

The integration of local vibration training into strength protocols: the acute effects on lower-body isokinetic strength and power in healthy, active females and males

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## Abstract

**Background:** Vibration stimulation has the potential to benefit individuals in the areas of therapeutic rehabilitation and exercise performance, namely in improving the strength and power of musculature. Vibration stimulation has been proven to promote neurophysiological responses within the body, such as increasing circulation to certain areas of the body and improving muscle and tendon functioning thereafter. Recent advances in technology have allowed vibration stimulation to be localised through the utilisation of localised vibration devices that can be placed directly onto or strapped around a desired anatomical location e.g. the hamstrings muscle. Applying localised vibration into a progressive exercise protocol has proven beneficial for improving bone density, increasing flexibility, improving strength and power outcomes in musculature, and enhanced ability to apply force across a range of muscle contractions. However, the best practice for integrating localised vibration into clinical, strength and power performance programs is yet to be established. The neurophysiological function of a muscle differs depending on whether it is lengthening (eccentric contraction), shortening (concentric contraction), or being held at a constant length (isometric contraction). Isometric muscle contractions are the most common actions prescribed during clinical, applied rehabilitation and strength and power programs because they are safe and allow relatively high forces to be applied. Currently there is a dearth of information within the literature on whether localised vibration during isometric muscle contractions has an acute effect on the isokinetic strength and power once the vibration stimulus has been removed. Therefore, an exploration of this information may shed light on the utility of using localised vibration training to induce strength and power adaptations to muscle.

**Aims:** This dissertation firstly aimed to review the current literature on acute localised vibration effects on strength and power of various musculature. The second aim of this dissertation was to then integrate this information into an experimental protocol to investigate the acute effect of localised vibration stimulation during an isometric strength exercise on the subsequent isokinetic strength of the hamstrings and quadriceps muscles once the localised vibration was removed from the hamstrings muscles.

**Methods:** Firstly, a systematic review was carried out to investigate the current literature on the acute effects of localised vibration on strength and power outcomes, in which 23 published articles were critiqued from four different databases. Secondly a random cross-over trial was conducted with 16 healthy participants (7 = female; 9 = male); aged:  $24.6 \pm 4.52$  years, height:  $172.8 \pm 8.83$  m, weight:  $74.3 \pm 14.5$  kg. Participants volunteered to take part in an isokinetic strength test protocol with localised vibration applied during an isometric hamstring exercise; the subsequent eccentric and concentric strength of both the hamstrings and quadriceps was then tested once the vibration stimulation was removed. The peak torque, angle of peak torque, mean power and time to peak torque were measured for both the flexors and extensors. A repeated measures ANOVA with post hoc contrasts was employed to analyse data for statistical difference.

**Results:** Overall the findings from the literature review revealed that acute localised vibration has a positive effect on both strength and power, with different vibratory settings having a different effect on both. The review revealed that higher frequencies ( $> 100$  Hz), lower amplitudes ( $< 5$ mm) and longer durations (30 minutes) of vibration stimulation effected muscular strength the most, whereas lower frequencies ( $< 100$  Hz), higher amplitudes ( $\geq 6$ mm) and shorter durations ( $< 1$  minute) had more of an effect on muscular power outcomes. The randomised cross-over trial resulted in no statistically significant differences in peak torque, angle of peak torque, mean power and time to peak torque of both the extensors and flexors, between and within vibration and non-vibration groups.

**Conclusion:** Acute localised vibration does have a positive effect on both muscular strength and power when the vibratory stimulus is placed onto or around the desired muscle when the appropriate loading protocol is used. However, the exact loading parameters for both strength and power are not exclusively defined and thus far ranges of effective stimulus (frequency, amplitude and duration) have been determined for both strength and power; nonetheless the literature review holds critical importance for the future application within the field. It can also be determined that one bout of localised vibration applied during an isometric hamstring exercise for  $\sim 8 - 12$  minutes does not have an effect on the subsequent isokinetic strength of the hamstrings and quadriceps muscles. This was most likely due to a too low frequency and/or amplitude utilised for the particular muscle groups involved.

**Key words:** vibration, vibration stimulation, local vibration, localised vibration, muscular strength, muscular power.

## Abbreviations:

LV: Local Vibration

WBV: Whole Body Vibration

TVR: Tonic Vibration Reflex

1RM: One Repetition Maximum

MVC: Maximal Voluntary Contraction

MVIC: Maximal Voluntary Isometric Contraction

CMJ: Countermovement Jump

VJ: Vertical Jump

PT: Peak Torque

APT: Angle of Peak Torque

TPT: Time to peak torque

MP: Mean Power

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## Attestation of Authorship

I hereby declare that this submission is my own work and that I as the student, Hannah Rose Tiedt, hold the position of the principle author of the manuscripts within this dissertation. As principle author I hold a stated contribution of 80%, and my co-authors hold the stated combined contribution of 20% in the leadership and writing up of the work reported only on the two manuscripts of this dissertation. I hereby declare any other work within this dissertation is my own work and to the best of my knowledge and belief, this dissertation contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor used artificial intelligence tools or generative artificial intelligence tools (unless it is clearly stated, and referenced, along with the purpose of use), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

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## Ethics Approval

All experimental procedures of this dissertation were approved by the Auckland University of Technology Ethics Committee on 5<sup>th</sup> September 2022 (AUTEC references number 22/217, Appendix 4).

# Chapter 1 Introduction

## 1.0 Introduction

Strength and power are vital for daily life; strength training allows one to build a robust, healthy body, making everyday tasks easier. Strength and power also enhance the ability of athletes to perform well during sporting movements, contributing to their sports competency and motor skills (Logan et al., 2012), as well as reducing the risk of injury occurrence (Rössler et al., 2014). Being able to produce maximum strength and power, (i.e., peak force, over a short periods of time), increases an athletes explosiveness and their overall athletic performance. Peak force and power output of a muscle depends on the (1) muscle and fibre size and length, (2) fibre type, (3) number of cross-bridges in parallel, (4) force per cross-bridge, and (5) the force-velocity relationship, (6) muscle architecture (i.e., the structural design of the muscle itself relating to its pennation angle, arrangement of fibres and muscle units, and the connective tissue elements within and around which the muscle embeds in) (Fitts et al., 1991). This all contributes to how well a muscle will adapt to loading, (i.e., resistance training). In addition to the peak force a muscle can produce, the muscle's length at which peak force is generated influences force expression, and therefore limb function (Alegre et al., 2014; Oranchuk et al., 2019). The measurement of a muscles maximal strength, (i.e., peak torque), is used to determine the physical condition of a muscle during training or rehabilitation programs, however, the ability of a muscle to generate and maintain this torque quickly throughout a joint range of motion during exercise/sport may be more important than generating maximal force alone (Simpson et al., 2019). Injured limbs have been found to have significantly lower angles of peak torque compared to uninjured limbs (Clark et al., 2005). This suggests that the angle of peak torque provides a measure of susceptibility for injuries. Therefore, increasing the angle of peak torque may reduce the likelihood of sustaining a future injury i.e. making muscles stronger at longer lengths. The development of these qualities can be achieved through the utilization of resistance training, however, more recent advancements in technology have enabled training protocols that supersede those of resistance training alone, as in the inclusion of vibration training.

## 1.1 Background to dissertation

Vibration training with athletes has been around since the 1990's, specifically in European countries, where it was utilised to enhance strength and power performance, and also for health purposes (Cochrane, 2010). There are two main types of vibration training: whole-body vibration training (WBV) where vibration is initiated via a WBV platform (oscillating or vertical) and localised vibration (LV) training where a portable device transmits vibration energy to a target muscle (e.g.

hamstrings) locally, the most common being WBV. This has been reported to increase muscle strength and power acutely post-vibration training, improve blood flow to an area, increase flexibility of muscles, enhance efficiency of muscle and tendon function, and reduce delayed onset muscle soreness (DOMS) (Alghadir et al., 2018; Cho et al., 2020; Couto et al., 2013; Iodice et al., 2011; Jordan et al., 2005). Despite the wide use of vibration training to this day, there are still gaps of knowledge relating to certain types of vibration training, settings and standardization of protocols. WBV is the most prominent type of loading within both clinical and academic settings, however there are limitations to this form of vibration stimulus. WBV is typically expensive, non-portable and lacks the ability to target muscles directly, as a person will either stand, lie or kneel on the platform which in turn targets a number of muscles and muscle groups (Germann et al., 2018). This has raised uncertainty regarding the stimulus reaching the targeted muscle, as the vibration energy will dissipate during transmission through the soft-tissues, which may hinder the sought after effects (Luo et al., 2005; Germann et al., 2018; Souron et al., 2017). Recent advancements in technology have allowed the application of direct vibration to targeted muscles through the utilization of LV devices, which appear to be promising, however there is less known about this type of stimulus.

## 1.2 Rationale of dissertation

LV devices are portable vibrational devices (e.g., Myovolt wearable strap, VYPER, Hyperice vibration foam roller) that directly target the desired muscle by being placed onto or strapped directly to the muscle of interest, such as being strapped around the arm on the biceps brachii, or through indirect placement via a gym machine cable which targets the specific muscle group the gym machine works, (e.g., hamstring curl machine targets the hamstring muscle group). Because of this, LV devices overcome some of the limitations associated with WBV training and have been reported to acutely enhance the strength and power properties of muscles after one session of vibration stimulation (Cho et al., 2020). LV stimulation activates the tonic vibration reflex (TVR) (Germann et al., 2018), where muscle spindles are stimulated via the Type-Ia afferents neurons and the extrafusal muscle fibres via the alpha-motor neurons and increases the muscle activity within the vibrated muscle; following on from this, an acute increase in strength and power occurs within the muscle (Cormie et al., 2006; Delecluse et al., 2003; Germann et al., 2018). During LV stimulation, rapid muscle stretching and contraction occurs and consequentially the muscles being vibrated generate an involuntary production of strength (Germann et al., 2018). There have also been reports of nervous system activation post-vibration stimulation through an increase of corticospinal excitability, and has shown to lengthen the muscular extrafusal fibrils, permitting muscles to be

stronger through movements and exercises where they are at longer lengths compared to during rest (Alghadir et al., 2018; Sagiroglu., 2017).

