Robertson, 2006; Duncan et al., 2006; Colado et al., 2012; 2014; Diniz et al., 2014; Hiscock et al., 2015), with increasing divergence in these ratings as intensity increases (Lagally et al., 2002b; 2004). Ribeiro et al. (2013) showed no significant difference between RPE-AM and RPE-O ratings, during circuit weight training; however, this study assessed both RPE types 10, 20 and 30 minutes after the exercise had finished, where they would normally be assessed immediately following a repetition or set, which could account for these conflicting results.

There are conflicting results in the current literature regarding the outcome of S-RPE compared to RPE-O. It has been suggested that mean RPE-O, taken immediately after each set, elicits significantly higher ratings than S-RPE (Sweet et al., 2004; Singh et al., 2007). Conversely, Day et al. (2004) showed non-significant differences in RPE-O (taken immediately post set) and S-RPE (taken 30 minutes post-exercise) at 50% and 70% 1RM, and no differences at 90% 1RM. Likewise, Costa et al. (2015) showed no difference between RPE-O, collected immediately after the last set, and S-RPE collected 30 minutes post-exercise. In addition to these results, there are conflicting results concerning the implementation of S-RPE; Kraft et al. (2014b) suggests there is no difference between S-RPE taken at 10- and 30-minutes post-exercise, while Singh et al. (2007) showed significant differences between S-PRE taken at 5- and 10-minutes when compared to 30-minutes. Singh suggests that 30-minute S-RPE is a better overall indicator of training session intensity.

The optimum implementation of S-RPE requires further investigation, but the results of this analysis would suggest that all three types of RPE rating can all be used to accurately measure EI.

2.4.4.4 Anchoring procedure

Anchoring is regularly used as part of the standardised instructions given to users to explain how to use the given RPE scale properly. Anchoring aims to give the user a clear understanding of what one or more points on the scale mean in relation to EI. This is often done by anchoring the extremities of the scale, so that the user can then estimate what the other points should feel like based on those anchors. It is suggested that providing standardised instructions and anchoring is important to accurately gauge EI (Gearhart et al., 2001).

There are several methods of anchoring, including: memory anchors, exercise anchors and combined memory-exercise anchors. Memory anchors call upon previous experience, for example, maximal is the hardest exertion previously experienced (Hollander et al., 2003; Hiscock et al., 2015; 2016). Exercise anchors utilise exercise at a set percentage of the user's maximum, followed by an explanation of what level on the RPE scale that exercise is; for example, isometric holds at 10% and 100% of MVC for 5 seconds are 1 and 10 in the CR-10 respectively (Pincivero & Gear, 2000), or following a 1RM lift the participant is told that that is 'maximal exertion' on the scale (Gearhart et al., 2001). Finally, the combined memory-exercise anchor uses both methods, anchoring some points on the scale using exercise and others using the participants memories and estimations (Lagally & Robertson, 2006; Lagally & Amorose, 2007; Hollander et al., 2008). Lagally and Costigan (2004) compared these anchoring methods at 6 intensities from 40% - 90% MVC; their results showed no significant differences in the mean rating at each intensity between anchoring groups, however, the exercise and memory-exercise groups did show better reliability between the first two sessions, when compared to the memory group. It would seem that valid results can be obtained using all three anchoring methods. While reliability was suggested to be improved across the first two sessions with the inclusion of an exercise anchor (Lagally & Costigan, 2004), it is likely that this difference will diminish in later sessions due to familiarity with the specific exercise. It should also be noted that no studies were identified that compared any anchoring procedures with a non-anchored group, it may therefore be an assumption that anchoring is important to increase validity and/or reliability.

2.4.5 Study characteristics

2.4.5.1 Outcome measure

Moderator analysis showed that RPE validity was not statistically significantly affected by the outcome measure used to quantify resistance EI. Likewise, the secondary analysis, using EMG as the only outcome measure, showed a very large effect size comparable to that shown in the primary analysis. These results further emphasise the accuracy of RPE as a measure of both external and internal (physiological exertion) measures of exercise intensity, as was shown previously during team sports (McLaren et al., 2018). During aerobic exercise, Chen et al. (2002) showed differences in validity coefficients based on the outcome measure used; additionally, there were contradictory moderator results dependant on the outcome measure used. It is possible that this shows a genuine improvement in RPE validity during resistance exercise over aerobic exercise when using certain outcome measures; conversely, this could simply be a consequence of the specific outcome measures and research articles included in each analysis.

2.4.5.2 Exercise intensity variable manipulated

While the outcome measure used did not significantly affect validity; however, in the studies that used EI as the outcome measure, the variable used to modify EI did significantly affect validity. The meta-regression analysis showed that significantly higher validity coefficients were shown in studies that manipulated workload ($p < 0.001$) or repetition time ($p < 0.002$), when compared to the use of total number of repetitions or rest interval time.

The accuracy of RPE to express changes in workload is well supported within the current literature. It has been suggested that RPE is sufficiently accurate to perceive differences in load at 20% intervals of 1RM, during dynamic bicep curls and knee extensions (Eston & Evans, 2009); 10% differences in bench press power (Naclerio et al., 2011); and 10-degree differences in knee angle during isometric wall squatting, as shown in study 4 (Chapter 6). Fisher et al. (2017) showed no differences in peak RPE or RPD between loads of 30% and 80% of 1RM in a test to fatigue. However, as both conditions were tested to fatigue, peak RPE and RPD would be expected to be the same (i.e., maximal) in both conditions. This was evident in a study by Vasquez et al. (2013), that showed significant differences in RPE between different %1RM workloads at set repetition numbers but showed no significant differences between RPE at volitional fatigue. Genner and Weston (2014) found that volume load (workload x total repetitions) showed stronger relationships with S-RPE than workload alone (%1RM), this result warrants further investigation.

The increased strength of the validity coefficients for repetition time could be related to the significantly greater coefficients seen with isometric exercise over the other forms of muscle contraction, as isometric contractions are normally sustained contractions and often controlled using contraction time. However, it is not clear whether the quantifiability of repetition time makes RPE during isometric contractions more accurate, or whether greater validity coefficients for isometric exercise have contributed to increased validity with repetition time modification.

The reduced validity shown with rest interval time should be interpreted with caution, as only two studies (Hiscock et al., 2015; Saraiva et al., 2017) were included in the meta-analysis using rest time as the EI variable. Therefore, it is unclear whether manipulation of rest time really does produce lower validity coefficients, when compared to adjusting workload or repetition time, or whether there is just insufficient data at this time. Significant increases in S-RPE were shown with reduced rest interval, when volume load was matched between conditions (Kraft et al., 2014b). Senna et al. (2011; 2012) showed inconsistent trends towards higher RPE ratings with lower rest times, however, these studies did not control the number of repetitions completed in each set, meaning significantly greater numbers of repetitions were achieved in the longer rest interval conditions. Additionally, Tibana et al. (2013) showed no differences in RPE following exercise using either a 1.5- or 3-minute rest period, but once

again, these trials were both completed until volitional fatigue meaning that both conditions should elicit a maximal RPE response.

Gearhart et al. (2002) explored differences in RPE during exercise with matched volume loads (tonnage); significantly higher RPE-AM ratings were seen with higher loads and fewer repetitions (5 reps @ 90% 1RM) compared to lighter weights with higher repetitions (15 reps @ 30% 1RM). Likewise, Kraft et al. (2014a) suggested that load had a greater effect on RPE than training volume (reps x sets) changes. However, neither of these studies controlled the repetition time, meaning repetition time could have been increased in the higher load conditions without this increase being included in the exercise intensity calculation. In support of this, no significant differences were shown in RPE-O or S-RPE between conditions with matched volume load, but different workloads, when rest interval and repetition time were controlled (Costa et al., 2015). In contrast, RPE was shown to increase with workload increase, despite matched volume load, during eccentric elbow flexion with standardised repetition and rest interval times. These conflicting findings and differences in procedures make interpretation difficult and prompt further investigation with full control over all EI variables (O'Connor et al., 2002).

Most of the studies included in the current review and meta-analysis, have manipulated one or more EI variable without measuring or controlling at least one of the other variables. Most commonly repetition time and rest interval are not measured, controlled, or reported. As shown in this analysis, changes in repetition time and rest interval time are correlated with changes in RPE. Additionally, increases in workload have been shown to inversely correlate with repetition velocity when repetition velocity/time are not controlled (Zourdos et al., 2016). Ideally, studies looking to accurately manipulate exercise intensity should control and report all five of these EI variables, otherwise uncontrolled variables may change and thus magnify or nullify an expected change or create an unexpected change.

2.4.6 RPE reliability

Only 13 (Kraemer et al., 1987; Pincivero et al., 2003a; Day et al., 2004; Lagally et al., 2009; Lampropoulou & Nowicky, 2012; Hackett et al., 2012; Row et al., 2012; Colado et al., 2012; 2014; Row et al., 2017; Studies 1-3) of the 75 studies in the meta-analysis and 3 studies in the qualitative analysis (Elfving et al., 1999; Gearhart et al., 2002; Egan, 2003) reported a measure of RPE repeatability. While single validity measurements are legitimate, for RPE to be considered useful in a real-world exercise setting, especially when it is being used to prescribe exercise intensities, its' results must be shown to be reliable between exercise sessions. In estimation mode, RPE-AM showed 'good' to 'excellent' reliability with Intraclass Correlation Coefficients (ICC) of r = 0.67 – 0.96 (Gearhart et al., 2002; Row et al., 2012; Colado et al., 2012; 2014; Hackett et al., 2012; Row et al., 2017; Studies 2-4), RPE-O showed 'fair' to 'excellent' reliability (r = 0.58 – 0.76) (Colado et al., 2012; 2014), and S-RPE showed excellent reliability (r = 0.95; 95% CI = 0.90-0.97) (Egan, 2003). These studies used

various forms of exercise including isometric exercise (Elfving et al., 1999; Lampropoulou & Nowicky, 2012; Studies 2-4), dynamic bench press and squatting (Hackett et al., 2012), and mixed upper and lower body circuit training (Day et al., 2004). RPE was also shown to be reliable (r = 0.88; 95% CI = 0.89-0.91) during a home-based intervention (Study 4, Chapter 6), and when used in production mode (r = 0.69–0.95) (Lagally et al., 2009).

Two studies (Pincivero et al., 2003a; Lagally & Costigan, 2004) showed lower ICC results than the rest of the included studies. The first (Lagally & Costigan, 2004) showed ICC results ranging from r = 0.07 to 0.80. The authors suggest that the lower scores were due to high inter-subject variance, and that while the ICC scores were low, agreement between the two sessions was much higher (60-90%). The second study (Pincivero et al., 2003a) showed significantly lower RPE scores on the second testing day, when compared to the first day ($p < 0.05$) and showed ICC scores of r = -0.05 to 0.46. It was argued that habituation with the exercise task, through additional testing days, could have reduced the between day differences as shown in previous studies (Elfving et al., 1999).

Overall, these results suggest that RPE can be a reliable measure and prescribing tool. Additionally, it is suggested that RPE reliability will increase with habituation to the task, such as throughout the course of an IWS intervention; however, more research is required to confirm that RPE is reliable across a range of exercise intensities, participants, and exercise modes, and to elucidate which factors may positively and negatively affect its reliability.

2.4.7 Limitations

There were several limitations in the present systematic review and meta-analysis. Firstly, we were only able to include studies written in the English language. Despite this, studies were included from a total of 11 countries, including 7 countries where English is not the first language: Brazil, Spain, Switzerland, Italy, Denmark, Taiwan, and France.

Secondly, some evidence of publication bias was present in the forest plot (Figure 2.2), indicating that some studies could exist that show less favourable results and have not been published. However, the Classic and Orwin's fail safe tests showed that such a large number of non-significant studies would be required to change the validity level, and as such, it is extremely unlikely that this would have affected the meta-analysis results.

Finally, there was high between-study variance in the reported effect sizes, including a large amount of unexplained heterogeneity following the moderator analysis. This could largely be the consequence of the varied study designs, study populations, outcome measures and data reporting in the included studies. For example, exercise modalities including TheraBand exercise (Colado et al., 2012; 2014), isometric elbow flexion (Lampropoulou & Nowicky, 2012), and simulated manual work movements (Jakobsen et al., 2014) were included. Additionally, studies using any rating and scale type for perceived

pain or exertion were included. Inevitably, when including such a large number and variety of studies, greater between study variance is expected. Moreover, identifying, grouping, and coding these varied characteristics, in order to find moderators and explain heterogeneity, becomes increasingly difficult.

2.4.8 Conclusion

In conclusion, these results suggest that RPE provides a valid measure of exercise intensity and physiological exertion during resistance exercise, with effect sizes comparable or greater than those shown during aerobic exercise and team sports. Larger validity coefficients were seen in studies using greater workload ranges, isometric muscle action, and when EI was manipulated using workload or repetition time. Conversely, participant age, sex, training status, RPE scale used, and outcome measure used did not affect the validity coefficients reported. As such, the development of a protocol to prescribe IWS interventions using RPE is supported by the current literature. Additionally, the evidence supports the implementation of such an intervention in a broader participant group of both sexes, and across all ages and training levels.

CHAPTER 3:

General Methods

3.1 Overview

This chapter details the research approach and common methodologies used throughout the studies contained within this thesis. Details of measurement procedures will be outlined, including participant stature, mass, BP, HR, wall squat angle, and RPE. The necessary information regarding the validity and reliability of each variable will be presented. Additionally, the incremental isometric wall squat test (IIWST) and home-based isometric wall squat (IWS) training protocols will be explained.

3.2 Research approach

The research approach adopted in this thesis was quantitative and experimental in nature. This research project was split into 5 studies (Figure 3.1). Study 1 (Chapter 2) was a systematic review and meta-analysis that aimed to collate the current research relating to the use of RPE during resistance exercise, in order to; assess the validity of RPE during resistance exercise, clarify some of the contradictory findings presents in the literature, and give clear recommendations on the use of RPE during resistance exercise. Study 2 (Chapter 4) adopted a repeated measures design to explore the validity and reliability of two RPE scales during the maximal incremental wall squat test. Study 3 (Chapter 5) implemented a randomised cross-over design to examine the validity and reliability of RPE to measure exercise intensity and physiological exertion at different isometric wall squat workloads. In addition, this study examined the ability of RPE to distinguish between different wall squat workloads. Study 4 (Chapter 6) used a repeated measures design to investigate the effectiveness of RPE to monitor exercise intensity during three sessions of the home-based isometric training protocol, that is currently used for the reduction of resting blood pressure. Finally, study 5 (Chapter 7), implemented a 4-week home-based isometric wall squat training programme, based on the findings of the previous studies, with exercise intensity prescription based on either; the current IIWST protocol, or a production RPE selection protocol. Following the 4-week intervention, the effects on resting and ambulatory arterial blood pressure were assessed.

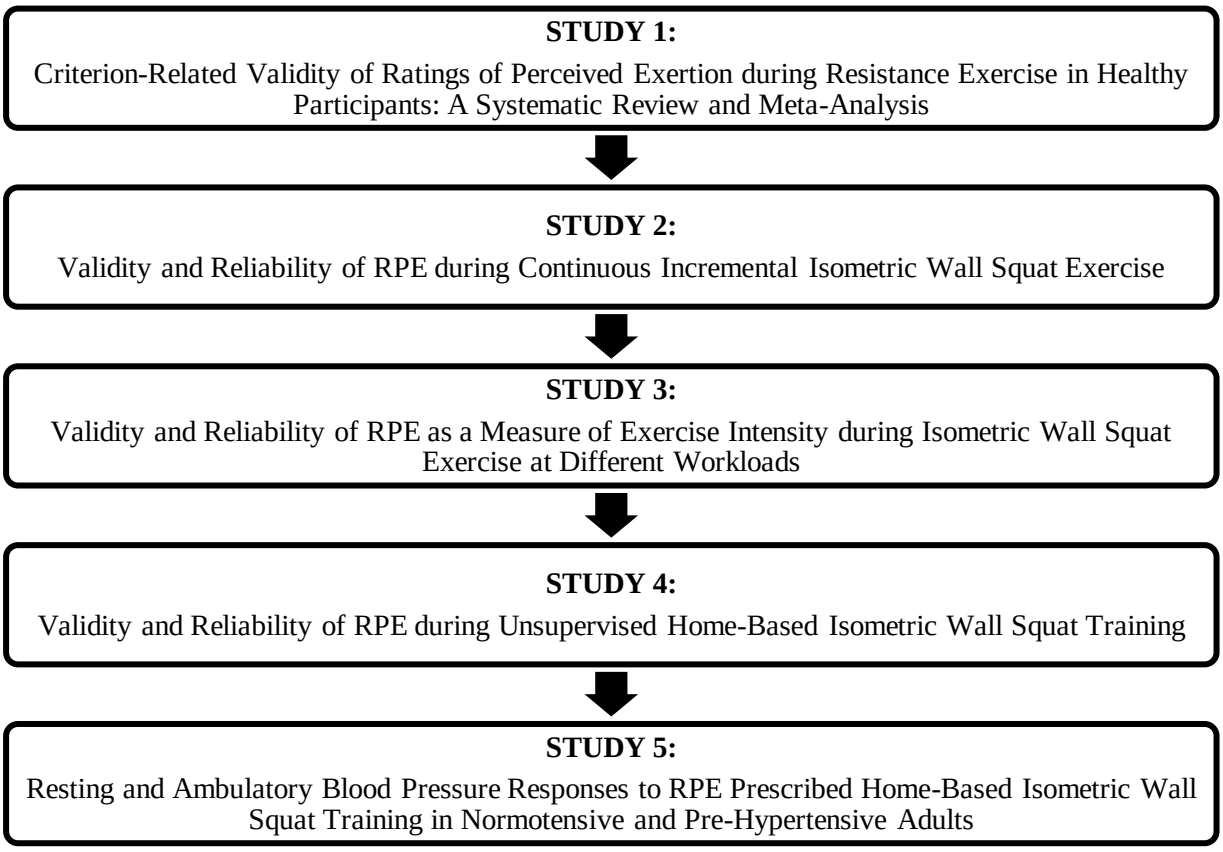


Figure 3.1. Schematic of the studies contained within this thesis.

3.3 Testing conditions

3.3.1 Ethical consideration

Before commencement of this research project, ethical approval was obtained from the Canterbury Christ Church University Ethics Committee (Appendix 1). All testing procedures were completed according to the declaration of Helsinki.

Prior to undertaking any testing procedures all participants had the purpose of the study, testing protocols, and their right to withdraw explained to them; completed an informed consent and exercise readiness/health screen questionnaire form (Appendix 2): and had the opportunity to ask any questions/raise any concerns they might have about the study.

3.3.2 Testing and measurements

To ensure reliability of measurements and control of data; all testing, measurements and analyses were completed by the principal researcher (John Lea). Additionally, the same equipment was consistently used throughout the testing and analysis.

3.3.3 Laboratory environment

All laboratory testing took place in the Sport and Exercise Science laboratories on the North Holmes Road campus of Canterbury Christ Church University, in accordance with all safety procedures and risk assessments.

3.3.4 Homed-based training

Participants completing studies 4 and 5 (chapters 6 & 7 respectively), were required to complete home-based training sessions. These training sessions were completed at a location of the participants choosing and whilst they were provided with general safety guidelines, participation was ultimately at their own risk. Participants were informed to stop exercising immediately if any adverse effects were experienced and to contact the lead researcher with any concerns or if any clarification was required.

3.4 Participant information

3.4.1 Inclusion criteria

Healthy normotensive and pre-hypertensive adults, between the ages of 18 and 65, were recruited for each of the experimental studies. Normotension was defined as an SBP between 90 and 120 mmHg and a DBP between 60 and 80 mmHg, while Pre-HTN was defined as an SBP between 120 and 140 mmHg and/or a DBP between 80 and 90 mmHg (Pickering et al., 2005). Blood pressure status was assessed based on 3 seated resting oscillometric BP measurements (Section 3.5.2). Volunteers with a resting BP outside of the accepted ranges were advised to visit their GP and were not included as a participant. 'Healthy' was defined as having no injury or illness that could affect the participants wellbeing or performance during the testing period. As such, participants were free from any clinical diagnosis for cardiovascular conditions or dysfunction, with the exception of Pre-HTN. Additionally, participants were required to be non-smokers (for at least 6-month) and not taking any medication that could affect exercise performance or cardiovascular function. Participant health status was assessed using a self-reported health screen and exercise readiness questionnaire (Appendix 2).

3.4.2 Recruitment

The majority of the participants who volunteered for this research were students or staff at Canterbury Christ Church University. Other participants were recruited from local sports clubs and from personal acquaintances. No monetary or material rewards were offered for participation, but a free BP screening was offered to all participants, and participants were informed that the exercise interventions could have positive health benefits. Upon showing interest to take part in the study, participants were sent the relevant participant information sheet (e.g., Appendix 3), containing the purpose of the investigation, the testing requirements, and a full written explanation of the testing protocols. Participants that still wished to be part of the study were then invited to attend the laboratory for their first session. Several

participants volunteered for multiple studies, with the exception of study 5, where previous knowledge of the IWS exercise could affect the results so this was not permitted.

3.4.3 Testing requirements

Prior to all laboratory-based testing sessions, across the four experimental studies (Chapters 4, 5, 6 & 7) participants were required to abstain from food for 4-hours, caffeine for 12-hours, alcohol for 24-hours, and strenuous exercise for 24-hours. It was important to control and standardise the eating, drinking and exercise of participants, as comparisons of multiple participants, across multiple sessions was required (Shapiro et al., 1996) and because each of these has been shown to influence HR and/or BP measurements (Uijtdehaage et al., 1994; Kojima et al., 1993; James, 2004; Rezk et al., 2006). Participants were also asked to empty their bladders prior to each session (Pickering et al., 2005). Additionally, participants were instructed to maintain their regular level of physical activity and dietary habits for the duration of the study. At the start of each testing session, participants were asked to verbally confirm that they had adhered to these instructions; if the participant had not followed these instructions, the testing session was re-scheduled.

3.4.4 Familiarisation

Before taking part in any experimental testing or exercises, a full explanation of the study was given to each participant, including the number of testing sessions, the measurements to be taken each session and the exercise protocols to be undertaken. As part of the explanation, a demonstration of the wall squat, including correct foot and body positioning, was given. The RPE scale, or scales, to be used in that study, were then shown to the participants, and explained using standardised instructions and anchoring protocols (Section 3.6).

Participants were then informed of their right to withdraw, given an opportunity to ask any questions, and if they were still happy to take part in the research, all pre-testing paperwork was completed (as described in Section 3.3.1). Following completion of the paperwork, resting HR and BP measurements were collected.

After the resting HR and BP measurements, while the participant was still in a rested state and seated position, the use of the RPE scale(s) was once again explained. To assess the participants understanding of the scale, all participants were asked to rate their current RPE (expected rating of zero).

Study 2 aimed to assess the number of IWS sessions required to obtain stable/reliable RPE results, therefore, the participants did not practice the wall squat before the first maximal incremental wall squat test. Conversely, in studies 3, 4, and 5, participants had an opportunity to experience the correct wall squat position and provide an exercising RPE rating, prior to the first exercise session.

3.5 Measurement of studied variables

3.5.1 Anthropometric measurements

Participant stature was measured barefoot with feet flat on the floor, heels together and touching the back of the base plate of the stadiometer (Seca 213, Hamburg, Germany). Participants were asked to stand up straight with their back against the stadiometer, with their head in the Frankfurt plane, and to take in and hold a maximal breath. The horizontal headboard was lowered to the top of the participants head and stature was measured to the nearest 0.1 cm. Body mass was measures with the participants in minimal clothing, with an empty bladder, and free of any excess items in pockets or jewellery. Individuals were asked to step onto the scales (Seca 711, Hamburg, Germany), face forward, and remain still whilst the measurement was obtained. Body mass was measured to the nearest 0.1 kg. Body mass index (BMI) was calculated for each participant using the following equation:

$$BMI = Body\ Mass/Height^2 \text{ (McArdle, Katch \& Katch, 2010)}$$

3.5.2 Oscillometric blood pressure monitoring

To ensure that participants met the BP inclusion criteria (Section 3.4.1), seated BP was measured using an automated oscillometric BP monitor (Dinamap® Pro, GEMedical Systems, Slough, UK). Participants were asked to remove any clothing that covered the location of the cuff placement. The sleeve was not allowed to be rolled up, as this can cause a tourniquet effect above the blood pressure cuff (Pickering et al., 2005). The participant's left upper arm circumference (greatest circumference whilst relaxed) was then measured, in centimetres, using an ergonomic circumference measuring tape (Seca 201, Hamberg, Germany). This measurement was used to ensure the correct sized BP cuff was used, as incorrect cuff size has been shown to cause inaccurate measurements, with overly small cuffs causing greater error than oversized cuffs (Arcuri et al., 1989; Russell et al., 1989; Bovet et al., 1994). As such, if a participant's arm circumference fell within the overlapping ranges of two cuff sizes, the larger cuff was used.

It is common for differences in BP to be recorded between the left and right arms (Pickering et al., 2005); therefore, to ensure consistency, all seated oscillometric BP measurements in this thesis were conducted with the cuff on the left arm. To fit the bladder correctly, the brachial artery was first palpated in the antecubital fossa. The midline of the bladder in the cuff (marked by the manufacturer with an arrow), was aligned with the brachial artery. The lower end of the cuff was positioned 2 to 3 cm above the antecubital fossa, and the cuff was secured flat to the arm, with no folds in the material that could cause a tourniquet effect (Pickering et al., 2005).

Prior to measurement, individuals were given 10-minutes of quiet rest in a comfortable seated position, with their back supported, feet flat on the floor, legs uncrossed, and with their left arm relaxed and

supported (Figure 3.2). The left arm was positioned such that the middle of the BP cuff was at the level of the right atrium, estimated as the mid-point of the sternum (Pickering et al., 2005).

Figure 3.2: Seated BP positioning

Participants were instructed to relax as much as possible. Silence was maintained throughout each measurement, with neither the participant nor researcher permitted to speak. While the participant remained in the resting position, three BP measurements were taken with 60 seconds rest in-between (Pickering et al., 2005). If differences between the consecutive measurements exceeded 5 mmHg, then an additional measurement was taken. The mean of the results for HR, SBP, DBP and MAP were calculated for analysis, and use to categorise participant BP status. If the mean results did not fall within the inclusion criteria (Section 3.4.1), then the participant was removed from the study and advised to seek medical advice.

To aid the reliability of repeated BP measurements, the same Dinamap® Pro device was used for all seated rested BP measurements collected for this thesis.

3.5.2.1 Validity of the Dinamap® Pro

The accuracy of the Dinamap® Pro has previously been questioned, with research to suggest that it consistently underestimates SBP and DBP (O'Brien et al., 1990), and conflicting research suggesting that it overestimates DBP (Beaubien et al., 2002). However, rather than comparing the Dynamap to a direct gold standard measurement such as intra-aortic catheterisation, these comparisons were made using the indirect auscultatory method with sphygmomanometers (Friedman, 1997).

When compared to results from invasive intra-aortic catheter measurement, the Dynamap® Pro was within the required accuracy by the American National Standards Institute (ANSI) for BP

measurements (Baker, 1986). Additionally, the results from the Dynamap® have been shown to be accurate when compared to other semi-automated devices (Lewis et al., 2002), and may eliminate the user error and experimenter bias that can be seen with manual measurement. As such, the Dinamap® pro is listed by the British Hypertension Society (2016) as a validated BP monitor for clinical use, having been tested in according to the European Society of Hypertension International's protocols (O'Brien et al., 2002). This classification shows that the device can produce measurements with a mean difference of less than 5 mmHg when compared to a gold standard device and produces results for both SBP and DBP with a standard deviation of less than 8 mmHg (O'Brien et al., 1993). Therefore, this is a clinical standard device and was deemed sufficiently accurate for the current research.

3.5.3 Continuous cardiovascular measurements

Continuous non-invasive monitoring of several cardiovascular variables, including BP, HR, stroke volume (SV), cardiac output (Q) and total peripheral resistance (TPR), was conducted at rest and during IWS exercise using the Task Force® Monitor (TFM, CNSystems, Graz, Austria; Figure 3.3). The TFM combines continuous BP measurement, beat-to-beat stroke volume measurement via impedance cardiology (ICG) and 4 lead ECG (Fortin et al., 2006a). Several of the haemodynamic variables measured by the TFM are calculated relative to the participant's body surface area, therefore stature and body mass were measured at the start of each session (Section 3.5.1) and were inputted into the TFM.

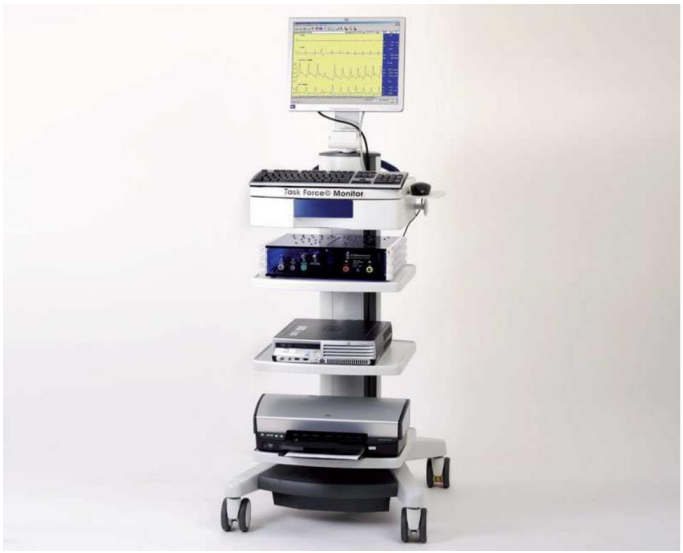


Figure 3.3: The Task Force® Monitor

Continuous cardiovascular measurement was used at rest and during IWS exercise throughout this research. Resting measurements were conducted while the participant was in a supine position for 15-minutes; involving 10-minutes of quiet rest followed by 5-minutes of data collection. During this period, the participant was asked to make themselves as comfortable as possible with a single pillow for their head, legs un-crossed, left arm relaxed resting on the bed, and right arm raised up and supported using

a towel so that the middle of the BP cuff was level with the right atrium (approximately halfway between the bed and the level of the sternum) (Pickering et al., 2005). The room was kept quiet, and the lights were dimmed. Participants were instructed not to talk and to remain as still as possible throughout this period. The supine position has been shown to produce DBP results approximately 5 mmHg lower than the seated position (Pickering et al., 2005); however, as these measurements are easily affected by movement and change in posture, it was decided that use of the supine position would increase the accuracy of the multiple pre- and post-intervention comparisons that were required in this research.

During exercise, isometric wall squat position was controlled as described below (Sections 3.7.2 to 3.7.5). Additionally, the participants were instructed to keep their arms relaxed down by their sides, and not to clench their fist, as this movement is known to affect the reading of the continuous BP monitor.

3.5.3.1 Blood pressure

Continuous BP was recorded using a finger cuff on the index and middle fingers of the left hand. Blood flow was measured using an infrared sensor, while pressure was exerted by a pneumatic cuff. Real arterial BP corresponded to the pressure required to maintain constant blood flow and pulsation (CNSystems, 2014). These measurements were automatically corrected to oscillometric BP values obtained from the brachial artery of the right arm (Figure 3.4). This correction allows true arterial pressure of the larger central arteries to be represented, rather than finger artery pressure that is highly susceptible to change based on environmental temperature and blood volume (Fortin et al., 2006b).

The recording of beat-to-beat fluctuations in arterial pressure enabled more accurate monitoring of the changes in BP during IWS exercise and the evaluation of cardiovascular control mechanisms (Benditt et al., 1996; Low, 1996). The use of non-invasive BP measurements such as this, when compared to the invasive intra-arterial measurement, is more convenient, lowers the risk of infection and is less stressful for the participant (Pickering et al., 2005). The mean, SBP, DBP, and MAP values were calculated for the 5-minute data collection period for analysis.

3.5.3.2 Heart rate measurement

Accurate measurement of HR during isometric training interventions, such as the one used in this thesis, is vital as HR is used to prescribe isometric exercise intensity, to control the provided stimulus (Goldring et al., 2014). Furthermore, it is also useful to measure HR as it is an indication of exercise induced physiological adaptations (Laukkanen & Virtanen, 1998). As HR is a determinant of cardiac output (Q = HR x SV) (Tortora & Derrickson, 2012), its measurement provides further insight into the origin of chronic changes to Q that may occur, such as those due to isometric exercise training.

During all laboratory testing and training sessions in this thesis, HR was monitored using the 6-channel electrocardiogram (ECG) provided by the TFM. Heart rate is determined using the R-R interval

(Valipour et al., 2005; Fortin et al., 2001), which enables the calculation of HR variability (Fortin et al., 2001; Bianchi et al., 1997). Electrocardiogram (ECG) is the gold standard for HR measurement in the clinical and laboratory setting (Engström et al., 2012), provides reliable results (Hojgaard et al., 2005), and as such is regularly used as the validation standard for new HR monitors and devices (Terbizan et al., 2002; Gamelin at al., 2006; Engström et al., 2012).

To record ECG, four electrodes were fitted to the participants torso; the two upper limb electrodes were placed directly anterior to the head of Humorus on the left and right sides, while the lower limb electrodes were positioned in line with and superior to the left and right legs, below the umbilicus (Figure 3.4).

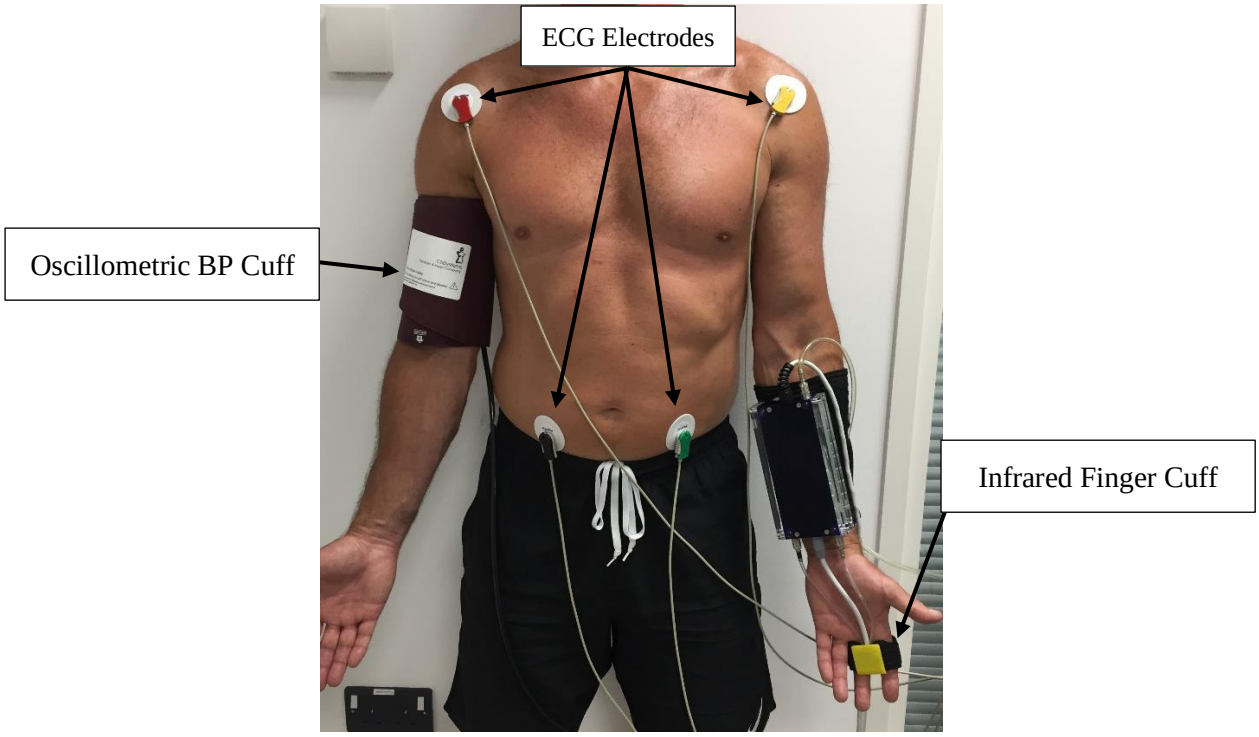


Figure 3.4: Task Force Monitor BP cuffs and ECG electrode placement

3.5.3.3 Impedance cardiography

Impedance cardiography (ICG) was used to continuously measure changes the total conductivity of the thorax in relation to the cardiac cycle (Fortin et al., 2001; Fortin et al., 2006a), in order to determine SV, which together with HR and BP enables the continuous beat-to-beat real time calculation of Q and total peripheral resistance (TPR) (Ventura et al., 2000; Drazner et al., 2002).

The TFM calculates left ventricle SV via measurement of the maximum rate of thoracic electrical impedance during ventricular ejection. This is divided by the base impedance and multiplied by the LV ejection time (ET) and volume constant of the chest (Fortin et al., 2006a). The volume constant of the chest is determined by the individuals' age, stature, mass, and body surface area (Valipour et al., 2005; Fortin et al., 2006a). Cardiac Output (Q) is then calculated indirectly by multiplying SV by HR, while

TPR and total peripheral resistance index (TPRI) are determined according to Ohm's law, where TPRI is equal to mean BP divided by cardiac index (Fortin et al., 2006a).

To measure ICG, three impedance electrodes were fitted to the participant. The first was placed on the nape of the neck (superior to C7), while two electrodes were placed on the left and right side of the thorax, level with the xiphoid process (Fortin et al., 2006a), as shown in Figure 3.5. Each electrode consisted of an adhesive strip with two precisely distanced electrode bands, through which a non-invasive uniform high frequency alternating current field is created within the thorax for impedance measurement (Fortin et al., 2006a).

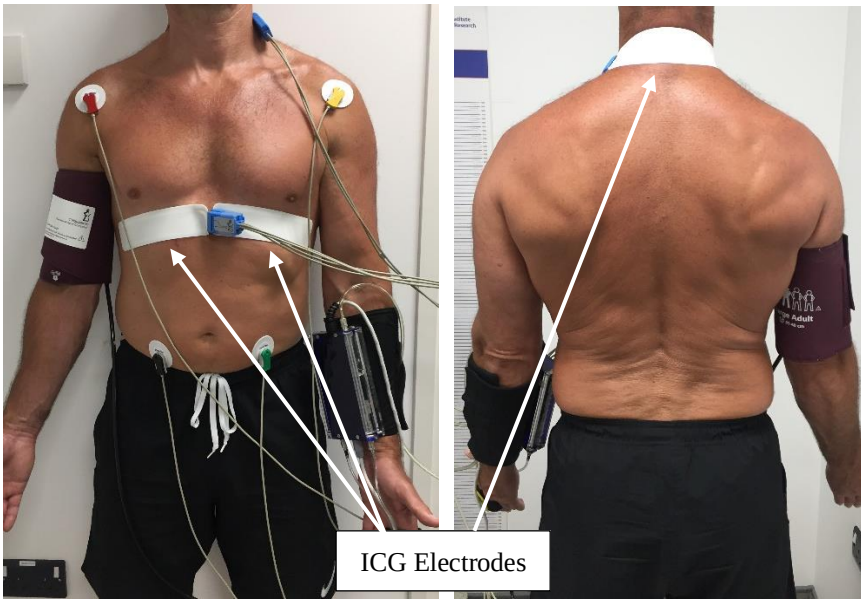


Figure 3.5: Task Force Monitor impedance cardiography electrode placement

3.5.3.4 Validity and reliability of the Task Force® Monitor

Blood pressure measurement using the TFM has previously shown excellent construct validity when compared to the Finapres, the only other commercially available non-invasive continuous BP monitoring device, while eliminating the frequent calibration interruptions present with the Finapres (Fortin et al., 2001; 2006b). The TFM has also demonstrated good agreement with simultaneous measurement using the gold standard intra-arterial BP measurement (Fortin et al., 2006b). Likewise, the oscillometric BP measurements produced by the TFM were shown to be valid when compared to results from the Dinamap® BP monitor (Fortin et al., 2001), and has been approved by the American national standard for electronic or automated sphygmomanometers (ANSI AAMI SP10-1992).

Fortin et al. (2001) showed the TFM gave accurate and reliable measurement of haemodynamic data, with ICG measurement at least as reliable as the previous industry standard device the BioZ-PC (CardioDynamics, San Diego, CA, USA). Additionally, the TFM Q recordings comparable to those

shown with the gold standard thermodilution technique (Fortin et al., 2006a; Drazner et al., 2002; Parrot et al., 2004).

The TFM has shown high ICG reproducibility, as reported by Fortin et al, (2006a) (r=0.971) and Fortin et al, (2001) (r=0.963). Similarly, the TFM showed low intra-participant variance between 4-repeated sessions, over a two-week period (Goswami et al., 2009).

Together these results suggest the TFM provides a valid and reliable method of continuous cardiovascular measurement.