The acute and long-term utilisation of LV stimulation in conjunction with resistance training has been found to increase strength and power outcomes (Alghadir et al., 2018; Cho et al., 2020; Couto et al., 2013; Iodice et al., 2011). However, the acute utilisation of LV loading in conjunction with exercise has also reported enhancements within an athlete's explosive abilities and increases in muscular strength within one session of LV stimulation (Cho et al., 2020; Couto et al., 2013; Iodice et al., 2011; Jordon et al., 2005; Filipi et al., 2020). The current research on LV provides a comprehensive analysis of the immediate effects of LV during various muscular actions and exercises that examine the effects on strength and power outcomes. This includes concentric actions, eccentric actions, one repetition maximum (1RM) testing, isokinetic dynamometry exercises, maximal voluntary contraction (MVC), maximal voluntary isometric contraction (MVIC), countermovement jump (CMJ) and vertical jump (VJ) heights and cycle power tests (Cho et al., 2020; Cochrane, 2016; Cochrane, 2017; Couto et al., 2013; Dickerson et al., 2012; Filipi et al., 2020; Hong et al., 2010; Iodice et al., 2011; Issurin and Tenenbaum, 1999; Issurin et al., 2010; Jacobson et al., 2017; Mileva et al., 2006; Moran et al., 2007; Pamukoff et al., 2014; Sagiroglu, 2017). However, primarily the upper extremity muscle groups (e.g., biceps brachii) have been investigated alongside LV stimulation and although there have been various positive strength and power outcomes from this, there is a dearth of research on LV training and the lower extremity muscle groups. Even more so, there is a lack of research on the combination of isometric exercises and LV stimulation. Isometric exercises are important as they help build strength, balance and range of motion without lengthening one's muscle and causing too much damage to the muscle fibres in the process. Combining isometric exercises and LV would be beneficial to healthy populations as they could possibly enhance strength without causing much damage to the muscles, but also increase strength and power properties of the muscles due to the vibration stimulation benefits. Therefore, an exploration of this contention may shed light on the utility of using LV training alongside traditional resistance training methods to induce strength and power adaptations to critical knee musculature deemed important in both academic and applied environments. This dissertation aims to provide a review of the current research surrounding the acute effects of LV during strength and power exercises, and to investigate the effects of LV used in combination with isometric contractions of the hamstring muscle on the strength, power, angle of peak torque and time to peak torque of the hamstrings during an isokinetic strength test.

### 1.3 Significance of dissertation

Although there is broad research on LV effects on strength and power properties of various musculature, there are still obvious gaps in the knowledge. For example, the optimal vibration settings are yet to be defined within the literature for both strength and power adaptation. LV is also a fairly new concept in the field and more extensive research is required for the exact loading parameters that result in adaptations within specific musculature as well as the fact that each new device that is developed can be different to the next. This dissertation aims to provide a review of the current information on LV settings and will explicitly provide an overall understanding of the acute effect of the various vibration settings being utilised for improving strength and power outcomes, and which are most effective for strength and for power separately. The significance lies in the fact that nobody has attempted thus far to understand the acute effects of LV once the stimulus has been removed. This dissertation will have great applications for the development and utilisation of these devices alongside strength and conditioning practices. If we can understand the effectiveness of acute strategies of LV stimulation alongside resistance training, it will help inform whether they can be used to induce chronic effects. Of interest to this research is whether an acute bout of LV application during an isometric contraction can potentially enhance the subsequent isokinetic strength and power of the targeted musculature once the LV stimulus has been removed. A review of the current research regarding different vibratory stimulus and the acute effects on strength and power properties of musculature helped guide the experimental protocol that was implemented.

#### 1.4 Dissertation Framework and Methodology

To answer the overarching question of this dissertation, “what are the acute effects of LV during an isometric hamstring contraction on the subsequent isokinetic strength of the quadriceps and hamstrings of healthy, active individuals,” this dissertation is organised into four chapters, beginning with this general introduction Chapter 1. Chapter 2 is a systematic literature review; here a systematic approach is used to review and investigate the current literature on the acute effects of localised vibration on strength and power of various muscle groups, the gaps and limitations that exist within the research, and describe the future research directions. In Chapter 3, the methods of the acute, cross-over design protocol adopted for this dissertation is described in journal article format as a pilot study, and describes how the data was collected and then further analysed; the results of this experimental protocol are also discussed within this chapter. Chapter 4 summarises the findings of the dissertation and the practical applications applicable to future research relating to this topic. Finally, references and appendices are listed at the end of this dissertation.

**Table 1.** Purpose of each chapter in this dissertation

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<b>Chapter</b>	<b>Title</b>	<b>Purpose</b>
1	Introduction	General introduction to the contents of this dissertation, the rationale of the dissertation and the significance of this topic in relation to the field.
2	Literature Review	Systematic literature review titled, “The acute effects of localized wearable vibration on muscular strength and power, a systematic review”
3	Research Design and Results	Experimental pilot study titled, “Integrating local vibration training into an isometric strength protocol: acute effects on lower-body isokinetic strength in healthy, active individuals” which investigates the acute effects on muscular strength and power of the hamstrings and quadriceps based upon the integration of local vibration into an isometric strength protocol.
4	Conclusion and Recommendations	Summary on the observed findings of this dissertation, with comparison to existing research, answering the research question “ <i>what are the acute effects of local vibration during an isometric hamstring contraction on the subsequent isokinetic strength of the quadriceps and hamstrings of healthy, active individuals</i> ” and the practical applications to be utilized in future research relating to this topic.

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## **Chapter 2 The Acute Effects of Localised Wearable Vibration on Muscular Strength and Power: A Systematic Review**

This chapter comprises the following manuscript which will be submitted to *The Journal of Strength and Conditioning Research* and formatted accordingly:

Tiedt, H. R., Cronin, J., Uthoff, A & Jones, D (2023). The acute effects of localised wearable vibration on muscular strength and power: a systematic literature review.

### **2.0 Prelude**

The emphasis of this chapter was to explore the utilisation of LV devices and their effectiveness in strength and conditioning practices as they provide a means to overcome many of the limitations of WBV platforms. The key focus of this chapter was to investigate the acute effects of localised vibration stimulus during resistance training on strength and power outcomes of various musculature. The purpose of this was to determine what vibratory settings best suit strength and power adaptation and also to determine what were the current gaps and limitations relating to the research pertaining to LV. The results of this systematic review help inform and guide the future utilisation of LV devices in practice for coaches and practitioners in both clinical and applied environments.

### **2.1 Introduction**

Strength and power are important components of various sporting codes, athletic activities and the functional aspects of daily life (Luo et al., 2005). They are particularly important for athletes and active individuals, as they enable and optimise motor skills and movements, which can contribute to sports competency (Logan et al., 2012), as well as reduce the risk of injuries in the long-term (Granacher et al., 2016; Rössler et al., 2014). As such, optimising the restoration or development of strength and power, has become a focus for physiotherapeutic and strength and conditioning practice. Many training methods are available to the practitioner to achieve these ends, the focus of this article however, is the combination of resistance training with vibration.

Whole body vibration (WBV) is a widely used modality within sports to enhance strength, power, and range of motion. With WBV a person stands on a platform that vibrates at a certain frequency (Hz) and amplitude (mm); the frequency and amplitude determines the magnitude of the overload experienced by the neuromuscular system. There are two main types of WBV platforms, these can be either an oscillating or a vertical vibration platform (Mingorance et al., 2021). Vertical platforms utilize high frequencies of vibration and lower amplitudes, and uses an eccentric wheel device supporting springs to produce a forced vertical vibration through the platform moving up and down at a rapid speed. The oscillating platform whereas, operates more like a seesaw apparatus around a

centre pivot point while acting in the direction of gravity utilizing lower frequencies with higher amplitudes (Mingorance et al., 2021). The vibration stimulation activates the tonic vibration reflex (TVR) (Germann et al., 2018), which stimulates the muscle spindles primarily through the Ia afferents neurons, and the extrafusal muscle fibres through the alpha-motor neurons, increasing the activation of muscles vibrated resulting in acute increased strength and power gains (Cormie et al., 2006; Delecluse et al., 2003). However, WBV as a training option is limited due to its expense, the non-portability of this type of technology, and the inability to directly target certain muscles and muscle groups (Souron et al., 2017). Furthermore, it is intimated that WBV stimulates multiple receptors throughout the body resulting in a decreased stimulation of the intended muscles, as well as a decreased net force output of vibration to both the agonist and antagonist muscles (Kurt, 2015; Germann et al., 2018), making WBV implementation less desirable for future use.

In more recent years the development and utilisation of local vibration devices has emerged, this technology enables direct placement on the desired muscle belly or tendon. As such, localised vibration devices provide a means to overcome some of the aforementioned limitations of WBV and are of great interest in terms of their acute potential to enhance strength and power (Cho et al., 2020). Localised vibration application is performed through a portable device that can be directly placed or strapped onto the desired anatomical location of the body and stimulates the tissues directly through the skin. The vibration can also be applied indirectly through an automated device attached to a gym machine cable which targets a desired muscle group. During acute bouts of localised vibration, the type Ia afferent neurons are activated immediately as a response to the vibration of the muscle, causing a TVR response similar to WBV (Germann et al., 2018). Though, the TVR associated with localised vibration has been reported to be more effective than the stimulation associated with WBV (Sagiroglu, 2017). Intuitively this makes sense since the vibration stimulation interacts with the muscle of interest directly and rapid muscle stretching occurs triggering a muscle contraction, resulting in an involuntary production of strength within the vibrated muscle (Germann et al., 2018). It has also been reported that corticospinal excitability following acute vibratory stimulation is present within the nervous system (Alghadir et al., 2018; Sagiroglu., 2017), and that this specific vibrational afferent feedback mechanism changes the length of the muscular extrafusal fibrils, allowing muscles to be stronger at longer lengths and thus through various sporting movements (Sagiroglu, 2017). The utilisation of localised vibration stimulation in conjunction with exercise has been found to increase flexibility of musculature, blood flow, and ultimately results in greater strength and power outcomes (Alghadir et al., 2018; Cho et al., 2020; Couto et al., 2013; Iodice et al., 2011). Localized vibration loading has also been reported to enhance the explosive abilities of athletes and

increase muscular strength acutely (i.e., within one session of localized vibratory stimulation) (Cho et al., 2020; Couto et al., 2013; Iodice et al., 2011; Jordon et al., 2005; Filipi et al., 2020).

Of interest to the present authors, is whether acute bouts of localised vibration application can potentially enhance strength and power of targeted musculature. The exact protocols for the utilisation of localised vibration training to enhance these qualities, however are yet to be defined. Understanding these protocols and loading parameters, will enable practitioners to better prescribe localised vibration for better human and sporting performance, as well as clinical outcomes. With this in mind, the authors of this review seek to synthesize and critique the current research and provide guidelines on how acute bouts of localised vibration may enhance strength and power capability.