3.5.4 Home-based heart rate monitoring

To record HR during the home-based IWS sessions, participants were provided with a Polar RS400 HR monitor (HRM) and a Polar WearLink transmitter (Polar Electro Oy, Kempele, Finland). Heart rate is measured by detection of the QRS-complexes and subsequent calculation of the R-R interval to display an instantaneous HR in beats per minute (Engström et al., 2012). The sampling rate was set to 1-second intervals prior to use, so that HR was recorded continuously throughout the IWS sessions.

Before commencing the training period, the participants were given instructions, verbally and in the provided Training Manual (Appendix 4) regarding the attachment and use of the HRM. Participants were required to moisten the electrodes on the chest strap with water, and then adjust the chest strap so that it fit 'snugly', with the electrodes firmly against the skin (Figure 3.6). Additionally, they were required to position the watch so that it could be easily read.

At the start of each training session, participants fitted and set up the HRM and then recorded a seated resting HR value, in their Training Manual (Appendix 4) after 5-minutes of sitting. Following this, participants were instructed to start the training session, pressing the button on the HRM to start recording as soon as they were in the correct squatting position. The HRM was left to record throughout the entire session, including the rest intervals in between bouts. The participants were required to record the displayed HR value at the end of each 2-minute wall squat bout. At the end of the IWS sessions, the participants were instructed to stop the HRM, at which point the data was stored on the device.

At the end of each week, the participants returned the HRM to the laboratory and the data was downloaded from the HRM to a computer using the Polar ProTrainer5 software (Polar ProTrainer 5, Polar Electro Oy, Kempele, Finland).

Figure 3.6: Polar HR monitor positioning

3.5.4.1 Validity and reliability of the Polar HR monitor

The validity and reliability of the wireless HRM has been extensively investigated, with results suggesting they are both accurate and reliable during exercise conditions and at rest (Seaward et al., 1990; Godsen et al., 1991; Terbizan et al., 2002; Engström et al., 2012). The manufacturers information for the Polar RS400 HRM, suggests that it provides accurate measurements of HR to within ± 1 beats·min^{-1} or 1% variance (Polar Electro Oy, 2010). Further to this, the Polar RS400 has been shown to produce valid and reliable results when compared to ECG, the gold standard HR measurement (Engström et al., 2012).

3.6 Ratings of perceived exertion

3.6.1 Isometric Exercise Scale

Participants were asked to rate the perceived exertion of their active muscles (Quadriceps) using the Isometric Exercise Scale (IES; Figure 3.7) developed specifically for use with IE. Participants were prompted to rate their perceived exertion with the standardised questions: "How hard do you feel your leg muscles are working now". During the familiarisation and at the start of each testing session, prior to exercise, the participants were provided a set of standardised instructions and anchoring descriptions, as follows:

"*This scale is used to rate how hard you think your active muscles are working. This scale has 3 different columns: Rating, Description and TTF. The 'Rating' numbers are from 0-10 and are used to rate the exertion or effort in the active muscle group(s). The 'Description' words and 'TTF' are used to help you choose a rating. 0 (Rest) is absolutely no effort, as felt during complete rest. 5 (Moderate) is right in the middle of 0 and 10. It's not especially hard and it is no problem to continue; but it no longer feels*

comfortable. 10 (Maximal) is maximum effort; your muscles are working as hard as they can, and you can only maintain this for seconds before you will have to stop.
TTF (Time to Failure) indicates the amount of time remaining, during an isometric contraction, before you will be unable to continue. In other words, this describes how much you have left in your 'fuel tank'. 100% - your muscles are fresh; you haven't started the contraction yet (fuel tank is full). 50% - means you can continue to hold the contraction for the same amount of time that you have already completed (fuel tank is half full). 0% - your muscles are failing/have failed (fuel tank is empty). When you give your rating; focus only on the muscle group(s) that is working. You can use the 'Description' words, the Time to Failure (TTF), and/or you can simply rate the exertion out of ten."

Rating	Description	TTF
0	Rest	100%
0.5		
1	Extremely Easy	90%
1.5		
2	Very Easy	80%
2.5		
3	Easy	70%
3.5		
4	Somewhat Easy	60%
4.5		
5	Moderate	50%
5.5		
6	Somewhat Hard	40%
6.5		
7	Hard	30%
7.5		
8	Very Hard	20%
8.5		
9	Extremely Hard	10%
9.5		
10	Maximal	0%

Figure 3.7: The Isometric Exercise Scale for measuring RPE

3.6.1.1 Development of the Isometric Exercise Scale

At the time of starting this research project, no RPE scale had specifically been designed for use during isometric exercise. The CR-10 scale was the most commonly used scale in isometric research, including isometric wall squat exercise (Wiles et al., 2010). While the CR-10 has been shown to be a valid measure of resistance exercise intensity (Desgorces et al., 2015), it was not sufficient to assume that the CR-10 would provide the most accurate measure of RPE during isometric exercise. Therefore, it was decided that a second scale should be used, as a comparison to CR-10, while validating RPE during IWS exercise. Rather than picking one of the various RPE scales available, it was decided that collating features from previous scales, that were seen as more specific to the demands of isometric exercise, would be advantageous. As such the IES was developed.

The numerical part of the IES was adapted from the simple 0-10 numbering system used in the popular OMNI-RES scale (Robertson et al., 2003) and the modified version of the CR-10 scale (Pincivero et al., 2001), both of which had been shown to be valid measures of resistance exercise intensity

(Robertson et al., 2003; Pincivero et al., 2001 respectively). This numerical scale was seen as beneficial as it gave the ratio properties of an absolute zero, rank-order and equal intervals between neighbouring points. Additionally, the fixed maximum (10), rather than the open-ended nature of the 1998 CR-10 scale, was seen as more appropriate for isometric contractions where a definitive maximum end point exists, where the contraction can no longer be maintained. Previous research has suggested that the finer increments present at the lower end of the earlier version of the CR-10 scale (Borg, 1998), allowed that part of the scale to be more sensitive, when compared to the whole integer increments on the Borg 6-20 scale, and that as such the CR-10 may be more appropriate for measuring localised muscle sensation during strength training (Buckley & Borg, 2011). As such, the 0.5 increments were added to the IES. Looking forward to possible prescription using RPE, the increased number of points on the scale would allow for larger RPE target ranges to be given, which in turn may make it easier for participants to stay within the required zone.

The wording used on the scale was modified from the Borg 6-20 scale, which has been shown to be an accurate measure of RPE and physiological exertion during aerobic (Chen et al., 2002) and resistance exercise (Springer & Pincivero, 2010; Tiggemann et al., 2010). The wording on the Borg 6-20 Scale, displays symmetry around the central point of the scale, with for example 'Very Light' (9) mirroring 'Very Hard' (17) and 'light' (11) mirroring 'Hard' (15). This symmetry of the wording around a central 'moderate' rating would help to reinforce the ratio properties of rank-order and equal intervals between points on the IES. Evidence for the ratio properties of the Borg 6-20 scale is shown in the linear relationships that have been demonstrated between Borg 6-20 RPE and exercise intensity (Springer & Pincivero, 2010; Tiggemann et al., 2010) and HR (Borg, 1998; Chen et al., 2002). This quality is desirable in a scale designed for isometric exercise, as linear relationships have been demonstrated between isometric exercise intensity and HR (Goldring et al., 2014).

The Time to Failure (TTF) part of the IES, was based on various scales in use that asked the participant to estimate the number of repetitions or time before failure at a set workload. The repetitions in reserve (RIR) and estimates percentage of maximum number of repetitions (MNR) scales had both been shown to accurately measure RPE and intensity during resistance exercise (Hackett et al., 2012; Testa et al., 2012 respectively). While these studies and scales show the potential of participants to estimate their remaining capacity, the estimation of repetitions is not directly relevant for isometric contractions. The Estimated Time Limit (ETL) scale was designed and validated for aerobic exercise (Garcin et al., 1999; 2003), with a non-linear design to allow good correlation with blood lactate (Garcin et al., 1999). The non-linear design was not desirable for the IES, additionally, the ETL used arbitrary timings on the scale; for example, 19 on the scale was equal to 2-minutes estimated time remaining. Having suggested timings of this nature on the scale would require that there would be isometric intensities that would cause the participant to immediately start at an RPE of 19/20, i.e. if the contraction would last less than 2 minutes. Whereas, it was deemed that for isometric contractions all participants should start at rest

and then move up through the ratings, with the speed at which this happens changing with exercise intensity rather than the start point changing. This would allow the scale to match the response of HR from resting to maximal during such contractions. Shepherd et al. (2013) used the perceived task duration scale, a simple 10cm line, with the cues 'start' and 'finish' at each end. In the manner suggested above, this allows the same scale to be used for any intensity, with the participant able to adjust the speed at which they move along the line to represent the intensity of the exercise. From marks made on the scale, the perceived percentage of total task duration at different time points was correlated with the actual percentage of task duration, showing extremely strong validity (r = 0.99). Modified from this concept, the TTF a percentage scale, starting at 100% capacity (at rest) and finishing at 0% capacity (at failure), was added to the IES.

3.6.2 CR-10 scale

The Borg CR-10 scale (Figure 3.8) was also used to measure perceived exertion in the active muscles, in study 2. As with the IES, participants were given standardised instructions and anchoring examples prior to each exercise test, as previously published in Borg's work (Borg, 1998). The standardised instructions were as follows:

"You will use this scale to tell how strong the perception of exertion is in your leg muscles. As you can see, the scale stretches from 'nothing at all' to 'absolute maximum'. 'Extremely strong – Max P' (10) is such an extremely strong perception of exertion that it is the strongest exertion you have ever experienced. Therefore, 'absolute maximum – Highest possible' level, is placed somewhat farther down the scale without a fixed number and marked with a '•'. If you should perceive an intensity to be stronger than 10, 'Extremely strong – Max P', you may use numbers on the scale above 10, such 11, 12, or even higher. 'Extremely weak', corresponding to 0.5 on the scale, is something just noticeable, i.e., something that is on the boundary of what is possible to perceive.

You use the scale in the following way: Always start by looking at the verbal expressions. Then choose a number. If your perception corresponds to 'very weak', you say 1. If it is 'moderate', you say 3, and so on. You may use whatever numbers you want, also half values, such as 1.5 or 2.5, or decimals, e.g., 0.3, 0.8, 5.6 or 11.5. It is very important that you answer what ***you*** *perceive and not what you believe you ought to answer. Be as honest as possible and try not to overestimate or underestimate the intensities. Remember to start by looking at the verbal expressions before every rating, then give a number."*

Rating	Description	
0	Nothing at all	"No Pain"
0.3		
0.5	Extremely weak	Just noticeable
1	Very weak	
1.5		
2	Weak	Light
2.5		
3	Moderate	
4		
5	Strong	Heavy
6		
7	Very Strong	
8		
9		
10	Extremely Strong	"Max Pain"
11		
ǂ		
•	Absolute maximum	Highest possible

Figure 3.8: Borg's CR-10 Scale

3.7 Isometric wall squat testing and training

The isometric wall squat exercise used throughout this thesis was based on previously validated protocols used for the reduction of arterial BP (Wiles et al., 2017). The current protocol requires an incremental isometric wall squat test (IIWST; Wiles et al., 2017), which was then used to calculate and prescribe an isometric workload based on the relationship shown between knee joint angle and HR during IWS exercise (Goldring et al., 2014). The prescribed isometric workload was then used in a 4-week IWS programme, involving 12 exercise sessions (3 per week), that has been shown to significantly reduce resting blood pressure (Wiles et al., 2017). Study 2 (Chapter 4) examined the validity and reliability of RPE during the maximal incremental wall squat test; study 3 (Chapter 5) explored the relationships between RPE, knee joint angle, HR and BP, based on the work of Goldring et al. (2014); study 4 (Chapter 6) examined the validity and reliability of RPE during the first week (3 sessions) of unsupervised home-based IWS training; and study 5 (Chapter 7), based on the findings of the previous studies, compared the effects of an RPE prescribed 4-week IWS programme with the current HR prescribed 4-week IWS programme by Wiles et al. (2017).

3.7.1 Measuring knee joint angle

During wall squat testing it was necessary to accurately control the workload via knee joint angle. The internal knee joint angle between the femur and fibula was measured, to the nearest 1-degree, using a clinical long arm goniometer (MIE Medical Research Ltd, Leeds, UK). Measurements were recorded with approximately 180-degrees representing a fully extended knee joint. The goniometer was made of clear plastic, with 2 mounted arms (one stationary and one moveable), that rotate around a central pivot and 360º measurement gauge. Measurement of knee joint angle, using this style of device, has been shown to be accurate and reliable in a clinical setting (Enwemeka, 1986; Gogia et al., 1987; Watkins et

al., 1991), with greater accuracy than short arm goniometry or use of a mobile phone app (Hancock et al., 2018). Additionally, this style of device has previously been used to accurately quantify knee joint angle during squatting (Youdas et al., 2007).

Participants were instructed to wear shorts to all laboratory testing sessions, to allow the required bony landmarks to be accurately located, and the goniometer to be fitted correctly. Any loose clothing was adjusted and secured as necessary to allow palpation of the ankle, knee and hip. To fit the device, the participant was seated with their knee at a 90-degree angle. The goniometer was fitted to the lateral side of the left leg, with the fulcrum in line with the lateral epicondyle of the femur (Figure 3.9). The stationary arm of the goniometer was aligned with the limb that would move least, while the moving arm was positioned with the limb that would move the most (Dutton, 2012); therefore, the stationary arm of the goniometer was positioned on the lower limb in line with the left lateral malleolus, and the moving arm was positioned on the upper leg in line with the greater trochanter of the femur. The stationary arm of the goniometer was fitted with a spirit level, to aid in achieving a vertical lower leg during the wall squat. Four elastic Velcro straps were used to secure the goniometer to the leg, two on each arm of the goniometer. The straps were carefully attached so that they did not excessively squeeze the muscles or occlude blood flow. The goniometer was checked and adjusted with each change in knee angle, to ensure it remained in the correct position for accurate knee joint measurement.

Figure 3.9: Goniometry of the knee joint.

3.7.2 Incremental isometric wall squat test

Following the protocol first described by Wiles et al. (2017), the IIWST required participants to complete five consecutive 2-minute stages, beginning at a knee joint angle of 135° and reducing every

2 min by 10° (125°, 115°, 105°, and 95°; Figure 3.10). Participants were required to squat with their back against a fixed wall, feet flat on the floor, while maintaining a vertical lower leg and an erect trunk. On completion of a 2-minute stage, participants were instructed to slowly move their back down the wall and then move their feet out slightly, until the required knee joint angle was reached, and the lower leg was once again in a vertical position. Knee joint angle was measured and controlled using a clinical goniometer (as in Section 3.7.1) throughout the movement, with palpation of the bony landmarks to ensure correct alignment of the goniometer.

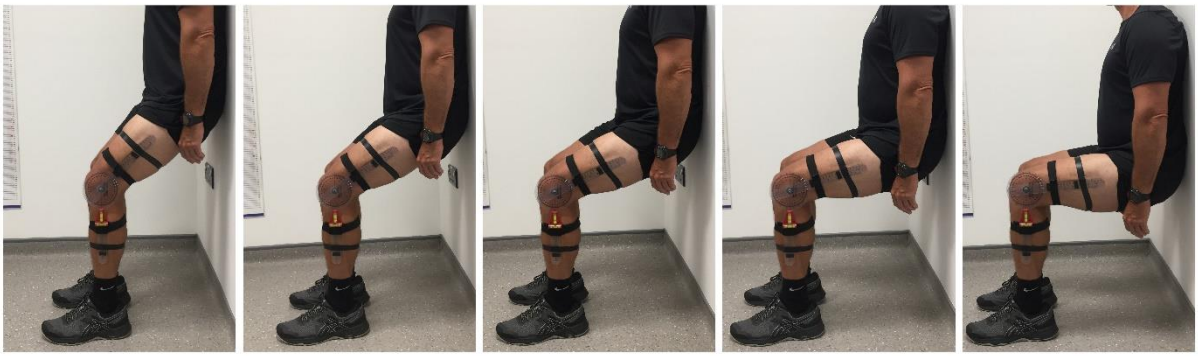


Figure 3.10: The Incremental Isometric Wall Squat Test (IIWST) knee joint angles displayed in order from 135˚, 125˚, 115˚, 105˚, 95˚ (left to right).

The participant's foot position and squat height were measured immediately following a change in knee angle. Foot position was measured from the back of the left heel to the wall, and back position was measured as the distance from the ground to the lower back, which was defined as the lowest point of contact that the participants back had with the wall (Figure 3.11). These measurements were used to ensure consistency where participants were required to complete more than one incremental test, and to calculate the IWS position for participants who were required to complete home-based training (Section 3.7.4).

Participants were not permitted to stand or rest between angles. The test continued until volitional exhaustion, the participant was unable to maintain the required knee angle, or completion of the full 10-minute test. Participants were monitored for signs of physical distress throughout the test and were instructed to terminate the exercise at the first signs of dizziness or feeling unwell. Verbal encouragement was given throughout, with instructions to maintain normal breathing to avoid the Valsalva manoeuvre (MacDougall et al., 1985). Heart rate and BP were recorded continuously during the test; mean HR and BP (SBP, DBP and MAP) were calculated for the last 5 seconds of each minute of the test. Similarly, RPE was recorded at the end of each minute of the test.

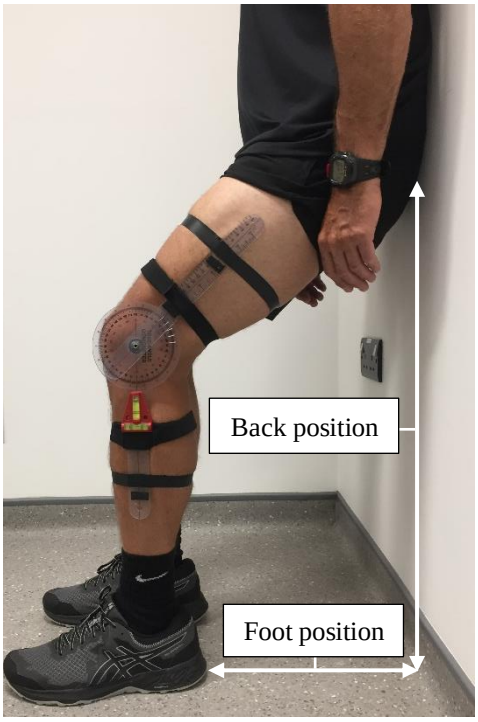


Figure 3.11: Measurement of the isometric wall squat foot and back positions.

3.7.3 IWS intensity prescription

Following completion of the incremental test, HR data from the final 30-seconds of each stage of the test was used to calculate the training knee joint angle. To do this, knee joint angle was plotted against the mean HR data for the last 30-seconds of each stage. This relationship was then analysed using linear regression analysis or one-phase exponential decay model, for linear or non-linear relationships respectively. Previous research has shown that a 4-week IWS intervention prescribed at 95% of HRpeak (defined as the mean HR for the last 30-seconds of the test) can induce significant reductions in resting arterial BP (Devereux et al., 2010; Wiles et al., 2010). Therefore, the equation for the relationship between HR and knee joint angle was used to predict the knee angle required to elicit 95% of HR peak. Once the training knee angle had been calculated, the linear relationships between knee angle, squat height and foot distance, were used to calculate the required distances.

To help monitor the training intensity, a target HR range (THRR) was calculated for each participant. The THRR was calculated from the 95% peak HR value, using a modified limits of agreement equation (Hopkins, 2000; Wiles et al., 2017).

3.7.4 Bend and Squat

During home-based training, direct measurement of knee angle with goniometry was not practical, as user error could easily lead to the participant exercising at an intensity that was either too easy or too hard. Additionally, measurement with this sort of device would require the help of an additional person to take the measurements while the participant was squatting, which may be prohibitive for some

participants. Therefore, the Bend and Squat device (Figure 3.12) was created to allow control of the wall squat position and workload during home-based training.

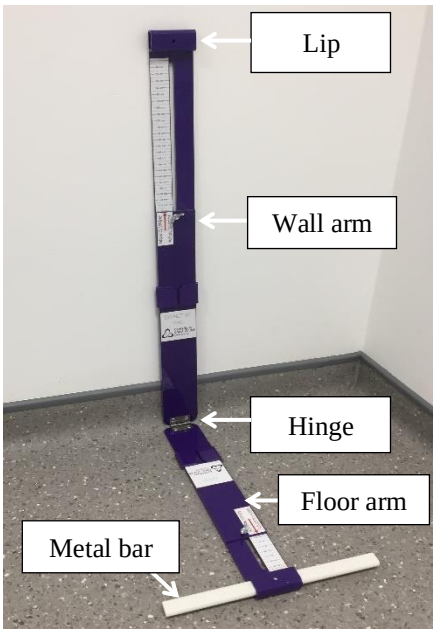


Figure 3.12: The Bend and Squat device

The Bend and Squat has two adjustable arms, that can be set at different lengths to set the correct squat height and foot distance. These dimensions were calculated using the linear relationships shown between squat height, foot distance and knee angle (Section 3.7.3).

Participants were instructed to position their feet shoulder width apart, with their heels against the metal bar attached through the floor arm; then to lower themselves down the wall until they feel the Bend and Squat on the first contact with their back, but that they should not rest their weight or sit on the device.

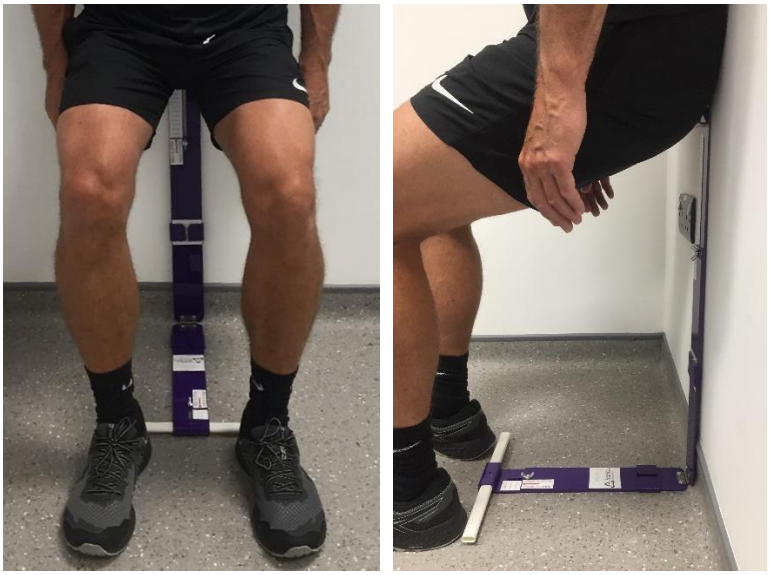


Figure 3.13: The Bend and Squat device in use during isometric wall squat exercise.

3.7.5 Home-based wall squat training

The current home-based isometric wall squat training protocols, as outlined in Wiles et al. (2017), were used in Study 4 (Chapter 6) and by the HR prescribed intervention group in Study 5 (Chapter 7). These home-based interventions were 4-weeks in duration, consisting of 3 sessions per week, separated by a minimum of 48 hours (12 sessions in total). Each exercise session was a total of 14-minutes long, consisting of four 2-minute isometric wall squat holds, separated by 2-minute rest intervals (Figure 3.14).

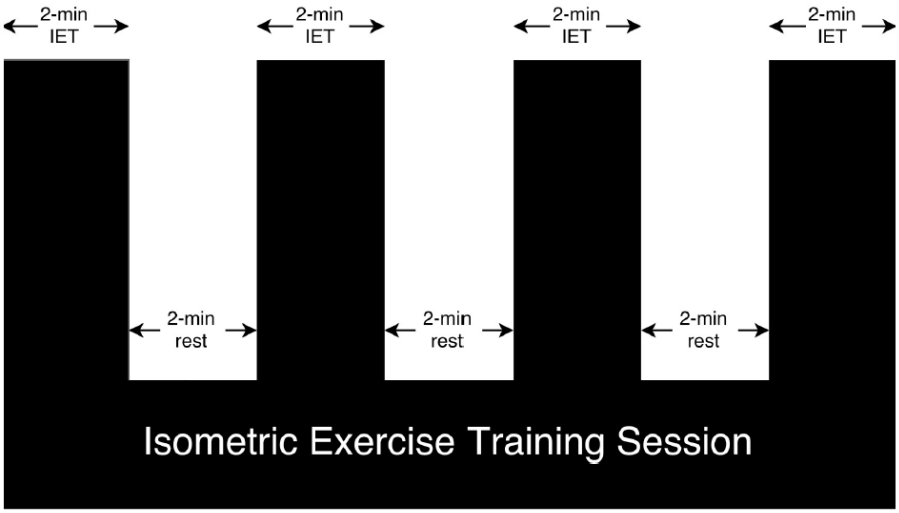


Figure 3.14: Schematic of the isometric wall squat training session (Taylor et al., 2017b)

The squat technique for the 2-minute isometric squat bouts was the same as during the IIWST, with the back against a fixed wall, feet flat on the floor, maintaining a vertical lower leg and an erect trunk. However, during IE training, knee angle remained constant throughout the session and the Bend and Squat was used to set the individually prescribed knee joint angle, via control of the squat height and foot distance (Section 3.7.4).

Prior to starting the home-based training, participants were given a full explanation of the training procedures and received a training manual (Appendix 4), with the full study outline, procedures, safety information and data entry sheets. Participants were informed of their training squat height and foot distance, based on the incremental test (Section 3.7.3), and were shown how to use and adjust the Bend and Squat to the correct dimensions. Before the participants were sent home to complete the IWS training programme, the Bend and Squat was set to the correct height and foot distance and the knee joint angle produced was manually checked using a goniometer.

During the training sessions, HR was continuously recorded using the Polar HRM (Section 3.5.4), additionally, participants were required to record the HR and RPE at the end of each 2-minute exercise bout. The recorded training data was sent to the lead researcher at the end of each training session, via

email, text, or picture message, so that training intensity and compliance with the training intervention could be monitored. All participants were given a target HR training zone (Section 3.7.3) for the IWS sessions. If the mean self-reported HR for two consecutive sessions fell outside of this training zone, then the participant was asked to attend the laboratory to repeat the maximal incremental test, so that the training intensity could be re-calculated.

3.8 General statistics

All statistical analyses were performed using IBM SPSS versions 22-24 (IBM SPSS for Windows, Armonk, NY). Before analysis, all data were checked for conformity with the parametric assumptions (Field, 2009).

Where parametric assumptions were met, difference testing was conducted using two-way analysis of variance (ANOVA) with post-hoc t-tests. Where parametric assumptions were not met, Friedman's tests with post-hoc Wilcoxon signed rank tests were used. All pots-hoc tests were completed using a Bonferroni adjustment for multiple comparisons, to reduce the risk of type 1 error.

Relationships and validity coefficients were calculated using; Pearson's product-moment correlations (parametric data), Spearman's rank-order correlation (non-parametric data), and/or simple linear regression analysis. Any non-linear relationships were explored through a one-phase exponential decay model using GraphPad Prism version 8 (GraphPad Software, San Diego, CA).

Between-session reliability was assessed using: 1. Difference testing (as described above) to test for significant changes in results between sessions; 2. Intraclass Correlation Coefficients (ICC 3,1) to assess agreement between sessions; and 3. Coefficients of Variation (CoV) to assess within-participant variance. Between session differences in ICC and CoV results were considered significant if the mean results for either session lay outside of the 95% confidence interval of the other.

All data are presented as mean ± standard deviation, unless otherwise stated. An alpha level < 0.05 was set as the threshold for statistical significance. Detailed descriptions of data analysis procedures are given within the specific chapters.

CHAPTER 4:

Study 2 -

Validity and Reliability of RPE during Continuous Incremental Isometric Wall Squat Exercise

Work from this chapter was presented at the British Association of Sport and Exercise Sciences Annual Conference (Lea, O'Driscoll & Wiles, 2017) and was published in Scientific Reports (Lea, O'Driscoll, Coleman & Wiles, 2021a).

4.1 Introduction

Isometric exercise (IE) interventions have consistently been shown to be an effective and time efficient means of reducing resting blood pressure (Wiles et al., 2010; Cornelissen & Smart, 2013; Devereux et al., 2015). However, the previous methods of administering IE training and monitoring its intensity have tended to require specialist equipment that is not commonly owned by the general public, requires expertise to use, and is often prohibitively expensive; for example, isokinetic dynamometers (Devereux et al., 2010; Wiles et al., 2010; Baross et al., 2012), handgrip dynamometers (McGowan et al., 2007) and electromyography (EMG; Devereux et al., 2015). It has been suggested that the need for expensive equipment and time-consuming testing protocols, may present unnecessary barriers that could ultimately limit the effectiveness of these interventions in a wider public setting (Millar et al., 2009b). Consequently, more accessible modes of IE training that could be implemented in the home have been explored. One such intervention, is the use of the isometric wall squat (IWS) exercise, where intensity is controlled by manipulation of the knee joint angle (Goldring et al., 2014). This new home-based IWS intervention represented a significant step forward in the accessibility of IE interventions, while allowing access to the potentially greater benefits of lower limb isometrics (Smolander et al., 1998). However, IWS interventions still have several significant limitations, as a consequence of the methods used to accurately prescribe and monitor exercise intensity (EI). These include the need for; a trained researcher/exercise professional to orchestrate the intervention via maximal exercise testing and uncommon equipment, such as the Bend and Squat device, to control and monitor knee angle. The control of exercise intensity is a key to ensure the safety and efficacy of physical activity in any context, including athletic, recreational, and therapeutic settings (Robertson et al., 2004); therefore, it would be desirable to find methods to accurately control IE intensity, without presenting barriers to participants, that could ultimately reduce uptake, adherence and thus the effectiveness of the intervention as a whole.

Ratings of perceived exertion (RPE) could provide an easy to use and accessible alternative means of assessing, monitoring, and prescribing exercise intensity (Colado et al., 2014). Indeed, it has long been established that RPE provides an accurate estimation of exercise intensity and physiological exertion during cardiovascular exercise (Chen et al., 2002). In addition, there is now a growing body of evidence that indicates that various RPE scales provide a valid measure of exercise intensity during resistance exercise, including the Borg 6-20 (Lagally et al., 2004), OMNI-RES (Aniceto et al., 2015), and the Borg CR-10 (Buckley & Borg, 2011) scales. During isometric exercise, RPE has shown large effect sizes when correlated with workload of $r = 0.92$ (Li & Yu, 2011), $r = 0.52$ (Rudroff et al., 2011), and $r = 0.995$ (Lampropoulou & Nowicky, 2012). Likewise, large effect sizes were recorded when RPE was correlated to EMG, during isometric exercise; $r = 0.76$ (Hummel et al., 2005), $r = 0.99$ (Troiano et al., 2008), and $r = 0.995$ (Lampropoulou & Nowicky, 2012).

While there is a growing body of evidence for the use of RPE during resistance, and more specifically during isometric exercise, at the time of the start of this research project, no RPE scale had been designed specifically and validated for use during IWS exercise. Indeed, it has been suggested that it is important to design and validate scales for specific populations, exercise types and modalities (Colado et al., 2014), and that caution should be taken when using RPE scales with modalities and materials other than those they have been validated for (Robertson et al., 2003). Moreover, Borg (1998) suggested that it is important to study the relationships between RPE and concurrent measures of physiological exertion and performance (EI), for each specific situation, scale, exercise, and population, in order to integrate this data into the models used. Therefore, before RPE can be used to prescribe and monitor IWS interventions, it must be validated for this mode of exercise.

The Borg CR-10 scale has been the most commonly used RPE scale in isometric research, including previous isometric wall squat research (Wiles et al., 2010). The CR-10 was originally intended for rating pain/muscle discomfort, with no numerical ceiling effect (Borg, 1998). Therefore, the CR-10 was produced with an open-ended design, that would allow the participants to recalibrate the meaning of '10 - Max Pain', based on their previous greatest experience (Borg, 1998). In an exercise setting, where the average participant's understanding of RPE is likely to be limited, the open-ended nature of the CR-10 scale be more confusing and therefore harder to use. Additionally, the possible recalibration of the RPE values, based on a new maximum score, may reduce the reliability of RPE during the first sessions of an intervention, making prescription and control of EI more difficult. Furthermore, the CR-10 was designed with smaller intervals at the lower end of the scale (i.e., 0, 0.3, 0.5, 1) and integer intervals at the top end (i.e., 8, 9, 10). This was done to allow the CR-10 scale to better correlate with variables that show an exponential relationship with EI, such as blood lactate (Borg, 1998). This could be a disadvantage during IWS exercise, where the linear relationship between HR and EI is used to prescribe and monitor intensity.

Despite these possible limitations, the CR-10 has been shown to be a valid measure of resistance exercise intensity (Desgorces et al., 2015), and thus as the current standard RPE measure during IE training (Wiles et al., 2017); thus, it was used in this current study to validate RPE during IWS exercise. However, with these limitations in mind, it was not enough to assume that the CR-10 would provide the most accurate measure of RPE during IE. Therefore, it was decided that a second scale should be used, as a comparison to the CR-10. Rather than selecting one of the various other un-validated RPE scales available, it was decided that collating features from previous scales, that were potentially beneficial for isometric exercise, could be advantageous. As such, the IES was developed for validation alongside the CR-10 (Section 3.6.1.1, Page 72).

Therefore, the aim of this research was to assess the efficacy of RPE, using the CR-10 and IES, during the incremental isometric wall squat test (IIWST), with the following objectives:

(1) To examine the validity of RPE, from both scales, to measure changes in isometric wall squat intensity during the continuous incremental test.

(2) To explore the concurrent validity of both scales using criterion measures of physiological exertion (HR and BP).

(3) To quantify any differences in the results from the CR-10 scale and the isometric exercise scale (IES).

(4) To assess the reliability of the RPE responses from each scale over time.

4.2 Methods

4.2.1 Participant information

Twenty-nine males, 19 normotensive and 10 prehypertensive, completed this study (age: 23.2 ± 4.0 years; stature: 180.9 ± 7.8 cm; body mass: 82.7 ± 17.3 kg; BMI: 25.2 ± 4.5). Thirty-two participants volunteered to take part in this study in total, with 3 participants withdrawing due to changes in life commitments. All participants were non-smokers (≥ 6-months), with no injury or illness, including no clinical diagnosis of any cardiovascular condition or dysfunction, and were taking no medication that could affect exercise performance or cardiovascular function. All participants met the study's participant inclusion (Section 3.4.1, Page 62) and health status was assessed using a self-reported health screen and exercise readiness questionnaire (Appendix 2). Participants gave verbal confirmation that they had followed all pre-testing instructions (Section 3.4.3, Page 63), at the start of each session. If they had not followed the instructions, the session was re-scheduled.

BP has been shown to be greatly affected by the menstrual cycle (Dunne et al., 1991; Sato et al., 1995). As completion of 4 testing sessions was required over a maximum span of 1-month, it was guaranteed that participants would be tested at different stages of the menstrual cycle, thus results would be affected. It has also been suggested that there are sex differences in RPE (Koltyn et al., 2001; Chen et al., 2002; O'Connor et al., 2002; Troiano et al., 2008) and BP (Koltyn et al., 2001; Cornelissen et al., 2013; Inder et al., 2016) responses to exercise; consequently, to date the isometric wall squat protocols have only been tested on male participants (Goldring et al., 2014). Therefore, to eliminate additional intra- and inter-participants variance, females were excluded from this study.

4.2.2 Sample size calculation

A-priori sample size calculation was conducted using GPower (Version 3.1, University of Düsseldorf). Two separate sample size calculations were completed: The first was for correlation testing of RPE ratings with squat duration, HR and BP. The second was for analysis of variance (ANOVA) to assess differences in resting measurements of HR and BP between the 4 testing sessions. For both calculations the alpha level was set at $p < 0.05$, power was set at 0.8 (Cohen, 2013) and a medium effect size (Faul et al., 2007) was selected. The results of the analyses showed that a minimum sample sizes of $n = 29$ and $n = 24$ were recommended for the correlation and ANOVA respectively; consequently, a target sample size of $n \geq 29$ participants was set for this study. Due to recruitment and laboratory space logistics, not all participants were able to start the study at the same time; therefore, participants were recruited to fill any drop out positions until the minimum sample size had completed the study.

4.2.3 Study design

This study used a repeated measures design, where each participant was required to attend the laboratory on 4 separate occasions. These sessions were separated by a minimum of 48 hours and a maximum of

7 days. Each session followed the same procedures, starting with resting measurements before completion of an IIWST. Where possible, all testing sessions were completed at the same time of day to limit the effects of circadian rhythm on resting cardiovascular values. This study was approved by Canterbury Christ Church University's Ethics Committee (15/SAS/223) and conducted according to the Declaration of Helsinki.

4.2.4 Experimental procedures

4.2.4.1 Familiarisation

Prior to the first testing session participants received an information pack outlining the testing protocols and measurement procedures included in the study. At the start of the first laboratory session participants had the study design, resting and exercise measurements, and exercise protocols explained to them verbally. As part of this explanation, participants were shown the equipment that would be used and were given a demonstration of the wall squat, including the correct wall squat technique. Finally, participants were shown the RPE scales and received the standardised instructions and anchoring (Section 3.6, Page 71). Following this, if the participant agreed to take part in the study, written informed consent was collected and resting measurements were taken.

At the start of each subsequent session, during the seated resting period, participants received an explanation of the IWST protocol, wall squat position, and RPE instruction, as in the first session.

4.2.4.2 Resting measures

Upon arrival to the laboratory, participants rested in a seated position for 10 minutes. After 10 minutes rest, HR, systolic BP (SBP), diastolic BP (DBP) and mean arterial pressure (MAP) were recorded using an oscillometric BP monitor on the participants left arm (Dinamap® Pro, GEMedical Systems, Slough, UK), as in section 3.5.2, Page 64. Three measurements were taken with 60 seconds rest in-between; however, if differences between the consecutive measurements exceeded 5 mmHg, then an additional measurement was taken (Pickering et al., 2005). The mean result for each variable was calculated for analysis.

Following the seated measurements, participants were attached to the TFM (CNSystems, Graz, Austria) and then rested in a supine position for 15-minutes. After an initial 10-minute quiet rest period, continuous measurements of HR and BP were collected for a further 5 minutes (Section 3.5.3, Page 66). The average results for this 5-minute period were used to categorise the participant's resting HR and BP status in the descriptive data.

Resting measurements were collected in a quiet room with the lights dimmed. Participants were instructed not to talk and to remain as still as possible throughout this period.

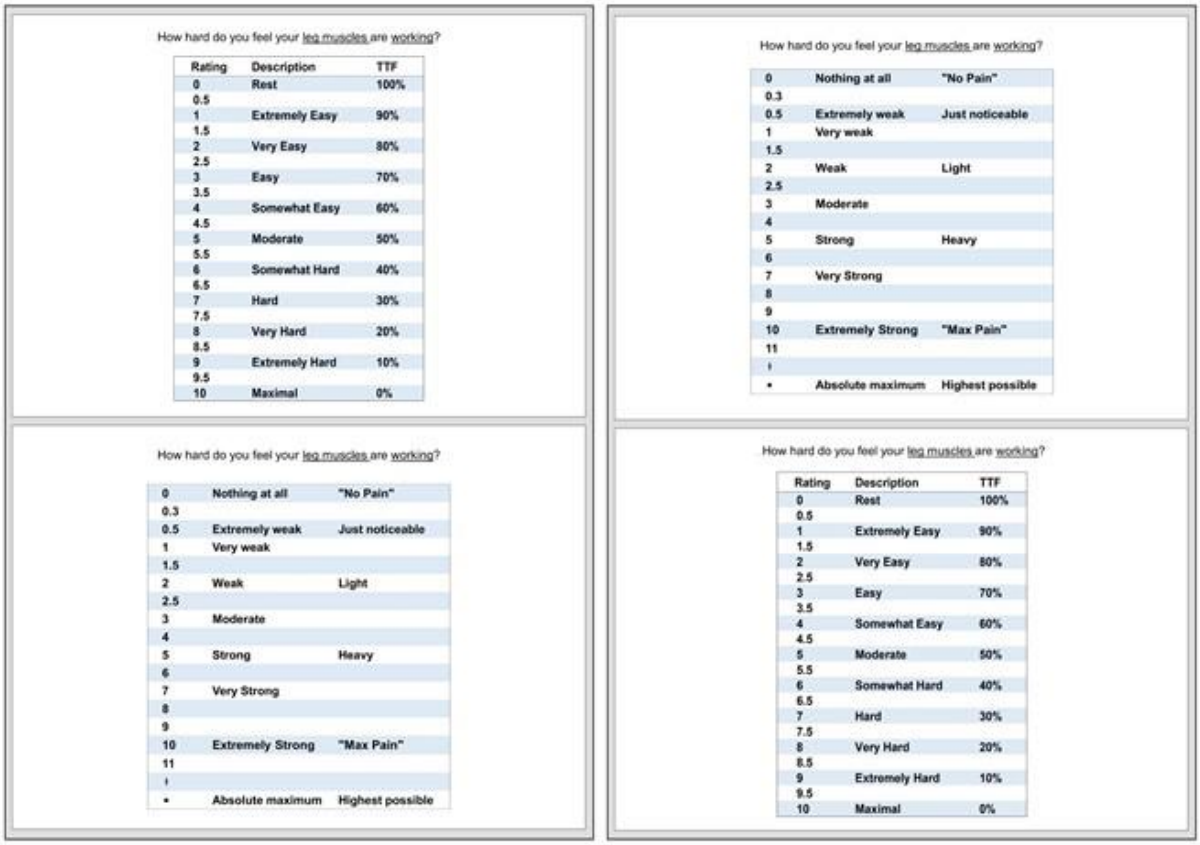
4.2.4.3 Incremental isometric wall squat test protocol

Following completion of the supine resting measurements, the participants remained connected to the TFM and were moved slowly into a seated position. While the participants continued to rest, the RPE scale instructions were given for a final time, and the participant was asked to rate their current RPE score on both scales (expected to be zero on each).

The participants then completed the IIWST (Section 3.7.2), starting at a knee joint angle of 135° and reducing every 2 minutes by 10° (125°, 115°, 105°, and 95°), with no rest between stages. During the first session, knee joint angle was monitored and controlled using a clinical goniometer (Section 3.7.1, Page 48). In subsequent sessions, the squat height and foot distance were controlled using measurements taken during the first session (Section 3.7.2, Page 76), with the use of the goniometer to confirm knee angle. Heart rate and BP were monitored continuously using the TFM and RPE was collected each minute. The test continued until volitional exhaustion, the participant was unable to maintain the required knee angle (within 5º of target value), or completion of the full 10-minute test.

4.2.4.4 Ratings of perceived exertion

Participants were asked to rate their perceived exertion, at 50 and 110 seconds into each stage, using the IES and Borg's CR-10 scales. The scales were arranged in two formats, with one scale above the other (Figure 4.1). The scales were presented in this way, rather than side-by-side, to avoid participants finding a rating on the first scales and then moving sideways to the corresponding value on the second scale, without consideration of the differences in the two values. To eliminate the risk of bias, participants were randomly assigned into one of two groups; group one was presented with RPE format 1 (IES above CR-10), while group two was presented with format 2 (CR-10 above IES).



Format 1 Format 2

Figure 4.1: RPE scales presentation formats

4.2.4.5 Anthropometric measurements

Participant stature and body mass were measured at the end of each session, in minimal clothing and with bare feet. Body Mass Index was calculated for each participant using these measurements (Section 3.5.1, Page 64).

4.2.5 Data analysis

The mean resting HR and BP results, collected at the start of each session, were assessed for statistical differences between the 4 sessions. As the mean HR measurements for sessions 2-4 were not normally distributed, differences between the sessions were assessed using Friedman's related-samples analysis of variance. The mean results for each BP variable were normally distributed, across all 4 sessions, therefore differences were assessed using one-way repeated-measures ANOVAs.

The concurrent validity of each scale to represent changes in the criterion measures: exercise intensity, HR, and BP, was assessed using Spearman's rank-order correlations. Linear regression analysis was also used to produce prediction equations for RPE based on each criterion measure. Exercise intensity was represented by wall squat duration, which in this case represented an increase in time under tension and workload (knee joint angle). As the absolute values achieved for wall squat duration, HR and BP differed between participants, relative values were calculated as a percentage of the peak score for each

variable achieved by that participant across the 4 sessions. To test for differences in concurrent validity, between the IES and CR-10 scales, validity coefficients underwent Fishers Z score transformation, followed by statistical analysis for differences in the Z-Scores (Meng et al., 1992).

To assess whether there were any differences in the results obtained from each RPE scale, the results from each scale were correlated using Spearman's rank-order correlation and linear regression analysis. Additionally, a two-factor (Scale x Intensity) repeated measures Friedman's ANOVA, with post hoc testing, was used to explore any differences in RPE results at the different exercise intensities. RPE was collect twice during each stage (knee angle) of the test, at the end (last 10 seconds) of the first and second minutes. Therefore, 'peak' RPE was defined as the RPE score given at the end of the second minute of a stage, and 'stage average' RPE was calculated as the mean of both RPE measurements taken at each stage. Differences were assessed in both the stage average and peak RPE results.

Reliability of the IES, CR-10, HR and BP results across the 4 testing sessions were examined separately using: Two-factor (Session x Intensity) repeated measures ANOVA's or Friedman's test (normal distribution dependant); Intraclass Correlation Coefficients (ICC); and Coefficient of Variations (CoV). For the difference tests, the 'Session' factor had 4 levels (testing sessions 1-4), and the 'Intensity' factor had 5 levels (knee angle - 135°, 125°, 115°, 105° & 95°). Where main effects were found, post-hoc testing was conducted with Bonferroni adjustment for multiple comparisons. The ICC (3,1) model was used to assess the agreement between the repeated measures taken during consecutive sessions. Within-participant variance was calculated as CoVs with 95% confidence intervals (CI), derived from log-transformed two-way ANOVA for each variable. ICC and CoV results, for the IES and CR-10 scales, were considered to be significantly different if the mean results for each scale lay outside of the 95% confidence interval of the other.

4.3 Results

4.3.1 Resting data

The mean resting values, across the 4 sessions, for HR, SBP, DBP and MAP were 61 ± 8 b·min^{-1}, 109 ± 7 mmHg, 63 ± 5 mmHg, and 80 ± 6 mmHg respectively. There were no significant differences in any resting measures between trials ($P > 0.05$). The ICC results for the resting measures ranged from r = 0.52 to 0.91. Coefficients of Variation (with 95% CI) were 4.0% (3.5-4.9%) for resting HR, 2.9% (2.5-3.5%) for SBP, 6.2% (5.3-7.6%) for DBP, and 4.2% (3.6-5.1%) for MAP.

4.3.2 Exercise intensity

The validity of the IES and CR-10 to represent isometric exercise intensity was assessed by correlating the RPE ratings against relative exercise intensity (workload x wall squat duration). Strong positive correlations were shown for the IES ($r = 0.89$, $P < 0.001$) and CR-10 ($r = 0.88$, $P < 0.001$) with exercise intensity (Figure 4.2).

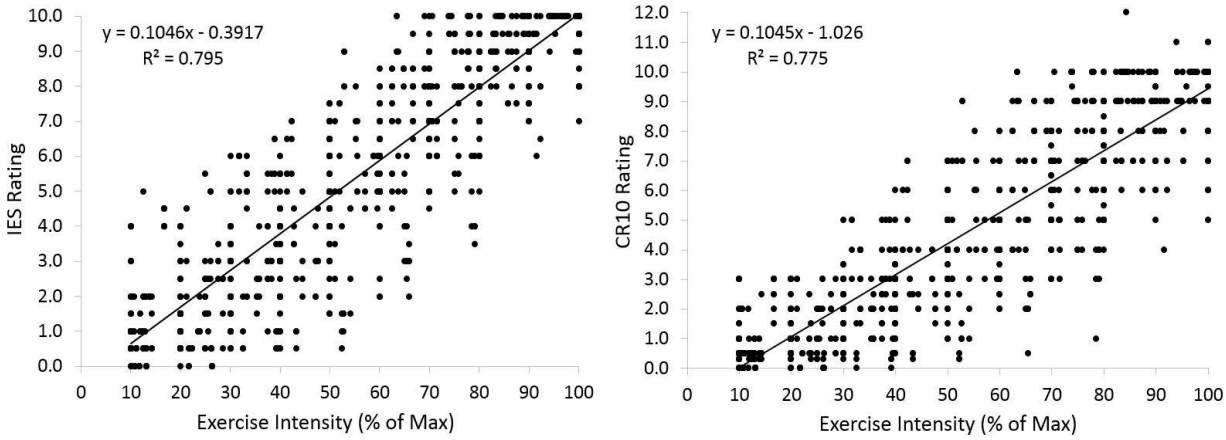


Figure 4.2: The relationships of the IES and CR-10 ratings with isometric exercise intensity (as a percentage of maximum)

4.3.3 Physiological exertion

Significant positive relationships were found when correlating the physiological measures of exercise intensity: HR ($r = 0.82$ & $r = 0.81$, $P < 0.001$), SBP ($r = 0.84$ & $r = 0.84$, $P < 0.001$), DBP ($r = 0.81$ & $r = 0.80$, $P < 0.001$), and MAP ($r = 0.84$ & $r = 0.83$, $P < 0.001$) with RPE ratings from the IES and CR-10 respectively (Figure 4.3).

Significant linear regression equations ($P < 0.001$) were produced between all physiological variables and both RPE scales (Figure 4.3). The regression equations for the IES and CR-10 scales based on HR results, show that RPE values of 8.4 and 7.8 correspond to 95% HR peak, for the IES and CR-10 respectively.

Analysis of the Z-score transformed validity coefficients showed no significant differences in the relationships between each RPE scale and HR (P = 0.345), SBP (P = 0.469), DBP (P = 0.416), MAP (P = 0.424), or wall squat duration (P = 0.356).

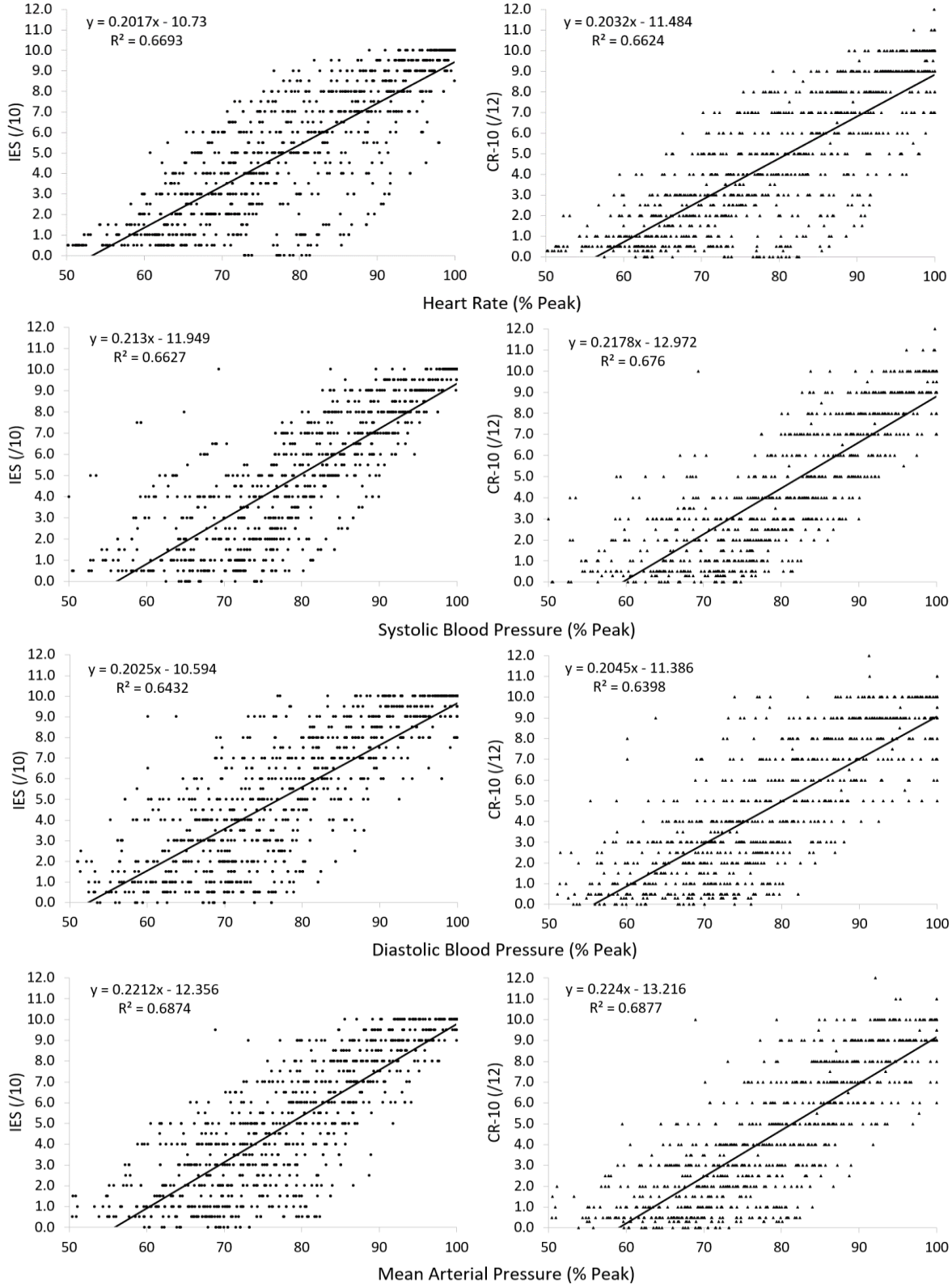


Figure 4.3: The relationships of the IES and CR-10 ratings with the physiological measures of exercise intensity
Peak – The maximum values achieved across the 4 testing sessions

4.3.4 Comparison of RPE scale results

Spearman's rank-order correlation showed a strong positive linear relationship ($r = 0.97$, $P < 0.001$) between the CR-10 and IES ratings of exertion. Likewise, linear regression analysis to assess the ability of the CR-10 results to predict the IES results, showed a significant ($p < 0.001$) linear regression equation with an r value of 0.97 (Figure 4.4).

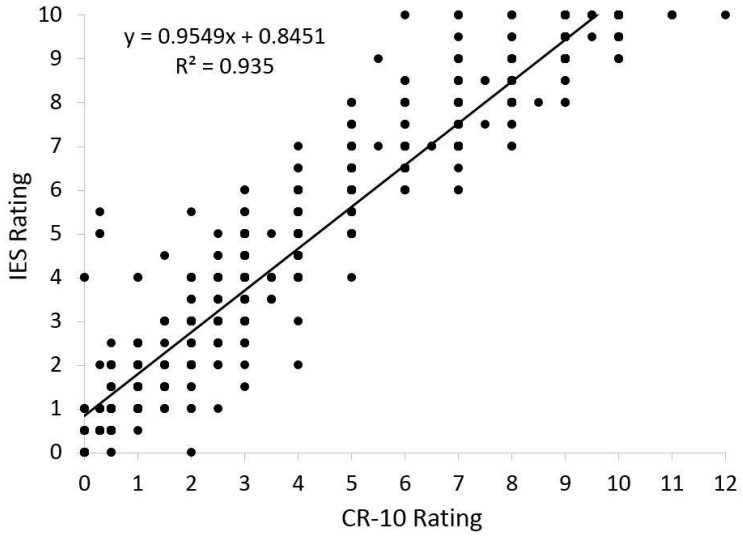


Figure 4.4: The relationship between the IES and CR-10 ratings of perceived exertion

Friedman's two-way analysis of variance revealed main effects for scale and knee angle, for both peak and stage average RPE measurements ($P < 0.001$). Post hoc testing revealed significant increase ($P < 0.001$) in RPE with each consecutive increase in wall squat workload (reduction in knee angle), for both scales and measurement types. Additionally, the results from the IES were significantly higher than the CR-10 results ($P < 0.001$) at all stages except for the final (95º) stage ($P > 0.05$; Table 4.1).

Table 4.1: Peak and stage average RPE results from the IES and CR-10 at each knee angle

Knee Angle	Stage Average		Peak	
	CR-10	IES	CR-10	IES
135º	1.0 ± 0.9	1.6 ± 1.3*	1.3 ± 1.0	1.8 ± 1.4*
125º	2.9 ± 1.8	3.6 ± 1.9*	3.4 ± 2.0	4.0 ± 1.9*
115º	5.4 ± 2.3	6.3 ± 2.0*	6.0 ± 2.2	6.8 ± 1.8*
105º	7.7 ± 1.7	8.3 ± 1.3*	8.3 ± 1.4	8.8 ± 1.1*
95º	8.9 ± 1.2	9.2 ± 0.8	9.3 ± 1.1	9.5 ± 0.6

*Each result is the mean of the measurements taken across the 4 testing sessions. Peak = the maximum result collected during that stage (i.e. at the end of each 2-minute stage), Stage Average = the mean of the two results collected during each stage (i.e. at minutes 1 and 2 of each stage). *Significantly greater RPE value than corresponding CR-10 result.*

4.3.5 Reliability

There were no significant differences in either the IES or CR-10 ratings between sessions at any knee angle ($P > 0.05$). The ICCs and CoVs between sessions 1 and 2, fell outside of the confidence intervals for the between sessions 2-4 comparisons; therefore, the reliability data for sessions 1 and 2 are presented separately while combined statistics were calculated and presented for sessions 2-4. Intraclass Correlation Coefficients between sessions 1 and 2, across all knee joint angles, ranged from r = -0.49 to 0.76 and r = 0.30 to 0.76 for the IES and CR-10 respectively. Additionally, the CoVs between sessions 1 and 2 ranged from 42.1% to 10.5% for the IES and 77.2% to 12.1% for the CR-10, with the highest variance seen at the easiest workload, reducing as the workload increased.

The ICCs for sessions 2-4 ranged from r = 0.81 to 0.91 and r = 0.79 to 0.90 for the IES and CR-10 respectively (Table 4.2). The CoVs for session 2-4 ranged from 54% to 4.5% and 41.9% to 7% for the IES and CR-10 respectively, with the lowest variances seen at the higher intensity levels (Table 4.2). The ICC for the CR-10 at 135º was significantly higher than the ICC for the IES at the same workload. Likewise, the CR-10 showed significantly lower variance at 135º than the IES. Conversely, The IES showed significantly lower variance, when compared to the CR-10 at 115, 105 and 95-degree workloads (Table 4.2).

Table 4.2: IES and CR-10 results at each knee angle between sessions and the corresponding reliability statistics.

	Knee Angle	Session Number				ICC	CoV
		1	2	3	4		
IES	135º	1.9 ± 1.5	1.4 ± 1.3	1.3 ± 1.1	1.7 ± 1.5	0.81 (0.70-0.89)	54.0% (44.9-70.0%)
	125º	3.9 ± 1.8	3.5 ± 1.8	3.3 ± 1.9	3.7 ± 2.2	0.86 (0.78-0.92)	33.1% (27.8-42.1%)
	115º	6.6 ± 1.7	6.2 ± 2.0	6.1 ± 2.0	6.1 ± 2.3	0.91 (0.85-0.95)	14.2% (12.0-17.6%)*
	105º	8.6 ± 1.2	8.5 ± 1.2	8.2 ± 1.4	8.1 ± 1.5	0.83 (0.72-0.91)	8.1% (6.8-10.4%)*
	95º	9.4 ± 0.5	9.3 ± 0.8	9.3 ± 0.8	9.1 ± 1.0	0.84 (0.66-0.93)	4.5% (3.5-6.7%)*
CR-10	135º	1.2 ± 1.0	1.0 ± 1.0	0.9 ± 0.9	1.0 ± 0.9	0.90 (0.83-0.94)†	41.9% (35.0-53.7%)*
	125º	3.0 ± 1.7	3.0 ± 1.7	2.7 ± 1.8	3.0 ± 2.1	0.87 (0.78-0.92)	38.9% (32.6-49.7%)
	115º	5.7 ± 2.3	5.4 ± 2.1	5.3 ± 2.3	5.4 ± 2.5	0.90 (0.83-0.94)	18.7% (15.9-23.5%)
	105º	7.6 ± 1.8	8.0 ± 1.5	7.5 ± 1.8	7.5 ± 1.7	0.79 (0.64-0.88)	13.7% (11.4-17.7%)
	95º	8.6 ± 1.1	9.0 ± 1.2	9.0 ± 1.5	8.9 ± 1.2	0.86 (0.69-0.94)	7.0% (5.4-10.3%)

*ICC = Intraclass correlation coefficients (95% confidence intervals), CoV = Coefficient of variation (95% confidence intervals). ICC and CoV values for comparisons of sessions 2, 3 and 4 only. †Significantly greater r-value than the other RPE scale at the same Knee angle. * Significantly lower variance than the other RPE scale at the same Knee angle*

4.4 Discussion

This is the first study to validate RPE during IWS exercise. This study demonstrated that RPE ratings, from both the CR-10 and the IES, provide valid and reliable measures of exercise intensity and physiological exertion during the IIWST.

Ratings from both RPE scales were shown to be an accurate representation of EI during the IIWST, as shown by the strong positive correlations of the IES (r = 0.89) and CR-10 (r = 0.88) results with wall squat duration, which in this case represents an increase in both contraction time and workload throughout the test. These results are similar to those shown for the OMNI-RES scale when correlated with EI, with correlations ranging from r = 0.89 to 0.91 (Robertson et al., 2003). Similarly, the CR-10 was previous shown to be a valid measure of dynamic resistance exercise intensity at baseline (r = 0.77) and following a 12-week training intervention (r = 0.91) (Desgorces et al., 2015). Likewise, in production mode, the Borg 6-20 scale has also been shown to be valid when used by sedentary, active and strength trained individuals alike (r = 0.83 – 0.92) (Tiggemann et al., 2010). As such, the validity coefficient shown in this study are comparable to those shown in previous resistance exercise research, suggesting it is an accurate measure of exercise intensity.

Strong positive relationships were seen for both the CR-10 and IES with the criterion measures of physiological exertion (HR and BP). These results were comparable to previous findings for the CR-10 when correlated with HR (r = 0.76) and blood lactate (r = 0.730) during dynamic weight training (Hollander et al., 2003), and with HR (r = 0.71) during bodyweight suspension training (Giancotti et al., 2015). Likewise, the CR-10 has previously shown comparable relationships during aerobic training (Chen et al., 2002). If RPE is to be used to monitor and prescribe exercise intensity, especially in interventions requiring a specific physiological stimulus, as is required in BP reduction interventions, it is vital that RPE can accurately represent the internal load, or physiological exertion, that the participant is experiencing; especially given that physiological responses are likely to fluctuate day-to-day even at the same absolute intensity. These findings suggest that both RPE scales are sufficiently accurate to represent the physiological changes during the IIWST, and therefore accurately measure the internal load and physiological stimulus that the participant is experiencing.

A strong positive relationship was shown between the results from the CR-10 scale and the IES (r = 0.97). In addition, there were no significant differences in the relationships shown with exercise intensity and physiological measures between the IES and CR-10 scales. The Borg CR-10 scale has previously been used to validate the OMNI Elliptical Ergometer Scale, during aerobic exercise, yielding similar construct validity coefficients to the present study (r = 0.96-0.98) (Mays et al., 2010). During dynamic resistance exercise, the CR-10 scale was also used to validate a novel Estimated Repetitions to Failure Scale, giving strong validity coefficients ranging from r = 0.86 to r = 0.96, dependant on the specific exercise used (Hackett et al., 2012). Likewise, the now widely used OMNI-RES scale was

validated during resistance exercise using the Borg 6-20 scale (Lagally & Robertson, 2006); this analysis showed relationships from r = 0.94 to 0.97. The strong relationship between the two scales, coupled with the statistically similar relationships with EI and the physiological variables, suggest that the from the CR-10 ad IES are equally valid during isometric exercise. However, there were statistically significant differences in the group mean RPE scores given between the two scales. The IES gave higher average and peak ratings during the first 4 stages of the test (135º - 105º), with no different in either score during the final stage (95º). As a result of this, the predicted RPE score at 95% HR peak, an important reference value in the prescription of IWS interventions, was higher for the IES (8.4) when compared to the CR-10 (7.8). It should be noted that this score for the IES, given by the linear regression equation, is closer to the theoretical 95% intensity score of 9.5/10 than the CR-10 score. This could make the use of the IES preferable for the prescription of IWS interventions.

There were no significant differences in either the IES or CR-10 ratings between sessions at any knee angle, showing that the group mean was stable across the 4 sessions. Despite this, the ICC and CoV measures of reliability and variance between sessions 1-2 were significantly different for both scales, when compared to between sessions 2-3 and 3-4 results. This indicates a learning effect following the first session and suggests that habituation with the isometric wall squat exercise and RPE is required before a stable relationship is achieved.

The ICC results for the IES and CR-10 showed excellent between session agreement (r = 0.81 to 0.91 and r = 0.79 to 0.90 respectively) across sessions 2 – 4, indicating that the RPE scores are reliable over time. These results are comparable to those shown previously for the OMNI-RES Thera-band (r = 0.72 - 0.76) (Colado et al., 2012) and Borg CR-10 (r = 0.88) (Day et al., 2004) scales during different forms of resistance exercise. Additionally, when the OMNI-RES scale was used in production mode similar reliability coefficients were found (r = 0.69 - 0.95) (Lagally et al., 2009).

While both scales showed excellent reliability, the ICC results showed significantly greater between session agreement at the lowest squat workload for the CR-10 (r = 0.90) compared to the IES (r = 0.81). This corresponded with significantly lower variance in the CR-10 results at the 135-workload (41.9% vs 54%) when compared to the IES. Conversely, the IES showed statistically lower variation and significantly higher ICC scores at the 3 highest workloads, when compared to the CR-10. Previous analysis of the reliability of the CR-10 showed a CoV of 17%, for dynamic squat and bench press exercise eliciting an average RPE of approximately 6.5 (Egan, 2003). This RPE is approximately equivalent to the mean IES results seen at the 115º knee angle (CR-10 = 6.0, IES = 6.8) which produced between session variance of 14.2% for the IES and 18.7% for the CR-10. Similarly, Day et al. (2004) assessed the reliability of the CR-10 across 2-sessions at 3 difference intensities, giving a CoV of 14.5%. The three intensities used in Day's study gave mean RPE scores of 3.7, 5.6 and 6.9, approximating the mean IES ratings achieved across the 125º and 115º knee angles in the current study (IES = 4.0 – 6.8,

CR-10 = 3.4 – 6.0); The CoV scores for these knee angles ranged from 14.2 - 33.1% and 18.7 – 38.9%, for the IES and CR-10 respectively. Therefore, both scales showed between session reliability comparable that that shown in previous RPE validation studies, in a range of other exercise settings.

Both scales showed higher percentage variance at the lighter intensities and lower variances at the higher intensities; this is to be expected as the lowest average RPE values seen in the earlier stages of the test (IES = 1.6 and CR-10 = 1.0 in the first stage) mean that even the smallest possible change between session (0.5 and 0.2 respectively) would elicit 20-30% variance. Arguably, this high variance makes comparison of CoVs from RPE with CoVs from other measurement methods, e.g., HR, inappropriate; however, this can still be a useful measure of the variance/reliability when comparing two like measures, such as two RPE scales. The CR-10 scale produced significantly lower variance at the lowest intensity (135 degrees), possibly due to the increased number of lower value numbers and therefore smaller differences between values at the lower end of that scale (0, 0.3, 0.5 and 1). Whereas, the significantly lower variance seen at the highest three intensities with the IES (115°, 105° and 95°), was possibly due to the simpler closed-ended nature of the IES when compared to the open-ended CR-10. Since these intensities are more representative of the intensities used during IWS training for reducing resting blood pressure (Goldring et al., 2014), this may suggest the IES is more appropriate during this type of intervention. These results suggest that RPE is reliable across sessions following habituation, especially at the higher workloads associated with BP training interventions.

Conclusion

The IES and CR-10 scales provide valid and reliable measures of exercise intensity during continuous incremental isometric wall squat exercise. Additionally, strong positive relationships were shown with the criterion measures of physiological exertion (HR and BP). Consequently, RPE could be useful in the selection and monitoring of exercise intensity during IE interventions for the reduction of resting blood pressure. There were no significant differences in validity between the two RPE scales. However, the IES produced significantly higher ratings than the CR-10 at most workloads, and as such gave results closer to the theoretical prediction. Additionally, the IES showed significantly greater reliability at the three highest workloads, meaning that the IES is more reliable at the workloads relevant to IWS training for BP reduction.

CHAPTER 5:

Study 3

Validity and Reliability of RPE as a Measure of Exercise Intensity during Isometric Wall Squat Exercise at Different Workloads

Work from this chapter was presented at the European College of Sport Science Annual Congress (Lea, O'Driscoll, Coleman & Wiles, 2018) and was published in the Journal of Clinical and Translational Research (Lea, O'Driscoll, Coleman & Wiles, 2021b).

5.1 Introduction

Study 2 (Chapter 4) showed that RPE provided a valid and reliable measure of exercise intensity during the incremental isometric wall squat test (IIWST). Additionally, strong positive relationships were shown with the criterion measures of physiological exertion (HR and BP). Consequently, it is proposed that RPE could be useful in the selection and monitoring of exercise intensity during isometric wall squat (IWS) training interventions for the reduction of resting BP. There were no statistically significant differences in validity between the two RPE scales used (IES and CR-10). However, the IES did produce significantly higher ratings than the CR-10 at most workloads, and as such gave results closer to the theoretical predictions (e.g., RPE of 1 = 10%, 5 = 50%, and 10 = 100% of maximum exertion etc.). Additionally, RPE from both scales was only shown to be reliable following completion of the first testing session, suggesting that habituation, rather than just familiarisation, is necessary to achieve reliable results. Furthermore, the IES showed significantly greater reliability at the three highest workloads, meaning that the IES was more reliable at the workloads most relevant to IWS training for BP reduction.

During the development of the IIWST, Goldring et al. (2014) examined the validity of eliciting a physiological response by manipulating knee joint angle, to recreate the stimulus used in previous interventions using leg extension (Baross et al., 2012; Devereux et al., 2010; Howden et al., 2002; Wiles et al., 2010). Goldring et al. (2014) also examined the resolution to which HR and BP were able to distinguish changes in isometric wall squat intensity. To do this, Goldring's participants were required to complete 15 separate testing sessions involving a single 2-minute wall squat bout. During the first ten visits, the squat test was at one of ten counterbalanced knee joint angles from 135° to 90° in 5° increments. During the final five visits, five of the aforementioned knee joint angles were randomly assigned and repeated as a test of reliability. Heart rate and BP, which were monitored continuously during the tests, showed statistically significant inverse correlations with workload ($r = -0.80$ to -0.99). Additionally, significant changes in HR and BP were detectable with 10-degree differences in joint angle ($P < 0.05$) , but not at 5 degrees ($P > 0.05$). Furthermore, when results for all knee angles were combined to give an average result for each time-point, there were significant increases in each BP parameter with each increase in time under tension (30, 60, 90 and 120s). Likewise, significant increases were seen in HR results between the first 3 time points ($P < 0.05$), but not between the 90s and 120s timepoints ($P > 0.05$). As such, Goldring et al. (2014) proposed that isometric wall squat intensity can be altered by manipulating knee joint angle, which will consequently also reliably alter the HR and BP values. While this study demonstrated consistent physiological responses to this exercise, it is not yet known whether RPE responses can be as accurate or reliable.

Few studies have examined the accuracy or resolution at which RPE is able to distinguish different exercise intensities or workloads. During dynamic bilateral bicep curls and knee extensions significant

increases were shown in RPE with 20% 1RM increases in load, from 20% to 40% of 1RM and from 40% to 60% 1RM (Eston & Evans, 2009). Following Eston's work, Naclerio et al. (2011) showed that RPE was able to distinguish 10% increments in 1RM, between 30% and 90% 1RM, during dynamic bench press exercise. More recently, significant increases in active muscle RPE (RPE-AM) were shown during single arm bicep curls with an increase in repetitions from 3 x 8 repetitions to 3 x 13 repetitions, at the same relative load (70% 1RM) and the same rest period (Hiscock et al., 2016). In this case, RPE represented the change in exercise volume more accurately than blood lactate (BLa), which showed only a non-significant trend between trials (Hiscock et al., 2016).

In production mode, 6-second isometric elbow flexion and extension contractions at 1, 3, 5, 7 and 9 on the Borg CR-10 scale produced statistically greater joint torques with each consecutive increase in RPE (John et al., 2009). Similarly, during an isometric finger flexion task consisting of 5-second contractions at different RPE levels, using the verbal cues from the Borg's CR-10 scale, Hampton et al. (2014) reported significant increases in force between the 3 highest RPE levels used (Somewhat Hard-Hard and Hard-Very Hard) but not between the lower RPE Levels (Very Light-Light and Light-Somewhat Hard). The resolution of RPE, as shown in these studies, may be scale and exercise specific, and therefore to understand the usefulness of RPE to accurately monitor and control EI, its accuracy should be assessed for the specific mode of exercise being used.

Thus, if RPE is to be used to prescribe and monitor isometric wall squat (IWS) intensity, it's validity and reliability must first be demonstrated during discontinuous exercise, as was used by Goldring et al. (2014) and as is used in current home-based interventions for BP reduction (Wiles et al., 2017). Additionally, the resolution of RPE to distinguish between workloads and time-points during this type of exercise must be established. Therefore, the aim of this study was to explore the ability of RPE to accurately represent changes in discontinuous isometric wall squat intensity, by:

(1) Assessing the validity of RPE as a measure of isometric wall squat intensity, during single bouts performed at different angles.

(2) Examining the resolution of RPE to discern isometric wall squat workloads and time-points.

(3) Exploring the relationships between RPE and the measures of physiological exertion (HR and BP) during this type of exercise.

(4) Examining the reliability of the RPE responses across repeated sessions.

5.2 Methods

5.2.1 Participant information

Twenty-nine males, 17 normotensive and 12 prehypertensive, completed this study (age: 24.3 ± 3.6 years; stature: 180.4 ± 6.8 cm; body mass: 79.3 ± 14.1 kg; BMI: 24.3 ± 3.9). Thirty-five participants volunteered to take part in this study, with 4 participants subsequently withdrawing from the study and 2 participants unable to complete the testing sessions within the time limit. All participants were non-smokers (≥ 6-months), with no injury or illness, including no clinical diagnosis of any cardiovascular condition or dysfunction, and were taking no medication that could affect exercise performance or cardiovascular function. All participants met the study's participant inclusion criteria (Section 3.4.1, Page 62) and health status was assessed using a self-reported health screen and exercise readiness questionnaire (Appendix 2). Participants gave verbal confirmation that they had follow all pre-testing instructions (Section 3.4.3, Page 63), at the start of each session. If they had not followed the instructions, the session was re-scheduled.

As in study 2, females were excluded from this study to reduce additional variance caused by the menstrual cycle (Dunne et al., 1991; Sato et al., 1995) and possible differences in the responses of RPE (Koltyn et al., 2001; Chen et al., 2002; O'Connor et al., 2002; Troiano et al., 2008) and BP (Koltyn et al., 2001; Cornelissen et al., 2013; Inder et al., 2016) during exercise (Section 4.2.1, Page 86).

5.2.2 Sample size calculation

A-priori sample size calculation was conducted using GPower (Version 3.1, University of Düsseldorf). Two separate sample size calculations were completed: The first was for analysis of variance (ANOVA) to assess differences in mean and peak RPE measurements across 5 workloads. The second was for correlation testing of RPE ratings with workload, HR and BP. For both calculations the alpha level was set at $p < 0.05$, power was set at 0.8 (Cohen, 2013) and a medium effect size (Faul et al., 2007) was selected. The results of the analyses showed that minimum sample sizes of $n = 24$ and $n = 29$ were recommended for the ANOVA and correlation respectively; consequently, a target sample size of $n \geq 29$ participants was set for this study. Due to recruitment and laboratory space logistics, not all participants were able to start the study at the same time; therefore, participants were recruited to fill any drop out positions until the minimum sample size had completed the study.

5.2.3 Study design

This study was approved by Canterbury Christ Church University's Ethics Committee (15/SAS/223) and conducted according to the 1964 Declaration of Helsinki. A repeated measures design was used, where each participant was required to attend the laboratory for 8 separate testing sessions, with an additional familiarisation session. Each testing session followed the same procedures, starting with

resting measurements before completion of a 2-minute isometric wall squat contraction, at one of five randomised wall squat workloads (135º, 125º, 115º, 105º and 95º).

It was essentials that participants were fully recovered between sessions to not adversely affect results. Previous data has shown that the cardiovascular system is able to recover in a matter of minutes following a sustained isometric contraction (Humphreys & Lind, 1963; Lind et al., 1964). Muscular recovery takes significantly longer, with 70-57% recovery from an isometric handgrip (IHG) contraction at 33% MVC taking on average 40 minutes (Lind, 1959) and 87% recovery following a 50% MVC IHG contraction taking approximately 43 minutes (Stull & Kearney, 1978). Extrapolation of these recovery curves suggests that the longest recovery time for this higher intensity exercise was a little over 4-hours. The exercise used in the current study, and the Goldring et al. (2014) study, was significantly lower intensity and duration than the previous references. As such, Goldring et al. (2014) used a minimum recovery interval of 4-hours between testing sessions. For the current study, a more conservative minimum recovery time of 5-hours was chosen between sessions to ensure full recovery and consistency of results, with a maximum of two testing sessions in any 24-hour period. To limit the effects of any external factors, a maximum time limit for study competition was set as 1-month for each participant.

5.2.4 Experimental procedures

5.2.4.1 Habituation session

Before taking part in any experimental testing sessions, all participants were invited into the laboratory to complete a familiarisation and habituation session. Prior to the session, participants received an information pack outlining the testing protocols and measurement procedures included in the study. The habituation session started with seated rest while the study design, resting and exercise measurements, and exercise protocols were once again explained to the participant. As part of this explanation, participants were shown the equipment that would be used and were given a demonstration of the wall squat, including the correct wall squat technique. Finally, participants were shown the RPE scale and received the standardised instructions and anchoring (Section 3.6.1, Page 71). Following this, if the participant wished to take part in the study, written informed consent was collected (Section 3.3.1, Page 61).

Following completion of the study paperwork and 10-minutes of quiet seated rest, resting HR and BP were recorded using an oscillometric BP monitor affixed to the upper left arm (Section 3.5.2, Page 64). Three measurements were taken with 60 seconds rest in-between (Pickering et al., 2005). If differences between the consecutive measurements exceeded 5 mmHg, then an additional reading was collected. The mean results for HR, SBP, DBP and MAP were calculated, to ensure compliance with the inclusion criteria (Section 3.4.1, Page 62).

Following the resting measurements, based on the findings of study 2, participants were habituated with the wall squat protocol and use of the RPE scale; a 30-second wall squat was completed, at a knee angle of 135°, under full test conditions. During this time the squat height and foot position were recorded. Participants were unaware of the knee angle being used or how this related to the other knee angles in the study. After 25 seconds the participant was asked to give an RPE rating (Section 5.2.4.4). Finally, after a short break, the squat height and foot positions were recorded for the 125°, 115°, 105°, and 95° squat positions (Section 3.7.2, Page 76). The participant was only required to hold each position for 10-15 seconds while the measurements were taken, and a break was given between each measurement.

Participants were encouraged to ask questions throughout the habituation session to ensure that all testing procedures were understood. Once any remaining questions had been answered, the familiarisation session was completed, and the participant was free to leave.

5.2.4.2 Resting measures

At the start of each testing session, stature and body mass were recorded, in minimal clothing and with bare feet. Body mass index was calculated for each participant using these measurements (Section 3.5.1, Page 64).

Participants were then asked to lay supine and were attached to the TFM as in section 3.5.3 (Page 66). After 10 minutes of quiet rest, in the supine position with the lights dimmed, resting cardiovascular variables were collected for a further 5 minutes (Section 3.5.3.1 & 3.5.3.2, Page 67); the average results for this 5-minute period were used to categorise the participant's resting HR and BP status in the descriptive data.

5.2.4.3 Isometric wall squat protocol

Following the resting BP measurements, the participants remained connected to the TFM and were moved into a seated position where they received a final explanation of the IWS exercise protocol, wall squat position, and RPE instruction. Participants were then asked to rate their current RPE score, to assess their understanding of the scale (expected result of zero).

Each wall squat session consisted of 2-minutes of squatting at one of 5 possible workloads (Knee angles 135º, 125º, 115º, 105º, and 95 º). The 125° and 105° angles were completed just once, while the 135°, 115° and 95° angles were completed twice to allow measurement of reliability. These 8 sessions were performed in a random order. Participants were not told which knee joint angle they were squatting at and whilst they were aware that some knee angles would be repeated, they were not told which angles.

The wall squat technique, position and knee angles were the same as was used during the IIWST (Section 3.7.2, Page 76), except that each session only required a single 2-minute bout at one of the knee joint angles. To ensure consistency, workload was controlled using the squat height and foot

distance measurements collected in the familiarisation session, with a goniometer used to confirm correct knee angle (Section 3.7.1, Page 75). Heart rate and BP were monitored continuously using the TFM; mean values were calculated for each 2-minute contraction and results for each 30-second period were calculated as the mean of the last 5-seconds of that time point. The results for the 120-second time-point were taken as the peak results for that contraction. The test continued until volitional exhaustion, the participant was unable to maintain the required knee angle, or completion of the 2-minute test.

5.2.4.4 Ratings of perceived exertion

Ratings of perceived exertion were collected every 30-seconds, in-line with the physiological measurements collected by Goldring et al. (2014). This frequency was increased from study 2, where RPE was collect every minute (Section 4.2.4.4, Page 88). In study 2, where two RPE scales were used, it was common for collection of both RPE measurements to take in excess of 30-seconds, especially during the earlier sessions; therefore, it was not possible to use two RPE scales in this study. Consequently, based on the increased reliability and agreement with theoretical predictions shown in Study 2, the IES was used to measure RPE in this and all subsequent studies contained within this thesis. Participants were asked to rate the perceived exertion in their active muscles (Section 3.6.1, Page 71), at 25, 55, 85 and 115 seconds of the IWS contraction, to allow calculation of the peak RPE for each 30-second period.