## 2.2 Methods

### 2.2.1 Search Strategy

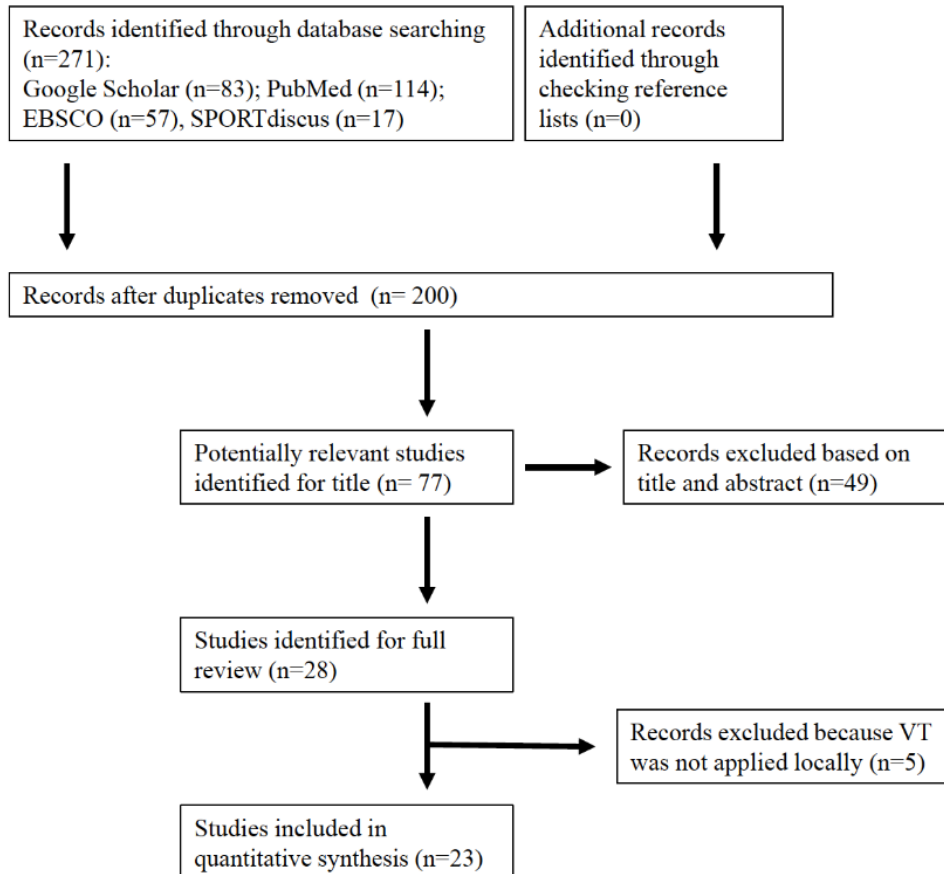
The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) reviews guidelines were followed for this review. Google Scholar, EBSCO, SPORTdiscus and PubMed were searched using the following keywords: (Wearable vibration OR local vibration OR localized vibration OR focal vibration) AND (acute effects OR immediate effects OR acute bouts) AND (muscular strength OR muscular power OR strength OR power) AND (vibration therapy OR punctual vibration therapy OR vibration training OR VT). The reference lists of each included study were also examined to identify potential relevant studies.

### 2.2.2 Study Inclusion and Exclusion Criteria

For inclusion in this review, articles were required to abide by the following: 1. Published in English; 2. Examined only the acute (single session) or the short term effects (1-2 sessions performed on different days/within different sessions) of localized vibration application or training; 3. Participants involved were healthy, semi-or-well trained or physically active with no specific health ailments present; and 4. Conference abstracts were not included. Localized vibration was defined as the application of a vibration stimulus directly to a muscle group or tendon, or indirectly through a gym machine, dumbbell or foam roller. Vibration therapy applied via a whole-body vibration device was excluded, unless the platform provided vibration to a specific body part by the participant leaning against the device, e.g. gluteal muscles. The dependant variables of interest included in this review were measures of muscular strength and power.

### 2.2.3 Data Extraction and Analysis

Relevant data from each study was extracted and placed into Table 2, which included; study design, aim, sample characteristics, vibration device utilised and vibration protocols (location of device, treatment duration in minutes, frequency and amplitude settings), and the training protocols (sets, repetitions, rest periods, and training sessions per week/in days) that were followed.



**Figure 1.** Flow chart of the selection procedure from identification to inclusion

### 2.3 Results and Discussion

Of interest to the authors was identifying the loading parameters that have been used to elicit strength and power gains, using acute bouts of localised vibration. Understanding and implementing these loading parameters may enable practitioners to better prescribe localised vibration to enhance performance and clinical outcomes. The following sections discuss the results with this in mind, as well as the various aspects of localised vibration loading detailed. The reader needs to be cognisant, however, that even though the loading parameters are discussed as single entities, it is difficult to determine definitively the optimal loading parameters given the many permutations in amplitude,

frequency, duration and location, and their interaction. The studies included in the review were evaluated based upon their eligibility for the review. The results and discussion are detailed below

### 2.3.1 Outcome Measures

Muscle strength and power were the outcome measures of interest. Within these two categories, mean strength, peak strength, MVC, peak torque, dynamic strength, mean power, average power, dynamic power, and counter movement jump (CMJ) and vertical jump (VJ) height were assessed as variables of interest in relation to muscle strength and power. Of the included studies, 7 investigated variables relating to only strength outcomes (Cho et al., 2020; Cochrane, 2017; Couto et al., 2013; Hong et al., 2010; Pamukoff et al., 2014; Rongsawad and Ratanapinunchai, 2018; Siegmund et al., 2014), 10 investigated variables relating to only power outcomes (Bosco et al., 1999; Cochrane, 2016; Custer et al., 2017; Filipi et al., 2020; Issurin and Tenenbaum, 1999; Issurin et al., 2010; Jacobson et al., 2017; Maeda et al., 2020; Moran et al., 2007, Sagiroglu, 2017) and 6 studies investigated both strength and power outcomes (Cochrane and Hawke, 2007; Dickerson et al., 2012; Iodice et al., 2011; Mileva et al., 2006; Souron et al., 2018; Wang et al., 2022).

### 2.3.2 Subject characteristics

The participant's characteristics are detailed in Table 2. The total sample size from the 23 studies was 593 participants, and the sample size for each study ranged from 8 to 44 participants, with an age range of 18 to 76.8 years, which included both females (n=206) and males (n=387). All studies included a range of various athletes and non-athletes of various sporting codes, age groups, and recreationally active individuals. Of the studies included, the most common population utilized in 12 research groups was recreationally active individuals with some experience in resistance training (Cho et al., 2020; Cochrane, 2017; Couto et al., 2013; Custer et al., 2017; Dickerson et al., 2012; Filipi et al., 2020; Hong et al., 2010; Iodice et al., 2011; Maeda et al., 2020; Mileva et al., 2006; Pamukoff et al., 2014; Souron et al., 2018). Amongst the recreationally active participants, the main findings were significant increases in strength (22.6 to 30.9%) (Cho et al., 2020), peak power (11.4%), average power (6.6%) and total work (5.7%; ES = small to medium) (Filipi et al., 2020), external rotation (13.5%) peak torque and internal rotation (33.6%) and external rotation (28.2%) time to peak torque (Hong et al., 2010), MVC (9.8 to 11.5%) (Iodice et al., 2011; Souron et al., 2018), quadriceps strength (33.0 to 41.0%) (Iodice et al., 2011), CMJ height (1.7%) changes (Maeda et al., 2020) and dynamic strength (3.3 to 4.0%) (Mileva et al., 2006) changes. Eight of the included studies involved testing on trained to elite athletes part of various sporting codes (International boxers, football players, climbers, soccer players, masters field hockey players, kayakers and tennis players)

(Bosco et al., 1999; Cochrane and Hawke, 2007; Issurin and Tenenbaum, 1999; Issurin et al., 2010; Jacobson et al., 2017; Sagiroglu, 2017; Siegmund et al., 2014; Wang et al., 2022). The greatest changes within these included studies were found in the kayakers (13.6 to 25.7%) increase in power gain during a one arm pulling action similar to a kayak stroke (Issurin et al., 2010), elite power trained athletes gain in maximal power (10.4%) and gain in mean power (10.2%) during an explosive elbow flexion action (Issurin and Tenenbaum, 1999), and increases (13.3%) in mean power amongst elite international boxers during isometric arm flexion with an extra load equal to 5% of the participant's body mass (Bosco et al., 1999). From these results it can be suggested that general populations gain more benefits utilizing LV devices for strength purposes and elite athletes benefit more in terms of power enhancement.

### 2.3.3 Anatomical Locations of Localised Vibration

It is important for practitioners to understand how muscles in different anatomical locations are affected by LV. This is because, different muscles have different architecture and some may or may not benefit more from LV stimulation, (e.g., biceps brachii versus hamstring muscle group). The placement and application of LV devices is important in eliciting strength and power adaptations within musculature, as well as placing the device in the same position throughout experimentation, as placing it on different locations of the muscle (e.g., distal versus proximal), could potentially result in contradictory motor unit activation (Germann et al., 2018). The purpose of this section within the results was to examine how many studies investigated each region or muscle/muscle group and what the consequent effects of LV was on those, so future practitioners can take this into account.

The main locations found between all research groups were as follows: nine studies examined the effects of acute LV on upper body muscle strength and power, with the most commonly vibrated muscle being the biceps brachii (Bosco et al., 1999; Cochrane and Hawke, 2007; Cochrane, 2016; Cochrane, 2017; Couto et al., 2013; Hong et al., 2010; Issurin and Tenenbaum, 1999; Issurin et al., 2010; Moran et al., 2007). Research groups who included the upper body muscles in their studies saw significant increases in mean power of the biceps brachii (10.20 to 13.33%) (Bosco et al., 1999; Issurin and Tenenbaum, 1999) and peak power of the biceps brachii (3.60 to 7.90%) during elbow flexion exercises (Cochrane and Hawke, 2016; Issurin and Tenenbaum, 1999), internal and external rotation peak torque of the shoulder muscles (13.5%) (Hong et al., 2010), and increased power gains (13.60 to 25.67%) and dynamic power (12.07 to 25.65%) during a one arm pulling action similar to a kayak stroke (Issurin et al., 2010). These results show promising potential for the future use of LV to enhance power outputs in the upper body muscles, particularly in the biceps brachii and shoulder