5.2.5 Data analysis

The mean resting HR and BP results, collected at the start of each session, were assessed for statistical differences between the 8 sessions. As the mean SBP measurements for various sessions were not normally distributed, differences between the sessions were assessed using Friedman's related-samples analysis of variance. The mean results for HR, DBP and MAP were normally distributed, across all 8 sessions, therefore differences were assessed using one-way repeated-measures ANOVAs.

Mean RPE results were assessed for differences between workloads using a Friedman's related-samples analysis of variance test, with Wilcoxon signed rank tests for post-hoc comparisons. For peak results across each workload and time point, HR was assessed using a two-factor (workload x time) repeated measures analysis of variance (ANOVA) with post-hoc paired-samples t-tests. While for RPE and BP, non-parametric Friedman's tests were used with the Wilcoxon signed rank tests for post-hoc comparisons. All post-hoc testing used a Bonferroni adjustment for multiple comparisons.

The concurrent validity of RPE to represent changes in the criterion measures: Workload, HR, and BP, was assessed using Spearman's rank-order correlations. Additionally, the relationships between workload and the physiological variables were measured using Pearson's product-moment correlations (HR & SBP) and Spearman's rank-order correlations (DBP & MAP).

Reliability of the peak IES, HR, and BP results between repeated sessions were examined separately using: Two-factor (session x workload) repeated measures ANOVA's or Friedman's test (normal distribution dependant); Intraclass Correlation Coefficients (ICC); and Coefficient of Variations (CoV). For the difference tests, the 'session' factor had 2 levels (sessions 1 & 2), and the 'Intensity' factor had 3 levels (knee angle - 135°, 115° & 95°). Where main effects were found, post-hoc testing was conducted with Bonferroni adjustment for multiple comparisons. The ICC (3,1) model was used to assess the agreement between the repeated measures taken during consecutive sessions. Within-participant variance was calculated as CoVs with 95% confidence intervals, derived from log-transformed two-way ANOVA for each variable. ICC and CoV results, for the IES and CR-10 scales, were considered to be significantly different if the mean results for each scale lay outside of the 95% confidence interval of the other.

5.3 Results

5.3.1 Resting data

At the start of each of the 8 testing sessions resting measures were recorded for each participant. The mean resting values for HR, SBP, DBP and MAP were: 61 ± 7 beats.min^{-1}, 113 ± 10 mmHg, 66 ± 8 mmHg, and 84 ± 8 mmHg respectively. There were no significant differences in any resting measures between trials ($P > 0.05$). The ICC coefficients for resting measures ranged from r = 0.71 to 0.80.

5.3.2 Workload and time

All the participants completed each knee joint angle for the full 2-minutes. Mean (calculated as average of all time points) and peak (calculated as the mean of the last 5-seconds of each 2-minute bout) results were calculated for RPE, HR and BP for each knee joint angle (Goldring et al., 2014) . The peak results were significantly higher ($P < 0.001$) than the mean results for all variables at all workloads. Significant inverse relationships were found between mean ($r= -0.77$, $P < 0.001$) and peak ($r= -0.78$, $P < 0.001$) RPE results and knee joint angle (Figure 5.1). Likewise, a significant inverse relationship was found between HR and knee joint angle ($r= -0.68$, $P < 0.001$). The correlations between blood pressure parameters (SBP, DBP and MAP) and knee joint angle also revealed significant inverse relationships ($r = -0.79$, $r = -0.62$ and $r= -0.72$ respectively; $P < 0.001$).

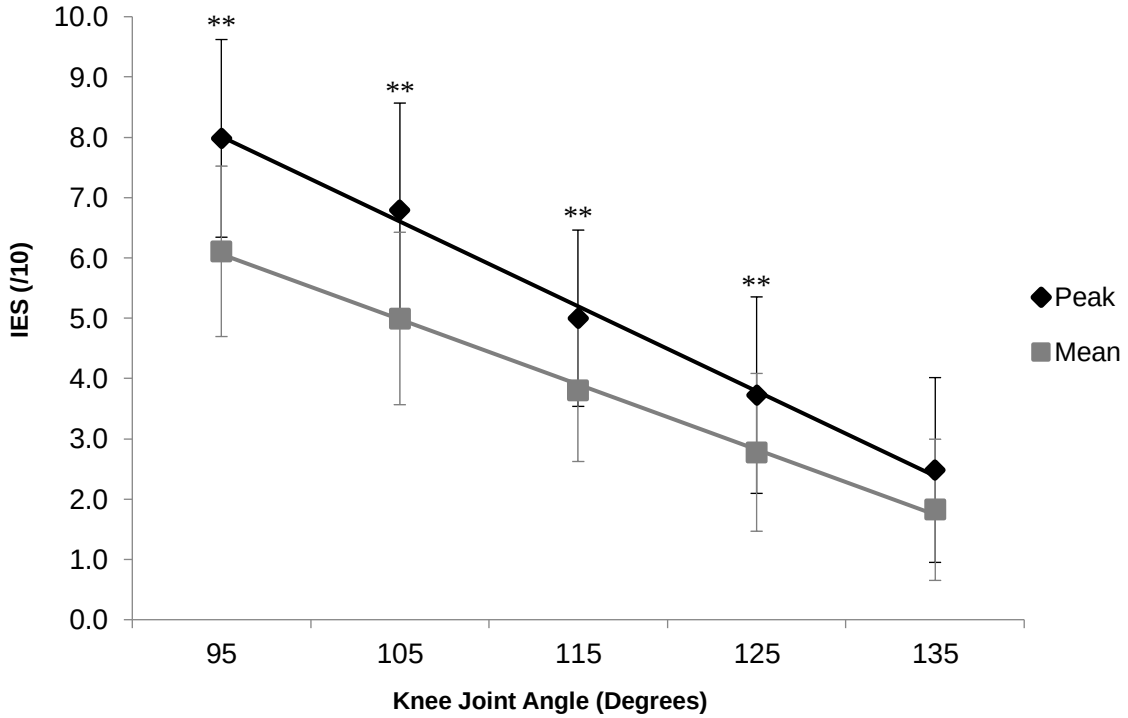


Figure 5.1: The relationships between mean and peak RPE results and knee joint angle. ** *Significant increase (P < 0.001) compared to the previous lower workload (higher knee joint angle).*

One-way analysis of variance revealed significant increases ($P < 0.001$) in mean RPE with each increase in squatting workload (Table 5.1). Likewise, significant increases in mean HR ($P < 0.001$) and blood pressure ($P < 0.001$) were seen for all consecutive squatting workloads (Table 5.1).

Table 5.1: Mean RPE, HR and BP results for each knee joint angle.

	Knee Joint Angle				
	135°	125°	115°	105°	95°
RPE (/10)	1.8 ± 1.2	2.8 ± 1.3**	3.8 ± 1.2**	5.0 ± 1.4**	6.1 ± 1.4**
HR (beats.min^{-1})	85 ± 11	92 ± 11**	97 ± 10**	104 ± 10**	111 ± 11**
SBP (mmHg)	135 ± 15	145 ± 14**	155 ± 14**	166 ± 13**	178 ± 17**
DBP (mmHg)	93 ± 13	99 ± 14**	104 ± 13**	111 ± 15**	123 ± 20**
MAP (mmHg)	109 ± 14	117 ± 13**	124 ± 14**	133 ± 13**	146 ± 18**

** Indicated significant increase ($P < 0.001$) compared to the previous lower workload (higher knee joint angle).

Two-way analysis of variance was used to explore the resolution of the exercise measures across all workloads and time-points; the results from the first session at each intensity were used for this analysis. Significant increases ($P < 0.001$) in peak RPE results (Table 5.2) were seen with each consecutive increase in workload (Figure 5.1). Likewise, peak HR and BP results (Table 5.2) increased significantly ($P < 0.001$) with each increase in workload (Figure 5.2). Significant increases ($P < 0.001$) were also found in RPE, HR, SBP and MAP results with each consecutive 30-second increase in contraction time, at each workload (Figure 5.2). A similar trend of increasing results with each consecutive time-point was evident with DBP; however, at the 135º workload there were no significant differences between 30-second timepoints ($P > 0.05$), while significant increases were seen at 60-second intervals (30-90s: $P = 0.002$; 60-120s: $P = 0.001$). Likewise, at the 125º workload increases at the 60-second ($p = 0.003$) and 90-second ($p = 0.023$) time-points were not significant when compared to the previous time-points, while the 90-second result was significantly greater than the 30-second results ($P < 0.001$). Additionally, no significant increases were seen in the peak results (120-second) when compared to the 90 second result at 105 º ($P = 0.04$) or 95 º ($P = 0.017$); once more, both of these results were significantly greater that the 60-second time-point ($P < 0.001$). All other DBP results showed significant increases with each 30-second increase in time (Figure 5.2).

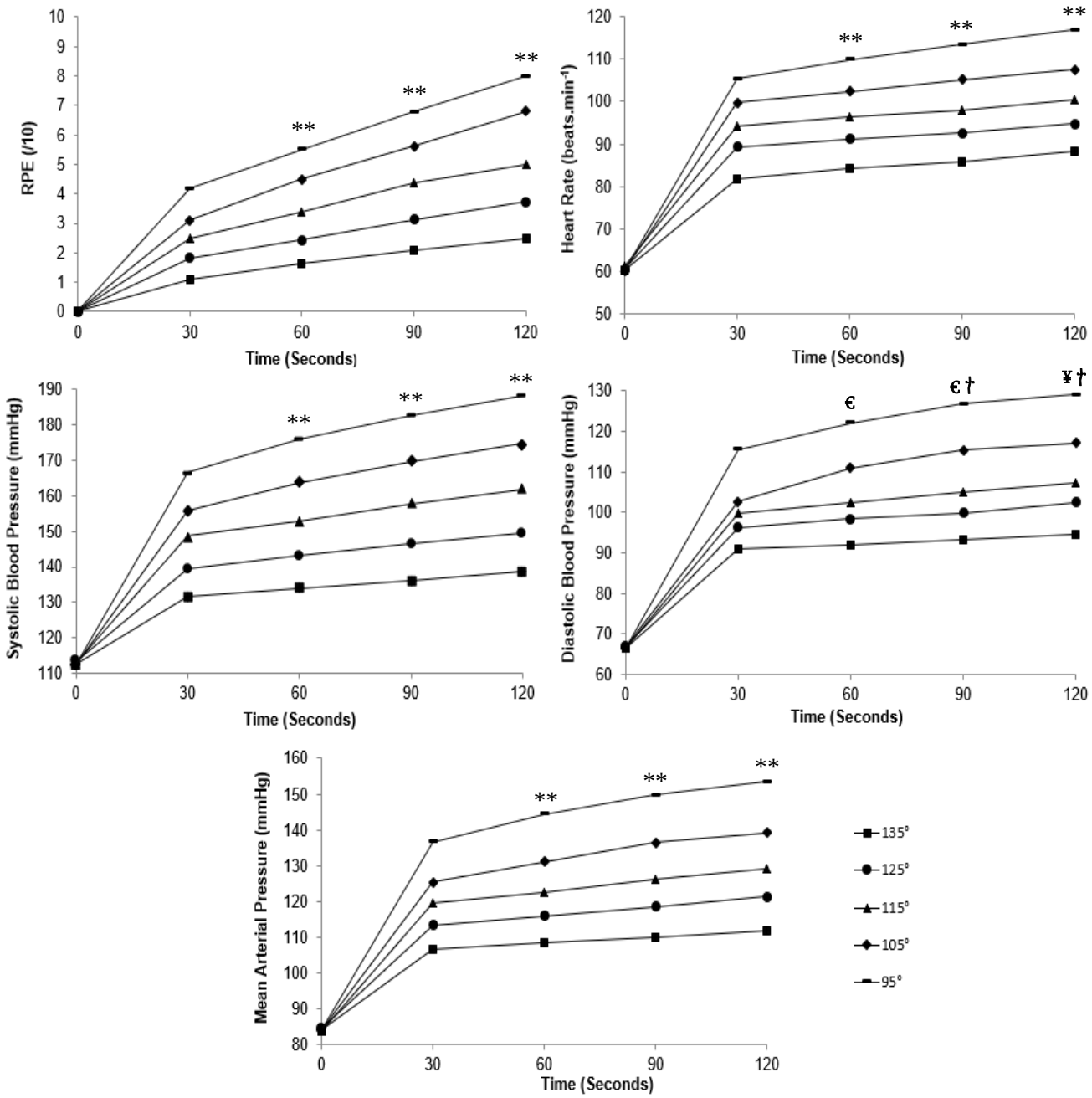


Figure 5.2: The effects of knee joint angle and time on RPE, heart rate and blood pressure. RPE, heart rate, and blood pressure results for each 30-s time point throughout the isometric contraction. *** Significant increases when compared to the previous time-point, for all knee joint angles. € Significant increases compared to the previous time-point at 115º, 105º, and 95º. ¥ Significant increases compared to the previous time-point at 125º and 115º. † Significant increases compared to results from 60-seconds previous.*

5.3.3 Physiological exertion

Exploration of the relationships between RPE and the concurrent measures of exercise intensity: HR, SBP, DBP and MAP, produced significant positive correlations of r = 0.53, r = 0.77, r = 0.62 and r = 0.70 (P < 0.001) respectively (Figure 5.3).

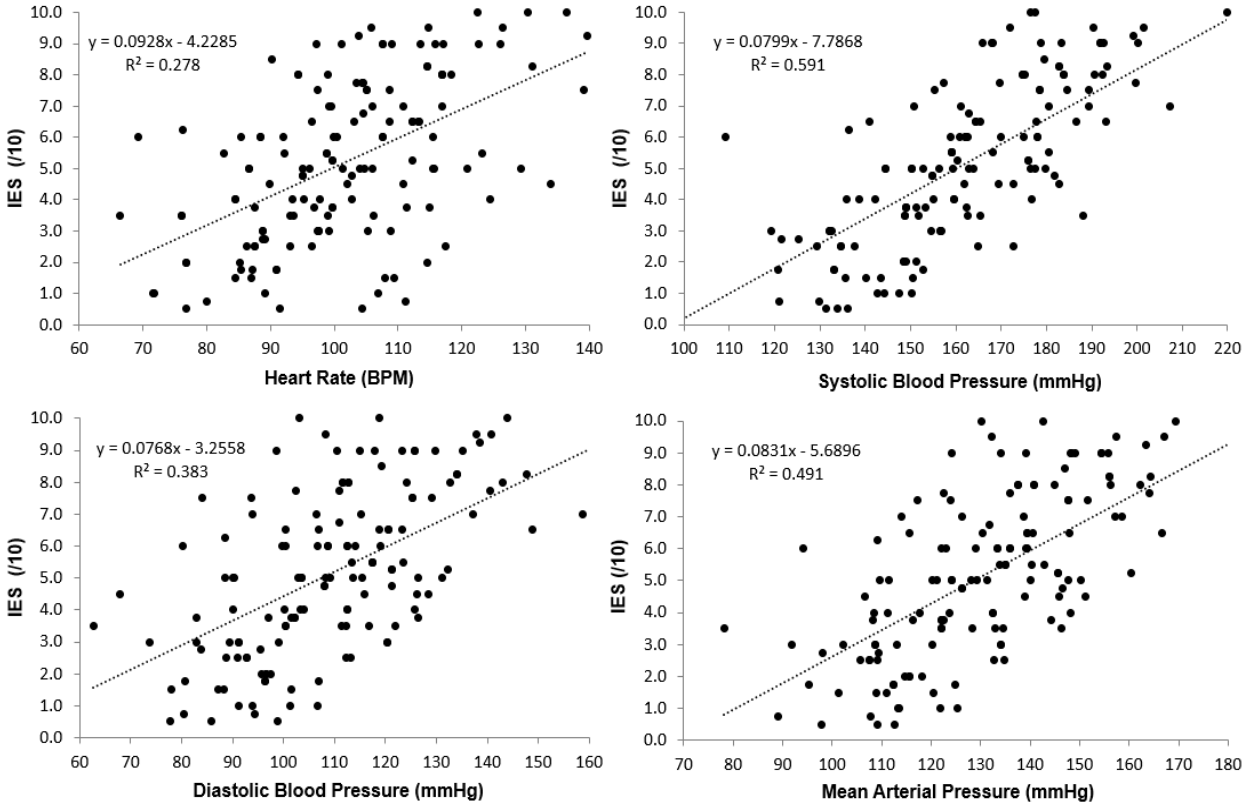


Figure 5.3: The relationships between RPE and physiological measures of exertion

5.3.4 Reliability

Reliability of the peak values for each exercise variable was assessed between the first and second training sessions at the 135°, 115° and 95° workloads (Table 5.2). There were no significant differences between trials (P > 0.05), for any of the exercise variables at any workload. The Intraclass Correlation Coefficients (with 95% confidence intervals) for RPE, HR, SBP, DBP and MAP were: r = 0.78 (0.65-0.88), r = 0.96 (0.92-0.98), r = 0.95 (0.91-0.97), r = 0.83 (0.72-0.91) and r = 0.92 (0.86-0.96) respectively. Mean between session within-participant variance of the RPE results was 29.9% (25.1-37.3%). The highest variance was seen at the 135° workload (49.5 %; 95% CI = 37.6-72.2%), decreasing at the 115° workload (21.2%; 95% CI = 16.5-29.7%), with the lowest variance seen at 95° (8.2%; 95% CI = 6.5-11.2%). The CoVs for HR (2.5%; 95% CI = 2.1-3.0%), SBP (2.4%; 95% CI = 2.1-3.0%), DBP (6.7%; 95% CI = 5.7-8.1%) and Map (3.7%; 95% CI = 3.2-4.5%) were not significantly different between workloads.

Table 5.2: Peak RPE, heart rate and blood pressure values for each two-minute bout including repeat reliability sessions.

	Knee joint angle							
	135°(a)	135°(b)	125°	115°(a)	115°(b)	105°	95°(a)	95°(b)
RPE (/10)	2.3 ± 1.6	2.3 ± 1.5	3.7 ± 1.6	4.9 ± 1.6	5.1 ± 1.6	6.8 ± 1.8	8.1 ± 1.7	7.9 ± 1.7
HR (beats.min^{-1})	88 ± 12	88 ± 11	95 ± 11	100 ± 11	101 ± 10	108 ± 10	116 ± 12	117 ± 11
SBP (mmHg)	135 ± 16	139 ± 15	149 ± 14	162 ± 14	162 ± 14	175 ± 14	188 ± 18	188 ± 21
DBP (mmHg)	92 ± 14	92 ± 12	102 ± 13	107 ± 14	107 ± 14	117 ± 17	129 ± 22	129 ± 24
MAP (mmHg)	109 ± 14	112 ± 13	121 ± 13	130 ± 15	129 ± 14	139 ± 13	153 ± 19	154 ± 22

Peak values calculated for the last 5-seconds of each bout. (a) first session completed at that workload; (b) repeat session at that workload

5.4 Discussion

This is the first study to assess the validity of RPE during discontinuous isometric wall squat exercise and to examine the resolution of RPE to distinguish wall squat workloads and time-points. Goldring et al. (2014) showed that manipulation and monitoring of knee angle based on HR and BP provided a valid way to produce, select and monitor an isometric training stimulus. This has subsequently been used to carry out isometric training interventions sufficient to cause reductions in resting BP in just 4 weeks (Wiles et al., 2017). This current study has shown that RPE can provide a valid and reliable measure of exercise intensity and workload during this type of exercise. Therefore, RPE could be used to monitor changes in intensity during and between individual training sessions and could also be used to prescribe IWS intensity without the need for laboratory visits and maximal exercise tests; this may in turn remove possible barriers to participation for some people who could otherwise benefit from this type of intervention.

There were no significant differences in resting HR and BP measurements between the 8 testing sessions ($P > 0.05$). Consequently, the between session reliability of these resting measures was high ($r= 0.71$ to 0.80). These results suggest that the participants were sufficiently rested and recovered between testing sessions, as their cardiovascular systems were able to return to baseline. It was important to ensure that this was the case so that any differences measured in exercising values were due to changes in wall squat intensity only.

The validity of RPE as a measure of workload was demonstrated by the strong validity coefficients between both mean (average for full 2-minute contraction) and peak RPE ratings and knee joint angle. These relationships were greater than those previously shown during validation of a repetitions in reserve scale during dynamic squatting exercise (Zourdos et al., 2016), and were equal to those shown for the CR-10 prior to a training intervention (Desgorces et al., 2015). As previously demonstrated by Goldring et al. (2014), the results of this study showed similarly large inverse relationships between cardiovascular responses and workload (HR: $r = -0.68$; SBP: $r = -0.79$; DBP: $r = -0.62$; and MAP: $r = -0.72$). These results suggest that RPE could be an equally useful indicator or IWS workload as HR and BP.

In this study the measurement of isometric exercise intensity (i.e., how hard the isometric contraction was) was the combination of two main factors: workload (knee joint angle) and time under tension; it was important to assess whether RPE was able to discern between changes in exercise intensity caused by manipulation of both these variables. The mean and peak RPE results showed significant increases with each 10-degree decrease in knee joint angle. This same resolution was previously shown to be the limit for HR and BP, during single bouts of isometric wall squat exercise (Goldring et al., 2014). This result is important as it shows that RPE is sufficiently accurate to distinguish wall squat workloads within a 2-minute period, which is the length of each contraction in the current IWS protocol for BP

reduction (Wiles et al., 2017). As such, it would be possible to use RPE to monitor and adjust workload after each contraction, including the first of any session, rather than needing to complete multiple bouts or an entire training session before workload could be adjusted. Furthermore, the current study demonstrated a significant workload x time interaction, where RPE, HR, SBP and MAP results significantly increased with each consecutive 30-second time point at each knee joint angle. Diastolic BP showed a similar trend but with some non-significant differences between 30-second time-points. Goldring et al. (2014) calculated overall mean knee joint angle results for HR and BP at each 30-second time-point. Significant increases were shown in these mean HR and BP results with each consecutive increase in time under tension, except for HR between the 90 and 120-second timepoints. While Goldring's results showed a main effect for time across all knee angles, they do not demonstrate whether this time effect is significant for each of the individual workloads (i.e., a workload x time interaction). The current results build on the work of Goldring et al. (2014) in demonstrating that RPE, HR, SBP and MAP can distinguish time-points as small as 30-seconds during an IWS contraction, across the full range of workloads used in the prescription of IWS interventions.

The RPE results produced strong positive relationships with HR and BP results, demonstrating that RPE can accurately represent the changes in physiological exertion during this mode of IE. These relationships are similar to those previously shown during dynamic squatting (Hollander et al., 2003) and isometric handgrip exercise (Morrin et al., 2018). When taken together with the previous resolution results, this study suggests that RPE is able to monitor and reflect changes in exercise intensity with the same accuracy as HR and BP during this type of exercise. Consequently, it seems likely that RPE can be used to replace HR and knee joint angle in the selection of IWS workload to create a more accessible version of the current IWS intervention.

The ICC results showed excellent agreement for the RPE ratings (r = 0.78; 0.65-0.88) and physiological variables between the repeated sessions. This RPE reliability closely matches the findings of previous studies using different RPE scales and resistance exercise modalities; such as, Row et al. (2012) during explosive resistance exercise using Borg's 6-20 scale (r = 0.729), Colado et al. (2012) using a modified OMNI-Res scale during elastic band exercise (r = 0.76), and Colado et al. (2014) using the Thera-band resistance exercise scale during elastic band exercise (r = 0.67). To reduce the burden placed on participants and consequently the attrition rate, only 3 of the knee joint angles (135º, 115º and 95º) were repeated as a measure of reliability, and thus the number of testing sessions was limited to 8 rather than 10. While it may have been preferable to conduct reliability testing at every knee joint angle, the current sample represented the highest, lowest and middle workloads used in the current selection protocols for IWS interventions, and therefore results would suggest that RPE is reliable between sessions across the full range of IWS workloads.

Conclusion

Ratings of perceived exertion from the IES scale provides a valid and reliable measure of isometric wall squat intensity. RPE ratings are sufficiently accurate to distinguish between knee joint angles at a 10° increment, and isometric contraction time-points with a 30-second resolution. Additionally, changes in perceived exertion accurately represented the changes in physiological exertion. As such, RPE could be useful in the selection and monitoring of IE workloads and intensities to provide a sufficient training stimulus to reduce resting and ambulatory blood pressure.

CHAPTER 6:

Study 4 -

Validity and Reliability of RPE during Unsupervised Home-Based Isometric Wall Squat Training

Work from this chapter was presented at the British Association of Sport and Exercise Sciences Student Conference (Lea, O'Driscoll, Coleman & Wiles, 2019).

6.1 Introduction

Study 2 (Chapter 4) and Study 3 (Chapter 5) demonstrated that RPE is a valid and reliable measure of exercise intensity and physiological exertion during the incremental isometric wall squat test (IIWST) and single bouts of isometric wall squat (IWS) exercise at different workloads, in a laboratory-based setting. Additionally, Study 3 showed that RPE could distinguish different IWS workloads during a 2-minute IWS bout and is sensitive enough to distinguish 30s time-points throughout the contraction period. This demonstrates that RPE is sufficiently accurate to monitor exercise intensity (EI) during each bout of an IWS training session.

Since the start of the current research, work has been published showing significant reductions in resting BP following a 4-week IWS intervention, with knee angle prescribed based on the IIWST (Wiles et al., 2017). Wiles et al. (2017) used data from the IIWST, to plot the relationship between HR and knee joint angle, and then extrapolated the specific knee angle required to elicit a HR response at 95% of the peak HR achieved during the IIWST (HRpeak). The use of percentage HRpeak to predict relative IE intensity was used previously for bilateral leg extension exercise, where it was shown that intensities chosen to produce both 75% and 95% HRpeak were sufficient to reduce resting BP after 8-weeks (Wiles et al., 2010). Following on from this, 95% HRpeak was shown to reduce resting BP after just a 4-week bilateral leg extension intervention (Deveraux et al., 2010). Goldring et al. (2014) then used this proven HRpeak method, adapting it to allow the selection of an IWS knee joint angle. Wiles et al. (2017) suggested that IWS interventions provide an effective method for reducing resting BP in the home, during a 4-week intervention, with BP reductions mainly resulting from a reduction in resting HR.

Consequently, if a universal RPE level could be found that would equate to 95% HRpeak, it could be possible to use this to select a knee joint angle, and therefore an IWS intensity, sufficient to reduce arterial BP. Based on the results from Study 2 (Chapter 4), using the regression equation produced by the relationship between RPE and HR during the IIWST, it was suggested that an RPE rating of 8.4 would correlate to 95% HRpeak (Section 4.3.3, Page 91). When rounded to the nearest whole rating on the IES, this would suggest that a target rating of 8.5 would be required if RPE was to be used to prescribe an IWS intervention attempting to achieve the same EI as Wiles et al. (2017). However, this first requires corroboration by direct measurement of the RPE scores given during each exercise bout when working at the 95% HRpeak intensity. This would allow greater certainty of the correct RPE value for each bout of the training sessions.

Recent research has used RPE to select exercise intensity during upper-extremity explosive resistance training (ERT). Ratings of perceived exertion was used to reliably select loads sufficient to elicit both strength and power gains (70– 90% 1RM) corresponding to RPE ratings of 14–17 on the Borg 6-20 scale (Lazzarini et al., 2016). This result followed previous findings demonstrating that RPE can also be used to accurately select explosive leg press loads to achieve the same results (Row et al., 2012).

Lazzarini et al. (2016) suggested that this demonstration that ERT can be regulated using RPE, may allow ERT to be accurately prescribed and monitored without maximal strength testing, which may increase the adoption of this training method for a broader spectrum of participants, including seniors. These findings strengthen the justification for the development of a similar method for use with IWS training, that may in turn increase the adoption of IWS in the demographics that arguably need it most.

One of the limitations of the current research regarding the validity and implementation of RPE, for monitoring or prescription, is that they are conducted in a laboratory-based setting or in a field-based setting but under the supervision of an exercise professional and strict controls. It has previously been suggested that many sports medicine studies demonstrate the efficacy of treatments, tools, and interventions, in a laboratory-based setting, using controls and methods that are impractical in the real world (Beedie et al., 2015). As such, these interventions may not be effective at achieving the intended outcome in the intended final setting; and therefore, there is a need for more high-quality effectiveness research (Beedie et al., 2015). Further to this, Beedie et al., (2015) suggest there are two categories of intervention effectiveness, 'implementational effectiveness' and 'clinical or treatment effectiveness', where implementational effectiveness relates to the collection reporting of data on exercise behaviours and 'treatment effectiveness' demonstrates the real-world ability of the implementation to achieve its intended effect. Based on this distinction, the majority of RPE research has demonstrated the efficacy of RPE in the laboratory but does not show the effectiveness of RPE as a tool during home-based interventions or for the average person who wishes to use RPE to help them quantify their training effort.

As such, there is a need to show the 'implementation effectiveness' of RPE in the real-world setting in which it is hoped to be used, before moving on to test the 'treatment effectiveness' of using RPE to prescribe an intervention in the home to assess whether a meaningful BP reduction can be achieved. Therefore, the primary aim of this study was to investigate the implementation effectiveness of RPE during the current un-supervised home-based IWS training intervention protocol. This was achieved with the following objectives:

(1) Assessing the validity of RPE as a measure of exercise intensity, during home-based isometric wall squat training.
(2) Examining the ability of RPE to discern between repeated IWS bouts (x4), separated by a rest period, at a set workload.
(3) Quantifying the average peak RPE responses given for each of the IWS bouts completed during the training sessions, when working at a workload prescribed to elicit 95% of HRpeak.
(4) Exploring the validity of RPE as a measure of physiological exertion, using HR as a criterion measure, during this type of training.
(5) Examining the reliability of the RPE responses across duplicated training sessions.

6.2 Methods

6.2.1 Participant information

Forty-two males, 21 normotensive and 21 prehypertensive, completed this study (age: 24.3 ± 3.6 years; stature: 180.4 ± 6.8 cm; body mass: 79.3 ± 14.1 kg; BMI: 24.3 ± 3.9). All participants were non-smokers (≥ 6-months), with no injury or illness, including no clinical diagnosis of any cardiovascular condition or dysfunction, and were taking no medication that could affect exercise performance or cardiovascular function. All participants met the study's participant inclusion criteria (Section 3.4.1, Page 62) and health status was assessed using a self-reported health screen and exercise readiness questionnaire (Appendix 2). Participants gave verbal confirmation that they had follow all pre-testing instructions (Section 3.4.3, Page 63), at the start of each session. If they had not followed the instructions, the session was re-scheduled.

As in studies 2 and 3, females were excluded from this study to reduce additional variance caused by the menstrual cycle and possible differences in the responses of RPE and BP during exercise (Section 4.2.1, Page 86).

6.2.2 Sample size calculation

A-priori sample size calculation was conducted using GPower (Version 3.1, University of Düsseldorf). The sample size calculation was completed for two-way repeated measures analysis of variance (ANOVA) to assess the differences in RPE between exercise bouts (x4) and sessions (x3). The calculation was for a single group, alpha level was set at $p < 0.05$, power was set at 0.8 (Cohen, 2013), with a medium effect size (Faul et al., 2007). The results of the analysis showed that a minimum sample size of n = 38 was recommended; consequently, 42 participants were recruited for this study to allow for a 10% drop out rate during the home-based training.

6.2.3 Study design

This study was approved by Canterbury Christ Church University's Ethics Committee (15/SAS/223) and conducted according to the Declaration of Helsinki. The study consisted of a familiarisation session, followed by an initial laboratory testing session, and then 3 home-based IWS training sessions. To simulate the first week of the current IWS intervention procedures (Wiles et al., 2017), the home-based training sessions were competed over the course of a 1-week period (7 days) with a minimum of 48-hours rest between sessions.

6.2.4 Laboratory testing procedures

6.2.4.1 Habituation session

Before taking part in any testing or training sessions, all participants were invited into the laboratory to complete a familiarisation and habituation session. Prior to the session participants received an

information pack outlining the testing protocols and measurement procedures included in the study. The habituation session started with seated rest while the study design, resting and exercise measurements, and exercise protocols were once again explained to the participant. As part of this explanation, participants were shown the equipment that would be used and were given a demonstration of the wall squat, including the correct wall squat technique. Finally, participants were shown the RPE scale and received the standardised instructions and anchoring (Section 3.6.1, Page 71). Following this, if the participant wished to take part in the study, written informed consent was collected (Section 3.3.1, Page 61).

Following completion of the study paperwork and 10-minutes of quiet seated rest, resting HR and BP were recorded using an oscillometric BP monitor affixed to the upper left arm (Section 3.5.2, Page 64). Three measurements were taken with 60 seconds rest in-between; however, if differences between the consecutive measurements exceeded 5 mmHg, then an additional measurement was taken (Pickering et al., 2005). The mean results for HR, SBP, DBP and MAP were calculated, to ensure compliance with the inclusion criteria (Section 3.4.1, Page 62) and to classify each participant's BP status.

Based on the findings of study 2, participants were then habituated with the wall squat protocol and use of the RPE scale. Following the resting measurements, a 30-second wall squat was completed, at a knee angle of 135°, under full test conditions. During this time the squat height and foot position were recorded. Participants were unaware of the knee angle being used or how this related to the other knee angles in the study. After 25 seconds the participant was asked to give an RPE rating (Section 4.2.4.4, Page 88). Finally, after a short break, the squat height and foot positions were recorded for the 125°, 115°, 105° and 95° squat positions (Section 3.7.2, Page 76). The participant was only required to hold each position for 10-15 seconds while the measurements were taken, and a break was given between each measurement.

Participants were encouraged to ask questions throughout the habituation session to ensure that all testing procedures were understood. Once any remaining questions had been answered, the familiarisation session was completed, and the participant was free to leave.

6.2.4.2 Incremental isometric wall squat test protocol

At the start of the laboratory testing session, stature and body mass were recorded, in minimal clothing and with bare feet, to be imputed into the TFM (Section 3.5.3, Page 66). Body mass index was calculated for each participant using these measurements (Section 3.5.1, Page 64).

Following the anthropometric measurements, participants were connected to the TFM (Chapter 3.5.3, Page 66). While the participants rested in a seated position, the RPE scale instructions were given for a final time, and the participant was asked to rate their current RPE score (expected to be zero).

The participants then completed the IIWST (Section 3.7.2, Page 76), starting at a knee joint angle of 135° and reducing every 2 minutes by 10° (125°, 115°, 105°, and 95°), with no rest between stages. Squat height and foot distance were controlled using the measurements taken during the habituation session, with the use of a clinical goniometer (Section 3.7.1, Page 75) to confirm that the target knee angle was achieved. Heart rate and BP were monitored continuously using the TFM and RPE was collected each minute. The test continued until volitional exhaustion, the participant was unable to maintain the required knee angle (within 5º of target value), or completion of the full 10-minute test.

6.2.4.3 IWS training intensity prescription

Using the data from the IIWST, an individual training knee joint angle was calculated for each participant (Section 3.7.3, Page 78). To do this, knee joint angle was plotted against the mean HR for the last 30-seconds of each incremental stage (Goldring et al., 2014). This relationship was then used to calculate the specific knee joint angle required to elicit a target HR of 95% heart rate peak (HRpeak), where HRpeak was calculated as the mean HR of the last 30-seconds of the test. Once the training knee joint angle had been calculated, the linear relationships between knee angle, squat height and foot distance, were used to calculate theses required measurements. In addition, a target heart rate range (THRR) was established for each participant using a modified limits of agreement equation (Hopkins, 2000; Wiles et al., 2017).

6.2.5 Home-based isometric training procedures

Following the laboratory testing session, participants were required to complete three IWS training sessions in their home (Section 3.7.5, Page 80). The testing sessions were required to be completed within a 7-day period, starting 48-hours after the laboratory testing session. Additionally, each training session was separated by a minimum of 48-hours to guarantee participants were fully recovered between each session. Each testing session consisted of four 2-minute isometric wall squat bouts, separated by 2-minute rest intervals (Figure 6.1). Squat position and knee joint angle were controlled using the Bend and Squat device (Section 3.7.4, Page 78), to ensure consistency of the squat height and foot positioning. The Bend and Squat device was set to the correct dimensions by the principle researcher before the participant left the laboratory testing session.

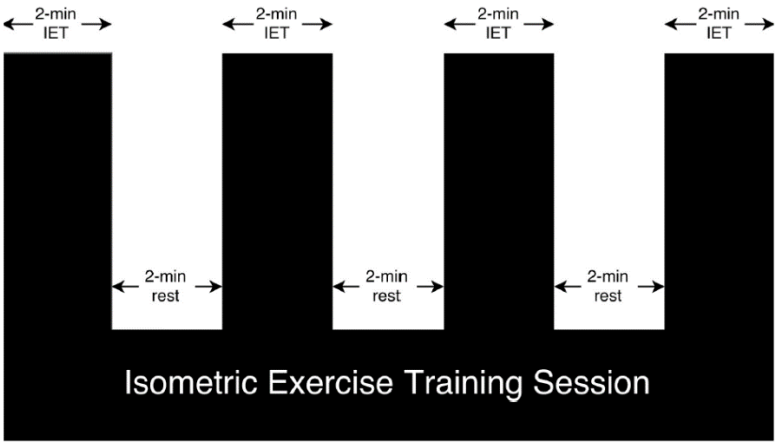


Figure 6.1: Schematic of the isometric wall squat training session (Taylor et al., 2017b)

Participants were given a training manual (Appendix 4) containing a full explanation of the study procedures, details on the correct use of all the equipment, an RPE scale, and a data collection sheet. At the start of each session, the participants fitted and started a Polar heart rate monitor (HRM) while seated at rest, and after 5-minutes recorded a resting HR. HR was continuously recorded (1 Hz) using the HRM during the training session (Section 3.5.4, Page 70). Additionally, participants were required to record a visual measurement of their HR, from the HRM, at the end of each 2-minute bout. For analysis the average HR for the final 30-seconds of each bout was calculated (Goldring et al., 2014). Additionally, these results were calculated as a percentage of the HRpeak collected for each participant during the IIWST.

Participants were asked to rate their perceived exertion immediately at the end of each 2-minute bout, on the data sheet provided, using the IES (Section 3.6.1, Page 71). The scale and standardised instruction were included in the training manual and participants were instructed to place the RPE scale where it could easily be seen during the IWS exercise.

6.2.6 Data analysis

The mean seated resting HR results, collected at the start of training each session, were assessed for statistical differences between the 3 testing sessions. As the data were normally distributed, a one-way repeated-measures ANOVA was used.

The concurrent validity of RPE was assessed using the criterion measures of exercise intensity, wall squat duration and HR, using Spearman's rank-order correlations. Additionally, the relationship between wall squat duration and HR was measured using Pearson's product-moment correlation.

Differences in peak RPE and %HR results were assessed using a two-way (bout x session) related-samples Friedman's analysis of variance test, with Wilcoxon signed rank tests for post-hoc comparisons. Differences in peak HR results were assessed using a two-factor (bout x session) repeated

measures analysis of variance (ANOVA) with post-hoc paired-samples t-tests. All post-hoc testing was conducted using a Bonferroni adjustment for multiple comparisons.

Reliability of the RPE, HR and %HR results between repeated sessions were examined separately using difference testing (as described above), Intraclass Correlation Coefficients (ICC), and Coefficient of Variations (CoV). The ICC (3,1) model was used to assess the agreement between the repeated measures taken during consecutive sessions. Within-participant variance was calculated as CoVs with 95% confidence intervals, derived from log-transformed two-way ANOVA for each variable.

6.3 Results

6.3.1 Resting data

The mean Resting HR results, as recorded by the participants at the start of each training session were 67 ± 10 for session 1, 67.4 ± 12 for session 2, and 66.8 ± 11 for session 3. There were no significant differences ($P > 0.05$) in resting HR between sessions ($P > 0.05$). The ICC coefficient for the between session agreement was 0.972.

6.3.2 Exercise intensity

The validity of RPE to measure isometric exercise intensity was assessed by correlating the RPE ratings with wall squat duration. This analysis revealed a strong positive relationship ($r = 0.80$, $P < 0.001$) between the two variables (Figure 6.2).