musculature. Fourteen studies examined the effects of acute LV on the lower body muscle strength and power, with the most commonly vibrated muscle being the quadriceps found in eleven studies (Cho et al., 2020; Custer et al., 2017; Dickerson et al., 2012; Filipi et al., 2020; Iodice et al., 2011; Jacobson et al., 2017; Maeda et al., 2020; Mileva et al., 2006; Pamukoff et al., 2014; Rongsawad and Ratanapinunchai, 2018; Sagiroglu, 2017; Siegmund et al., 2014; Souron et al., 2018; Wang et al., 2022). The research groups saw significant increases in muscle activity and eccentric peak torque (22.62%) of the gastrocnemius muscle (Cho et al., 2020), peak power (11.4%), average power (6.6%), and total work (5.70%) of the quadriceps muscles during a series of cycle tests (Filip et al., 2020), and increases in MVC (9.67 to 11.5%) and overall strength of the quadriceps (3.3 to 41%) during knee extension exercises (Iodice et al., 2011; Mileva et al., 2006; Souron et al., 2018). VJ height (1.55 to 3.80%) increases were found (Jacobson et al., 2017; Maeda et al., 2020; Sagiroglu, 2017) and greater peak velocity sequentially each jump (2.40%) (Jacobson et al., 2017), and a significant change in CMJ height (8.06%) was also found (Wang et al., 2022). These results indicate that LV can be used to acutely enhance strength and power performance in the lower limb musculature, and particularly within the quadriceps muscles. In spite of this, the hamstrings muscles were only investigated in six of the 23 included studies (Custer et al., 2017; Dickerson et al., 2012; Jacobson et al., 2017; Sagiroglu, 2017; Siegmund et al., 2014; Wang et al., 2022), with only three of the six showing a significant increase for CMJ height (8.06%) (Wang et al., 2022) and VJ height (1.55 to 3.80%) (Jacobson et al., 2017; Sagiroglu, 2017). This is a crucial finding, as the hamstrings muscles are an important component of power and strength outcomes in the lower limbs. This is mainly because they are utilised within many sporting movements, such as strikes in soccer, change of direction in netball, rugby and soccer, sprinting abilities, and during jumping (Struzik and Pietraszweski, 2019). During a jumping movement, the hamstrings muscle responsible for extending the hips and flexing the knees is the semitendinosus muscle, since it possesses a larger moment arm at the knee than the biceps femoris muscle, a larger knee flexion moment is generated, making it a key muscle involved in jumping (Bobbert, 1996; Struzik and Pietraszweski, 2019). Since the hamstrings muscle group is essential in movements like jumping, running and change of direction, it is unfortunate that the included research groups did not find as great significant differences when utilizing LV on the hamstrings, or found none. The reason behind the non-findings and small increases is still unknown within the research, but it is postulated that larger muscles such as the hamstrings need greater stimulation in terms of larger frequencies and amplitudes to stimulate muscle spindles sufficiently to elicit adaptation. Future research should focus on both the hamstrings and quadriceps muscles as they are both important muscles involved in many movements of the lower limbs. Nonetheless, enhancements in lower body strength and power were relatively lower than those

seen in the upper body. This may be due the lower limbs being naturally larger in musculature and therefore requiring a greater vibratory stimulus (i.e., greater frequencies, amplitudes, durations or all three) to elicit adaptations similar to the upper body.

#### 2.3.4 Device Type and Mode of Vibration

Despite the promising adaptations LV has on upper and lower body strength and power, there are large variations in methodological approaches used in these studies around the application of vibration. The devices used for vibratory stimulation varied across studies, the most common technologies used were wearable straps with a pulse-mode vibratory stimulation (Cho et al., 2020; Cochrane, 2016; Cochrane, 2017; Maeda et al., 2021), an electromotor with electromagnetic device powered by an eccentric wheel with speed regulation driven by a digital sinusoidal generator (Filipi et al., 2020; Iodice et al., 2011; Issurin and Tenenbaum, 1999; Issurin et al., 2010), an oscillatory device (Cochrane et al., 2007; Pamukoff et al., 2014), local vibration applied through a gym machine via either a tri-phase induction motor (Couto et al., 2013), Or a Vibrex, Exoscience (UK) device (Mileva, 2006), a vibrating foam roller or various portable devices placed onto the target muscle/s (Bosco et al., 1999; Custer et al., 2017; Dickerson et al., 2012; Hong et al., 2010; Jacobson et al., 2012; Moran et al., 2007; Rongsawad and Ratanapinunchai, 2018; Sagiroglu, 2017; Siegmund et al., 2014; Souron et al., 2018; Wang et al., 2022). An overview of the devices can be found in Table 4.




The most common device utilised by four research groups was a Myovolt (Christchurch, New Zealand) wearable vibration strap which provided an intermittent pulsing mode of vibratory stimulation (Cho et al., 2020; Cochrane, 2016; Cochrane, 2017; Maeda et al., 2020 ). These four research groups reported significant increases in strength (22.63 to 30.92%) (Cho et al., 2020), peak power ( $p = 0.013$ ;  $ES = 1.1$ , moderate ) and mean concentric power ( $p = 0.334$ ;  $ES = 1.5$ , large ) during the concentric phase of an elbow flexion exercise (Cochrane, 2016), but no significant differences were found for isometric and concentric strength between vibration and control groups in another study utilising this device (Cochrane, 2017). The second most common method of application of local vibration was through an eccentric wheel with speed regulation utilised by three research groups (Filipi et al., 2020; Issurin and Tenenbaum, 1999; Issurin et al., 2010). They reported significant increases in mean power measures (6.60 to 25.67%) during the following movements: Wingate tests, bilateral elbow flexion exercises and a one arm pulling action similar to a kayak stroke. The research groups who utilised an oscillatory device reported no significant differences for peak torque during maximal voluntary contraction of the knee extensors (Pamukoff et al., 2014), however they did report trivial increases in hand grip strength (1.69%) and power (1.67%) (Cochrane and

Hawke, 2007). Iodice et al. (2011), used a modulated sinusoidal device and reported an increase in bilateral MVC (11.5%) and a significant increase in quadriceps strength (33.0 to 41.0%) during knee extension exercises. Research groups who applied local vibration through a gym machine reported significant differences in dynamic strength during a knee extension exercise between control and vibration groups (12.1%) (Mileva et al., 2006). The research groups who applied the vibration through various other localised vibration devices reported significant changes in both strength (9.67 to 28.15%) during isokinetic elbow flexor testing (Hong et al., 2010; Souron et al., 2018) and MVC of the quadriceps, and power measures (0.60 to 13.33%) during maximal dynamic elbow flexion, and CMJ, vertical jump and drop jump tests (Bosco et al., 1999; Jacobson et al., 2012; Sagiroglu, 2017; Wang et al., 2022).

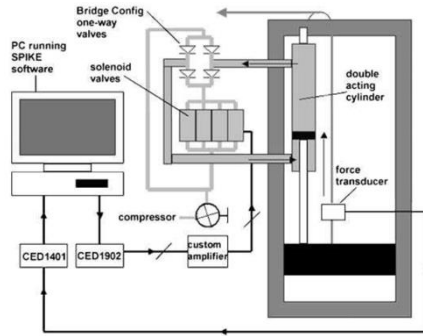
Based on the metrics assessed and devices utilised amongst all research groups, the greatest changes in strength and power outcome variables were seen when using devices that were either directly strapped onto the desired muscle (i.e., Myovolt wearable vibration strap), or the device was placed onto the muscle location, or applied through the cable of a gym machine (Cho et al., 2020; Cochrane, 2016; Cochrane, 2017; Filipi et al., 2020; Iodice et al., 2011; Issurin and Tenenbaum, 1999; Issurin et al., 2010; Maeda et al., 2020; Mileva et al., 2006). When the vibration stimulation is directly placed onto the desired muscle and the frequency and amplitude are large enough to directly expose the muscle to rapid stretching and contraction (i.e., the TVR), it results in an involuntary production of strength within the vibrated muscle, then it is plausible that acute strength and power enhancements will occur as the muscle is experiencing a mechanical load (Alghadir et al., 2018; Germann et al., 2018). This could likely have been the case of above mentioned research groups, especially since they utilized an intermittent pulsing mode vibration setting. This setting allows the muscle to experience a range of vibration frequencies (30-170 Hz) and amplitudes (0.12 – 1.2mm) during one cycle of 10 minutes vibration stimulation. By taking the muscle through this cycle of frequency and amplitude ranges it increases the firing frequency of the  $\alpha$ -motoneurons, ultimately initiating a more forceful muscle contraction through the TVR experienced during vibration stimulation (Cho et al., 2020; Cardinale and Lim, 2003). This is different to what the muscle undergoes during normal resistance training, (i.e., where muscles work against a weight force), without the added vibration stimulation. When LV is applied while performing a strength or power movement, the additional motor unit activation and subsequent adaptations may be due to increases in blood flow, synchronization of motor units, or reduced muscle soreness, allowing quicker recovery of muscles during sessions (Alghadir et al., 2018; Germann et al., 2018; Sagiroglu, 2017). However, there is still

no consensus as to which device or vibratory mode is ideal for stimulating strength and power adaptations, and should be a key focus for future research in the area.

**Table 2.** Local vibration devices utilised in each research group

Table 2	Local vibration devices utilised in each research group			
Device	Picture of device	How the device works	Research groups	
Wearable strap with pulse-mode vibratory stimulation		With a 1:1 ratio of intermittent pulsing mode the vibration frequency runs through a range of 30 to 100 Hz at an amplitude of 0 to 0.12 mm in 0.5 seconds which creates a pulsing effect on the area the device is strapped	Cho et al., 2020; Cochrane, 2016; Cochrane, 2017; Maeda et al., 2021	
(Myovolt, Christchurch, New Zealand)				
Electromotor with an electromagnetic device powered eccentric wheel, modulated by a sinusoidal generator		The device produces a square wave mechanical vibration which is transferred to the skin by the self-standing transducer and passes through the surface layers and fat tissue, stimulating the mechanical receptors within the muscles and changes the course of different pathologies during the vibration stimulation. The device runs through a frequency range of 120 to 300 Hz	Filipi et al., 2020; Iodice et al., 2011; Issurin and Tenenbaum, 1999; Issurin et al., 2010	
(VISSMAN, Rome, Italy)				
Oscillatory pulley system or dumbbell device		The device consists of an electromotor with a speed reduction and eccentric wheel, and the load is held by either a cable connected to a gym machine pulley system or to a dumbbell device (as pictured). The load is then passed through the eccentric wheel in the motor via one of the two cable systems and elicits peak-to-peak oscillations of 3mm around a horizontal axis and a frequency range of 30 to 44 Hz.	Cochrane et al., 2007 and Pamukoff et al., 2014	
Galileo TOP (Novotec) device				

A tri-phase induction motor or resistance with rapid variable frequency applied through a gym machine



Vibrex, Exoscience, UK system attached to gym machine



Siemens tri-phase induction motor

The tri-phase induction motor applies vibration directly to the steel cable of the gym machine (e.g., lat pulldown machine) and then the steel cable passes the local vibration directly to the trained limb. The motor is coupled to an eccentric axis with a sheath at the end, and this allows the steel cable of the gym machine to be pushed. Resistance with rapid variable frequency devices are attached to the framework of a gym machine (e.g., Technogym leg extension machine), and are computer controlled. The computer controls a vibration frequency of 1 to 30 Hz when motion is applied to the bar of the gym machine through a controlled dampening mechanism.

Couto et al., 2013 and Mileva, 2006

Vibrating foam roller



VYPER 2.0, Hyperice, United States

The Hyperice vibrating foam roller is constructed of a high-intensity vibrating core and rechargeable lithium-ion battery encased in eco-friendly high-density polypropylene foam for maximum vibration transfer. It has three vibration settings, low, medium-, or high-intensity, which can be selected by one button on the side. To use the device, simply turn it on and select your speed of vibration stimulation, then perform normal foam rolling stretches while rolling on the device.

Wang et al., 2022

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Various portable  
vibration devices



Thumper Versa Pro Massager

These devices were either made in-house by the research group or they utilised one such as the Thumper Versa Pro Massager in the column to the left. The device was then placed onto the muscle of interest to the research group, where it elicited local vibratory stimulation at varying frequencies and amplitudes. Bosco et al., 1999; Custer et al., 2017; Dickerson et al., 2012; Hong et al., 2010; Jacobson et al., 2012; Moran et al., 2007; Rongsawad and Ratanapinunchai, 2018; Sagiroglu, 2017; Siegmund et al., 2014; Souron et al., 2018

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### 2.3.5 Vibratory and Rest Period Durations Effects

Vibratory stimulation length and rest periods are important to consider as they contribute to the amount of load that is taken up by the muscle during the stimulation. If the muscle can take up more load with less rest, the possibility exists for the LV to be more effective in terms of acute strength and power enhancements. Essentially in the beginning, the more LV that can be experienced the better in terms of acute enhancements to strength and power. However, researchers must be aware that there is not sufficient evidence on LV to diminish the fact that more load with less rest could mean less strength and power in return if the responses to the LV become maladaptive within the muscle. Localised vibratory stimulation was applied for durations of 10 seconds to 30 minutes, using 2-10 sets of exercise and 1 to 12 repetitions or the maximum repetitions possible per set within the included studies. The research groups that were reviewed utilised rest periods of 15 seconds to 15 minutes. Short durations of vibration application ( $\sim 30$  s to  $\leq 5$  minutes) resulted in significant improvements (0.60 to 33.57%) in mean power, hand grip strength, peak torque, time to peak torque, peak power, CMJ height and MVC (Bosco et al., 1999; Cochrane, 2007; Hong et al., 2010; Jacobson et al., 2017; Maeda et al., 2020; Souron et al., 2018; Wang et al., 2022). Longer durations ( $> 5$  minutes to 30 minutes) of vibration application also resulted in significant improvements (11.4 to 41.0%) in muscle activity, peak torque, peak power, mean concentric power, total work, mean power and MVC during isometric testing, dumbbell elbow flexion exercises, cycle tests, CMJ height tests and maximal voluntary isometric contraction tests (Cho et al., 2020; Cochrane, 2016; Filipi et al., 2020; Iodice et al., 2011; Pamukoff et al., 2014). While longer vibratory applications appear to be marginally better than shorter application periods, there is no clear differences or benefits to being exposed to shorter or longer durations of localised vibration.

During longer periods of rest the muscle can relax and recover for a longer duration and during shorter periods of rest the muscle is stimulated more due to decreased time between bouts of vibratory stimulation. Rest periods of 50 s to 3 minutes between sets of exercise, resulted in significant improvements in average power (6.6%) and peak power (11.4%) during multiple Wingate tests (Filipi et al., 2020), MVC of the knee extensors during isometric knee extensions (9.7 to 11.5%) (Iodice et al., 2011; Souron et al., 2018), CMJ height (8.06%) (Wang et al., 2022) and quadriceps isokinetic strength (30.0 to 41.0%) (Iodice et al., 2011). Longer rest periods of  $\geq 5$  to 15 minutes between sets of vibratory exercise, resulted in significant improvements ranging from 7.9% to 25.7% in

dynamic power, mean power and maximal power during isokinetic testing of the elbow flexors and a one arm pulling action (Bosco et al., 1999; Issurin and Tenenbaum, 1999; Issurin et al., 2010). Adequate rest between sets of resistance exercises, regardless of LV stimulation, do help maintain high levels of force production for the subsequent set and which may transfer to chronic adaptations within the muscles, with the scientifically researched consensus being between 3 - 5 minutes rest between sets of resistance exercises (de Salles et al., 2009). Shorter rest periods between exercises are advantageous because they induce increased metabolic stress, and with the added LV stimulation causing increased physiological functions to take place (e.g., increased firing frequency of motor units causing muscle contractions within the vibrated muscle) this could potentially be why there were significant changes amongst research groups using shorter rest periods (50 s to 3 minutes) (Filipi et al., 2020; Hong et al., 2010; Iodice et al., 2011; Souron et al., 2018; Wang et al., 2020). On the other hand, longer rest periods give one the advantage of increased total volume during resistance exercise, allowing one to essentially increase the mechanical load applied to the muscle group (Freitas et al., 2009). This could appear to be slightly different with LV stimulation during resistance exercises, as it would seem that shorter or longer rest period durations have similar effects on strength and power capabilities, and both short and long rest periods can be utilised when applying LV. When combined with LV stimulation, where muscles are already exposed to an increased load, the result is increased power outcomes in the research groups who utilized longer rest periods ( $\geq 5$  to 15 minutes) (Bosco et al., 1999; Issurin and Tenenbaum, 1999; Issurin et al., 2010). In saying this, future research is required to investigate this more carefully with experimental designs directly comparing short versus long rest periods combining LV with resistance training.

### 2.3.6 Amplitude Effects

Amplitude is an important variable to consider during LV stimulation as it is one of the variables that accounts for the mechanical load that the muscle is exposed to, and therefore the intensity of vibratory stimulation the muscle receives. Essentially the greater the amplitude, the greater the vibratory stimulation and therefore energy transferred to the muscles from the vibration device. Researchers used localised vibration amplitudes ranging from 0.12 to 12 mm to affect changes in strength and power measures. Lower amplitude vibratory stimulation (0.12 to 5 mm) was utilised in 13 studies. Significant differences in strength were reported by three research groups (Cho et al., 2020; Hong et al., 2010; Iodice et al., 2011), these changes ranging from 11.5% to 41.0%. The greatest

changes were found in eccentric peak torque (22.62%) during isokinetic testing of the gastrocnemius (Cho et al., 2020), peak torque (13.5%) during elbow flexion (Hong et al., 2010), and MVC of the leg extensors (11.5%) and quadriceps isokinetic strength (30 to 41%) (Iodice et al., 2011). However, it needs to be noted that not all researchers reported significant strength changes with these same amplitudes (Cochrane, 2017; Moran et al., 2007). Amplitudes  $\leq 3$ mm produced trivial changes (1.69 to 4.0%) in muscular strength measures of the shoulder and arm muscles and the knee extensors, however these were not significant increases (Cochrane, 2007; Mileva et al., 2006).

Power outputs were also found to significantly increase when utilising lower amplitude vibratory stimulation ( $\leq 5$  mm) as reported by five research groups (Cochrane, 2016; Filipi et al., 2020; Issurin and Tenenbaum, 1999; Issurin et al., 2010; Wang et al., 2022), these changes ranging from 6.60 to 25.63%. The greatest changes were found for peak power (6.6 to 10.4%) during multiple Wingate tests (Filipi et al., 2020) and an elbow flexion exercise (Issurin and Tenenbaum, 1999), dynamic power (12.07 to 20.10%) during a one arm pulling action similar to a kayak stroke (Issurin et al., 2010), mean power (10.7%) (Issurin and Tenenbaum, 1999), and countermovement jump height (10.98%) (Wang et al., 2022). Smaller changes (0.6 to 3.8%;  $p < 0.05$ ) in power measures, VJ and CMJ height and explosiveness were reported for amplitudes  $\leq 1.2$  mm (Cochrane, 2007; Jacobson et al., 2012; Maeda et al., 2020; Sagiroglu, 2017). However, not all research groups found significant differences in power outputs using lower vibratory amplitudes (Custer et al., 2017; Iodice et al., 2011; Moran et al., 2007). This was attributed to a few limitations within these research groups, mainly utilizing recreational individuals and not acutely injured individuals (Custer et al., 2017), as vibration has proven advantageous for subjects suffering from acute ankle sprains and acute hamstring strains opposed to healthy, uninjured subjects; as well as LV training having more of an influence on a phenotype of altered fibre distribution in skeletal muscle, and not increasing muscle fibre-specific tension to improve power outputs (Iodice et al., 2011). Moran et al. (2007), argued that their research did not find any significant findings relating to the power outputs of the biceps brachii muscles during a submaximal-effort isometric elbow flexion exercise due to the varying vibration training amplitude and frequency settings from past research, making it more difficult to determine what is appropriate for a submaximal-effort isometric exercise compared to a maximal-effort dynamic exercise.

Higher amplitudes of vibratory stimulation (6 mm to 12 mm) were utilised in four studies (Table 3) (Bosco et al., 1999; Couto et al., 2013; Dickerson et al., 2012; and Issurin et al., 2010). Interestingly, these research groups only investigated power outcomes and not strength outcomes. Significant differences in power were reported by two of these research groups with the greatest changes in power (13.33%) during maximal isometric elbow flexion exercises (Bosco et al., 1999) using 6 mm amplitude and dynamic power (25.63%) during a one arm pulling action similar to a kayak stroke (Issurin et al., 2010) using 8 mm amplitude. Conversely, the other two research groups reported non-significant power changes with amplitudes of  $\geq 6$  mm during a lat pulldown exercise (Couto et al., 2013) and during peak strength testing of the quadriceps and hamstrings (Dickerson et al., 2012).

Amplitude accounts for some of the mechanical load the muscle experiences alongside the athletic tasks participants performed in each research group, regardless of longer or shorter durations of LV. Because of this, it is postulated that if there is a large amplitude ( $\geq 6$  mm) range for short period ( $< 5$  minutes), or a smaller amplitude ( $\leq 5$  mm) for a longer period ( $\geq 5$  minutes), it could possibly induce a similar physiological effect on the muscle, regardless of the duration of vibration, though this should be investigated further. However, having a sufficient amplitude great enough to elicit a sufficient vibratory stimulation to the muscle is important so that the different physiological responses within the muscle take place (i.e., rapid stretching and shortening resulting in muscle contractions) (Ghazi et al., 2021). Adding to this, the muscle tendon size or muscle group (biceps brachii versus gluteus maximus) will have an effect on how much amplitude is required to transfer enough energy to allow for adaptation to the muscle (Ghazi et al., 2021). For example, a larger muscle or group may require higher amplitudes or longer durations with relatively low amplitudes, but effective values for amplitude are still undefined at this time due to the unstandardized approach previous research has taken with LV stimulation.