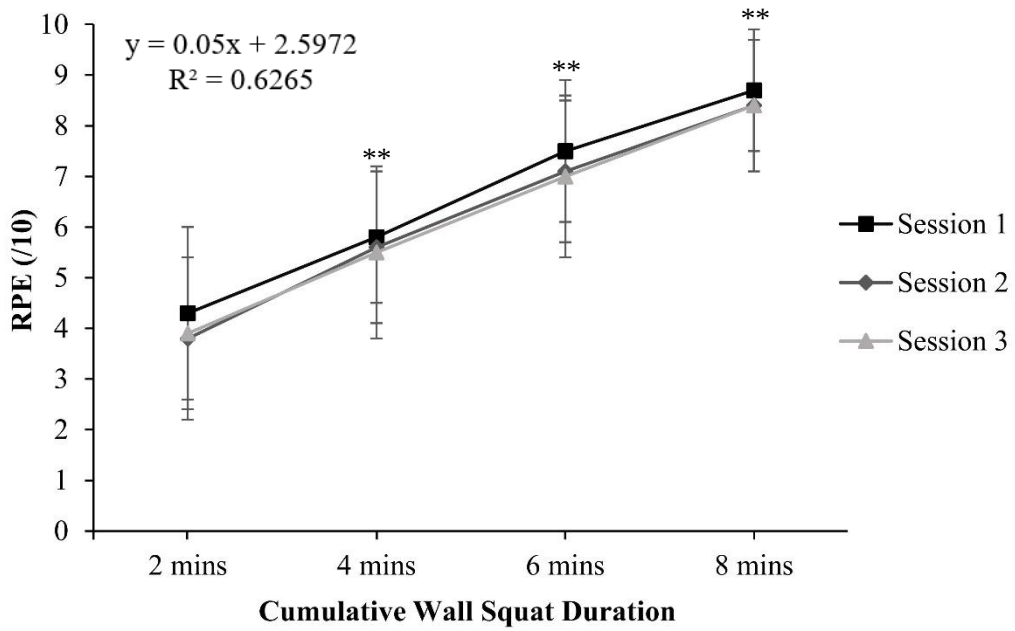


Figure 6.2: The relationship of the IES ratings and wall squat duration. *Regression equations is for the correlation of mean peak RPE results for the 3 sessions. ** Significant increases (P < 0.001) compared to the previous 2-minute bout.*

The mean (average of the 3 sessions) peak RPE results are presented in Table 6.1. There were significant increases in peak RPE results ($P < 0.001$) with each consecutive IWS bout (increase in wall squat duration) during each of the 3 training sessions (Figure 6.2). Conversely, there were no significant differences in RPE results ($P > 0.05$), for any of the exercise bouts, between training sessions (Table 6.3). Likewise, there were no significant differences in HR between sessions ($P > 0.05$), while there was a main effect for exercise bout (Table 6.1) and a significant session x bout interaction ($P = 0.012$), with significant increases in peak HR with each consecutive bout ($P < 0.001$). Similarly, %HR demonstrated no significant differences between training sessions ($P > 0.05$) but did show significant increases with each consecutive exercise bout ($P < 0.001$).

Table 6.1: Mean peak RPE, HR and %HR results for each bout of the IWS training session

	Bout 1	Bout 2	Bout 3	Bout 4
RPE	4.0 ± 1.5	5.7 ± 1.4*	7.2 ± 1.3*	8.5 ± 1.1*
HR (BPM)	94.5 ± 12.1	102.2 ± 13.9*	109.8 ± 16.7*	117.2 ± 18.5*
HR (% Peak)	79.1 ± 12.2	85.4 ± 13.1*	91.5 ± 14.4*	97.7 ± 15.7*

* Significant increase from all previous bouts

Based on the mean peak RPE ratings for each bout, target ratings were calculated by rounding the mean results to the nearest IES rating (Table 6.2). Additionally, target zones were created by splitting the differences between the target ratings, to provide the widest possible target zone without overlap (Table 6.2).

Table 6.2: Mean peak RPE values collected during each bout of the IWS training session and the corresponding target RPE ratings and RPE zones.

	Bout 1	Bout 2	Bout 3	Bout 4
Mean RPE	4.0	5.7	7.2	8.5
Target Rating	4.0	5.5	7.0	8.5
Target Zone	3.5 - 4.5	5.0 - 6.0	6.5 - 7.5	8.0 - 9.0

6.3.3 Physiological exertion

Concurrent validity of RPE was assessed by correlating the IES ratings with HR. A moderate positive relationship ($r = 0.41$, $P < 0.001$) was shown between RPE and HR (Figure 6.3). Heart rate also demonstrated a moderate linear relationship ($r = 0.49$, $P < 0.001$) with wall squat duration (Figure 6.4).

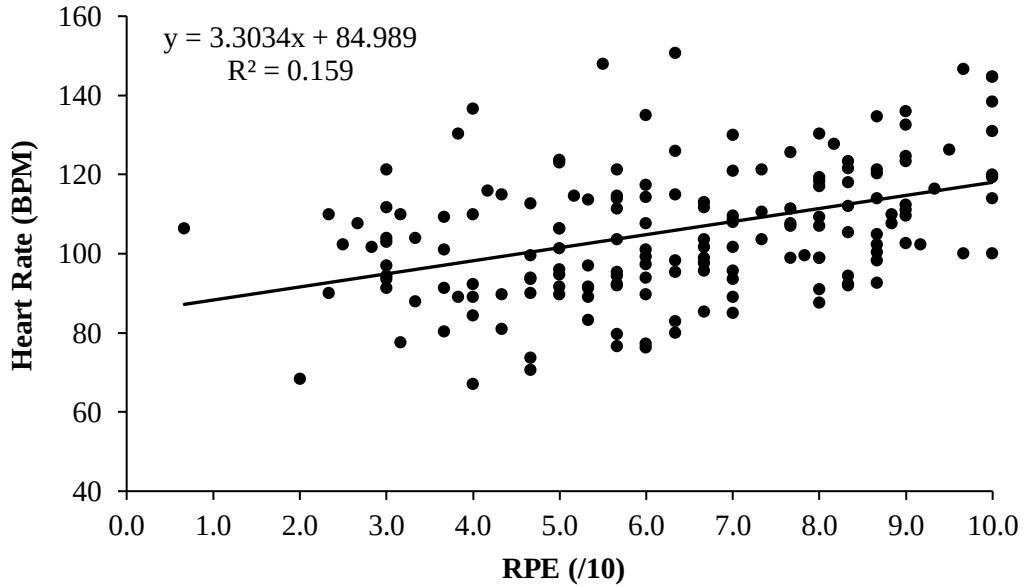


Figure 6.3: The relationship between IES ratings and heart rate.

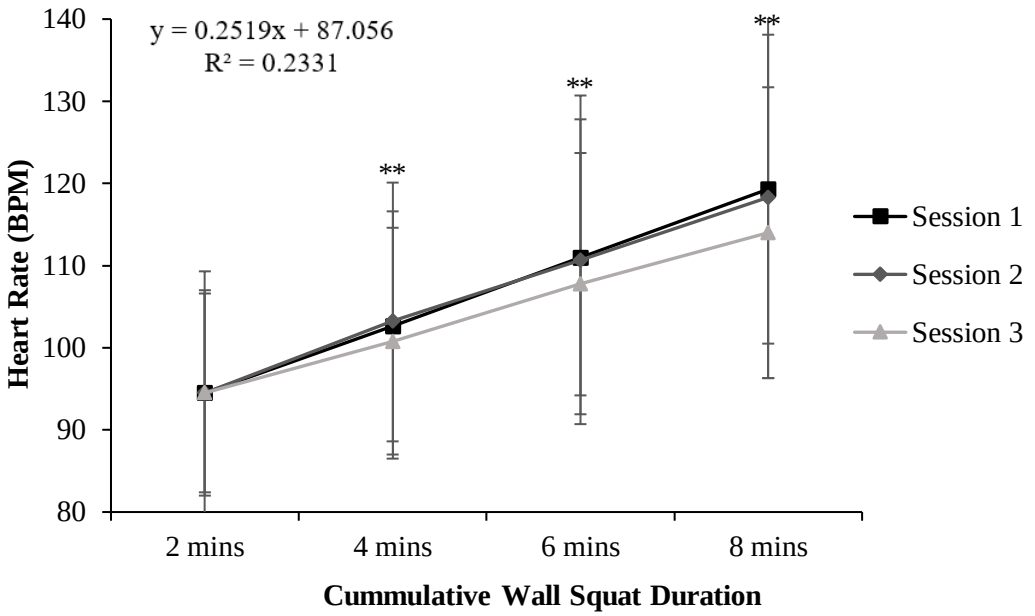


Figure 6.4: The relationship between heart rate and wall squat duration. *Regression equations is for the correlation of mean peak HR results for the 3 sessions. ** Significant increases (P < 0.001) compared to the previous 2-minute bout.*

6.3.4 Reliability

As previously stated, there were no significant difference in RPE, HR or %HR between sessions (Table 6.3). The ICC result (with 95% CI) demonstrated excellent between session agreement for the RPE (0.88; 0.86 – 0.91), HR (0.93; 0.89-0.96), and %HR (0.88; 0.82-0.92) results. Likewise, CoV results (with 95% CI) demonstrated low between session variance for RPE (10.9%; 9.5-13%), HR (4.6%; 4-5.4%), and %HR (5.5%; 4.8-6.5).

Table 6.3: Mean RPE, HR and %HR results for each IWS training session

	Session 1	Session 2	Session 3
RPE	6.6 ± 1.2	6.2 ± 1.2	6.2 ± 1.3
HR (BPM)	106.9 ± 14.5	106.7 ± 17.8	104.3 ± 14.3
HR (% Peak)	89.2 ± 13.1	88.9 ± 15.1	87.1 ± 14.1

6.4 Discussion

This was the first study to assess the effectiveness of RPE as a measure of EI during un-supervised home-based resistance exercise. This study demonstrated that RPE was a valid and reliable measure of exercise intensity and physiological exertion during repeated bouts of home-based IWS Training.

The RPE results showed a strong positive correlation with wall squat duration, which in this case represented the increases in exercise intensity (workload x time under tension). The validity coefficient ($r = 0.80$) was comparable to those shown during lab-based dynamic squatting exercise ($r = 0.77$-0.88; Zourdos et al., 2016), and during laboratory-based IWS exercise in studies 2 ($r = 0.89$) and 3 ($r = -0.78$). As suggested by Beedie et al. (2015), the current results suggest that RPE is effective as a measure of EI in the environment in which it is intended to be used, and this effectiveness has been shown to be comparable to the efficacy shown in the previous studies (as outlined above). Consequently, the use of RPE as an additional measure of EI during the currently used IWS interventions is supported and future research to explore the treatment effectiveness of an RPE prescribed IWS intervention is justified.

Heart rate demonstrated moderate positive relationships with wall squat duration ($r = 0.49$) and RPE ($r = 0.41$). These relationships were not as strong as the relationships shown for HR with EI and RPE when compared to studies 2 and 3. However, this study was the first to use an exercise protocol involving rest periods and therefore differences in participant recovery rates between bouts may have affected the strength of the relationships. Likewise, the relationship between HR and RPE was not as strong as previously shown with laboratory-based measures of physiological exertion during IE (Morrin et al., 2018). However, increased variance is arguably to be expected when analysing unsupervised home-based RPE ratings and HR measurement methods.

There were significant increases in RPE with each consecutive wall squat bout, during each of the 3 training sessions. While no significant differences were seen between sessions for the RPE ratings given for any of the training bouts. Meaning that RPE was sufficiently accurate to distinguish between IWS training bouts separated by a rest period, and that this ability is stable across sessions. Concurrent increases in HR were shown, as previously demonstrated during laboratory based IWS training (Wiles et al., 2017). As RPE ratings were significantly different between bouts it allowed quantification of a target RPE rating for each bout (Table 6.2). This quantification had two main purposes: Firstly, to give target zones for use in estimation mode during IWS interventions using the current HR prescription method, to allow researchers, medical professional, and participants to better use RPE as an additional method of monitoring the stimulus that is being elicited. Secondly, future research can use these target zones, in production mode, to see whether an RPE prescribed IWS intervention can be effective at reducing arterial BP. Importantly, the results of the current study were in agreement with the results from study 2 (Chapter 4), that a peak RPE rating of 8.5 would be required to elicit the 95% HRpeak stimulus necessary to induce reductions in resting arterial BP in just 4-weeks (Wiles et al., 2017). These

results show a similar link between the predicted RPE level from the IIWST and the actual RPE level during training, as was previously shown for EMG activation of the quadriceps (Deveraux et al., 2010) and knee joint angle (Goldring et al., 2014; Wiles et al., 2017). Now that this RPE level has been quantified, it may be possible to use it to select IWS workloads sufficient to elicit the required stimulus without the need for a maximal test to measure HRpeak.

As previously stated, there were no significant differences in RPE or HR between training sessions ($P > 0.05$). Additionally, the RPE results showed excellent between session agreement (0.88 and 0.99 respectively). These reliability results are greater than laboratory-based results previously shown for the Borg 6-20 (Row et al., 2012) and OMNI-RES scales (Colado et al., 2012; 2014). Additionally, these results are comparable to the reliability shown in studies 2 and 3 (Chapters 4 & 5) during laboratory based IWS exercise, suggesting that RPE is an equally reliable measure of exercise intensity during home-based IWS training.

Conclusion

RPE provided a valid and reliable measure of exercise intensity and physiological exertion during un-supervised home-based IWS training. RPE was sufficiently accurate to distinguish between IWS training bouts, with a peak RPE rating of 8.5 during the final bout corresponding to the required intensity previously shown for BP reduction.

CHAPTER 7:

Study 5

Resting and Ambulatory Blood Pressure Responses to RPE Prescribed Home-Based Isometric Wall Squat Training in Normotensive and Pre-Hypertensive Adults

7.1 Introduction

Studies 2-4 (Chapter 4-6) demonstrated the validity and reliability of RPE, using the IES, during the protocols currently used for isometric wall squat (IWS) interventions. More specifically, Studies 2 and 3 showed the efficacy of RPE during laboratory-based protocols, while Study 4 showed the 'implementation effectiveness' of RPE in the home-based setting where it is intended to be used. These findings demonstrated the utility of RPE as a measure of exercise intensity (EI) and physiological load during the current IWS intervention protocols and lay the foundations for future research to test the real-world 'treatment effectiveness' of an RPE prescribed IWS intervention. Study 1 (Chapter 2) collated the available research on RPE, confirming the validity of RPE as a measure of EI during resistance exercise, including isometric exercise (IE). Study 1 also examined the possible confounding variables that may affect the validity or magnitude of RPE responses, to better inform future studies attempting to implement RPE for monitoring or prescription. The meta-analysis results (Chapter 2) demonstrated that the validity of RPE ratings was greater during isometric exercise, when compared to dynamic, concentric, or eccentric exercise. Conversely, there were no differences in RPE validity based on participate age, sex, or training status. Likewise, RPE was equally valid when used in estimation mode and when used in production mode; suggesting that RPE would be equally valid when used to prescribe an IWS intervention as was previously demonstrated during estimation IWS tasks (Study 2-4).

7.1.1 Isometric exercise and blood pressure reductions

As previously outlined (Chapter 1), IE interventions have been used as an effective means of reducing resting BP (Carlson et al., 2014). Indeed, both isometric handgrip (Millar et al., 2013; Badrov et al., 2013a, 3013b; Garg et al., 2014) and isometric leg extension (Deveraux et al., 2013; Baross et al., 2012; Gill et al., 2015) modalities have been used successfully. Inder et al. (2016) conducted a meta-analysis to assess the efficacy of IE intervention for cardiovascular benefit, reporting mean SBP and DBP reductions of 5.2 mmHg and 3.9 mmHg respectively. These findings are considered clinically significant, as a reduction of ≥5 mmHg, in either SBP or DBP, is associated with a 10% reduction in the risk of stroke, myocardial infarction, and mortality (NICE, 2011). Since the start of this research project, more work has been done to advance the progress of IE interventions for BP reduction and to understand the mechanisms behind the proposed benefits. These findings (as outlined below) together with the findings of the previous four studies, further informed the methods used in this intervention study.

A 6-week isometric handgrip (IHG) intervention, at 5% and 10% MVC, elicited clinically meaningful but non-significant reductions in SBP (-4 and -6 mmHg respectively) in normotensive and pre-hypertensive (>90/>60 to ≤139/≤90 mmHg, SBP/DBP) males and females (Hess et al., 2016). While these results were not statistically significant, the ability to elicit clinically meaningful BP reductions

while using an EI considerably lower than the standard 30% MVC could be useful for the highest risk populations. In hypertensive males and females, an 8-week IHG intervention at 30% MVC resulted in significant SBP (-7 mmHg) and MAP (-4 mmHg) reductions, but non-statistically significant changes in DBP (Carlson et al., 2016). Likewise, Somani et al. (2017) showed that a 10-week intervention of IHG at 30% MVC and isometric leg extension (ILE) exercise at 20% MVC, can both produce significant reductions in SBP and pulse pressure (PP). These results agree with previous findings, that a greater exercising muscle mass allows similar BP reductions despite using a lower EI, which may indicate the potential for greater reductions, if the exercise is performed at the same intensity as IHG.

Conflicting results were shown in medicated hypertensive adults following a 12-week IHG intervention (at 30% MVC), completed either supervised in the laboratory or un-supervised at home (Farah et al., 2018). Farah et al. (2018) showed significant reductions in central and brachial BP in the supervised group, but no effects in the home-based group, when compared to a control. However, as the portable IHG equipment used did not allow EI or adherence to be monitored during home-based training, it is possible that the unsupervised participants did not perform the exercise correctly, at the correct intensity, or did not perform the required number of sessions.

Subsequently, a meta-analysis of the effects of exercise training for BP, in older adults, demonstrated that 3-months of aerobic exercise, dynamic resistance exercise, combined aerobic and resistance (combined), or isometric exercise training all elicited significant reductions in both SBP (approx. -5 mmHg) and DBP (approx. -3 mmHg), with no additional benefit of combined exercise when compared with any single modality (Herrod et al., 2018). It was also suggested that similar results are expected in younger adults. These recent findings strengthen the argument for the use of IE interventions for BP reduction in a wide range of participant groups; although, concerns are raised regarding the control, monitoring and effectiveness of home-based IE interventions.

7.1.2 Advancements in isometric wall squat research

In recent years, some significant advancements have been made in the understanding of the mechanisms and effectiveness of IWS interventions. Taylor et al. (2017b) explored the acute effects of a single IWS training session in pre-hypertensive males. During the IE they showed significant reductions in heart rate variability (HRV) and baroreceptor reflex sensitivity (BRS), accompanied by significant increases in HR, SBP, DBP, MAP, rate pressure product (RPP) and cardiac output (Q). Subsequently, during 5-minutes of recovery post-IE, Significant increases in HRV and BRS combined with significant reductions in total peripheral resistance (TPR) were associated with significant reductions in SBP, DBP, MAP when compared to baseline. In a similar study, using pre-hypertensive males, following acute IWS exercise (single session of IWS training) significant reductions in SBP, DBP and MAP were once again demonstrated, while no differences in HR were seen. These changes were accompanied by significant increases in left ventricle (LV) ejection fraction, stroke volume (SV), Q, LV twist, systolic

twist velocity and untwist velocity; suggesting that a single IWS session improves LV function and mechanics acutely, which may have important implications for clinical populations (O'Driscoll et al., 2017). These studies demonstrate potential mechanisms for the observed chronic reductions in BP following IE training programmes, however, further research is needed to confirm this post-intervention.

In the same year, Wiles et al., (2017) demonstrated the chronic effects of IWS interventions in normotensive males, revealing significant reductions in resting BP (SBP: −4 ± 5, DBP: −3 ± 3, MAP: −3 ± 3 mmHg), Q (−0.54 ± 0.66 $L.min^{-1}$) and HR (−5 ± 7 $beats.min^{-1}$) compared to a control. These findings suggested that IWS provided an effective method for reducing resting BP in the home, and that in normotensive participants these benefits resulted primarily from a reduction in resting HR, and consequently Q. Following this, Taylor et al. (2019) demonstrated the effectiveness of a 4-week home-based IWS intervention in pre-hypertensives males (130–139 SBP and/or 80–89 DBP). They showed significant reductions in resting (SBP: -12 ± 4, DBP: -6 ± 4, MAP: -8 ± 4 mmHg) and 24-hour ambulatory BP (SBP: -12 ± 4, DBP: -6 ± 4, MAP: -6 ± 3 mmHg), compared to a control. These BP reductions were associated with significant increases in resting SV and Q, significant reductions in resting TPR, and significant reductions in ambulatory PP and RPP. Taylor's findings represented the first evidence of BP reductions and cardiovascular benefits of IWS interventions in a relevant clinical population, thus supporting the role of IWS as a safe and viable therapeutic and preventative intervention in the treatment of hypertension. In addition, the findings of these two studies (Wiles et al., 2017; Taylor et al., 2019) suggest that home-based IWS did not suffer from the same reduction in effectiveness, relative to lab-based training, as was shown by Farah et al. (2018) for IHG training, suggesting that this method of administering IWS training is accurate at controlling EI.

7.1.3 Ambulatory blood pressure monitoring

Ambulatory blood pressure (AMBP) monitoring, as used by Taylor et al. (2019), involves measurement of BP at randomised intervals over a 24-hour period, to gain a better understanding of the participants BP responses during typical daily activity and stresses. Blood pressure is generally highest upon waking from sleep, with a gradual reduction in BP throughout the day (Opie, 2004); although, circadian variations of around 20 mmHg in SBP are normal based on factors such as respiration, emotion, temperature and eating (Beevers et al., 2001), with greater variations caused by exercise and acute psychological stress. Research indicates that AMBP measurement is a stronger predictor of future BP related cardiac damage (Protogerou et al., 2014), cardiovascular events, and final cardiac outcome than a single clinical measurement (Pickering et al., 2006; Fagard et al., 2008; O'Brien, 2011). Indeed, Benegas et al. (2018) showed that 24-hour SBP was more strongly associated with all-cause mortality than clinical measurement of SBP, irrespective of age, sex, obesity, diabetes, cardiovascular disease, and anti-hypertensive treatment. Additionally, masked hypertension (i.e., normal clinical and elevated

24-hour ambulatory blood pressure) was more strongly associated with all-cause mortality than sustained hypertension (i.e., elevated clinic and elevated 24-hour ambulatory blood pressure) or white-coat hypertension (i.e., elevated clinic and normal 24-hour ambulatory blood pressure). Despite a greater ability to predicted future outcomes, AMBP is still largely under-used in BP intervention studies, possibly due to the high cost and time demand necessary to complete the measurements (O'Brien, 2011). As such, more research is required to explore the effects of IE interventions on AMBP, to better understand the magnitude of the possible health benefits.

7.1.4 Research using female participants

A key advancement in IE research, is the greater inclusion of female participants, with significant and clinically important reductions in BP shown in mixed sex (Millar et al., 2008; Hess et al., 2016; Somani et al., 2017), female majority (Carlson et al., 2016; Farah et al., 2018; Souza et al., 2018) and female only (Badrov et al., 2013a) cohorts. Likewise, Badrov et al. (2016) assessed the impact of an 8-week IHG intervention at 30% MVC on male and female participants; they demonstrated significant reductions in SBP (-8 ± 6 mmHg), DBP (-2 ± 3 mmHg), MAP (-4 ± 3 mmHg), PP (-5 ± 7 mmHg), and improvements in brachial artery flow-mediated dilation (+2.4 ± 4.1 %), with no differences present in any training improvements between males and females. Teixeira et al. (2018) explored responses to a single acute IHG session at 30% MVC, in normotensive males and females (n = 20 for each). During recovery, both males and females experienced an increase in BRS and associated decreases in HR. In females the increased BRS was sustained for around 30-minutes, while in males it returned to baseline after around 10-minutes. Teixeira et al. (2018) suggested that young women may buffer IE induced pressor responses primarily through reduction in HR and consequently Q; while men, may buffer increases in BP primarily through reduction of peripheral vasoconstriction and consequently TPR, as was reported by previous research (Kim et al., 2011). While this research may suggest possible differences in the adaptive mechanisms in males and females following IE, it is clear from the current research findings that significant and clinically meaningful BP reductions can be induced in both females and males.

The results of Study 1 (Chapter 2) demonstrated no sex-dependant difference in the validity of RPE during resistance exercise, in contrast to Chen et al. (2002) who previously showed lower RPE validity in females during aerobic exercise. Additionally, the weight of the available evidence suggested that there is also no sex difference in the magnitude of RPE responses, during IE (Pincivero et al., 2002; 2003a) or dynamic resistance exercise (Glass & Stanton, 2004), for active muscle and overall body RPE (Lagally & Robertson, 2006), in estimation mode (Pincivero et al., 2003b; Springer & Pincivero, 2010; Buckley & Borg, 2011), in production mode (Pincivero et al., 2002), and with no differences shown in 1RM prediction (Eston & Evans, 2009). Moreover, Tiggemann et al. (2016) implemented a 12-week training intervention in elderly females (n = 30), designed to elicit an RPE rating between 13 and 18 on

the Borg 6-20 scale. The intervention successfully improved muscle strength (58%), muscle power (27%), and functional performance of the lower limbs. More recently, in hypertensive women, it was demonstrated that RPE could distinguish between sets (3 sets of 10 repetitions) of knee extension exercise, with and without blood flow restriction in place (Pinto et al., 2018). These results suggest that RPE is sufficiently accurate in females to prescribe, control and monitor resistance EI.

Based on previous findings suggesting sex-related differences in BP responses (Koltyn et al., 2001; Cornelissen et al., 2013; Inder et al., 2016), reduced RPE validity (Chen et al., 2002), differences in RPE ratings (Koltyn et al., 2001; O'Connor et al., 2002; Troiano et al., 2008), and concerns around the additional variance in BP data caused by the menstrual cycle (Dunne et al., 1991; Sato et al., 1995), females were excluded from Studies 2-4. However, based on the findings of Study 1 (Chapter 2) and the most recent IE and RPE research findings, as outlined above, it was decided that exclusion of females from this final intervention study was no longer justified, and would reduce the overall effectiveness, accessibility, and real-world usefulness of this intervention and research; as such, female participants were included in this study. However, to further reduce the possibility of any sex differences in BP responses or adaptation mechanisms affecting the results, the male and female participants were counterbalanced as far as possible across groups to ensure an equal male/female split.

7.1.5 Exercise intensity prescription using RPE

There is a growing body of evidence for the usefulness and efficacy of exercise interventions using RPE to prescribe EI. For example, rating of 3, 6, and 9 using the OMNI-RES scale in production mode, have been used to accurately and reliably select intensities that are appropriate for improving muscular fitness in recreationally trained women (Lagally et al., 2009). Likewise, a 12-week training intervention at a production RPE of 4, on the OMNI-RES scale, produced significant increases in 1RM in 7 different resistance exercises (Gearhart et al., 2011). Moreover, Buckley and Borg (2011) showed that RPE could be used to set appropriate loads and repetitions for strength training, in line with the current weight training guidelines. Buckley and Borg (2011) also extrapolated RPE to predict 1RM, which they suggested was sufficiently accurate for use in the health promotion and rehabilitation settings, while being far less time consuming and more amenable that traditional 1RM testing. In agreement with this, in older participants RPE extrapolation was used to predict 1RM with reasonable accuracy despite using only 3 sub-maximal loads and only two repetitions of each (Desgorces et al., 2015). In addition, Desgorces et al. (2015) showed that RPE allowed detection and tracking of training induced increases in 1RM. Furthermore, during explosive chest press exercise in older adults, RPE ratings of 14-17 on the Borg 6-20 scale, were associated with training loads sufficient to elicit both strength and power gains, without the need for maximal testing (Row Lazzarini et al., 2017). It was suggested that removal of the need for 1RM testing could increase the adoption of this type of training in seniors (Row Lazzarini et al., 2017).

Several subsequent studies have explored self-selected training loads, in various participants groups, as a possible means of eliminating the need for maximal testing. In one study, sedentary individuals were asked to self-select a load during three sets of 10 repetitions of various resistance exercises. The load chosen (approximately 55% 1RM), which equated to an RPE of 5-6, was sufficient to increase strength in sedentary individuals (Elsangedy et al., 2016). In a similar study, recreational trained participants were asked to select a training load to achieve 'a good workout' after 3 sets of 10 repetitions of various exercises. The selected loads (43.6%–60.2% 1RM) were below the recommended loads typically recommended for strength and hypertrophy increases (>67%-85% 1RM). Thus, for recreational trained individuals to perform resistance training at recommended intensities, more specific instruction may be required (Dias et al., 2018). In support of this, Helms et al. (2018) reported that during a 3-week intervention, elite powerlifters were able to effectively self-regulate training load and volume by selecting a load to elicit a specific repetitions in reserve (RIR) target, and by ending each training sessions at the point the target RIR was reached. In that same year, a production RPE of 6 on the Borg CR-10 scale, was shown to be sufficiently accurate to self-regulate IHG exercise for reducing BP, in pre-hypertensive and hypertensive individuals (Morrin et al., 2018). This current evidence supports the use of RPE to prescribe and control EI during exercise interventions aiming to elicit a variety of physiological improvements, including specifically during IE for BP reduction.

7.1.6 Study aims

The aim of this research was to examine the effectiveness of a 4-week home-based isometric wall squat training intervention, using RPE to prescribe and monitor exercise intensity, as a means of reducing arterial blood pressure. This aim was achieved with completion of the following objectives:

(1) Assess the magnitude of any differences in resting or ambulatory BP following the RPE prescribed IWS intervention.

(2) Examine the training stimulus achieved during the training sessions using the RPE method.

(3) Compare the RPE prescribed IWS intervention with the previously validated and implemented HRpeak prescribed method (Wiles et al., 2017; Taylor et al., 2019).

7.2 Methods

7.2.1 Participant information

Thirty volunteers, 24 prehypertensive males and 6 females (4 normotensive and 2 prehypertensive), completed this study (age: 30.8 ± 10.9 years; stature: 177.5 ± 8.3 cm; body mass: 81.2 ± 13.7 kg; BMI: 25.8 ± 3.8). Forty-eight participants volunteered to take part in this study in total, with 4 participants unable to take part as they did not meet the BP inclusion criteria (Between 90/60 and 139/89, SBP/DBP), 3 self-withdrawing due to changes in life commitments during the intervention, and 11 participants unable to complete the study due to the COVID-19 pandemic. All participants were non-smokers (≥ 6-months), with no injury or illness, including no clinical diagnosis of any cardiovascular condition or dysfunction, and were taking no medication that could affect exercise performance or cardiovascular function. All participants met the study's inclusion criteria (Section 3.4.1, Page 62) and health status was assessed using a self-reported health screen and exercise readiness questionnaire (Appendix 2). Participants gave verbal confirmation that they had followed all pre-testing instructions (Section 3.4.3, Page 63), at the start of each laboratory session. If they had not followed the instructions, the session was re-scheduled.

7.2.2 Sample size calculation

A-priori sample size calculation was conducted using GPower (Version 3.1, University of Düsseldorf). The sample size calculation was completed for the primary analysis, a two-way repeated-measures analysis of variance (ANOVA) to assess differences in resting BP before and after the IWS intervention (within subjects) and between groups. The calculation was for 3 groups, alpha level was set at $p < 0.05$, power was set at 0.8 (Cohen, 2013), with a medium effect size (Faul et al., 2007). The results of the analysis showed that a minimum sample sizes of $n = 54$ was recommended, 18 per group; consequently, it was decided that 60 participants would be recruited to allow contingency in the event of incomplete data or withdrawal of participants due to non-compliance with the study requirements.

Due to the effects of the COVID-19 pandemic, Canterbury Christ Church University was required to close in compliance with a national lockdown. As such, 11 participants that were undertaking the intervention at that time were unable to attend the laboratory for post-intervention testing and consequently had to be removed from the study. As no further testing was possible, within the timeline of this PhD research, it was decided that this study would progress with 30 participants rather than the 54 participants indicated by the sample size calculation. As such, it is acknowledged that the study is underpowered and the implications of this are discussed later in this chapter.

7.2.3 Study design

This was a randomised control study with within subjects repeated measures and between group comparisons. Before attendance to the laboratory on the first occasion, participants were randomised in to one of 3 groups (two intervention and 1 control) as shown in Figure 7.1. Males and females were randomised separately, to ensure a more even sex split between the 3 groups. Participants allocated to the control group (CON) received no intervention and were required to attend the laboratory twice, separated by a 4-week period. The intervention groups were required to attend the laboratory on 4 separate occasions and were required to undertake a 4-week home-based IWS intervention, with EI prescribed using the 95% HRpeak method (HR-EX), as in Wiles et al. (2017) and Taylor et al. (2019), or with EI self-prescribed using an RPE selection protocol (RPE-EX). This study was approved by Canterbury Christ Church University's Ethics Committee (15/SAS/223) and conducted according to the Declaration of Helsinki.

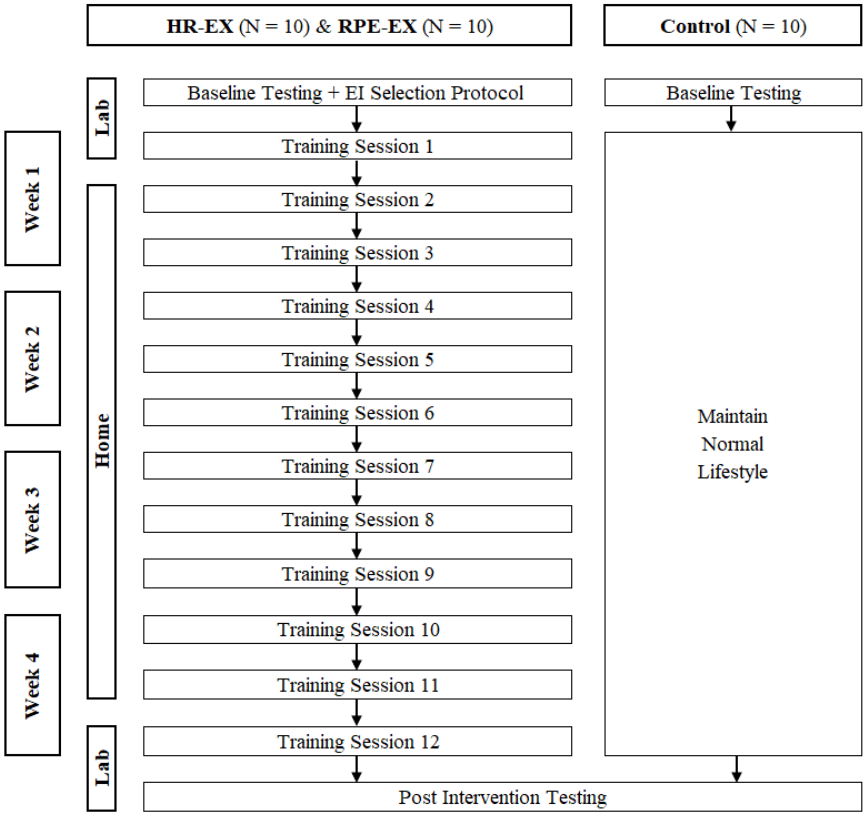


Figure 7.1: Schematic of the study design and group requirements.

7.2.4 Familiarisation

Prior to their first attendance to the laboratory, participants received an information pack outlining the study design, testing protocols, measurement procedures and participants instructions for each of the possible study groups. At the start of the first laboratory session, participants were informed of the group to which they were randomly allocated, and the relevant study protocols, measurements and requirements were explained to them verbally. As part of this explanation participants were shown the

equipment that would be used and, if relevant, were given a demonstration of the correct wall squat technique. Finally, participants in the intervention groups, were shown the RPE scale and received the standardised instructions and anchoring procedures (Section 3.6.1, Page 71). Participants were encouraged to ask questions throughout the familiarisation to ensure that all testing procedures were understood. Once any remaining questions had been answered, if the participant agreed to take part in the study, written informed consent was collected (Section 3.3.1, Page 61) and resting measurements were taken.

7.2.5 Experimental procedures – control group

7.2.5.1 Overview

Participants in the CON group were required to attend the laboratory twice, once at the start of the study and once at the end, to undertake resting and ambulatory cardiovascular measurements, including HR and BP. Following the first testing session, participants were sent home wearing an ambulatory BP cuff for 24 hours. After that 24-hour period, the participants were required to continue with their normal life and routines for 4-weeks (28 days). They were asked, as far as possible, not to make any changes to their usual diet or exercise routines. At the end of the 4-week period, participants were once again required to attend the laboratory, within a 72-hour window, for final resting and ambulatory cardiovascular measurement.

7.2.5.2 Resting measures

Upon arrival to the laboratory, stature and body mass were recorded, in minimal clothing and with bare feet, to be imputed into the TFM (Section 3.5.3, Page 66). Body Mass Index (BMI) was calculated for each participant using these measurements (Section 3.5.1, Page 64).

Participants were then rested in a seated position for 10-minutes. Following the 10-minutes rest, HR, systolic BP (SBP), diastolic BP (DBP) and mean arterial pressure (MAP) were recorded using an oscillometric BP monitor on the participants left arm (Dinamap® Pro, GEMedical Systems, Slough, UK), as in section 3.5.2 (Page 64). Three measurements were taken with 60 seconds recovery in-between (Pickering et al., 2005). If differences between the consecutive measurements exceeded 5 mmHg, then an additional measurement was taken. The mean result for each variable was calculated for analysis and for classification of each participant's resting HR and BP status in the descriptive data.

Following the seated measurements, participants were attached to the TFM (CNSystems, Graz, Austria) and then rested in a supine position for another 15-minutes. After an initial 10-minute quiet rest period, continuous measurements of HR, BP, SV, Q and TPR were collected for the final 5 minutes (Section 3.5.3, Page 66). The average results for this 5-minute period were used for analysis. Resting measurements were collected in a quiet room with the lights dimmed (Pickering et al., 2005). Participants were instructed not to talk and to remain as still as possible throughout this period.

7.2.5.3 Ambulatory blood pressure measurement

At the end of each testing session CON participants were fitted with an ambulatory blood pressure (AMBP) monitor (Welch Allyn 6100, Welch Allyn Inc, NY, USA). This consisted of a pneumatic cuff fitted to the left arm connected via a plastic tube to the monitoring unit, which was secured to a belt to be worn around the waist. Participants were asked to avoid tight fitting clothing and exercise, and to maintain their normal dietary habits during the 24-hour monitoring period. Once the device was fitted to the participant, it was turned on and a manual measurement was collected. This first measurement initiated the 24-hour data collection. The device was programmed to take measurements every 20-30 minutes during the day and every 30-60 minutes at night. For the purposes of data analysis, daytime was considered as 08:00 - 22:00 and night-time was 00:00-06:00 (Fagard et al., 2009). All BP readings were stored on the device until the data were uploaded to a computer using Welch Allyn CardioPerfect Workstation software (Welch Allyn Inc. Skaneateles Falls, NY, USA). The same AMBP monitor and cuff were used for both the 24h AMBP measurements. Data collection was considered acceptable if 14 daytime measurements and 6 night-time measurements were successfully recorded (Taylor et al., 2019).

7.2.6 Experimental procedures – intervention groups

7.2.6.1 Resting measures

At the start of the laboratory testing sessions (baseline and post-Intervention testing), for both intervention groups (HR-EX and RPE-EX), stature and body mass were recorded, in minimal clothing and with bare feet, to be imputed into the TFM (Section 3.5.3, Page 66). Body mass index was calculated for each participant using these measurements (Section 3.5.1, Page 64).

Once these measurements were taken, resting cardiovascular measurements were collected, as previously described for the control group (Section 7.2.5.2). This consisted of 10-minutes seated rest followed by 3 seated oscillometric BP measurements (Section 3.5.2, Page 64) and then 10-minutes of supine rest followed by a 5-minute continuous supine cardiovascular measurement (Section 3.5.3, Page 66).

7.2.6.2 Ambulatory blood pressure measurement

Ambulatory BP was measured twice in the intervention groups, once at baseline following the baseline testing session, and again following the final training session (session 12). Measurements were taken using the same devices and protocols as the control group (Section 7.2.5.3), with the exception that the intervention groups were given 24-hours to recover from the IWS exercise before the measurements were taken. As such, participants were shown how to fit, turn on and start the ambulatory BP cuff and were instructed to do so 24-48 hours after completion of the preceding laboratory sessions. The same AMBP device was used by each participant for their two measurements.

7.2.7 Experimental procedures – HR-EX group

7.2.7.1 Baseline testing and training intensity prescription

At the start of the baseline testing session, resting cardiovascular measurements were collected (Section 7.2.6.1). Following the supine resting measurements, participants remained connected to the TFM and were brought into a seated position. While the participants continued to rest, the RPE scale instructions were given for a final time (Section 3.6.1, Page 71), and the participant was asked to rate their current RPE score (expected to be zero).

Participants then completed an incremental isometric wall squat test (IIWST; Section 3.7.2, Page 76) using the same procedures as in Chapter 4 and Chapter 6. Cardiovascular variables were monitored continuously using the TFM and RPE was collected each minute. The test continued until volitional exhaustion, the participant was unable to maintain the required knee angle (within 5º of target value), or completion of the full 10-minute test.

Using the data from the IIWST, an individual training knee joint angle was calculated for each participant, by plotting knee joint angle against the mean HR for the last 30-seconds of each incremental stage (Goldring et al., 2014). Once the training knee joint angle had been calculated, the linear relationships between knee angle, squat height and foot distance, were used to calculate the required measurements for the Bend and Squat device (Sections 3.7.3 & 3.7.4, Page 78). In addition, a target heart rate range (THRR) was established for each participant using a modified limits of agreement equation (Wiles et al., 2017; Wiles et al., 2018).

At the end of the baseline testing session, participants were given an AMBP cuff, were shown how to fit and turn on the unit and were instructed to begin a 24-hour data collection after 24-48 hours (Section 7.2.6.2). Once the AMBP data collection was completed participants were able to start the 4-week training intervention.

7.2.7.2 IWS training sessions

Following the baseline testing session, participants were required to complete twelve IWS training sessions (Section 3.7.5, Page 80). Sessions 1 and 12 were completed in the laboratory, so that cardiovascular measurements could be collected, while the other 10 sessions were completed in the home. The 12 sessions were completed over a 4-week period with a maximum of 3 training sessions per week. It was recommended that sessions were conducted on alternate days (i.e., with a minimum of 48-hours between sessions), however, if necessary, a minimum rest period of 24-hours was acceptable. Each HR-EX participant was given a Bend and Squat device to control the training knee angle (Section 3.7.4, Page 78), a HR monitor, and a training manual (Appendix 4) which included full exercise and equipment instructions and a data recording sheet. During each session, participants were asked to record peak HR and RPE (using the IES) for each bout. To ensure adherence and the correct training

intensity, participants were asked to send their training data to the experimenter after each session. Training data were monitored to ensure that HR fell within the THRR. All participants remained within the THRR throughout the intervention so no adjustments to the training angle were needed.

Training session 1, was conducted in the laboratory so that measurements of training cardiovascular variables could be recorded. The researcher did not intervene, other than to connect the participant to the TFM. Participants were instructed to undertake the training session as they would at home. Participants then conducted session 2-11 in their homes before returning to the laboratory to undertake session 12, in the same manner as session one, without intervention other than cardiovascular measurement using the TFM.

At the end of training session 12, participants were given an AMBP cuff, and were instructed to take an ambulatory measurement, as in section 7.2.6.3, starting between 24 and 48-hours after completion of that session.

7.2.7.3 Post intervention testing

Participants were required to attend the laboratory for follow up measurements within 48–96 hours from completion of the final training session (Session 12). The post-intervention session followed the same procedures at the baseline session; with anthropometric measurements, resting seated and supine cardiovascular measurements (Section 7.2.6.1), followed by an IIWST (Section 7.2.7.1) to allow comparison to the IIWST completed pre intervention. The AMBP monitor with 24-hour measurements recorded, was collected during this session, at which point the participant was informed they had completed all the study requirements.

7.2.8 Experimental procedures – RPE-EX group

7.2.8.1 Baseline testing and training intensity prescription

As with the HR-EX group, the baseline session started with resting cardiovascular measurements (Section 7.2.6.1). However, the RPE-EX group did not complete an IIWST during this session, as knowledge of this test may have influenced their EI selection. Instead, RPE-EX participants conducted an RPE based EI selection protocol.

The selection protocol consisted of the following: first the participant was given 30-seconds to perform a wall squat, varying the squat height, to select a position that they estimated would elicit an RPE score of 4 after a 2-minute contraction. Participants were instructed to change their foot position as they adjusted the squat height to keep their lower leg vertical. Once the participant had selected a squat height, they marked the position using some Blue Tac stuck to mark the lower point of contact with the wall (Figure 7.2). The squat height, to the top of this marker, was then recorded for use in the home.

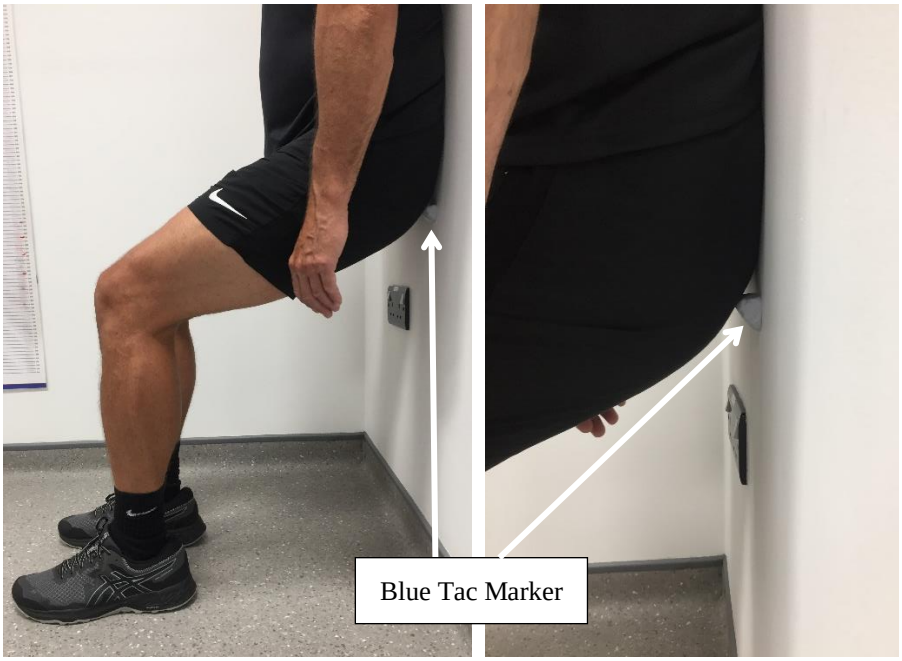


Figure 7.2: Squat height marker for RPE-EX group

Once the participant had selected a squat height, they stood up and were given two minutes rest either standing or seated on a stool. Following two minutes rest, the participant completed four 2-minute IWS contractions separated by 2-minute rest periods. The first bout was conducted at the height selected during the 30-second period. At the end of each bout, the participant gave an RPE score on a modified IES for EI selection (Figure 7.3), if the score fell outside of the target zone for that bout, the participant was instructed to change the squat height. Participants were encouraged to change the height 1 or 2 cm at a time and were reminded to change their foot position to maintain a vertical lower leg. Based on the final squat height and RPE score, after bout 4, participants were given a starting squat height for training session 1. Nine out of the 10 RPE-EX participants achieved an RPE score, within the target zone for bout 4, with 1 participant giving a final score of 7/10. This participant was instructed to further lower the squat height for the first training session.

Rating	Description	TTF	
0	Rest	100%	
0.5			
1	Extremely Easy	90%	
1.5			
2	Very Easy	80%	
2.5			
3	Easy	70%	
3.5			
4	Somewhat Easy	60%	Target Zone Bout 1
4.5			
5	Moderate	50%	Target Zone Bout 2
5.5			
6	Somewhat Hard	40%	
6.5			
7	Hard	30%	Target Zone Bout 3
7.5			
8	Very Hard	20%	
8.5			Target Zone Bout 4
9	Extremely Hard	10%	
9.5			
10	Maximal	0%	

Figure 7.3: Isometric Exercise Scale modified with target zones for each of the select protocol bouts.

At the end of this session, participants were given an AMBP monitor, were shown how to fit and operate it, and were instructed to complete a 24-hour data collection starting 24-48 hours from that time (Section 7.2.6.2). After this collection period, participants were free to start the 4-week training intervention.

7.2.8.2 IWS training sessions

Training session 1, was conducted in the laboratory so that measurements of training cardiovascular variables could be recorded. The researcher did not intervene, other than to connect the participant to the TFM. Participants were instructed to undertake the training session as they would at home, based on the instruction given to them previously. Participants then conducted sessions 2-11 in their homes. The 12 sessions were completed over a 4-week period with a maximum of 3 training sessions per week. It was recommended that sessions were conducted on alternate days (i.e., with a minimum of 48-hours) between sessions, however if necessary, a minimum rest period of 24-hours was acceptable. Each participant was given a training manual (Appendix 5) which included full instructions and a data recording sheet, and some Blue Tac if they did not have any in their home. They were not given a HR monitor, as viewing their exercising HR could have undermined the use of RPE to monitor intensity. During each session, participants were asked to record their peak RPE for each bout, using the modified IES for the training sessions (Figure 7.4). Participants also recorded the squat height for each bout, so that any changes could be monitored.

Rating	Description	TTF	
0	Rest	100%	
0.5			
1	Extremely Easy	90%	
1.5			
2	Very Easy	80%	
2.5			
3	Easy	70%	
3.5			
4	Somewhat Easy	60%	
4.5			
5	Moderate	50%	
5.5			
6	Somewhat Hard	40%	
6.5			
7	Hard	30%	
7.5			
8	Very Hard	20%	Target Zone Bout 4
8.5			
9	Extremely Hard	10%	
9.5			
10	Maximal	0%	

Figure 7.4: Isometric Exercise Scale modified with the target zone for peak RPE during training sessions.

To allow for greater variability in the RPE responses given during the earlier IWS bouts (as shown in Study 4, Chapter 6), and to limit the number of adjustments required to the squat position, participants were instructed to complete each training session at the same squat height. If the peak RPE result, at the end of bout 4, was outside the target zone then the starting squat height for the next session should be adjusted. It was also suggested that after 1 or 2 sessions they would probably be able to pick a squat height that would remain constant for the rest of the 4-week intervention.

The final training session (session 12) was again conducted in the laboratory, in the same manner as the home-based sessions, with no intervention from the researcher, other than to connect the TFM and take measurements. Following this session, participants were given an AMBP cuff, and were instructed to take a 24-hour ambulatory measurement, as in section 7.2.6.3, starting between 24 and 48-hours after completion of session 12.

7.2.8.3 Post intervention testing

Forty-eight to ninety-six hours after the final training session (session 12), participants were required to attend the laboratory for follow up measurements. This session followed the same procedures as the post intervention session for the HR-EX group (Section 7.2.7.3); which involved anthropometric measurements, resting cardiovascular measurements (Section 7.2.6.1) and completion of an IIWST (Section 3.7.2, Page 76). This IIWST was the first completed by the RPE-EX group and was used to calculate HRpeak, THRR, and knee joint angles (Section 3.7.3, Page 78) for comparison with training data and the HR-EX group. After the AMBP monitor, containing 24-hour data collection, was returned to the researcher, the participant was informed they had completed all the study requirement.

7.2.9 Data analysis

Participant data (age, stature, mass, and BMI) were assessed for differences between groups (3 levels: CON, HR-EX, RPE-EX) and time-points (2 Levels: pre and post intervention) using a 2-way analysis of variance (ANOVA). Post-hoc testing was completed using independent measures t-tests.

Exercise prescription data (Peak HR, 95% HRpeak, THRR, training knee angle, training squat height) was calculated for the HR-EX group based on the IIWSTs completed pre and post intervention, while the RPE-EX group was calculated based on the IIWST completed post intervention. Any differences in the exercise prescription values, between the HR-EX (pre & post IIWST) and RPE-EX (post IIWST) were tested using a one-way ANOVA. Training data (Max HR, Max HR as % HRpeak, knee angle and squat height) for sessions 1 and 12 were assessed for differences between groups (2 levels: HR-EX and RPE-EX) and sessions (2 levels: sessions 1 and 12) using a 2-way ANOVAs. Differences in average RPE and %time in THRR were assessed between groups (2 levels: HR-EX and RPE-EX) and exercise bouts (4 levels) and using 2-way Friedman's test and ANOVA respectively. All post-hoc testing was conducted using paired-samples or independent t-tests, or Wilcoxon signed rank tests.

Cardiovascular variables (resting and ambulatory) were assessed for differences between groups (3 levels: CON, HR-EX, RPE-EX) and time-points (2 levels: pre and post training period) using 2-way ANOVA with post-hoc paired-samples or independent t-tests. Additionally, the mean differences (Delta score) in pre and post values (post-result minus pre-result) were assessed between groups (3 levels) using one-way ANOVA with post-hoc independent t-tests or independent samples Kruskal-Wallis tests with post-hoc Mann-Whitney U tests, normal distribution dependant. Further to this, the clinical significance of any differences in BP (SBP & DBP) was determined by calculating the number of participants that achieved a BP reduction equal or greater than the minimal clinically important difference (MCID). According to the World Health Organisation Guideline Development Group (NICE, 2011), the MCID for SBP and DBP reduction is 5 mmHg, which is associated with a 10% reduction in the risk of mortality, cerebrovascular accident, and myocardial infarction.

7.3 Results

7.3.1 Participant data

Participant anthropometric data for each study group are presented in Table 7.1. Participants in the RPE-EX group were significantly (P = 0.005) younger (-19 years) than the participants in the HR-EX group, but not the CON group (P > 0.05). There were no other significant differences between groups or time-points for any other variable (P > 0.05).

Table 7.1: Participant data pre and post intervention for each of the study groups.

Variable	Control		HR-EX		RPE-EX	
	Pre	Post	Pre	Post	Pre	Post
Age (Years)	28 ± 4	28 ± 4	39 ± 15	39 ± 15	25 ± 4*	25 ± 4*
Stature (m)	178 ± 7	178 ± 7	175 ± 10	175 ± 10	180 ± 8	180 ± 8
Mass (kg)	82 ± 12	83 ± 12	85 ± 14	84 ± 15	77 ± 15	77 ± 15
BMI	26 ± 3	26 ± 3	28 ± 3	27 ± 3	24 ± 5	24 ± 5
Exercise/Week (Hours)	2 ± 2	2 ± 2	2 ± 2	2 ± 2	4 ± 3	3 ± 3

** Significantly lower than HR-EX at the same time-point. BMI, Body Mass Index. Exercise/Week, number of hours of exercise in the previous week excluding any prescribed IWS exercise.*

7.3.2 Exercise intensity prescription

Participants in the HR-EX group completed 2 IIWSTs, one at baseline and one post intervention, while the RPE-EX group only completed 1 IIWST post intervention. Results from these tests were used to calculate HRpeak, 95% HRpeak and THRR, and to prescribe knee joint angle and squat height (Table 7.2). There were no significant differences between groups or time-points for any of the calculated or predicted variables (P > 0.05). As no differences were demonstrated between the pre and post intervention results for the HR-EX group, the following IWS training variables for both groups were calculated based on the results of the post intervention IIWST.

Table 7.2: IWS intervention prescription variables based on the IIWST performed before or after the intervention

Variable	HR-EX		RPE-EX
	Pre IIWST	Post IIWST	Post IIWST
Peak HR (bpm)	124 ± 18	122 ± 12	126 ± 14
95% HRpeak (bpm)	118 ± 18	116 ± 16	120 ± 14
Upper HR Limit (bpm)	137 ± 21	135 ± 19	139 ± 16
Lower HR Limit (bpm)	96 ± 14	94 ± 13	97 ± 11
Prescribed Knee Angle (°)	106 ± 8	104 ± 8	111 ± 8
Prescribed Squat Height (cm)	59 ± 3	57 ± 3	60 ± 5

7.3.3 IWS training variables

There was a non-statistically significant ($P > 0.05$) trend for a reduction in the maximal HR achieved during the final training session when compared to the first, in both the HR-EX (-6 ± 12 $b.min^{-1}$) and RPE-EX (-3 ± 13 $b.min^{-1}$) groups. Additionally, while the RPE-EX group had higher maximum HR results in both sessions (Table 7.3) there were no statistically significant time-point or group differences ($P > 0.05$). Likewise, when calculated as a percentage of HRpeak, there was a trend for a reduction in maximum HR (HR-EX: -5.7 ± 11%; RPE-EX: -3 ± 10%), but there were no significant time-point of group interactions ($P < 0.05$). There were also no significant changes to knee angle ($P > 0.05$) or squat height ($P > 0.05$) in either group between sessions 1 and 12. When calculated as a percentage of the predicted values, based on the post-intervention IIWST, both groups appeared to be working at greater (easier) knee angles and squat heights than predicted (Table 7.3), with the RPE-EX group working at 120% of predicted squat height compared to 102% in the HR-EX group. Despite this, there were no significant between group differences in knee angle or squat height ($P > 0.05$).

Table 7.3: Group mean maximum HR, training knee angle and squat height during sessions 1 and 12.

Exercise Variable	HR-EX		RPE-EX	
	T1	T12	T1	T12
Max HR (bpm)	114 ± 16	108 ± 17	121 ± 16	118 ± 14
Max HR (% HRpeak)	95 ± 13	89 ± 8	97 ± 13	94 ± 12
Knee Angle (°)	108 ± 8	107 ± 7	121 ± 10	122 ± 8
Knee Angle (% Prediction)	103 ± 4	103 ± 4	110 ± 8	110 ± 5
Squat Height (cm)	59 ± 3	58 ± 3	72 ± 5	72 ± 4
Squat Height (% Prediction)	102 ± 4	102 ± 4	120 ± 12	119 ± 11

There were no significant differences in RPE ratings (Table 7.4) between groups for any of the IWS bouts ($P > 0.05$). Conversely, significant increase in RPE were seen, in both groups, with each consecutive IWS bout ($P < 0.001$).

Table 7.4: Mean peak RPE ratings for each during IWS training sessions

	Peak RPE			
	Bout 1	Bout 2	Bout 3	Bout 4
HR-EX	4.0 ± 1.0	5.6 ± 0.7**	6.8 ± 1.4**	7.9 ± 1.3**
RPE-EX	3.6 ± 0.9	5.1 ± 0.8**	6.9 ± 0.5**	8.3 ± 0.7**

***significant increase compared to the previous bout ($P < 0.001$)*

The percentage time for each bout spent below, in, and above the THRR were calculated for each group (Table 7.5). There was a non-significant trend ($P > 0.05$) for the RPE-EX group to spend greater time in the THRR than HR-EX. Likewise, both groups showed a trend for increased time in THRR with each

consecutive bout; however, the only significant differences were shown by the HR-EX group, with bouts 3 and 4 being significantly higher than bout 1 ($P < 0.01$).

Table 7.5: Mean time spent in the target heart rate range during training sessions 1 and 12

		% Time			
		Bout 1	Bout 2	Bout 3	Bout 4
HR-EX	Below	65 ± 38	51 ± 38	43 ± 33	37 ± 30
	In	35 ± 38	49 ± 38	57 ± 32*	62 ± 28*
	Above	0 ± 0	0 ± 0	1 ± 3	2 ± 6
RPE-EX	Below	36 ± 37	29 ± 31	20 ± 22	15 ± 23
	In	64 ± 36	71 ± 30	79 ± 21	81 ± 22
	Above	0 ± 0	0 ± 0	1 ± 3	3 ± 6

**Significant increase compared to Bout 1 (P < 0.01)*

7.3.4 Resting blood pressure and haemodynamic function

Seated SBP, DBP and MAP results were significantly reduced ($P < 0.001$) in both intervention groups, following the 4-week intervention when compared to baseline (Table 7.6). The group mean reductions in each variable for the HR-EX (SBP: -14 ± 6, DBP: -6 ± 4, MAP: -8 ± 4 mmHg) and RPE-EX (SBP: -9 ± 6, DBP: -6 ± 4, MAP: -6 ± 3 mmHg) groups were significantly greater ($P \leq 0.001$) than any changes in the CON group (Figure 7.6). There were no significant differences between intervention groups in the magnitude of the BP reductions ($P > 0.05$); However, at baseline HR-EX had significantly greater SBP ($P < 0.001$) and MAP ($P = 0.001$) results compared to RPE-EX (Table 7.6), but after the interventions there were no significant differences between groups ($P > 0.05$).

Table 7.6: Group mean seated resting BP and HR results pre and post 4-week intervention

Variable	CON		HR-EX		RPE-EX	
	Pre	Post	Pre	Post	Pre	Post
SBP (mmHg)	128.6 ± 8.5	127.0 ± 11.0	134.0 ± 4.0††	119.8 ± 5.8**	125.1 ± 5.3††	116.0 ± 3.8**
DBP (mmHg)	80.6 ± 7.0	80.4 ± 8.0	82.6 ± 5.3	76.2 ± 5.7**	77.3 ± 8.4	71.2 ± 7.6**
MAP (mmHg)	98.2 ± 8.3	97.4 ± 9.1	101.2 ± 3.0†	92.9 ± 4.3**	94.4 ± 4.4†	88.3 ± 4.1**
HR ($b.min^{-1}$)	64.3 ± 7.1	64.6 ± 9.1	62.5 ± 7.3	62.1 ± 10.5	71.5 ± 16.7	67.0 ± 11.3

**P < 0.05, **P < 0.001 significant with-in group differences. † P < 0.05, †† P < 0.001 significant difference compared to the other intervention group at the same time-point. ¥ P < 0.05, ¥¥ P < 0.001 significant difference compared to CON at the same time-point.*

Supine resting SBP, DBP and MAP results were significantly lower, in the HR-EX ($P = 0.002$) and RPE-EX ($P < 0.001$) groups, following the intervention when compared to baseline (Table 7.7). The group mean reductions in each BP variable (Figure 7.5) for RPE-EX (SBP: -7 ± 4, DBP: -8 ± 5, MAP: -8 ± 4 mmHg) were significantly greater than the changes seen in the CON group ($P < 0.001$). Likewise, the group mean reductions in SBP (-6 ± 4 mmHg) and MAP (-5 ± 3 mmHg) seen in the HR-EX group, were significantly greater than any changes present in the CON group. The DBP results for HR-EX were significantly greater at both time-points than the RPE-EX results (pre: $P = 0.002$; post: $P < 0.001$) but showed no difference to the CON results at either time-point ($P > 0.05$). Additionally, despite the significant DBP difference seen between the pre and post intervention results (Table 7.7), the group mean reduction in DBP for the HR-EX group (-4 ± 3 mmHg; Figure 7.5) was not statistically significant when compared to the CON ($P > 0.05$). There were no significant differences in the group mean reductions in any of the BP variables between the RPE-EX and HR-EX groups ($P > 0.05$).

There were no significant differences between groups or time-points in HR, SV, or Q ($P > 0.05$). The HR-EX group showed a significant ($P = 0.005$) reduction in TPR (-159 ± 136 dyne.s.cm^{-5}) following the intervention; while the RPE-EX group showed a similar trend (-112 ± 264 dyne.s.cm^{-5}), the reduction was not statistically significant (Table 7.7).

Table 7.7: Group mean supine resting BP and haemodynamic results pre and post 4-week intervention

Variable	CON		HR-EX		RPE-EX	
	Pre	Post	Pre	Post	Pre	Post
Resting BP						
SBP (mmHg)	113.9 ± 11.8	115.1 ± 10.7	124.9 ± 11.2	119.1 ± 10.7*	115.3 ± 5.6	107.9 ± 5.3**
DBP (mmHg)	69.2 ± 13.3	70.0 ± 12.0	77.9 ± 5.8†	74.2 ± 6.4*†	70.1 ± 3.7†	62.0 ± 5.3**†
MAP (mmHg)	85.8 ±11.0	87.1 ± 9.7	94.4 ± 6.8	89.7 ± 7.3*	87.8 ± 2.9	79.4 ± 4.8**
Haemodynamic Variables						
HR (b.min^{-1})	57.8 ± 4.9	57.8 ± 4.7	57.9 ± 7.0	57.6 ± 9.0	58.8 ± 9.6	57.4 ± 9.5
Stroke Volume (ml)	91.9 ± 24.6	86.7 ± 16.4	82.8 ± 14.1	88.4 ± 16.6	106.7 ± 22.8	105.3 ± 15.4
Cardiac Output (l.min^{-1})	5.4 ± 1.4	5.2 ± 1.1	5.1 ± 0.8	5.5 ± 1.2	6.3 ± 1.7	6.0 ± 1.1
TPR (dyne.s.cm^{-5})	1434 ± 557	1438 ± 460	1408 ± 165	1249 ± 211*	1171 ± 337	1059 ± 212

**P < 0.05, **P < 0.001 significant with-in group differences. † P < 0.05, †† P < 0.001 significant difference compared to the other intervention group at the same time-point. ¥ P < 0.05, ¥¥ P < 0.001 significant difference compared to CON at the same time-point. TPR, total peripheral resistance.*

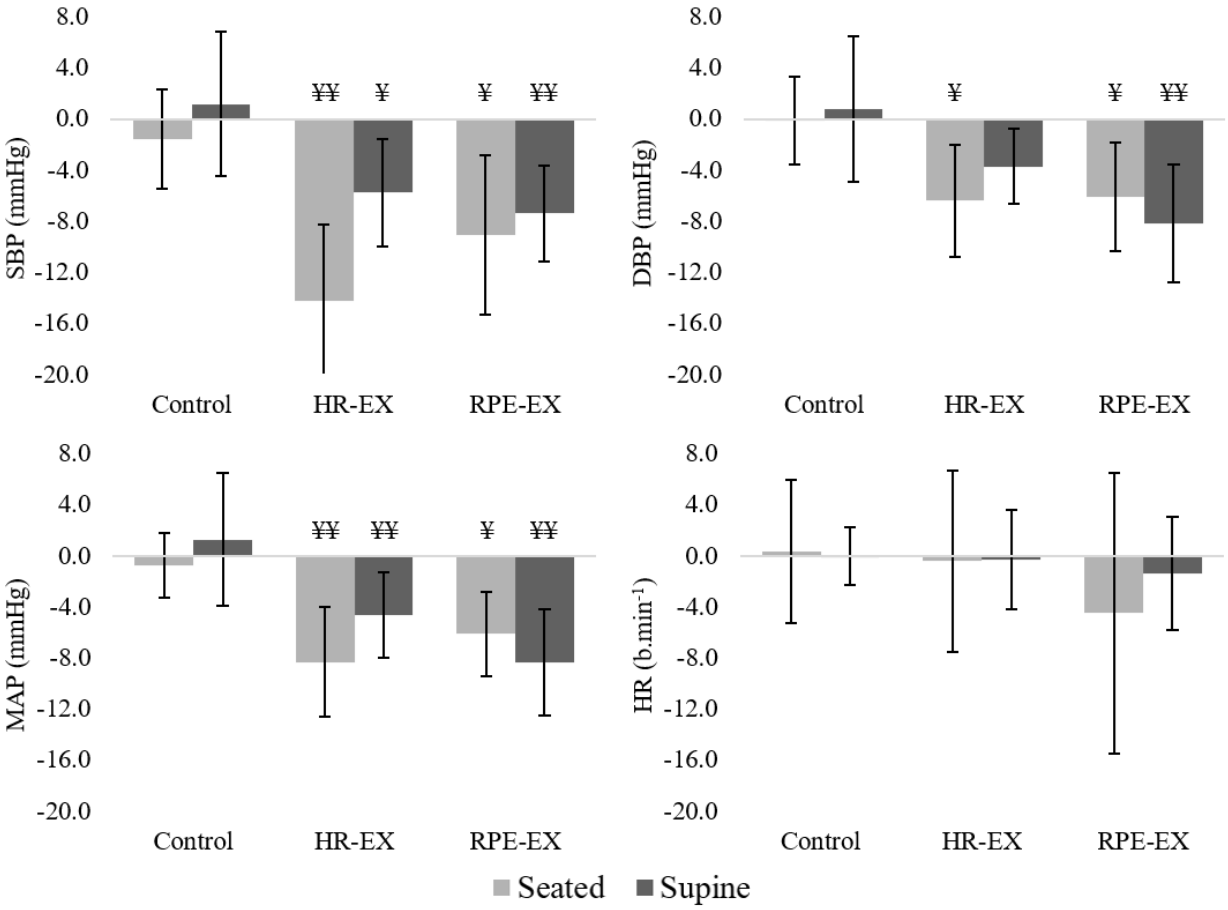


Figure 7.5: Group mean differences in seated and supine measurements of BP and HR following the IWS intervention (post result – baseline result). *¥ P < 0.05, ¥¥ P < 0.001 significantly greater reduction compared to the Control group.*

7.3.5 Ambulatory blood pressure and haemodynamic function

Both intervention groups showed significantly lower 24-hour (HR-EX: P < 0.001; RPE-EX: P = 0.004), daytime (HR-EX: P < 0.001; RPE-EX: P = 0.007) and night-time (HR-EX: P = 0.004; RPE-EX: P = 0.012) ambulatory SBP results post intervention when compared to the baseline (Table 7.8). The HR-EX group showed significantly lower post intervention DBP results, when compared to baseline, for the 24-hour (P = 0.007) and night-time (P = 0.001) measurements, but not for the daytime measurements (P > 0.05). Additionally, HR-EX did not show any significant difference in pre-post MAP results for any of the collect periods (P > 0.05). The RPE-EX groups did not show any differences in pre-post DBP measurements (P > 0.05) but did show a significantly lower post result for 24-hour MAP readings (P = 0.012).

The HR-EX groups showed significantly lower post results for: 24-hour HR (P = 0.006), PP (P = 0.008) and RPP (P = 0.001) results; daytime PP (P = 0.012) and RPP (P = 0.002) but not HR (P > 0.05); and night-time RPP (P = 0.001) but not HR or PP (P > 0.05). HR-EX showed a significantly lower post

results for the daytime RPP (P = 0.007) measurements but did not show any other HR, PP or RPP differences (P > 0.05). There were no significant differences between groups for any variable, measurement windows or time-points (P > 0.05).

Table 7.8: Group mean ambulatory BP, HR, partial pressure, and rate pressure product results pre and post 4-week intervention

Variable	Control		HR-EX		RPE-EX	
	Pre	Post	Pre	Post	Pre	Post
24 Hour Ambulatory BP						
SBP (mmHg)	126.6 ± 5.6	125.6 ± 6.7	130.8 ± 5.6	120.5 ± 7.3**	134.6 ± 17.2	126.7 ± 17.7*
DBP (mmHg)	69.7 ± 5.0	68.6 ± 5.1	73.0 ± 7.5	68.5 ± 5.4*	73.3 ± 8.0	70.7 ± 7.5
MAP (mmHg)	87.3 ± 5.8	86.2 ± 4.9	89.0 ± 5.4	86.3 ± 4.1	92.5 ± 9.7	89.3 ± 9.6*
HR (b.min^{-1})	70.9 ± 8.2	70.4 ± 10.0	70.7 ± 7.3	65.2 ± 7.8*	73.5 ± 10.3	73.1 ± 10.7
PP (mmHg)	53.6 ± 5.8	53.3 ± 7.4	55.5 ± 9.1	51.5 ± 7.1*	58.2 ± 15.8	55.4 ± 13.6
RPP	8698 ± 1016	8670 ± 1475	8982 ± 1155	7678 ± 1110*	9827 ± 1875	9229 ± 1744
Day Ambulatory BP (08:00-22:00)						
SBP (mmHg)	128.2 ± 4.5	127.6 ± 6.3	132.9 ± 6.8	124.1 ± 7.3**	139.2 ± 21.3	130.3 ± 19.7*
DBP (mmHg)	73.0 ± 4.9	71.6 ± 5.2	75.3 ± 7.4	72.1 ± 3.9	78.3 ± 10.7	75.5 ± 9.2
MAP (mmHg)	90.9 ± 5.4	89.3 ± 4.9	93.0 ± 7.4	89.7 ± 4.3	98.3 ± 13.3	93.9 ± 11.4
HR (b.min^{-1})	72.2 ± 6.9	73.0 ± 11.5	74.4 ± 7.2	70.4 ± 9.4	77.1 ± 11.3	75.5 ± 10.7
PP (mmHg)	53.6 ± 6.0	53.5 ± 7.4	55.7 ± 9.0	51.7 ± 7.2*	59.0 ± 15.9	55.0 ± 13.3
RPP	9210 ± 966	9259 ± 1672	9850 ± 1271	8671 ± 1031*	10797 ± 2464	9924 ± 1986*
Night Ambulatory BP (00:00-06:00)						
SBP (mmHg)	113.4 ± 10.5	112.1 ± 6.9	112.5 ± 9.7	105.8 ± 10.6*	118.9 ± 15.0	111.2 ± 14.1*
DBP (mmHg)	59.6 ± 5.5	60.2 ± 5.5	59.7 ± 2.4	56.2 ± 4.6*	60.4 ± 6.9	57.4 ± 6.6
MAP (mmHg)	76.3 ± 6.3	77.0 ± 5.3	76.6 ± 3.8	73.4 ± 5.9	78.8 ± 6.7	74.8 ± 6.7
HR (b.min^{-1})	62.1 ± 6.9	62.8 ± 6.4	65.1 ± 7.4	61.4 ± 7.3	62.0 ± 12.7	65.2 ± 13.6
PP (mmHg)	53.7 ± 9.8	51.9 ± 7.9	53.6 ± 9.5	50.3 ± 8.0	56.2 ± 16.1	54.0 ± 13.3
RPP	7054 ± 1188	7043 ± 916	7367 ± 989	6514 ± 1035*	7618 ± 1537	6970 ± 1570

**P < 0.05, **P < 0.001 significant with-in group differences. ŕ P < 0.05, ŕŕ P < 0.001 significant difference compared to the other intervention group at the same time-point. ¥ P < 0.05, ¥¥ P < 0.001 significant difference compared to CON at the same time-point.*

There were significant group mean reductions in 24-hour SBP in HR-EX (-10 ± 4 mmHg; P < 0.001) and RPE-EX (-8 ± 7 mmHg; P = 0.008) when compared to the reductions seen in the control group (Figure 7.6). Likewise, HR-EX showed significant reductions in daytime (-9 ± 4 mmHg; P = 0.012) and night-time (-7 ± 6 mmHg; P = 0.004) SBP when compared the CON. The RPE-EX group showed significant reductions in daytime (-9 ± 8 mmHg; P = 0.011) and non-significant reductions in night-

time SBP (-8 ± 8 mmHg; P > 0.05), when compared the CON. HR-EX showed significantly greater reductions in 24-hour (-1304 ± 802 mmHg; P = 0.001), daytime (-1179 ± 862 mmHg; P = 0.004) and night-time RPP (-853 ± 542 mmHg; P = 0.01) when compared to the CON group. No other between group effects were found in the mean differences for any variable (P > 0.05).

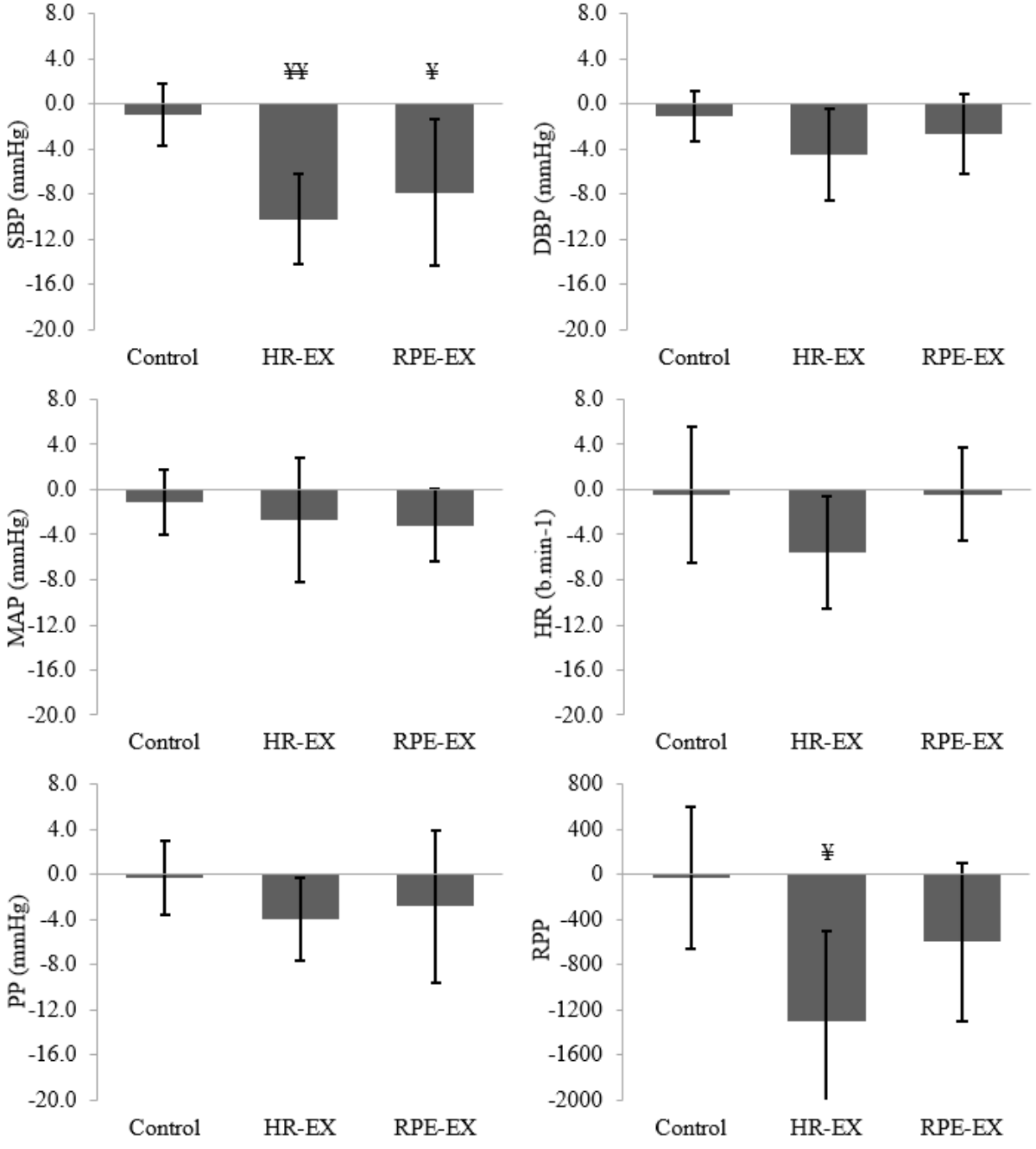


Figure 7.6: Group mean differences in 24-hour ambulatory BP and HR measurements following the IWS intervention. *¥ P < 0.05, ¥¥ P < 0.001 significantly greater reduction compared to the Control group.*

7.3.6 Minimum clinically important differences

The number or participants showing a MCID (-5 mmHg) or greater in SBP or DBP measurements was calculated for each BP measurement type (Table 7.9). In the CON group 1 participant showed a difference greater or equal to the MCID in seated SBP and DBP, and ambulatory SBP, but did not show a MCID in the supine measurements. In the HR-EX group, all participants showed an SBP difference equal to or greater than the MCID, with 7 of those participants also showing a MCID in DBP. Six of the HR-EX participants also showed MCIDs in the supine measurements and 9 participants in the AMBP measurements. Nine of the RPE-EX participants achieved MCIDs or greater in either the SBP or DBP seated measurements, with 5 participants showing MCIDs in both. Likewise, 9 participants showed MCIDs in the supine measurements and 7 in the ambulatory; both of which included the 1 participant that did not show a seated MCID, meaning all 10 RPE-EX participants showed a MCID in at least one measure. In addition to this, all 10 HR-EX participants were classified as pre-hypertensive at baseline, based upon the seated BP measurements; following the intervention 7 of the participants were classified as normotensive. Likewise, 8 of the RPE-EX participants were pre-hypertensive at baseline, with only 2 participants remaining pre-hypertensive following the intervention.

Table 7.9: Numbers of participants showing a minimum clinically important difference (-5 mmHg) in systolic or diastolic blood pressure following the 4-week intervention.

	Seated			Supine			Ambulatory (24h)			All Measures Total
	SBP	DBP	Total	SBP	DBP	Total	SBP	DBP	Total	
Control (n =)	1	1	1	0	0	0	1	0	1	1
HR-EX (n =)	10	7	10	6	3	6	9	4	9	10
RPE-EX (n =)	7	7	9	7	8	9	7	3	7	10

Total, the number of participants showing an MCID in either SBP or DBP results for that measurement type. All Measures Total, the number of participants showing an MCID in either SBP or DBP results in any one of the measurement types.

7.4 Discussion

The key findings of this study were clinically significant reductions in 100% of the intervention participants. This included significant reductions in both seated and supine resting measurements and significant reductions in ambulatory SBP. Blood pressure reductions matching or exceeding the MCID are associated with significant reductions in the risk of developing hypertension and cardiovascular disease (Prospective Studies Collaboration, 2002; Whelton et al., 2002), as well as reduced risk of myocardial infarction, stroke, and mortality (NICE, 2011). In addition, six RPE-EX and seven HR-EX participants would be reclassified as normotensive following completion of the 4-week IWS interventions. This reclassification to normotensive is associated with further risk reduction, in addition to receiving the MCID reductions alone (Vasan et al., 2001b). Indeed, the most recent guidelines from the American College of Cardiology and the American Heart Association have re-defined BP of 120-129 mmHg SBP and <80 mmHg DBP as 'elevated' and lowered the classification of 'Stage 1 Hypertension' to 130-139 mmHg SBP or 80-89 mmHg DBP (Whelton et al., 2017). It is hoped that this reclassification will encourage earlier prescription of anti-hypertensive treatments and interventions to reduce the associated health risks. This demonstrates the prophylactic importance of this IWS intervention, as shown in the current study, and its ability to lower participants back into a normotensive classification.