**Table 3.** Amplitude settings effects on the neuromuscular system of the included studies.

Table 3 Amplitude settings effects on the neuromuscular system		
Amplitude (mm)	Main Effects on Neuromuscular System	Studies Included
Lower amplitudes (0.12mm – 5mm)	Increased: <ul style="list-style-type: none"> <li>• muscle activity</li> <li>• EMG response</li> <li>• eccentric peak torque</li> <li>• peak power</li> <li>• time to peak torque.</li> <li>• isometric strength</li> <li>• concentric strength</li> <li>• average peak power</li> <li>• total exercise work</li> <li>• bilateral maximal isometric voluntary contraction</li> <li>• quadriceps peak force</li> <li>• counter movement jump performance.</li> </ul>	Cho et al., 2020; Cochrane, 2016; Cochrane, 2017; Custer et al., 2017; Filipi et al., 2020; Hong et al., 2010; Iodice et al., 2011; Issurin and Tenenbaum, 1999; Issurin et al., 2010; Maeda et al., 2020; Moran et al., 2007; Pamukoff et al., 2014 and Rongsawad and Ratanapinunchai, 2018.
Higher amplitudes (6mm – 12mm)	<ul style="list-style-type: none"> <li>• Significant differences found in power increases.</li> <li>• Increased dynamic power</li> </ul>	Bosco et al., 1999; Couto et al., 2013; Dickerson et al., 2012; and Issurin et al., 2010

### 2.3.7 Frequency Effects

Frequency, alongside amplitude, determines the mechanical load the muscle is exposed to during LV stimulation. Localised vibration frequencies ranging from 10 to 300 Hz were utilised in the reviewed studies to stimulate changes in muscular strength and power variables. Significant differences for both strength (4.0 to 41.0%) and power (6.60 to 25.67%) were found with the various frequencies used.

Lower frequencies (10 to  $\leq$  100 Hz) of vibration stimulation were utilised in 19 studies (Table 4). Significant differences in strength were reported by two research groups (Cho et al., 2020; Hong et al., 2010), these changes ranged from (4.00 to 33.57%). The greatest changes were found for dynamic strength of the knee extensors during a knee extension exercise (4.00 to 4.30%) (Mileva et al., 2006), peak torque (13.5%) and time to peak torque (28.15 to 33.57%) during elbow flexion exercises (Hong et al., 2010), and eccentric peak torque (22.62%) during isokinetic testing of the gastrocnemius (Cho et al., 2020). Lower frequencies of vibration also resulted in power changes ranging from 7.90 to 25.67% in five studies (Bosco et al., 1999; Filipi et al., 2020; Issurin and Tenenbaum, 1999; Issurin et al., 2010; Wang et al., 2022). The greatest changes in dynamic power (13.33%) during elbow flexion exercises (Bosco et al., 1999), peak power (7.90 to 11.4%) during cycling tests and an elbow flexion exercise (Filipi et al., 2020; Issurin and

Tenenbaum, 1999) and average power (6.60 to 10.70%) during the same cycling tests and an elbow flexion exercise (Filipi et al., 2020; Issurin and Tenenbaum, 1999), power gains (13.60 to 25.67%) resulting from a one arm pulling action (Issurin et al., 2010) and CMJ height (8.06%) during CMJ tests (Wang et al., 2022). Two research groups found trivial changes (1.55 to 3.80%) in VJ height and velocity when using 30 to 38 Hz of vibration frequency (Jacobson et al., 2017; Sagioglu, 2017). Six research groups reported that utilising 20 to 60 Hz vibration stimulation did not have any significant effect on muscular strength or power (Cochrane and Hawke, 2007; Couto et al., 2013; Custer et al., 2017; Dickerson et al., 2012; Pamukoff et al., 2014; Siegmund et al., 2014). One possible explanation as to why this could be the case, is that the methods of the research only investigated certain testing variables and not all physiological or performance changes that might have occurred (Cochrane and Hawke, 2007). Other research groups, concluded that the lack of their findings was due to the differences in the type of vibration applied, the frequency and amplitude compared to what previous research has found successful (Couto et al., 2013; Custer et al., 2017). Dickerson et al. (2012), concluded that their population size was too small (30 subjects), and having a greater sample size could have possibly added more credibility and strength to their results; they also did not use isokinetic dynamometry to test strength output, but rather utilized single leg hop tests and handheld dynamometry, which only tests the maximal strength output at a standardized joint angle opposed to a full range of motion. Pamukoff et al. (2014), stated that their research did not standardize knee position amongst their subjects, and thus accounts for the lack of results relating to peak torque increases. This research group and Siegmund et al. (2014), both stated that their investigations did not account for potential differential effects from stimuli either below or greater than their chosen frequencies (20 to 30 Hz) that they utilized.

Higher frequency vibratory stimulation ( $\geq 100$  to 300 Hz) was utilised in seven studies (Table 4), with significant strength (9.67 to 41.00%) and power (6.60 to 11.4%) differences found by five research groups (Cho et al., 2020; Cochrane, 2016; Filipi et al., 2020; Iodice et al., 2011; Souron et al., 2018). The greatest changes were found in MVC (9.67 to 11.5%) during a knee extension exercise (Iodice et al., 2011; Souron et al., 2018), quadriceps strength (33.00 to 41.00%) during a knee extension exercise (Iodice et al., 2011), peak power (11.4%) and average power (6.60%) during elbow flexion (Filipi et al., 2020). One research group utilised a range of vibration frequencies (0 – 170 Hz) and found a trivial increase (1.72%) during CMJ performance and height (Maeda et al., 2020).

It is postulated these minimal changes occurred due to the frequencies' ability to recruit high-threshold motor units to elicit power adaptation (Germann et al., 2018; Rose and McGill, 1998). However there are many other responses, such as increased muscle activity (Bosco et al., 1999), and neural responses like motor unit firing synchronization and frequency, and central motor command (Cochrane, 2011) during LV stimulation that could be the cause of these lower power outputs even though they were not necessarily statistically significant.

From these results, we can determine that the overall consensus is that higher and lower frequencies do have a positive effect on both strength and power purely because of the transfer of energy from the vibration to the muscles being stimulated, resulting in a TVR causing rapid stretching and shortening of the muscle generating a muscle contraction which leads to increased strength and power of the vibrated muscle (Alghadir et al., 2018; Cormie et al., 2006, Delecluse et al., 2003; Germann et al., 2018; Sagiroglu, 2017). Overall both lower and higher frequency utilisation had significant effects on both strength and power outcomes on various muscle groups performing various exercises. There are some varying reasons as to why some research groups did not find any significant results, such as too low of a frequency, or amplitude to stimulate the muscle based on its size and architecture (smaller muscles versus larger muscles), or even the duration of stimulation being too short and not allowing the muscle time to adapt to the vibration stimulation. Age and experience of the subjects would affect the results simply due to familiarity with resistance training, and even smaller versus larger sample sizes of subjects could have affected the results within the research groups analysed.

**Table 4.** Frequency settings effects on the neuromuscular system of the included studies.

Table 4 Frequency settings effects on neuromuscular system		
Frequency Settings (Hz)	Main Effects on Neuromuscular System	Studies Included
<i>Set Frequencies</i>		
20Hz	No significant differences found	Cochrane et al., 2007 and Siegmund et al., 2014
30Hz	<ul style="list-style-type: none"> <li>• Increased power</li> <li>• Significant differences in internal and external shoulder joint rotation peak torque and time to peak torque</li> <li>• Increased peak power in vertical jump</li> <li>• Significant difference in EMG amplitude and quadriceps activation</li> </ul>	Bosco et al., 1999; Hong et al., 2010; Jacobson et al., 2017 and Pamukoff et al., 2014
44Hz	<ul style="list-style-type: none"> <li>• Increased maximal and mean power</li> <li>• Significant difference between elite and amateur athletes</li> <li>• Significant difference between elite and amateur athletes maximal power</li> </ul>	Issurin and Tenenbaum, 1999
60Hz	No significant differences found	Couto et al., 2013 and Pamukoff et al., 2014
100Hz	<ul style="list-style-type: none"> <li>• Significant effect on muscle</li> <li>• Increases in peak power, average peak between bouts and total exercise work</li> </ul>	Filipi et al., 2020 and Souron et al., 2018
120Hz	Significant increase in isometric and concentric strength immediately after eccentric exercise	Cochrane, 2017
300Hz	<ul style="list-style-type: none"> <li>• Increased bilateral MVC</li> <li>• Increased quadriceps strength</li> </ul>	Iodice et al., 2011
<i>Frequency Ranges</i>		
17 – 38Hz	<ul style="list-style-type: none"> <li>• Increased power gains</li> <li>• Significant effect on dynamic power between frequency and amplitude interaction</li> </ul>	Issurin et al., 2010 and Sagiroglu, 2017
0 – 170Hz	<ul style="list-style-type: none"> <li>• Significant difference on vertical jump</li> <li>• Improved dorsiflexion</li> <li>• Improved CMJ and jump performance</li> <li>• Increased peak power and concentric power in biceps brachii</li> <li>• Significant difference in muscle activity</li> <li>• Significant difference in peak torque</li> </ul>	Cho et al., 2020; Cochrane, 2016 and Maeda et al., 2020

## 2.4 Practical Applications

Of interest to the authors was to explore the loading parameters that had been used previously to elicit strength and power adaptations using acute bouts of localised vibration. Understanding and implementing these loading parameters should enable practitioners to better prescribe localised vibration to enhance performance and clinical outcomes. In terms of strength 300 Hz frequency, 2mm amplitude and three 30 minute

sessions a week have been found to increase lower body strength by 5.4 to 11.5% and 33.0 to 41.0% in the quadriceps (Iodice et al., 2011), while 17 to 38 Hz frequencies, 2 to 8 mm amplitudes, and ~ 45 seconds in duration have been found to increase upper body power in the biceps brachii by 9.9 to 38.3%. However, it needs to be noted that a variety of loading parameters have been found to positively affect strength and power adaptation, and thus it is difficult to definitively state the efficacy of one set of loading parameters over another. Nonetheless, placement of the LV device on the target muscle, sufficient frequency and amplitude based on the desired strength and/or power outcome/s, mode of vibration and resistance exercise/s performed alongside LV stimulation is important to consider depending on the desired outcomes by practitioners and users. Moving forward it is important to note that larger muscles and/or groups may require greater LV stimulus to achieve adaptations relative to smaller muscles and/or groups. Overall, there is a certain level of agreement that the combination of varying vibration frequencies, amplitudes, durations, and rest periods do in fact influence the muscular strength and power through the transfer of energy from the LV device to the muscle directly. Finally, given the range of methodological approaches and device settings used, direct comparisons are challenging. Therefore, well-designed controlled studies using standardized methodological approaches are required to fully elucidate the effectiveness of LV on acute strength and power adaptations.