7.4.1 Resting blood pressure

The current study demonstrated statistically significant reductions in resting supine (SBP: -7 ± 4, DBP: -8 ± 5, MAP: -8 ± 4 mmHg) and seated (SBP: -9 ± 6, DBP: -6 ± 4, MAP: -6 ± 3 mmHg) BP in the RPE-EX group; with similarly significant reductions in the supine (SBP: -6 ± 4, DBP: -4 ± 3, MAP: -5 ± 3 mmHg) and seated (SBP: -14 ± 6, DBP: -6 ± 4, MAP: -8 ± 4 mmHg) BP measurements in the RPE-EX group. When comparing the results of the current study to previous research, 4-weeks of IWS exercise produced resting BP reductions comparable or greater than those previously shown following 8-weeks of IHG (Badrov et al., 2013b; Millar et al., 2013; Carlson et al., 2016) and ILE (Deveraux et al., 2010; Baross et al., 2012). Moreover, these reductions were greater than the averages previously reported (SBP: -5 mmHg and DBP: -4 mmHg) in a meta-analysis of laboratory-based IE interventions (Inder et al., 2016), and in the most recent meta-analysis (SBP -6/7, DBP -3, MAP -4/5 mmHg), that included a mixture of hypertensive (medicated and un-medicated), pre-hypertensive and normotensives participants (Smart et al., 2019). This may demonstrate a benefit of IWS exercise, possibly due to the additional isometric recruitment of postural and stabilising muscles when holding the constant position wall squat (Contreras, 2013), which are not required when conducting ILE or IHG exercise which isolates the quadriceps and forearm respectively. Interestingly, IHG but not isometric leg exercise has now been endorsed by the American Heart Association as an adjuvant BP lowering treatment (McGowen et al., 2017). Furthermore, the resting BP reductions shown in the current study were comparable to the reductions demonstrated following aerobic exercise interventions, SBP: -11 mmHg

and DBP: -5mmHg (Borjesson et al., 2016), a mode of exercise that is already widely recommended for the reduction of resting BP (Pescatello et al., 2004). Thus, this further demonstrates the potential usefulness and importance of this new RPE prescribed intervention, which can elicit BP reductions comparable to interventions that are already endorsed, whilst being more accessible and shorter in duration.

7.4.2 Ambulatory blood pressure

24-hour AMBP showed significant reductions in SBP (RPE-EX -8 ± 7 mmHg; HR-EX -10 ± 4 mmHg) and non-statistically significant reductions in DBP (RPE-EX -3 ± 4 mmHg; HR-EX -5 ± 4 mmHg) and MAP (RPE-EX -3 ± 3 mmHg; HR-EX -3 ± 6 mmHg). Previously, Somani et al. (2017) showed smaller reductions in 24-h SBP, of ∼4 mmHg following IHG training, and showed no differences in DBP or MAP results. However, Somani et al. used young normotensive adults, which may have meant they had limited capacity for AMBP change, when compared to the normotensive and predominately pre-hypertensives mix used in the current study. Indeed, when using a pre-hypertensive population, Taylor et al. (2019) showed similar reductions in 24-hour SBP (-11.8 ± 3.5 mmHg) and demonstrated significant reductions in DBP (-5.6 ± 3.3 mmHg) and MAP (-5.7 ± 4.4 mmHg). Taylor et al. (2019) used a cross-over design with 24 participants which reduces the inter-subject variance. Whereas high variance in the current study's AMBP data made the DBP and MAP reduction trends non-statistically significant. Despite this, the clinically significant reductions in 24-hour SBP shown in both intervention groups represent a significant reduction in the risk of all-cause mortality, with a greater association to health outcomes than resting clinical measurements (Benegas et al., 2018). Furthermore, HR-EX showed some potential for improvements in PP (-4 ± 4 mmHg) and showed significant reductions is RPP (-1304 ± 802). Again, these results were similar to the results of Taylor et al. (2019), PP -5.8 and RPP -1119, and represent potential benefits to arterial stiffness and cardiac function respectively. Further to this, O'Driscoll et al. (2017) showed acute improvements in cardiac function and LV performance following a single IWS training session. As such, this potential mechanism of chronic adaptation following IWS interventions warrants further investigation.

7.4.3 RPE vs heart rate prescription

Comparison of each intervention suggests that they were largely equally effective; indeed, there were no significant differences in any of the reductions between intervention groups. Seemingly, the mean seated SBP reductions were greater, although non-statistically significantly, in the HR-EX group compared to RPE-EX (-14 ± 6 mmHg vs -9 ± 6 mmHg respectively); however, this was likely due to the significantly greater baseline SBP recorded in HR-EX group. The HR-EX group also demonstrated greater numbers of participants showing a MCID and a greater number of significant differences in ambulatory measures such as PP and RPP. It is possible that the HR-EX method allows tighter control of and therefore a more consistent training stimulus between participants when compared to the RPE-

EX method. This is supported by greater variability in maximum training HR (% HRpeak), training knee angle (% Prediction) and training squat height (% Prediction) seen in the RPE-EX group. Arguably, this is to be expected, given the use of maximal testing, HR monitoring and the lack of subjectivity in the EI measurement with the HR-EX method. However, it should be noted that these differences in training variables were very small and 100% of RPE-EX participants did show MCID reductions. Therefore, more research is required to examine whether there is any advantage to the HR-EX method. In addition, even if the BP reductions and cardiovascular improvements using the RPE-EX method are more modest, it may still be that the accessibility of the RPE-EX method to a larger proportion of the target population, will make it an overall more effective intervention. It is also possible that participants that are introduced to this type of intervention via the more accessible RPE-EX method will then move on to using the more clinical HR-EX method for further improvements. Indeed, the aim of the RPE intervention is not necessarily to supersede the previous intervention thus rendering it obsolete, but rather is to increase the overall impact of IWS interventions, by working concurrently to increase overall participation.

7.4.4 Training data

There were no significant differences between groups in RPE for any bout, while both groups showed significant increases in peak RPE with each consecutive IWS bout. Despite only being given a single target RPE zone for the final bout of each training session, the RPE-EX group achieved RPE ratings within the target zones, as determined in Study 4 (Section 6.3.2, Page 122), for all 4 exercise bouts. Likewise, despite being given no RPE target zones, when rounded to the nearest 0.5 the HR-EX mean RPE ratings fell within the target zones for each bout; thus, confirming the findings of Study 4 and the efficacy of the suggested target RPE zones to achieve 95% HRpeak EI.

The time in THRR for both intervention groups was similar to that previously shown during IWS training (Wiles et al., 2018), confirming that both groups were prescribed an EI that elicited the required level of training stimulus for an appropriate amount of time per session. There was a non-statistically significant trend in the RPE-EX group for greater time in THRR, likewise, when examining the peak training HR, it would appear that the RPE-EX group were working at a higher percentage of HRpeak than the HR-EX group (94 ± 12% vs 89 ± 8% respectively during training session 12). This may be due to the greater reductions in peak training HR (Table 7.3) seen in the HR-EX group between training sessions 1 and 12, possibly as a result of training adaptations, which also elicited significant reductions in post-training 24-hour ambulatory HR in the HR-EX group, that were not seen in the RPE-EX group.

7.4.5 Limitations

The main limitation of this study was the sample size; unfortunately, due to the COVID-19 lockdown participants were lost and this study was terminated with a reduced number of participants. As a result,

there is an increased risk of type II error and therefore non-statistically significant results must be interpreted with caution, as meaningful results may be incorrectly found to be non-significant due to a lack of statistical power. This may explain some of the non-statistically significant trends in the current data, for example RPE-EX seated resting HR reductions and ambulatory RPP reductions, and the seemingly contradictory statistical findings, for example the significantly lower post 24-hour ambulatory results in the HR-EX group for DBP, HR and PP while the reductions in these variables were not significant when compared to the control. Despite this, statistically significant and clinically important BP reductions were seen in each intervention group when compared to the control. With further research the full magnitude of the effects of these interventions will be elucidated.

Analysis and comparison of training data was limited by the lack of pre-intervention IIWST in the RPE-EX group. While this is a limitation to this study, it was decided that the knowledge and experience of a maximal IWS session, prior to the RPE selection protocol, would affect the prescription process. Additionally, a pre-intervention IIWST would have required the RPE-EX group to complete an additional session meaning they would have received a greater total training stimulus than the HR-EX group. Thus, as the main aim of this study was to assess the effects of the intervention, no baseline IIWST was completed by the RPE-EX group.

A final limitation was the significantly greater baseline BP results and age in the HR-EX group when compared to the RPE-EX participants. It was not possible to counterbalance all participant characteristics in this study as too many existed for the number of participants; therefore, participants were randomised into groups prior to the first testing session (and before baseline BP measurement), with only sex being counterbalanced for the reasons previously explained. Differences in baseline BP must be considered when analysing the effect of training interventions, as it has previously been demonstrated that more pronounced BP reductions occur in participants with higher baseline BP (Millar et al., 2007). Likewise, increased age may have an effect on the results as it is common for SBP to increase progressively with age (Franklin et al., 1997a), often due to atherosclerosis within the arteries, decreased luminal diameter, and reduced arterial elasticity (Mancia et al., 2013; Wilson et al., 1998). As such, participants over the age of 45 years have been shown to present larger reductions in MAP than those under 45 years, while no differences were shown in SBP or DBP reductions (Inder et al., 2016). Taking this into account, it seems likely that the two interventions in this study were equally effective, although further research with a larger sample size is required to examine any possible differences.

7.4.6 Conclusion

Significant reductions in resting and ambulatory BP were seen following a 4-week home-based IWS intervention, using RPE to prescribe and monitor EI, with clinically important BP reductions in 100% of participants. As shown in previous studies the HR prescribed IWS intervention, also elicited significant and clinically important BP reductions. These results confirm the effectiveness of the previous IWS methodology and demonstrates the potential of this new, more accessible, RPE based method, as an effective lifestyle intervention for the prevention of hypertension in both normotensive and pre-hypertensive participants.

CHAPTER 8:

General Discussion

8.1 Summary of thesis findings

This thesis reports findings from 5 novel studies; Chapter 2 outlined a systematic review and meta-analysis of the available evidence for the validity of RPE and the possible moderating variables that affect RPE validity or results. Chapters 4, 5, and 6 explored the relationships between RPE, exercise intensity (EI) and physiological exertion, during the protocols currently in use during isometric wall squat (IWS) training interventions for the reduction of BP, in order to validate RPE for this specific form of exercise. In Chapter 7, the information gained from the previous 4 studies was used to inform a novel prescription method for IWS training using RPE, that may help to make IWS training accessible to a larger audience and consequently increase participation and adherence in this type of exercise. In addition, the effectiveness of the new RPE prescription method was compared to that of the previously validated 95% HRpeak prescription protocol and training methods.

The key findings from the studies included in this thesis were:

1. RPE is a valid and reliable measure of EI and physiological exertion during resistance exercise. RPE validity was unaffected by participant age, sex, training status, and the RPE scale used; conversely, RPE validity was significantly greater during isometric contractions, when compared to dynamic, concentric, or eccentric contractions.
2. RPE from the IES provided a valid and reliable measurement of EI, HR, and BP during the incremental isometric wall squat test (IIWST), which is currently used to prescribe IWS intervention intensities.
3. IES ratings were sufficiently accurate to distinguish between 10° increments in knee joint angle and 30-second time-points during each contraction, during 2-minute discontinuous IWS contractions.
4. During home-based IWS training, RPE was able to distinguish between IWS bouts separated by a 2-minute rest period; this allowed distinct RPE targets for each bout to be set.
5. A 4-week home-based IWS intervention, with EI prescribed and controlled using RPE, was used to successfully produce significant and clinically important reductions in resting and ambulatory arterial blood pressure, in normotensive and pre-hypertensive adults.

8.2 Consolidation of the previous findings relating to the use of RPE during resistance exercise (Chapter 2)

This was the first systematic review and meta-analysis to examine the validity of RPE during resistance exercise. A total of 1217 research articles were screened against the inclusion criteria; 113 studies met the inclusion criteria for the qualitative analysis, with 75 studies eligible for the quantitative analysis. Of these 75 studies, 28 used isometric exercise. The overall weighted mean validity coefficient was very large, $r = 0.880$ (95% CI: 0.842 to 0.910; $p < 0.001$), with an effect size that was greater than was previously shown for aerobic exercise (Chen et al., 2002), and during team-sports (McLaren et al., 2018). Thus, these results suggest that RPE is a valid measure of EI and physiological exertion during resistance exercise, and that RPE may be a stronger indicator of these variables during resistance exercise than during other forms of exercise.

Significant between study heterogeneity was demonstrated. Therefore, moderator analysis was conducted to explore which factors may affect the validity of RPE. Previously, Chen et al. (2002) demonstrated that during aerobic exercise the highest validity coefficients were shown in highly fit, male participants, when maximally exerted, during an unusual task, and when a 15-point Borg scale was used (rather than 21-point, 9-point or CR-10 Borg scales). Conversely, the current analysis showed that participant age, sex, training status, RPE scale used, RPE rating mode, and RPE rating type did not affect the validity coefficients reported during resistance exercise. However, studies that used isometric muscle contractions and those that manipulated EI using workload or repetition time showed significantly higher validity coefficients. In addition, studies that used a larger workload range also showed larger validity coefficients. The reasons for these differences, between aerobic and resistance training, in the effects of moderator variables are unclear and warrant further investigation.

These results demonstrated that RPE could be used equally in participants of any age, sex, and training status without affecting the accuracy or validity of the results. Likewise, the specific RPE scale used did not appear to be as important as previously suggested (Robertson et al., 2003; Colado et al., 2014). These results also suggested that RPE will be most accurate during IE and with manipulation of workload and contraction time, as is the case during IWS exercise and interventions. Additionally, as RPE mode did not affect validity, the previous findings relating to RPE during IWS in estimation mode (studies 2-4) would suggest that RPE will be valid and reliable during IWS exercise in production mode, i.e., when prescribing EI using RPE. Therefore, the results of this meta-analysis supported the development and implementation of an RPE prescribed IWS intervention, in a wider participant population, for example including females, than was previously suggested (Chen et al., 2002).

8.3 Establishing the efficacy of RPE during IWS exercise

The initial studies within this thesis successfully demonstrated the validity and reliability of RPE during laboratory based IWS exercise. As it had previously been suggested that RPE scales should not be used with modalities, materials, populations, or exercise types other than those they have been specifically validated for (Robertson et al., 2003; Colado et al., 2014), and no RPE scales had been validated for use during IWS exercise, this was seen as a necessary first step before any advancements could be made in the development of an RPE prescription method for IWS interventions.

Large concurrent validity coefficients were demonstrated with the criterion measures of EI and physiological exertion during the continuous IIWST (Study 2, Chapter 4) and during individual bouts of IWS exercise at different workloads (Study 3, Chapter 5). These validity coefficients were comparable or greater than those previously shown during IE using the OMNI-RES (Li & Yu, 2011) and CR-10 (Rudroff et al., 2011; Morrin et al., 2018) scales. Likewise, these results were similar to those shown during dynamic resistance exercise using the OMNI-RES scale (Robertson et al., 2003) and the CR-10 scale (Desgorces et al., 2015; Hollander et al., 2003). Consequently, the IES scale provides a valid measure of EI and physiological exertion during IWS exercise, comparable to other widely used and commonly validated scales during resistance exercise.

In addition to the strong relationships shown between RPE and EI, study 3 (Chapter 5) demonstrated that RPE was sufficiently accurate to discern 10-degree differences in IWS workload (knee joint angle) during distinct 2-minute contractions (Section 5.3.2, Page 106). Additionally, this study demonstrated that at each workload, RPE was able to significantly distinguish between 30-second time-points. Previously, significant acute changes in HR and BP were detectable with 10-degree differences in IWS knee joint angle, but not with 5-degrees changes (Goldring et al., 2014). As such, Goldring et al. (2014) proposed that isometric wall squat intensity can be altered by manipulating knee joint angle, which will consequently also reliably alter the physiological response (HR and BP) and thus exercise stimulus. Subsequently, Wiles et al. (2017) and Taylor et al. (2019) used these relationships to prescribe and monitor IWS training to significantly lower BP. The current results suggest that in the same way, RPE will reliably represent changes in knee joint angle and contraction time, such that RPE may be used to control and monitor these changes in EI during IWS training. Moreover, these results indicate that RPE can also make these distinctions during the first 2-minute contraction of an IWS session, which could be important during the RPE prescription process.

Study 2 demonstrated excellent agreement between the IES results and ratings from the Borg CR-10 scale (Section 4.3.4, Page 93). While the CR-10 scale has not previously been validated as a measure of EI or physiological exertion during IWS exercise, it has been validated as a measure of perceived

exertion during numerous other modes and types of exercise. As such, the CR-10 scale is widely used and accepted as a valid perceptual measurement tool and is regularly used as a criterion metric for RPE; even for modes of exercise that it has not itself been concurrently validated for (Lagally & Robertson, 2006). Therefore, the strong correlation shown between the IES and CR-10 results demonstrates the construct validity of the IES as a measure of perceived exertion. It has previously been proposed that for an RPE scale to be considered a valid measure for use in the clinical and/or health-fitness setting, it must demonstrate both concurrent and construct validity, evidenced by strong positive correlations with physiological variables (e.g., HR) and a previously validated criterion scale respectively (Mays et al., 2010). Consequently, the results of these studies suggest that the IES is sufficiently accurate for use in a clinical setting as demonstrated by concurrent validity with the criterion measures of performance (EI) and physiological exertion (HR and BP), the ability to distinguish IWS workloads and time-points, and the construct validity shown with the CR-10 scales during the IIWST.

Both studies 2 (Section 4.3.5, Page 94) and 3 (Section 5.3.4, Page 109) demonstrated excellent between session reliability in RPE results. In both cases, lower variance and higher agreement values were seen at higher intensities, closer to those used during IWS interventions for BP reduction. These studies were the first identified to measure reliability over a longer period, up to one month, and over 4 and 6 sessions for study 2 and 3 respectively. In contrast, the majority of previous reliability evidence is from a single test-retest between 2 sessions (Day et al., 2004; Colado et al., 2012; 2014). Despite this, the reliability coefficients demonstrated in studies 2 and 3 closely matched the findings of previous studies using different RPE scales and resistance exercise modalities, such as during various strength exercises using the CR-10 scale (Day et al., 2004), explosive resistance exercise using Borg's 6-20 scale (Row et al., 2012), during elastic band exercise using a modified OMNI-RES scale (Colado at al., 2012), and using the Thera-band Resistance Exercise scale during elastic band exercise (Colado et al., 2014).

Additionally, when compared to the reliability shown by the CR-10 scale (Study 2), the IES showed statistically lower variation and significantly higher ICC scores at the 3 highest workloads (115°, 105° and 95°), possibly due to the simpler closed-ended nature of the IES when compared to the open-ended CR-10. As these intensities are more representative of the intensities used during IWS training for reducing resting blood pressure (Goldring et al., 2014), it was suggested that the IES may be more appropriate for use during the remaining studies in this thesis.

While there were no significant differences in RPE results between repeated sessions in either study 2 or 3, study 2 did demonstrate significant differences in CoV and ICC measurements between sessions 1-2, when compared to between sessions 2-3 and 3-4. This indicated a learning effect following the first session and suggested that habituation with the IWS exercise and RPE was required before a stable relationship was achieved. Thus, study 3 implemented a habituation session prior to the first testing

session and as a result of this no significant differences in variance or agreement values were seen between repeated sessions.

Consequently, RPE from the IES demonstrated both validity and reliability as a measure of EI and physiological exertion in a laboratory-based setting. Additionally, RPE can distinguish IWS workloads and time-points to the same resolution as was previously demonstrated for HR and BP. As such, these results supported the use of RPE as a replacement for HR and knee joint angle in the prescription of IWS EI, in order to create a more accessible version of the current IWS intervention.

8.4 Assessing the implementational effectiveness of RPE during home-based exercise

A criticism and limitation of previous RPE validity research is that it only demonstrates laboratory-based efficacy, with ideal conditions and controls, which may lead to artificially high validity and reliability coefficients that are unrealistic or impossible to achieve in the real world (Beedie et al., 2015). As such, to build on the efficacy findings of studies 2 and 3, study 4 (Chapter 6) was the first study to assess the implementational effectiveness of RPE as a measure of EI during un-supervised home-based resistance exercise, and specifically IE training.

A large validity coefficient was demonstrated (Section 6.3.2, Page 122) for the relationship between RPE and wall squat duration, which in this case represented an increasing EI (workload x time under tension). This effect size was similar to those shown during lab-based dynamic squatting exercise (Zourdos et al., 2016) and during laboratory-based IWS exercise (Chapters 4 & 5). Likewise, the RPE ratings showed excellent reliability between the three training sessions (Section 6.3.4, Page 124). Indeed, the between session agreement was greater than laboratory-based results previously shown for the Borg 6-20 (Row et al., 2012) and OMNI-RES scales (Colado et al., 2012; 2014).

Heart rate demonstrated moderate positive relationships with wall squat duration and RPE (Section 6.3.3, Page 123). These relationships were not as strong as the relationships shown for HR with EI and RPE when compared to studies 2 and 3 (chapter 4 & 5). However, this study was the first to use an exercise protocol involving rest periods and it is likely that differences in participant recovery rates between bouts are likely to have affected the strength of the relationships. Because of this, it has previously been suggested that during intermittent activity such as resistance training, HR is less accurate as a measure of EI due to the recovery periods, when compared to during continuous exercise (Kraft et al., 2014a). In addition to this, the relationship between HR and RPE was not as strong as previously shown with laboratory-based measures of physiological exertion during intermittent IHG exercise (Morrin et al., 2018). However, increased variance is arguably to be expected when analysing unsupervised home-based RPE ratings and HR measurement methods.

Ratings of perceived exertion, from the IES, were sufficiently accurate and reliable to monitor EI during unsupervised home-based IWS training. The results may also suggest that RPE can provide a better

representation of group exertion and workload than HR during intermittent IWS training. Thus, these results demonstrated the implementational effectiveness of RPE in the environment of its intended use; therefore, it was reasonable to move on to test the treatment effectiveness of an RPE prescribed IWS intervention in the home.

8.5 Quantification of the relationships between RPE, EI and physiological exertion

It has previously been suggested that the theoretical RPE ratings expected at relative loads of, for example, 10%, 30%, 50%, 70% and 90% of maximum would correspond to RPE ratings of 1, 3, 5, 7, and 9 out of 10 respectively (John et al., 2009). However, as suggested by Borg (1998), these relationships are not always simple and linear in this way. Therefore, it was vital to quantify and understand the relationships between perceptual, performance and physiological responses to effort, to use these data to accurately prescribe and control EI (Borg, 1998).

Study 2 (Chapter 4) allowed the formulation of regression models for the relationships between RPE, HR and EI during the IIWST. The regression models for the IES more closely matched the theoretical predictions (John et al., 2009), when compared to results from the CR-10. The differences between theoretical and actual RPE ratings are termed "scaling error" (John et al., 2009). Thus, RPE from the IES showed reduced scaling error when compared to the CR-10. In addition, the scaling error shown by the IES reduced as EI increased, with the smallest differences between theoretical and actual RPE ratings seen at maximum, suggesting that at the intensities used during IWS interventions (95% HRpeak) RPE will be close to its maximum accuracy.

Linear regression of RPE and submaximal EIs has previously been used to predict 1RM in novice weightlifters, with no significant differences shown between the predicted and measured 1-RM (Eston & Evans, 2009). As such, it is suggested that submaximal RPE ratings can be extrapolated to predict maximum exertion and prescribe EI at specific relative loads with sufficient accuracy for health promotion (Buckley & Borg, 2011), as is required for prescription of IWS interventions using RPE. Using the regression equation produced for RPE (from the IES) and HR (Section 4.3.3, Page 91), it was suggested that an RPE rating of 8.4/10 (8.5 to the nearest whole RPE rating) would correlate to 95% HRpeak, the intensity used during IWS exercise interventions for BP reduction (Wiles et al., 2010, 2017; Taylor et al., 2019). This result was then confirmed experimentally during home-based training at 95% HRpeak (Study 4, Chapter 6), with peak RPE value of 8.5/10 obtained at the end of the final bout of the training sessions. This result demonstrates that the relationships between RPE, EI and HR were stable across different modes of IWS exercise, i.e., continuous incremental IWS and intermittent constant load IWS; suggesting that these relationships could be used to reliably prescribe IWS exercise intensities.

In addition to providing a target peak RPE value, study 4 demonstrated that RPE increased significantly with each consecutive 2-minute wall squat bout, during each of the training sessions; thus, demonstrating that RPE was sufficiently accurate to discern between bouts performed at the desired 95% HRpeak intensity in the home. This result was important because if RPE was not sufficiently accurate to distinguish individual IWS bouts at the correct intensity, then prescription using a sessional RPE rating or peak RPE-AM results for the entire session may have been necessary. Instead, these results demonstrated that peak RPE-AM can be used at the end of each bout to monitor and adjust IWS EI. As such, the target peak RPE ratings for each bout (Section 6.3.1, Page 122) were then used during the RPE prescription protocol (Chapter 7) to adjust squat height and prescribe the desired training EI.

8.6 The treatment effectiveness of a 4-week RPE controlled isometric wall squat intervention (Chapter 7)

8.6.1 Summary of findings

The primary aim of this thesis was to determine whether a 4-week home-based RPE prescribed and controlled IWS intervention could successfully lower arterial BP. All 10 RPE-EX participants showed a minimum clinically important difference (MCID) in at least one of the BP measures. Moreover, 8 of the RPE-EX participants were classified as Pre-HTV at baseline, with only 2 participants remaining Pre-HTV following the intervention.

The significant reductions demonstrated in the RPE-EX group in seated (SBP: -9 ± 6, DBP: -6 ± 4, MAP: -6 ± 3 mmHg) and supine (SBP: -7 ± 4, DBP: -8 ± 5, MAP: -8 ± 4 mmHg) resting BP measurements were greater than those previously reported for laboratory-based IE interventions (Inder et al., 2016) in a mixture of hypertensive (medicated and un-medicated), pre-hypertensive and normotensives participants (Smart et al., 2019). Likewise, significant reductions were shown in 24-hour (-8 ± 7 mmHg) and daytime (-9 ± 8 mmHg) ambulatory SBP in the RPE-EX group when compared to the control group. These results were similar to the ambulatory SBP results demonstrated by Taylor et al. (2019) following a 4-week HR prescribed IWS intervention.

8.6.2 Clinical implications of the induced BP reductions

Blood pressure reductions matching or exceeding the MCID (5 mmHg), as shown in this study, are associated with significant reductions in the risk of developing HTN and CVD (Prospective Studies Collaboration, 2002; Whelton et al., 2002), as well as a 10% reduction in the risk of myocardial infarction, stroke, and mortality (NICE, 2011). However, it has been suggested that even smaller reductions can also have a significant and meaningful clinical health benefit for those with and without hypertension (Millar et al., 2014). For example, a 2-mmHg reduction in SBP or DBP has previously been shown to a decrease the risk of developing hypertension (17%), coronary heart disease (5-6%), stroke (15%), and reduced the all-cause mortality risk by 3% (Cook et al., 1995; Stamler, 1997). In

addition to inducing these benefits in 100% of the intervention participants, 6 of the RPE-EX participants were re-classified as NTV following the intervention, which is associated with further health risk reductions, in addition to receiving the MCID reductions alone (Vasan et al., 2001b).

Significant reductions were also shown in ambulatory SBP, with 7 out of 10 RPE-EX participants receiving a MCID. It has previously been suggested that AMBP is a stronger predictor of future BP related cardiac damage (Protogerou et al., 2014), cardiovascular events, and final cardiac outcome than a single clinical measurement (Pickering et al., 2006; Fagard et al., 2008; O'Brien, 2011). In addition, 24-hour SBP is more strongly associated with all-cause mortality than clinical measurement of SBP, irrespective of age, sex, obesity, diabetes, cardiovascular disease, and anti-hypertensive treatment (Benegas et al., 2018).

These results indicate that this 4-week RPE prescribed IWS intervention was successful in significantly reducing the health risks associated with elevated BP, in this group of NTV and Pre-HTV participants. The majority of IE studies have demonstrated the efficacy of interventions when conducted under optimal laboratory-based conditions. As such, the generalisability of these results is limited (Sharp et al., 2019) and the methods used are often impractical in the real world (Beedie at al., 2015). This was the first study to demonstrate the effectiveness of an RPE prescribed IE intervention in the real-world setting in which it is intended to be used, i.e., in the home. As such, these results support the use of such an intervention to prevent HTN and to reduce the health risks associated with elevated BP.

This intervention may help to remove several of the remaining barriers to participation present in the previous IWS intervention methods. For example, this intervention does not require maximal or submaximal exercise testing and all the equipment used is readily available in most houses. In addition, whilst this intervention study did involve some laboratory visits for collection of data, it is possible that this intervention can be conducted without input from any researchers or exercise professionals, and therefore without the need for any laboratory or gym visits whatsoever. Therefore, this study has identified an effective and accessible means to establish and monitor appropriate training intensities (Gearhart et al., 2011) that can reduce the time burden, cost and fear of judgment that prevent many people from participating in exercise interventions (Zunft et al., 1999; Salmon, 2001), which may increase uptake and adherence (Baddeley-White et al., 2019), and consequently the overall effectiveness of this intervention.

8.6.3 Potential mechanisms for the reductions in arterial BP following IWS training

It is well established that MAP is determined by the interaction of Q and TPR (Pescatello et al., 2004; Millar et al., 2014), thus any changes to BP will be associated with changes in Q and/or TPR. The reductions in BP shown in Chapter 7 were accompanied by a non-statistically significant trend for reduced TPR. Indeed, in the HR-EX group, post-intervention TPR was significantly lower than at baseline, while the reductions (delta scores) were non-statistically significant. This trend may highlight

a potential mechanism of action for the reductions in BP through chronic reduction in TPR, as shown in Pre-HTV participants by Taylor et al. (2019). In support of this, it has previously been suggested that the majority of the anti-hypertensive benefits of IE are due to reductions in TPR (Carlson et al., 2014). These TPR reductions may occur due to the repeated stimulation of the acute IE exercise and PEH responses (as outlined in Section 1.4.4), leading to permanent adaptations caused primarily by changes in autonomic regulation (Taylor et al., 2003; Badrov et al., 2013a; Millar et al., 2013), improvements in endothelial function (McGowen et al., 2007a, 2007b; Badrov et al., 2013a), and structural vascular adaptations (Baross et al., 2012).

Taylor et al. (2019) demonstrated a 47% increase in BRS following 4-weeks of IWS training. This chronic resetting of the baroreceptors to a lower activation point, as seen acutely after IE (Halliwill et al., 1996b; 2013), is thought to have led to an increase in vagally mediated parasympathetic activation and a decrease in sympathetic activity (Taylor et al., 2019). Previously, Millar et al. (2013) demonstrated increase in vagal tone, demonstrating an increase in parasympathetic activation. Likewise, Taylor et al. (2003) demonstrated a reduction in the LF/HF component of HRV following 10-week of IHG, indicating similar increases in parasympathetic activity and reductions in sympathetic activation, leading to reductions in sympathetic controlled vasoconstriction and consequently TPR (Coats et al., 1992; Grassi et al., 1994). Moreover, the magnitude of the increase in BP seen during an IE training session has been shown to be attenuated following IE interventions (Badrov et al., 2013b; Gandhi, 2016). This attenuated response has been linked to reduced post-IE sympathetic nerve activity (Somers et al., 1992), which may reflect the improved capacity of the baroreflex to buffer acute BP rises (Badrov et al., 2013b).

Badrov et al. (2013a) reported increases in endothelial function following IHG training, which may lead to reduced arterial stiffness, improvements in arterial compliance (Cameron & Dart, 1994; Silva et al., 1997) and chronic increases in arterial diameter in the trained limb (Baross et al., 2012). It has been postulated that sheer stress on the endothelium during IE causes an increase in the release of vasodilating agents, such as NO (Jungersten et al., 1997; Raitakari & Celermajer, 2000), prostaglandins and histamine (Tinken et al., 2010), leading to increases in flow mediated vasodilation, improved endothelial function, and reduced TPR. In support of this, McGowan et al. (2007) measured improvements in NO dependent vasodilation in the trained arm only following unilateral IHG in medicated hypertensives, suggesting a localised response in trained muscles. Taylor et al. (2019) demonstrated an increase in NO bioavailability and associated vasodilatory capacitance, through a reduction in endogenous inhibitors of NO syntheses (NOS), following an IWS intervention.

Oxidative stress negatively affects the delivery of vasodilatory substances to blood vessels, including attenuated production of endothelial NOS (Laufs et al., 2005). Significant reductions in oxidative stress have been reported following 6-weeks of IHG training (Peters et al., 2006). It has been demonstrated

that repeated bouts of acute ischaemia, as seen during IE contractions, causes an elevation in antioxidant activity and a reduction in oxidative stress (Santangelo et al., 2003), which may lead to increased production of NOS, bioavailability of NO, and NO dependent vasodilation. In addition to reductions in oxidative stress, Taylor et al. (2019) demonstrated reductions in the inflammatory cytokine IL-6, following the IWS intervention. Over expression of IL-6 is linked to a down regulation in NOS and consequently NO bioavailability (Achan et al., 2003; Libby, 2002); therefore, reduction in IL-6 may be associated with improvements in vasodilatory capacity. It should be noted that Taylor et al. (2019) did not find significant differences in several other inflammatory markers, thus the role of inflammation in the improvements seen in endothelial function requires further investigation.

Finally, increases in endothelial function and arterial compliance are positively associated with BRS (Monahan et al., 2001a). Increased compliance in the aortic and carotid arterial vessels may in turn increases the discharge of the baroreceptor cells (Kingwell et al., 1997), contributing to the chronic increases demonstrated in BRS.

Many of these mechanisms have been demonstrated acutely following IE; however, further research is required to confirm the underlying mechanisms behind chronic BP reductions in Pre-HTV participants and to explore whether these mechanisms vary in different groups such as NTV participants.

8.6.4 Contextualizing the treatment effectiveness of the 4-week RPE prescribed IWS intervention

The most commonly used IE interventions have involved the use of a handgrip protocol (Millar et al., 2008), while earlier leg training interventions have used isometric leg extension (ILE) exercise (Devereux et al., 2010; Wiles et al., 2010; Baross et al., 2012). It has previously been suggested that activation of a larger muscle mass is accompanied by greater central and peripheral drive which induces greater cardiovascular and pressor responses (Galvez et al., 2000). This may explain the similar reductions demonstrated in BP following low intensity ILE interventions when compared to higher intensity IHG interventions (Howden et al., 2002). When compared to the mean proposed reductions following IHG (Smart et al., 2019; Loaiza-Betancur & Chulvi-Medrano, 2020) and ILE (Smart et al., 2019) interventions, the results of the current study along with the previous finding of Taylor et al. (2019) suggest that IWS interventions may produce greater reductions in a shorter timeframe. This demonstrates a potential advantage of IWS exercise compared to IHG and ILE, possibly due to the additional isometric recruitment of postural and stabilising muscles when holding the constant position wall squat (Contreras, 2013). The use of IHG training for BP management and cardiovascular health is now endorsed by the American Heart Association (Brook et al., 2013), which further highlights the potential usefulness of IWS exercise, especially in the current RPE prescribed format that makes it assessable to wider participation.

The most widely recommended form of exercise for BP reduction is aerobic exercise; however, dynamic resistance exercise is also commonly recommended for its range of health benefits including BP

reduction (Pescatello et al., 2004; Cornelissen & Fagard, 2005b; Cornelissen et al., 2011; Cornelissen & Smart, 2013). It has previously been demonstrated that aerobic exercise interventions are an effective method of reducing BP, with suggested mean SBP/DBP reductions ranging from -3.5/-2.5 mmHg (Cornelissen & Smart, 2013) to -11/-5 mmHg (Borjesson et al., 2016). Likewise, dynamic resistance training is suggested to elicit mean SBP/DBP reductions ranging from -1.8/-3.2 mmHg (Cornelissen & Smart, 2013) to -3.9/-3.9 mmHg (Cornelissen et al., 2011). As such, the results for the current IWS intervention (seated: -9/-6 mmHg and supine: -7/-8 mmHg, SBP/DBP), were comparable or greater than previously suggested for aerobic and dynamic resistance exercise interventions. Moreover, IWS training elicited these reductions following an intervention that was shorter in length (4 weeks vs 4-52 weeks) and with much shorter average training sessions (14-mins vs 40-60 mins) (Cornelissen et al., 2011; Cornelissen & Smart, 2013). It has previously been suggested that IE interventions are the most effective and time efficient type of exercise intervention to achieve clinically important BP reductions (Cornelissen & Smart, 2013; Millar et al., 2013) and the current results would suggest that this is also the case with RPE prescribed IWS interventions. Thus, the lower time commitment, coupled with the simplicity of the intervention and the lower cost, may contribute to increased adoption and adherence to the intervention (Carlson et al., 2014).

In Pre-HTV individuals (with a baseline BP of 130 mmHg) a two-drug anti-hypertensive treatment showed similar reductions (-10.2 mmHg) in SBP (Law et al., 2009) to those shown in the current study following the IWS intervention. However, medication requires daily administration and will require lifelong adherence to successfully control BP to within clinical target ranges (Heidenreich et al., 2011), which comes at a considerable expense (Chobanian et al., 2003; Sarafidis, 2011; Mills et al., 2015). In addition, the use of BP medication often comes with unpleasant side effects, such as headaches, dizziness, coughing and fatigue (Khurshid et al., 2012). As a result, adherence to BP medication treatment is poor (Caro et al., 1999), with estimations that between 50 and 70% of diagnosed patients are not controlled to within clinical target ranges (Chobanian et al., 2003; Sarafidis, 2011; Mills et al., 2015). Similarly, exercise interventions will likely require life-long adherence, although this may be intermittent in nature and at a lower level and/or frequency. Moreover, in contrast to medication the current RPE based intervention can be conducted for free, has no known side effects, and may in fact come with additional positive physiological (e.g. increased strength) and psychological benefits, in addition to lowering BP. Additionally, anti-hypertensive medication is not typically prescribed until the patient has considerable health risks, e.g. SBP/DBP $\geq$ 160/100 mmHg (NICE, 2011), whereas exercise interventions can be used to reduce the development of HTN and health risks much earlier for no cost. Therefore, for some participants IWS may be the most viable long-term option to help manage BP, reduce health risks, and thus reduce the need for medication (Millar et al., 2013).

8.7 Limitations

As previously discussed in Chapter 7, the final study of this research project had to be stopped early due to the COVID-19 pandemic, and therefore was underpowered. As a result, there is an increased risk of a type II error, i.e., that variables showing non-statistically significant differences may have correctly shown statistical significance in a full power study. This increase in non-statistically significant findings, meant that the final study was limited in its ability to explore variables that could provide a mechanistic explanation for the observed chronic BP reductions in this population, as was achieved previously by O'Driscoll et al. (2017) and Taylor et al. (2019). As such, the mechanisms that regulate the reductions in resting and ambulatory BP following IE interventions remain unclear (Millar et al., 2013; Smart et al., 2019). However, the main aim of this study was to examine the effectiveness of an RPE prescribed IWS intervention to induce BP reductions, which this study was able to do despite being underpowered. While it is important for future research to explore and fully understand the mechanisms behind these BP benefits, it is also noted that individuals with HTN or Pre-HTN can benefit from this short duration, cheap, and accessible form of exercise without the need for a definitive mechanistic explanation (Carlson et al., 2014).

While this thesis was able to successfully reduce arterial BP with an RPE based IE intervention, there is still a lack of understanding as to the long-term effects of these interventions, whether these BP benefits can be maintained long-term, and if so, what level (workload and volume) of exercise is required to do so. As such, the advantage of this short duration intervention, may be coupled with the disadvantage of short-lived benefits. Indeed, when exercise is stopped following an IE intervention, Taylor et al. (2017b) demonstrated that BP had returned to baseline within 3-weeks, Wiley et al. (1992) found that BP reductions were lost after a period of 10 days, and Deveraux et al. (2015) reported that benefits were lost in as little as one 1-week. In addition, the longest IE interventions to date have shown that significant BP reductions can be induced and maintained over a period of 10 (Badrov et al., 2013b; Taylor et al., 2003) to 12-weeks (Hooi et al., 2020), but no studies have examined the effects of IE over a longer duration. Lawrence et al. (2015) suggested that it may be possible to reduce overall training volume and/or workload, while still maintaining the improved BP level long term. However, this suggestion has not yet be substantiated. As such, if IE interventions are to be a useful tool in the long-term management of HTN, the effects over a period of at least 1-year (Loaiza-Betancur & Chulvi-Medrano, 2020) should be investigated.

While conducting the first three experimental studies (Chapters 4-6) to validate RPE for use during IWS exercise, the need for a comprehensive systematic review and meta-analysis of RPE use during resistance exercise was identified. It was hoped that this review and meta-analysis would help to clarify the apparent contradiction between individual RPE studies. While it is more common for a full systematic review and/or meta-analysis to be conducted at the start of a thesis to inform the work, based

on the suggestions of Borg (1998), Robertson et al. (2003), and Colado et al. (2014), the priority of the preliminary experimental studies in this thesis was to ensure that RPE was valid for this specific type of exercise before any inferences about RPE could be made based on previous research. This order of operations had the necessary limitation that studies 2-4 could not be informed by the finding of the meta-analysis in terms of, for example, the effects of moderator variables such as training status, age, and sex. As such, the participant groups used in studies 2-4 were relatively homogeneous, young, and were all male.

As stated above, studies 2-4 (Chapter 4-6) did not include female participants due to concerns surrounding the effect of the menstrual cycle on BP and possible differences in RPE and BP responses. Based on the results of Study 1 (Chapter 2), suggesting that participant sex did not affect the validity or magnitude of RPE responses, and evidence that significant BP reductions can be elicited in both sexes following IE (Carlson et al., 2016; Farah et al., 2018; Souza et al., 2018), females were included in the final intervention study. As a result, the data collected during the first three studies, from all male participant groups, was then applied to a mixed sex intervention group. Whilst the results of our meta-analysis and recent research would suggest that these results can be applied to both males and females equally, the inclusion of females in the initial three experimental studies would only have strengthened the applicability of and confidence in the results. More recently, an additional meta-analysis has confirmed that the BP reductions seen following IE interventions are not sex dependant (Smart et al., 2019), further strengthening the argument for the inclusion of both sexes in subsequent IE intervention studies.

8.8 Future directions

Future research should examine the implementation of the RPE prescription method without direct input from a researcher or exercise professionals. This could be done, by providing the participants with instructions via a mobile phone app, written instructions, or online videos. An acute study could assess how well participants can understand the instructions, whether the exercise is carried out correctly, and whether the correct exercise stimuli are elicited. Following which, a fully autonomous home-based IWS intervention could be implemented with no intervention from the researcher or laboratory testing other than to clinically assess baseline and post-intervention BP and cardiovascular measurements.

This thesis showed that RPE prescribed IWS can be used in a majority Pre-HTV population to decrease health risks and help to prevent the development of HTN. Future research should examine whether this intervention can be used to successfully and safely treat HTN, by lowering the BP of a HTV population down to a Pre-HTV or NTV level. Based on the positive results following IE demonstrated in previous research using HTV populations (Taylor et al., 2003; Peters et al., 2006; McGowan et al., 2006, 2007; Badrov et al., 2013b; Millar et al., 2013), and the suggestion that the greatest benefits following IE are

seen in HTV populations (Whelton et al., 2002; Cornelissen & Smart, 2013; Loaiza-Betancur & Chulvi-Medrano, 2020), it is probable that IWS exercise would elicit similar responses.

The exaggerated pressor response experienced during IE (Mitchell & Wildenthal, 1974), is a concern to some especially when implementing exercise interventions in HTV individuals (Ewing et al., 1973). While it is noted that no adverse reactions have been reported during or after IE interventions, such as unfavourable clinical events or lasting physical impairments (Millar et al., 2013; Taylor et al., 2019), it may still be favourable to use lower intensity interventions in this population. Moreover, while a fast 4-week intervention may be attractive to some looking for more of a 'quick fix' option, it is possible that a lower intensity intervention over a longer period would be more attractive to others, regardless of starting BP status. In addition, as previously discussed, a longer intervention may allow the benefits of IE to be enjoyed and maintained over a longer period, thus increasing the overall health benefits. As such, an RPE prescribed intervention at a lower EI should be explored. Isometric leg extension interventions have previously been shown to be effective over an 8-week period, when prescribed at 75% HRpeak (Wiles et al., 2010) and 85% HRpeak (Baross et al., 2012), in NTV and Pre-HTV populations respectively. Using the regression equation from study 2 (Chapter 4), target peak RPE values at the end of the final IWS bout of 4.5/10 (75% HRpeak), 5.5/10 (80% HRpeak), or 6.5/10 (85% HRpeak) could be explored. During longer interventions, the use of RPE would allow squat height to be adjusted, as required, to maintain a constant relative EI, despite any improvements in squatting ability, without the need for exercise testing to assess improvements and recalculate EI.

Finally, the RPE prescription method should be implemented during different modes of IE, for example IHG, elbow flexion/extension, leg flexion/extension, core training (Hooi et al., 2020), and/or standing pectoral fly (Anastasio, 2020) exercise. This may allow the benefits of RPE prescribed IE to be elicited in people who are physically unable to complete IWS exercise. Additionally, localised improvements in vasodilation were previously shown in the exercising muscle only, when compared to a control limb (McGowan et al., 2007), therefore the combination or variation of different exercises and muscle groups, may allow stimulation and adaptation of the vasculature in multiple locations, which may allow longer term benefits to TPR to be experienced and more global improvements in vascular health (e.g., increased arterial compliance). Moreover, this variation in the exercise mode may help to maintain motivation and therefore increase adherence compared to a single mode of IE.

8.9 Reflections

The purpose of this research was to use perceptual responses, i.e., RPE, to try and create a more accessible method of prescribing and implementing home-based IWS exercise. It was never an aim of this research to design and/or create a new RPE scale. As outlined in section 4.1, the CR-10 was the scale currently used in IWS research. However, I did not want to use the CR-10 by default and assume it would be the best RPE scale for this form of exercise. It was also suspected that the open-ended nature

of the CR-10 may make exercise prescription more difficult in the early sessions due to the possible recalibration of the scale following a score of more than 10. Finally, the CR-10 is exponential in nature, so there was a potential that a linear scale would correlate better with HR, the primary physiological variable used to prescribe IWS exercise. Therefore, a second scale was required to compare to the CR-10. Rather than picking another un-validated scale to compare the CR-10 to, features from several scales that were potentially beneficial for isometric exercise were collated and adapted. Indeed, this research did not actually create a new scale, as outlined in section 3.6.1.1, the numerical part of the IES is a simple 0-10 numerical scale, the verbal descriptors came from a modified CR-10 scale further adapted to fit a linear scale, and TTF is a modification of the concepts of estimated time limit and repetitions in reserve, adapted into a percentage scale to allow easier use with different IE intensities.

Building on the early work of E.H. Weber, G.T. Fechner, and S.S. Stevens in the 19th and 20th centuries (Nobel and Robertson, 1996), Gunnar Borg developed the first perceived exertion scales for use during exercise, the Borg 6-20 scale and the Borg CR-10 scale (Borg, 1998). Starting in the 1950's, Borg and his colleagues spent decades designing and validating the numerical and verbal parts of these scales, and quantifying the power relationships between the perceived, physiological, and performance variables (Borg 1998). All subsequent RPE work has built on the ground-breaking work of Borg and his colleagues. As such, it was never the intention of this thesis to attempt to replace or supersede the CR-10 scale, rather to build on the use of RPE in home-based exercise interventions for blood pressure.

In actuality, the RPE scale used was of little concern to this research, so long as the tool used was valid and reliable during this type of exercise. As such, once Study 2 (Chapter 4) had demonstrated a small benefit to reliability when using the IES over the CR-10, with equal validity shown by the two scales, it would have been incorrect to ignore the evidence and use the CR-10 regardless: especially in the context of a PhD thesis. As demonstrated in Chapter 2, the validity of RPE was independent of the scale used. Therefore, it should be acknowledged that the results seen in the final study (Chapter 7) could have been achieved if the CR-10 or any other RPE scale was used.

It is hoped that this work will be built upon and that accessible RPE based exercise interventions, regardless of the scale used, will be implemented in the general population to bring genuine improvements in people's health and wellbeing.

8.10 Conclusion

The work completed within this thesis has demonstrated the validity and reliability of RPE to represent EI and physiological exertion during various IWS protocols, that are currently used during BP reduction interventions. Moreover, this work expanded the understanding of the efficacy and effectiveness of RPE during resistance exercise, including elucidating the factors that potentially do (contraction type and EI variable manipulated) and do not (participant sex, age, training status, and RPE scales used) affect the validity of RPE during resistance exercise.

The increased understanding of RPE during IE, gained throughout the first 4 studies, was used to successfully develop an RPE based prescription method for IWS exercise. Subsequently, a 4-week home-based IWS intervention, using this RPE prescription and monitoring method, was successful in producing statistically and clinically significant resting and ambulatory BP reductions in 100% of the intervention participants. These BP reductions are associated with significant reductions in the risk of CVD, stroke, MI, kidney disease, and mortality. Furthermore, this novel prescription method may make the current IWS exercise more accessible to a larger population and helps to remove barriers that have previously been shown to reduce adherence to exercise interventions. These changes could potentially increase the overall effectiveness and impact of IE and IWS interventions for the prevention and treatment of high BP; thus, reducing the medical and economic burden of HTN and the associated CVD.

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Appendix 1:

Canterbury Christ Church University

15 October 2015 Ref: 15/SAS/223

Mr John Lea
c/o School of Human and Life Sciences
Faculty of Social and Applied Sciences

Dear John

Project Title: ***An investigation into the role and relevance of rating of perceived exertion (RPE) in isometric exercise training prescription to reduce resting blood pressure.***

The Faculty of Social and Applied Sciences Research Ethics Committee reviewed your application during July 2015, and agreed to grant approval once certain amendments and clarifications were made.

The Chair of the Committee is content that the amendments and clarifications submitted meet the Committee's requirements in full. I am therefore writing to confirm formally that you can commence your research. Any significant change in the question, design or conduct of the study over its course should be notified to the **Research Office**, and may require a new application for ethics approval. This approval is conditional on you informing me once your research has been completed.

With best wishes for a successful project.

Yours sincerely

Roger Bone

Roger Bone
Research Governance Manager
Administrator, Faculty of Social and Applied Sciences Research Ethics Committee
Research Office, Eg21
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Professor Rama Thirunamachandran, Vice Chancellor and Principal

Appendix 2:

Section of Sport and Exercise Sciences

Informed Consent & Health and Fitness Questionnaire

Name: ……. **Postcode: ……..**

Date of Birth: …… **Age: ……** **Sex: ……..**

Please answer the following questions by circling the appropriate response and if necessary, providing extra information in the spaces provided.

ANY INFORMATION CONTAINED HEREIN WILL BE TREATED AS CONFIDENTIAL

1. How would you describe your present level of fitness?

Untrained / Moderately trained / Trained / Highly trained

2. Average number of hours spent exercising ……..……. **per week**

3. How would you describe your present bodyweight?

Underweight / Ideal / Slightly overweight / Very overweight

4. How would you describe your smoking habits?

Non-smoker / Previous smoker / Currently smoking

5. How would you describe your alcohol intake?

Never Drink / An occasional drink / A drink every day / More than one drink a day

(Note 1 drink = 1 unit)

6. Have you had to consult your doctor within the last six months? **Yes / No**

If you have answered **yes**, please give details: …….

7. Are you presently taking any form of medication? **Yes / No**

If you have answered **yes**, please give details: ……

8. Do you suffer, or have you ever suffered, from any of the following?

a. Diabetes	**Yes / No**	b. Asthma	**Yes / No**
c. Epilepsy	**Yes / No**	d. Bronchitis	**Yes / No**
e. Any form of heart complaint	**Yes / No**	f. Serious Back or Neck Injury	**Yes / No**
g. High blood pressure	**Yes / No**	h. Aneurysm[1] or Embolism[2]	**Yes / No**

1: Arterial wall weakness causing dilation. 2: Obstruction in the Artery.

9. Is there a history of heart complaint in your family? **Yes / No**

If you have answered **yes**, please give details: ……

10. Do you have any allergies? **Yes / No**

If you have answered **yes**, please give details: ……

11. Do you currently have any form of muscle or joint injury? **Yes / No**

If you have answered **yes**, please give details: ……

12. Have you had to suspend your normal training/physical activity in the last two weeks? **Yes / No**

If you have answered **yes**, please give details: ……

INFORMED CONSENT

The full details of the tests have been explained to me. I am clear about what will be involved, and I am aware of the purpose of the tests.

I know that I am not obliged to complete the tests. I am free to stop the test at any point and for any reason.

The test results are confidential and will only be communicated to others such as my coach if agreed in advance.

As far as I am aware, there is nothing that might prevent me from successfully completing the tests that have been outlined to me.

Signature of Participant: ……...

Signature of Sport Scientist: ……..

Date: ……

Appendix 3:

THE VALIDITY AND RELIABILITY OF RATINGS OF PERCEIVED EXERTION (RPE) IN ISOMETRIC EXERCISE TRAINING FOR THE REDUCTION OF ARTERIAL BLOOD PRESSURE – STUDY 1

PARTICIPANT INFORMATION SHEET

An exciting research study is being conducted at Canterbury Christ Church University (CCCU) by Mr John Lea, Dr Jonathon Wiles & Dr Jamie O'Driscoll.

Background

Hypertension (High blood pressure) affects one in four adults in the UK and is a major risk factor for cardiovascular diseases. Poorly controlled BP is currently the world's number one attributable factor for increased risk of death and treatment is associated with high healthcare costs.

Recent studies have shown certain exercise programmes to be effective at reducing resting blood pressure. One such exercise programme uses isometric (static) wall squatting to achieve these results. Isometric wall squatting involves, squatting down to a set height (dependent on individual strength) with your back against a wall (Figure 1), and holding in that position for a period of time, normally two minutes. Unlike a normal squat, during isometric exercise the participant does not change position.

Figure 1: Example isometric wall squat position

Rating of perceived exertion (RPE) is a method for rating how hard you feel you are working during exercise. RPE has been shown to be a useful method of measuring exercise intensity in other forms of exercise; however, evidence is limited for its use during isometric exercise. Therefore, this study intends to explore the use of RPE as a method of measuring intensity and

effort during isometric wall squatting, as a possible means of adjusting or prescribing exercise intensity to encourage exercise benefits.

What will you be required to do?

Participants in this study will be required to attend the sports laboratory at Canterbury Christ Church University, on three separate occasions. Each visit should last around 45 minutes. You should come to the laboratory with sports clothes and shoes, ready to perform exercise. During each visit resting heart rate and blood pressure measurements will be taken; following this, a maximal isometric test will be completed. After the maximal test has been completed you will be given time to recover and then will be allowed to leave. There will be a minimum of 24 hours between each testing session. Ideally testing sessions will be performed at the same time of day.

To participate in this research you must:

- Be aged 18-65.
- Be healthy and have no signs or symptoms of muscle or joint injuries.
- Have no known medical conditions
- Not be taking any medication
- Be a non-smoker or ex-smoker for more than 6 months.
- Have been free from illness/infection for the preceding 2 weeks to testing.

Procedures

When you arrive at the laboratory height and mass measurements will be taken. You will then be linked to a system called a Task Force Monitor which requires a cuff to be placed around your arm, a cuff around two fingers on one hand and the sticking of electrodes (small circular sticky pads) to your chest (Figure 2); this will give a constant reading during exercise and at rest of your heart rate and blood pressure values. Once attached you will be asked to lie on your back for 15 minutes, this will allow you to fully relax before resting heart rate and blood pressure measurements are completed.

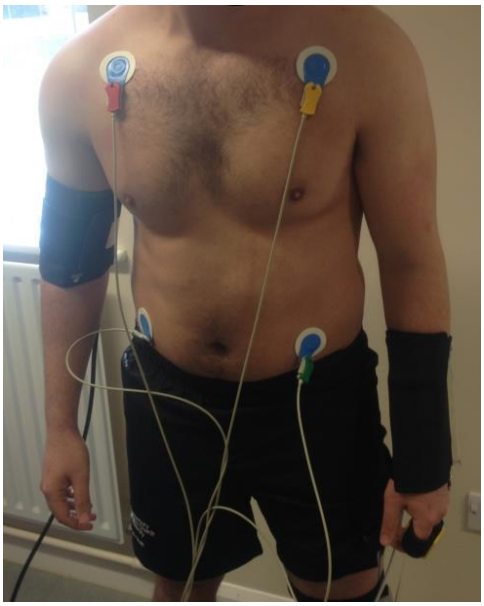


Figure 2: Task force monitor connections and set up

Following the resting measurements, you will move to the exercise area where you will complete the maximal incremental test. The incremental test will consist of several isometric

wall squat stages of increasing intensity, which will be adjusted by manipulating knee angle and squat depth. The first stage will begin at a knee angle of 135° and will be held for 2 minutes. You will squat with your back flat against the wall, feet flat on the floor shoulder width apart, with the lower leg vertical. Once each 2-minute stage is completed the knee joint angle will be decreased by 10° as follows, 135°, 125°, 115°, 105°, to 95°. The test will be continuous, so there will be no rest between the incremental stages. The exercise test will continue until: 1. You reach the end of the 95° stage 2. You can no longer maintain the knee angle within 5° of the requirement 3. The point of volitional fatigue (you wish to stop) 4. Your blood pressure reaches the recommended limit for during exercise as suggested by the ACSM guidelines. You will be given verbal instruction to ensure each wall squat position is held at the correct angle and to ensure the correct timing for each stage. You will be asked to rate your perception of the exertion you are experiencing every 30 seconds, based on a scale that you will be familiarised with. Heart rate and blood pressure will be recorded continuously throughout the incremental test using the task force monitor.

After completion of the maximal incremental test you will be allowed some time to recover on a seat or bed, will be offered an opportunity to shower and then will be free to leave the laboratory.

Feedback

Participants will be given feedback individually about their current resting heart rate and blood pressure values. Participants will also be given an indication of their cardiovascular (heart and circulation) health and any possible changes that have occurred after the study. Participants will be allowed access to their own results upon completion of the study.

Confidentiality

All data and personal information will be stored securely within CCCU premises in accordance with the Data Protection Act 1998 and the University's own data protection requirements. Data will only be accessed by Mr John Lea, Dr Jim Wiles & Dr Jamie O'Driscoll. After completion of the study, all data will be made anonymous (i.e. all personal information associated with the data will be removed).

Dissemination of results

Results will be written for a PhD thesis with the potential for publication in peer reviewed journal articles, conference posters and presentations. All results will be fully anonymous (all figures and numbers will not be traceable to you and personal details will be removed). Individual results discussed throughout the papers/presentations will also be presented with full anonymity.

Deciding whether to participate

It is completely up to you whether or not you decide to take part in this study. If you have any questions or concerns about the nature, procedures or requirements for participation do not hesitate to contact me (John Lea). If you do decide to take part, you will be given this information sheet to keep and be asked to sign a consent form. Agreeing to join the study does not mean that you have to complete it. You are free to withdraw at any stage without giving a reason.

Any questions?

Please contact Mr John Lea via phone: 01227 863600 (ext 1719) or email: John.lea1@canterbury.ac.uk. Room Af87, Sports & Exercise Department, North Holmes Campus, Canterbury Christ Church University, CT1 1QU.

Pre-Testing Session Requirements

Please adhere to the following before **EVERY** testing session:

- No food 4 hours before a training session, however you can drink water.

- No caffeine (tea, coffee, fizzy drinks, chocolate) 12 hours before a training session

- No alcohol 24 hours before a training session

- No strenuous physical exercise 24 hours before a training session.

Appendix 4:

Training Session Manual: HR-EX

Name: …… Participant I.D: ……

Training Session Information

- You will complete 12 training sessions in total over a 4-week period (3 sessions per week).
- Each training session requires you to perform a total of 4 wall squat exercises each lasting 2 minutes.
- Each wall squat will be performed at a specific angle (calculated from your incremental test) so that you reach your target heart rate.
- There will be 2 minutes seated rest between each wall squat.
- Each training session will last 14 minutes in total (see Exercise Protocol).

Your target heart rate is…….....

- You must leave 24 hours between each training session to ensure adequate recovery.
- You should try to ensure that all training sessions are at the same time of the day
- You must adhere to the pre-training session requirements.

Equipment

You will be given the following equipment to use whilst exercising at home:

1. Bend and Squat

- The Bend & Squat is a piece of exercise equipment designed to ensure that you are squatting at the correct angle.
- You will need to adjust the Bend & Squat for your specific training angle (*see Bend & Squat Instructions*).
- Your Bend & Squat measurements are:

WALL:…… **FLOOR**:……

- You must ensure that the Bend & Squat is always set to these measurements before use.
- For instructions on how to use the Bend & Squat to perform the Isometric Wall Squat Exercise see *page 6*.

2. Heart Rate Monitor

- You will record heart rate throughout the wall squat using the heart rate monitor provided
- At the end of every 2-minute wall squat you need to write down your heart rate on the Data Sheet provided
- At the end of every training session you will need to text or email *John Lea your heart rate and RPE data for the 4 exercises.
- Your heart rate monitor will be replaced at the end of each week so that your data can be downloaded.

3. Rating of Perceived Exertion (RPE) Scale

- You will be provided with an RPE scale (*see page 2*). This scale is used to measure how much exertion you feel in your legs (quadriceps).
- At the end of every 2-minute wall squat you need to write down your RPE on the Data Sheet provided

***If you are unable to continue with the training sessions for any reason please do not hesitate to contact John Lea (via mobile: [redacted] or email: john.lea1@canterbury.ac.uk).**

Data Sheet

- Please record your heart rate and RPE at the end of **EVERY 2-minute wall squat exercise bout**.
- Please send me your **heart rate** data after **EVERY TRAINING SESSION** (via **mobile**: [redacted] or **email**: john.lea1@canterbury.ac.uk)

	Training Session	Location	Resting	Bout 1		Bout 2		Bout 3		Bout 4	
			Heart Rate	Heart Rate	RPE	Heart Rate	RPE	Heart Rate	RPE	Heart Rate	RPE
	Pre-Training Lab Visit										
WEEK 1	1	Lab Visit									
	2	Homebased									
	3										
WEEK 2	4										
	5										
	6										
WEEK 3	7										
	8										
	9										
WEEK 4	10										
	11										
	12	Lab Visit									
	Post-Training Lab Visit										

RPE Scale

How hard do you feel your leg muscles are working?

Rating	Description	TTF
0	Rest	100%
0.5		
1	Extremely Easy	90%
1.5		
2	Very Easy	80%
2.5		
3	Easy	70%
3.5		
4	Somewhat Easy	60%
4.5		
5	Moderate	50%
5.5		
6	Somewhat Hard	40%
6.5		
7	Hard	30%
7.5		
8	Very Hard	20%
8.5		
9	Extremely Hard	10%
9.5		
10	Maximal	0%

*Please turn over for RPE instructions

Scale Instructions

This scale is used to rate how hard you think your active muscles are working.

This scale has 3 different columns: Rating, Description and TTF. The '**Rating**' numbers are from 0-10 and are used to rate the exertion or effort in the active muscle group(s). The '**Description**' words and '**TTF'** are used to help you choose a rating.

0 - "**Rest**" is absolutely no effort, as felt during complete rest.

5 - "**Moderate**" is right in the middle of 0 and 10. It's not especially hard and it is no problem to continue; but it no longer feels comfortable.

10 - "**Maximal**" is maximum effort; your muscles are working as hard as they can, and you have seconds before you will have to stop.

TTF (Time to Failure) indicates the amount of time remaining, during an isometric contraction, before you will be unable to continue. In other words, this describes how much you have left in your 'fuel tank'.

100% your muscles are fresh; you haven't started the contraction yet (fuel tank is full).

50% means you can continue to hold the contraction for the same amount of time that you have already completed (fuel tank is half full)

0% your muscles are failing/have failed (fuel tank is empty).

When you give your rating; focus only on the muscle group(s) that is working. You can use the 'Description' words, the Time to Failure (TTF), and/or you can simply rate the exertion out of ten.

Exercise Protocol

Setup the Bend & Squat against a flat wall

Put on the heart rate strap and monitor

Remember to wet the strap electrodes

Write down your resting heart rate

0 mins

START the heart rate monitor

1. Perform the wall squat exercise for 2 minutes.

→ Record heart rate at the END of the 2 minute wall squat.

→Record Rate of Percieved Exertion (RPE) at the END of the 2 minute wall squat.

REST for 2 minutes in a **SEATED** position. — **2 mins**

2. Perform the wall squat exercise for 2 minutes. — **4 mins**

→ Record heart rate and RPE at the END of the 2 minute wall squat.

REST for 2 minutes in a **SEATED** position. — **6 mins**

3. Perform the wall squat exercise for 2 minutes. — **8 mins**

→ Record heart rate and RPE at the END of the 2 minute wall squat.

REST for 2 minutes in a **SEATED** position. — **10 mins**

4. Perform the wall squat exercise for 2 minutes. — **12 mins**

→ Record heart rate and RPE at the END of the 2 minute wall squat.

STOP the heart rate monitor — **14 mins**

Please send me your results after **EVERY** training session

Pre-Laboratory Session Requirements

Please adhere to the following before **EVERY** lab visit:

- No caffeine (tea, coffee, fizzy drinks, chocolate) 12 hours before the lab visit

- No alcohol 24 hours before the lab visit

- No strenuous physical exercise 24 hours before the lab visit. If you feel fatigued prior to a lab visit, please do not hesitate to contact John Lea for advice.

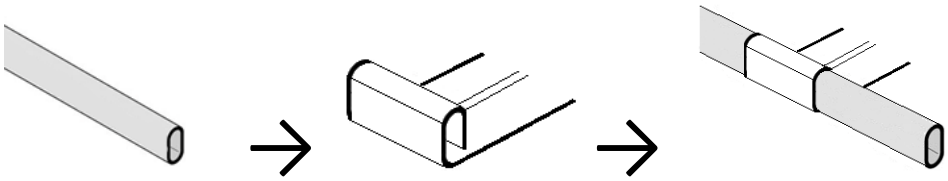
- No food 4 hours before the lab visit, however you can drink water.

Bend & Squat Instructions

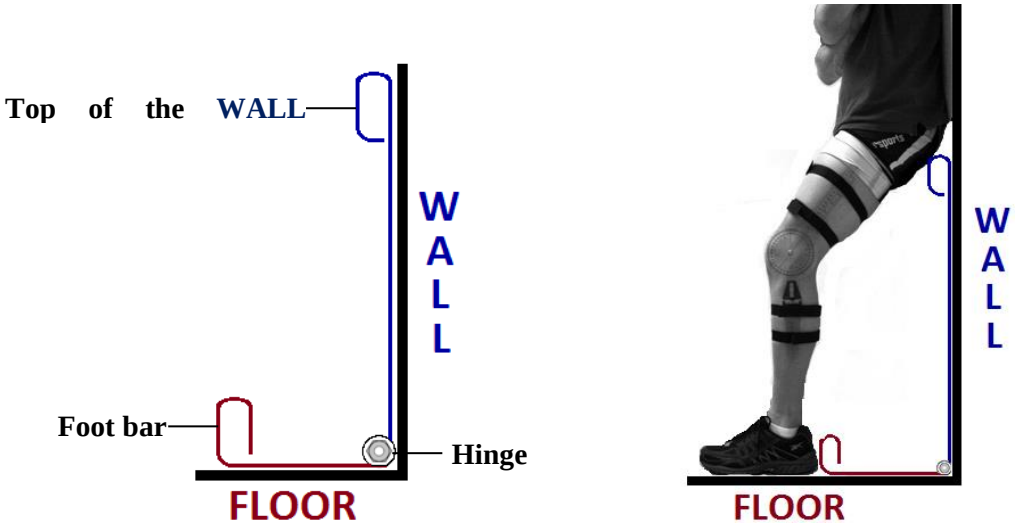
1. Adjust the **WALL** section to the required length by loosening wing nut (*turn anticlockwise*). Then slide the **blue** line to the required measurement and tighten the wing nut (*turn clockwise*). Make sure that the **WALL** section is secure and cannot move.

2. Adjust the **FLOOR** section to the required length by loosening wing nut (*turn anticlockwise*). Then slide the **red** line to the required measurement and tighten the wing nut (*turn clockwise*). Make sure that the **FLOOR** section is secure and cannot move.

3. Insert the bar into the slot at the end of the **FLOOR** section.



4. Put the bend and squat at a 90-degree angle against a flat wall, making sure that the hinge is in the corner between the wall and the floor.



Isometric Wall Squat Exercise

- Stand with your head and back firmly against a flat, sturdy wall that supports the full weight of your body.
- Position your feet shoulder-width apart against the **Bend & Squat** bar with your toes facing forward. Make sure your feet are firmly on the floor, as you may find that they slide forward (try and wear the same foot ware, or no foot ware for all the training sessions).
- To perform a wall squat, slowly bend your knees and allow your back to slide down the wall until your bottom is touching the upright of the **Bend & Squat**. ***DO NOT** use the **Bend & Squat** as a seat. It should **NOT** support your body weight*
- Look straight forward and hold this position for 2 minutes.
- Keep your arms crossed throughout the exercise and breathe steadily. ***DO NOT** hold your breath. *
- When you have completed the 2-minute wall squat, use your hands to push yourself away from the wall.

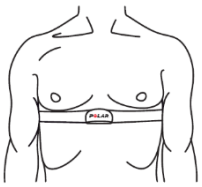
Do:

- ✓ Make sure the **Bend & Squat** is set up correctly.
- ✓ Keep your feet shoulder width apart.
- ✓ Keep your arms crossed.
- ✓ Hold the exercise position for 2 minutes.
- ✓ Breathe steadily throughout the exercise.

Do NOT:

- X Sit on the **Bend & Squat**.
- X Slide down/up the wall.
- X Move your feet.
- X Hold your breath.

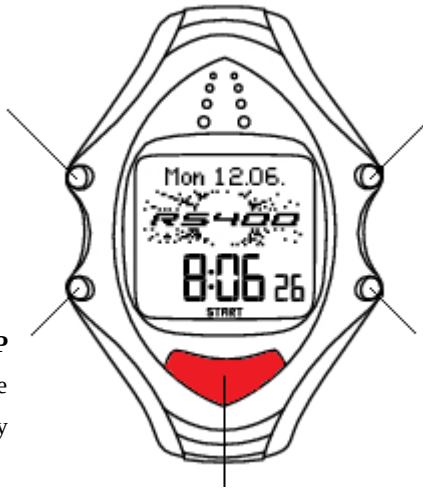
Heart Rate Monitor Instructions



Putting on the heart rate chest strap

1. Wet the electrode areas of the strap under running water and make sure that they are well moistened. ***Do not get the transmitter wet.***
2. Adjust the strap length to fit snugly and comfortably.
3. Put the strap around your chest, just below the chest muscles, and attach the hook to the other end of the strap.
4. Check that the wet electrode areas are firmly against your skin and that the number is in a central, upright position.

Using the heart rate monitor



LIGHT
Illuminate display

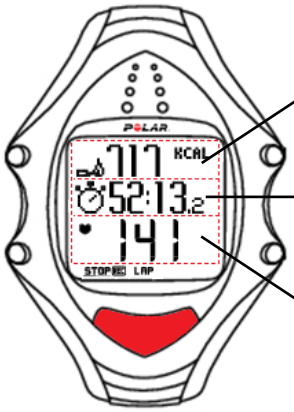
UP
Scroll selections/ values up

STOP
Returns to the previous display

DOWN
Scroll selections/ values down

OK
Accept selections

Heart rate



Calories

Time

Heart rate

1. Secure the heart rate watch to your wrist.
2. Start the heart rate measurement by pressing the red “OK” button.
3. Hold the watch close chest strap and within 15 seconds, your heart rate will appear on the display screen.
4. Write down the heart rate displayed on your Data Sheet (*page 1*). This is your resting heart rate.
5. When you are in the wall squat position start recording heart rate by pressing the red “OK” button.
6. When exercising, the information that appears on the display is your calories burned, time spent exercising and current heart rate.
7. Keep the heart rate monitor recording throughout the 14-minute training session. *__DO NOT__ stop and start the heart rate monitor for every wall squat.*
8. Stop recording heart rate at the end of the last wall squat by pressing the “STOP” button, (the bottom button on the left).
9. Press stop again. This will return you to the home screen.
10. Your heart rate data for the training session is now saved.

Your heart rate monitor will be replaced once a week so that your data can be downloaded.

Appendix 5:

Training Session Manual: RPE-EX

Name: …….. Participant I.D: ……

Training Session Information

- You will complete 12 training sessions in total over a 4-week period (3 sessions per week).
- Each training session requires you to perform a total of 4 wall squat bouts each lasting 2-minutes.
- There will be 2 minutes seated rest between each bout.
- Each wall squat will be performed at a squat height, determined by you, to reach a target RPE zone at the end of the 4th wall squat bout.
- Each training session, including rest periods, will last 14 minutes (see Exercise Protocol, *page 3*).

Rating of Perceived Exertion (RPE)

- You have been provided with an RPE scale (*see page 2*). This scale is used to measure how much physical exertion you feel in your leg muscles (quadriceps) during the exercise.
- At the end of every 2-minute wall squat bout you need to write down your RPE on the Data Sheet provided (*see page 1*).

Your target RPE zone is: 8.0 to 9.0 (inclusive)

- You must leave at least 24 hours between each training session to ensure adequate recovery.
- You should try to ensure that all training sessions are at the same time of the day (*see Training Timetable, page* 6).

Squat Height

- You will need a way of marking your squat height, that you will be able to feel as you squat down the wall (e.g. blu tack).
- Squat height should be measured from the floor to the top of your squat height marker
- You may need to adjust your squat height between bouts to ensure you reach the target RPE zone at the end of the 4th exercise bout (*see Isometric Wall Squat Instructions, page* 4).
- Within a few sessions you should be able to find a squat height that will consistently get you into the target RPE zone by the end of the 4th bout.
- Your starting squat height after the first session is:

Squat Height: ……

- Your lower leg should be vertical (i.e perpendicular to the floor) throughout the exercise.
- You will need to record your squat height at the end of each 2-minute bout.

Contact

- Text or email *John Lea your squat height and RPE data for the 4 exercise bouts at the end of each training session.
- If you have any issues or questions about the procedure, please contact *John Lea.

If you are unable to continue with the training sessions for any reason, please do not hesitate to contact *John Lea (via mobile: [redacted] or email: john.lea1@canterbury.ac.uk).

Data Sheet

- Please record your heart rate and RPE at the end of **EVERY 2-minute wall squat exercise bout**.
- Please send me your data after **EVERY TRAINING SESSION** (via **mobile**: [redacted] or **email**: john.lea1@canterbury.ac.uk)

	Training Session	Location	Bout 1		Bout 2		Bout 3		Bout 4	
			Squat Height	RPE	Squat Height	RPE	Squat Height	RPE	Squat Height	RPE
	Pre-Training Lab Visit									
WEEK 1	1	Lab Visit								
	2	Homebased								
	3									
WEEK 2	4									
	5									
	6									
WEEK 3	7									
	8									
	9									
WEEK 4	10									
	11									
	12	Lab Visit								
	Post-Training Lab Visit									

RPE Scale

How hard do you feel your muscles are working?

Rating	Description	TTF
0	Rest	100%
0.5		
1	Extremely Easy	90%
1.5		
2	Very Easy	80%
2.5		
3	Easy	70%
3.5		
4	Somewhat Easy	60%
4.5		
5	Moderate	50%
5.5		
6	Somewhat Hard	40%
6.5		
7	Hard	30%
7.5		
8	Very Hard	20%
8.5		
9	Extremely Hard	10%
9.5		
10	Maximal	0%

Target Zone Bout 4

*Please turn over for RPE instructions

Scale Instructions

This scale is used to rate how hard you think your active muscles are working.

This scale has 3 different columns: Rating, Description and TTF. The '**Rating**' numbers are from 0-10 and are used to rate the exertion or effort in the active muscle group(s). The '**Description**' words and '**TTF'** are used to help you choose a rating.

0 - "**Rest**" is absolutely no effort, as felt during complete rest.

5 - "**Moderate**" is right in the middle of 0 and 10. It's not especially hard and it is no problem to continue; but, it no longer feels comfortable.

10 - "**Maximal**" is maximum effort; your muscles are working as hard as they can, and you can only maintain this for seconds before you will have to stop.

TTF (Time to Failure) indicates the amount of time remaining, during an isometric contraction, before you will be unable to continue. In other words, this describes how much you have left in your 'fuel tank'.

100% your muscles are fresh; you haven't started the contraction yet (fuel tank is full).

50% means you can continue to hold the contraction for the same amount of time that you have already completed (fuel tank is half full)

0% your muscles are failing/have failed (fuel tank is empty).

When you give your rating; focus only on the muscle group(s) that is working. You can use the 'Description' words, the Time to Failure (TTF), and/or you can simply rate the exertion out of ten.

Target Zone Bout 4 indicates the RPE intensity that you need to achieve (8.5 to 9.5) at the **end** of the training session (i.e. the end of the fourth 2min exercise bout).

Exercise Protocol

Set up your squatting area (see instructions).

Mark your squat height using something appropriate, such as blu tack

Use the final squat height from your previous exercise session

↓

1. Perform the wall squat exercise for 2 minutes. — **0 mins**

Keep your lower legs verticle (perpendicular to the floor)

→ Record squat height and RPE at the END of the 2-minute wall squat bout.

Squat height should be measured from the floor to the top of your squat height marker

↓

REST for 2 minutes in a **SEATED** position. — **2 mins**

Adjust the squat height if necessary, to reach the target RPE at the end of Bout 4

↓

2. Perform the wall squat exercise for 2 minutes. — **4 mins**

→ Record squat height and RPE at the END of the 2-minute wall squat.

↓

REST for 2 minutes in a **SEATED** position. — **6 mins**

Adjust the squat height if necissary, to reach the target RPE at the end of Bout 4

↓

3. Perform the wall squat exercise for 2 minutes. — **8 mins**

→ Record squat height and RPE at the END of the 2-minute wall squat.

↓

REST for 2 minutes in a **SEATED** position. — **10 mins**

Adjust the squat height if necissary, to reach the target RPE at the end of Bout 4

↓

4. Perform the wall squat exercise for 2 minutes. — **12 mins**

→ Record squat height and RPE at the END of the 2-minute wall squat.

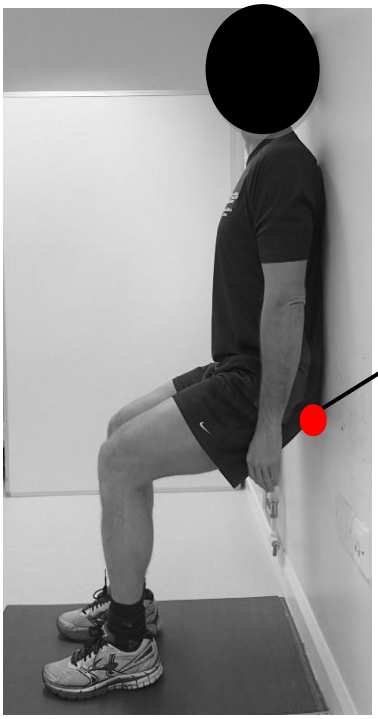
This squat height should be your starting height for the next session

↓

Please send me your results after **EVERY** training session — **14 mins**

Isometric Wall Squat Instructions

- Pick a flat, sturdy wall that can supports the full weight of your body.
- Mark the squat height using something that you will be able to feel (e.g blu tack).
  Your starting squat height should be your final squat height from the previous session
- Stand with your head and back firmly against the wall, feet shoulder-width apart, with your toes facing forward. Make sure your feet are firmly on the floor, with plenty of grip.
  try and wear the same footwear, or no footwear for all the training sessions
- To perform the wall squat, slowly bend your knees and allow your back to slide down the wall until your bottom touches the squat height marker. The marker should not take any of your body weight
- Ensure your lower legs are vertical, look straight forward and hold this position for 2 minutes.
- Keep your arms by your side or crossed on your chest throughout the exercise.
  ***DO NOT** hold your breath. Breathe steadily*
- At the end of the 2-min wall squat bout, push yourself away from the wall and rest.
- You should be between 8 and 9 on the RPE scale at the end of bout 4. If between bouts you feel you are not going to hit the target zone, you can increase or decrease the squat height for the subsequent bouts. Within a few sessions you should find a squat height that will consistently get you into the target RPE zone by the end of the 4th bout.
- If at any point you hit '10 - maximal' on the RPE scale, end the training session for that day and consider increasing the starting height for the next day.



Do:

- ✓ Keep your feet shoulder width apart.
- ✓ Keep your lower legs vertical.
- ✓ Keep your arms crossed or down by your side.
- ✓ Hold the exercise position for 2 minutes.
- ✓ Breathe steadily throughout the exercise.

Do NOT:

- X Put your hands on your legs.
- X Slide down/up the wall (during the bout).
- X Move your feet.
- X Hold your breath.
- X Go to maximal exertion on the RPE Scale

Pre-Laboratory Session Requirements

Please adhere to the following before **EVERY** lab visit:

- No caffeine (tea, coffee, fizzy drinks, chocolate) 12 hours before the lab visit

- No alcohol 24 hours before the lab visit

- No strenuous physical exercise 24 hours before the lab visit. If you feel fatigued prior to a lab visit, please do not hesitate to contact John Lea for advice.

- No food 4 hours before the lab visit, however you can drink water.

Appendix 6:

Study Methodological and Reporting Risk of Bias Assessment Tool for RPE Validation Studies

	Criterion	Explanation	Points for Inclusion	Score
1	Eligibility Criteria	Participant eligibility criteria is specified and fulfilled (including specific diagnostic test results)	1 Point	
2	Participant Information	Participant information is given, including age, sex, and training status	1 Point	
3	Power Analysis	Use of *a priori* power analysis/sample size calculation is acknowledged	1 Point	
4	Exercise Modality	Exercise type (dynamic, isometric etc.) and movement (squat, bench press etc.) is specified	1 Point	
5		Exercise intensity is specified (including load, number of sets, number of reps, rep time & rest time)	1 Point	
6	RPE Scale	Specify exact RPE scale used - including any modification	1 Point	
7	Anchoring Procedure	RPE instructions are specified	1 Point	
8		Anchoring procedures/methods are specified	1 Point	
9	Reliability Measure	A measure of repeatability/reliability was carried out and reported	1 Point	
			Total (/9)	