## 2.5 Acknowledgements

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## **Chapter 3 Integrating Local Vibration Training into an Isometric Strength Protocol: Acute Effects on Lower-Body Isokinetic Strength in Healthy, Active Individuals**

This chapter comprises the following manuscript which will be submitted to the European Journal of Sports Science and formatted accordingly:

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### **3.0 Prelude**

The focus of this chapter was to investigate the acute effect of LV stimulation during an isometric hamstring contraction on the subsequent isokinetic strength of the hamstrings and quadriceps muscles. The utilisation of LV in combination with different muscular contractions was identified as a knowledge gap from the systematic literature review in Chapter 2. The review also provided insight into the vibratory settings (frequency, amplitude, and duration) to be used for this experimental pilot study to elicit both strength and power adaptations. Additionally, given the review of literature, it was hypothesised that acute LV stimulation does have a positive effect on both strength and power and if there was to be an acute adaptation found within this experimental protocol the applications for the future would be fundamental in guiding strength and conditioning practices.

### **3.1 Introduction**

Adding vibration to resistance training exercises has been used to facilitate acute improvements in strength performance in trained and non-trained subjects for decades (Delecluse, Roelants, and Verschueren, 2003; Drummond et al., 2021). Vibration devices provide a mechanical oscillation that transfers vibration energy to the musculoskeletal system (Drummond et al., 2021). The application of vibration can be carried out via two different methods: whole body vibration (WBV) platforms or local vibration (LV) devices. During WBV subjects stand on either a vertical or oscillating platform (Mingorance et al., 2021), where the vibration is applied to the distal segment of the body directly in contact with the platform and transferred throughout the body. WBV is a widely used modality within sports to enhance athletic abilities and performance (Sharma and Hayat, 2022), however it has limitations, namely expense, portability, and its inability to directly target certain muscles and muscle groups (Souron et al., 2017). LV devices

have recently received attention due to their ability to directly target muscles and muscle groups, as well as their ease of portability, utility, and cost-effectiveness. These devices are seen as more efficient than WBV platforms as the vibration can be applied in the opposite direction to the resultant muscle forces at play (Silva et al., 2008), enhancing the mechanisms of involuntary muscle activity, thus, a more targeted approach for improving the overall strength of muscles.

Vibration stimulation in conjunction with exercise has been found to increase flexibility of musculature and blood flow, and this can ultimately result in greater strength and power outcomes (Alghadir et al., 2018; Cho et al., 2020; Couto et al., 2013; Iodice et al., 2011). Vibration stimulation activates the tonic vibration reflex (TVR) (Germann et al., 2018) within the vibrated muscle, which stimulates muscle spindles primarily through the Ia afferent neurons, and the extrafusal muscle fibres through the alpha-motor neurons, increasing the activation of muscles vibrated resulting in increased strength and power (Cormie et al., 2006; Delecluse et al., 2003). Previous researchers have focused on the effects of acute and long term bouts of LV on strength, particularly in the hamstrings, quadriceps, elbow flexors and biceps brachii (Alghadir et al., 2018; Drummond et al., 2014; Germann et al., 2018). These and other researchers have reported that applying LV during strength exercises has had an acute positive effect on the target muscle's strength. In the case of Silva et al. (2008) for example, the elbow flexors increased in isometric strength by 11% when utilizing LV, compared to only 5% for the control group utilizing isometric contractions alone. Similarly Iodice et al. (2011) observed an increase in bilateral maximal voluntary contractions of the quadriceps (11.5%) in their LV group compared to 5.4% in their control group who performed only resistance training. It has also been discovered that using the intermittent mode with LV devices, increases muscle activation (15.64%) and eccentric peak torque (22.63%) in ankle plantar flexors (Cho et al., 2020). These increases in strength of various muscle groups could be explained simply because when LV is combined with exercise, the target muscles undergo rapid stretching, triggering a muscle contraction and an involuntary production of strength within the muscle or muscle group (Germann et al., 2018). The firing frequency of motor units also increases during LV combined with exercise and improved synchronisation of those motor units permits a more forceful contraction while the muscle is being stretched (Goebel et al., 2017). Thus an acute increase of strength occurs within the muscles being vibrated. However, researchers to this point have focused their efforts on acute testing methods with LV directly applied during an exercise and not what happens after exposure

to LV during subsequent exercise as an acute enhancement strategy, which could be of great benefit towards the future use of these LV devices.

Skeletal muscles are known to have optimal lengths for producing maximum force (Guex et al., 2013). Additionally, peak force generated at certain lengths influence overall limb function (Alegre et al., 2014; Oranchuk et al., 2019). The use of LV to shift the angle of peak force to a longer muscle length has not been investigated thus far; however, isometric training alone at specific knee angles can influence shifting the angle of peak torque to longer muscle lengths (Alegre et al., 2014). Some researchers have found that isometric training at a knee angle of 90° can lead to significant increases in isokinetic strength (23.5%), compared to a knee angle of 50° which resulted in an insignificant increase (10%) (Alegre et al., 2014). These researchers also demonstrated a shift in the angle of peak torque at 90° (14.6%), compared to 50° (-7.3%); which reinforced that training at longer muscle lengths does aid in shifting the peak torque to a longer muscle length (Alegre et al., 2014). LV may offer a means to not only increase muscular strength and peak torque but also and shift the angle at which peak torque occurs to a longer muscular length, thus making muscles stronger in lengthened positions during athletic activities.

LV does show promise in its ability to enhance the strength (peak torque) of various muscle groups (Cho et al., 2020; Goebel et al., 2015; Iodice et al., 2011; Silva et al., 2008). However, there are many unknowns pertaining to LV and resistance exercise. For example, it is unknown whether LV can shift the angle of peak torque to longer muscle lengths and increase peak force simultaneously. Up until recently, most researchers have investigated adaptation while performing contractions with LV, and not if any acute neuromuscular enhancements exist after LV is removed, which is a focus of this research. Investigating these unknowns may shed light on the utility of LV loading to induce strength and power. The aim of this study, therefore, was to assess the effects of LV isometric loading on subsequent isokinetic peak torque, angle of peak torque, time to peak torque and power in the hamstrings and quadriceps muscle groups. It was hypothesized that when LV was applied to the hamstring muscles during an isometric contraction the subsequent isokinetic peak torque, angle of peak torque, time to peak torque and power of the hamstrings and quadriceps would increase compared to a non-LV condition.

### 3.2 Materials and Methods

### 3.2.1 Participants

Sixteen healthy individuals (7 female, 9 male), aged:  $24.6 \pm 4.52$  years, height:  $172.8 \pm 8.83$  m, weight:  $74.3 \pm 14.5$  kg, who were physically active at least three times a week volunteered for this research. For inclusion in the study each participant needed to meet the following criteria: 1) be in good health and exercise regularly, such as gym workouts, Cross Fit, running, walking, 3 – 4 times a week; (2) aged between 18-50 years of age; (3) possess no adverse health conditions, (i.e., hypertension, heart disease); (4) had no lower-limbs injuries within the last 6-months; and, (5) had no significant injury that could prevent them from performing the required exercises (leg extensions, leg curls and hamstring isometric holds). All procedures were approved by the Institutional Review Committee for the ethical use of human subjects (22/217). Each participant provided written informed consent before undertaking any form of familiarisation testing or data collection. All participants were informed about the experimental protocol and its potential risks and benefits prior to commencement of the research project. Participants were permitted to withdraw from the study at any time without prejudice.

### 3.2.2 Study Design

An acute experimental randomised cross-over design was utilised. Each participant underwent two sessions, which lasted approximately 45 to 60 minutes each on two separate days. This included a familiarisation session (day one) and a data collection session (day two) that took place separately with no more than seven days between and a minimum of one day apart. During the familiarisation session the participants were familiarised with the testing protocol, the exercises they would be performing and the equipment that was utilized (i.e., isokinetic dynamometer and wearable vibration device).

The intervention comprised of 10 sets of exercise which included two intervention exercise sets as shown in Figure 1 and Figure 2. During the intervention, the participants performed a series of leg extensions (4 sets), leg curls (4 sets) and isometric hamstring exercises (2 sets) on the isokinetic dynamometer in a randomised order (Figures 1 and 2). During one set of the isometric hamstring exercise (either the first or the second set) the participants received LV on the left hamstring muscle through a Myovolt wearable vibration strap (Myovolt, Christchurch, New Zealand) (Figures 3a and 3b) for the entire duration of the intervention (~ 8 minutes). Based on the testing sequence and exercises, it was hypothesized that there would be an acute strength and power enhancement on the subsequent isokinetic strength of the hamstrings and quadriceps after the isometric set of

exercises, compared to the isokinetic strength of the hamstrings and quadriceps after the isometric set of exercises where no LV was applied.

### 3.2.3 Assessment Protocol

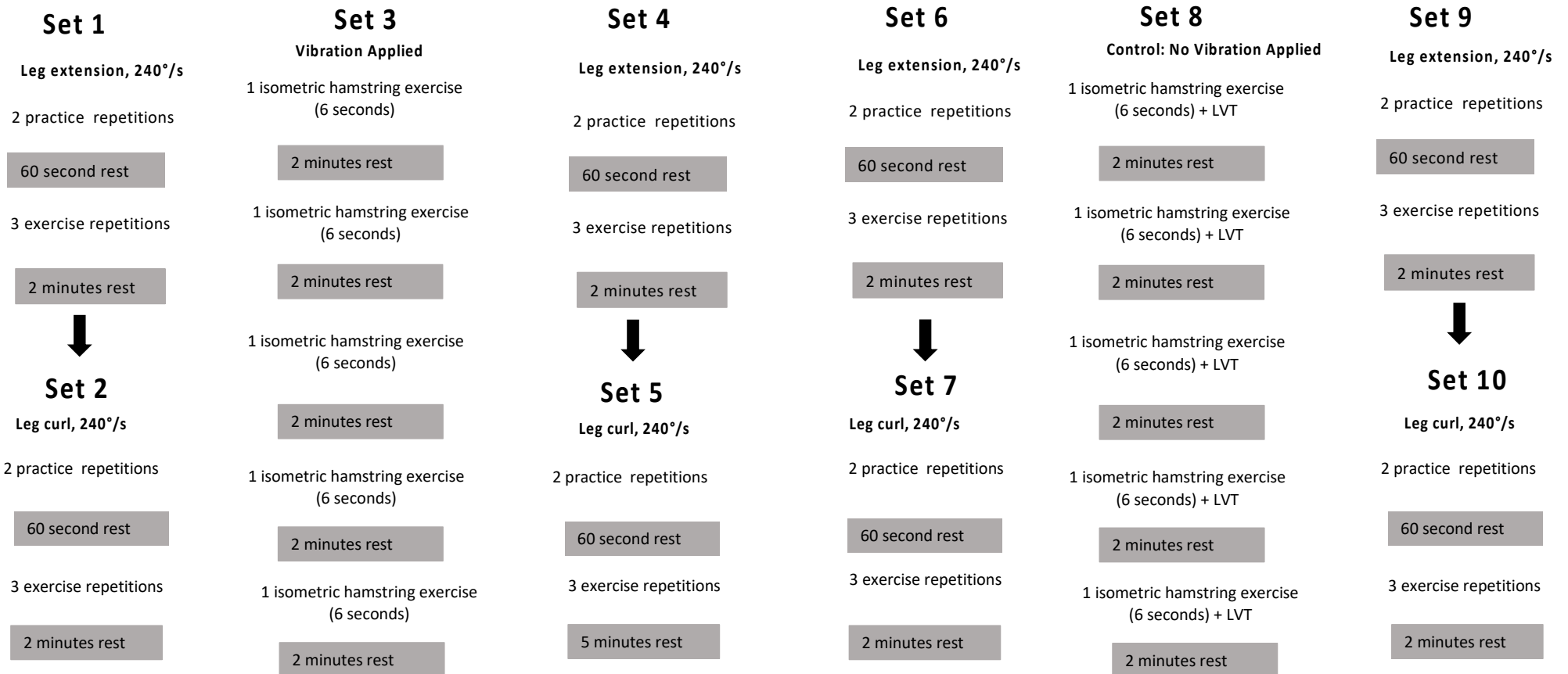
Prior to both the familiarisation and data collections session, the dynamometer was calibrated according to the operating manual's instructions so that the participant could start the exercises once warmed-up and seated in the chair. Participants performed a warm-up by completing a series of dynamic stretching, leg swings, body weight sumo squats, jumping squats and single leg deadlifts with a dumbbell weight of their choice. After the warm-up, participants were seated in the Humac Norm chair and their left-leg strapped into the isokinetic dynamometer leg attachment (Humac Norm, Boston, Massachusetts, USA), ensuring their left leg formed a 90° angle with the arm of the dynamometer. The leg extension and curls exercises performed by the participants were as follows: each session consisted of four sets of concentric leg extensions and four sets of eccentric leg curls, both performed at 240°/second. Each set was made up of two continuous practice repetitions followed by 60 seconds of rest and then three continuous repetitions, from which the data was collected, and then 2 minutes of rest before the next set of exercise (see Figures 1 and 2). Peak torque (PT), mean power (MP), angle of peak torque (APT) and time to peak torque (TPT) were explored for both eccentric and concentric leg extension and flexion conditions.

### 3.2.4 Intervention: Isometric Hamstrings exercises

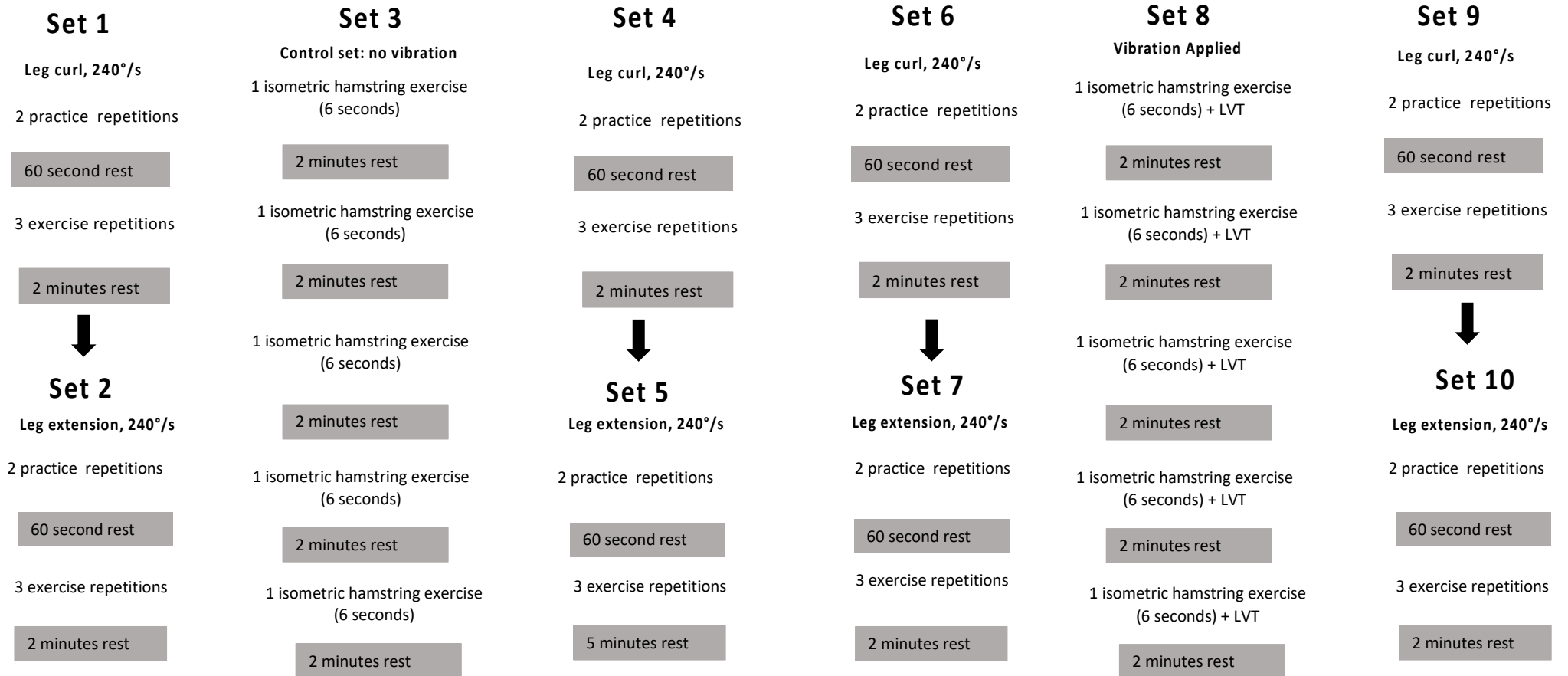
The isometric hamstring exercises comprised of five repetitions, but no practice repetitions were performed, and between each repetition was two minutes of rest to ensure recovery between bouts of maximal exercise. The exercise was performed at 60° knee flexion and lasted for six seconds per repetition. The five repetitions were performed at maximal effort with a 10 second countdown before the start of the exercise to ensure the participant started the exercise on time and lasted the full six seconds. During one set of these exercises the participant received direct vibration through the Myovolt device and during the other set they did not receive any form of vibration 2. Each exercise's repetitions, rest periods, duration and exercise order are detailed further in Figures 1 and 2.

The vibratory device (Myovolt, Christchurch, New Zealand) was tensioned around the left thigh of the participant, with the vibration actuators positioned onto the middle of the hamstrings muscle group. The device was a customised design (3MO BLE 9F67) with

wireless control function and fixed vibration frequency output. The device was operated in pulsing mode with a sinusoidal frequency profile between 0 to 60 Hz over a 4 second cycle with an amplitude of 0.1 -2mm. The device was applied continuously for a total vibration treatment time of ~ 8 -12 minutes during one set of the isometric hamstring exercises



**Figure 2.** Exercise order 1: Vibration applied during first isometric exercise set



**Figure 3.** Exercise order 2: Vibration applied during second set of isometric exercise set.



**Figure 4a.** Myovolt local vibration device    **Figure 4b.** Myovolt local vibration device and strap

### 3.3. Data Extraction

The averaged peak torque, total power, angle of peak torque and time to peak torque for each set of exercise was extracted from the isokinetic dynamometer software directly and then analysed further.

### 3.4 Statistical Analyses

Means and standard deviations (SD) were used to present measures of centrality and spread of data. A Shapiro Wilk's test was used to test for normality, as well as the distribution of the data analysed. Differences between and within groups before and after the testing conditions (vibration applied versus no vibration) were tested for significance using a two-way repeated measures ANOVA. In the event of a significant main effect, post hoc comparisons were conducted using the Tukey's test. Percent changes and 95% confidence intervals were also calculated. Magnitudes of differences were calculated as effect sizes (Hedge's G) and expressed using the following criteria:  $\leq 0.2$  = trivial, 0.2-0.49 = small; 0.5-0.79 = medium  $> 0.8$  = large (Cohen, 2013). A power analysis revealed that a sample size of 16,  $\alpha = 0.17$  and within treatment difference achieved a power level of 0.82. All statistical analysis was computed using Jamovi software (Version 2.3), all values are presented as mean  $\pm$  95% confidence interval (CI) and the level of significance was set at  $p \leq 0.05$  for all statistical analysis.

### 3.5 Results

The overarching results from the ANOVA found no significant main effects for time or group. Within-condition analysis revealed no statistically significant differences resulting from the wearable vibration application. Effects within the conditions ranged from trivial to medium for all contraction conditions. The changes in within-condition eccentric and concentric leg extension resulted in -3.73% to 1.99% in PT (ES = trivial), -2.42% to -1.42% for MP (ES = trivial to small), 0.58% to 5.01% for APT (ES = trivial to small), and -21.95% to 4.54% for TPT (ES = trivial). The changes in within-group eccentric and

concentric leg flexion resulted in -8.56% to -5.2% in PT (ES = trivial), -11.11% to 2.34% for MP (ES = trivial to small), -5.12% to 0.75% for APT (ES = trivial to small), and -13.64% to 2.94% for TPT (ES = trivial to medium).

No statistically significant differences were observed for between-conditions results. Differences between the conditions ranged from trivial to medium for all contraction conditions. Eccentric and concentric extension differences ranged from -1.94 to -4.03 for PT (ES = small), -9.06 to -0.68 for MP (ES = trivial to small), -0.09 to 1.34 for APT (ES = trivial to small), and -0.05 to 0 for TPT (ES = trivial to small). Eccentric and concentric flexion differences ranged from -4.53 to -1.34 for PT (ES = trivial to small), -0.69 to 1.8 for MP (ES = small to medium), -0.1 to -0.88 for APT (ES = trivial to small) and -0.05 to -0.01 for TPT (ES = trivial to small).

**Table 6.** Eccentric contraction results for extension and flexion conditions between control and intervention groups, including within-group changes from pre-intervention to post-intervention, and between groups differences in the mean changes.

<b>Eccentric Contraction Results</b>							
<b><i>Eccentric Extension</i></b>							
Variable	Group	Pre-intervention ( $\mu \pm SD$ )	Post-intervention ( $\mu \pm SD$ )	% Change	Post-Pre Training Effect Size (95% CI)	Difference INT - CON ( $\mu \pm SE$ )	INT – CON Effect Size (95% CI)
Peak Torque	CON	161±75.2	155±72.9	-3.73%	-0.08 (-0.61 to 0.77)	-1.94±3.37	0.48 (-0.22 to 1.18)
	INT	151±59.2	154±65.9	1.99%	0.05 (-0.74 to 0.64)		
Mean Power	CON	212±102	209±103	-1.42%	-0.03 (-0.66 to 0.72)	-0.68 ± 7.5	0.1 (-0.59 to 0.79)
	INT	206±89.8	208±98.7	0.97%	0.02 (-0.71 to 0.67)		
Angle of Peak Torque	CON	34.7±12.3	34.5±13.8	0.58%	-0.01(-0.7 to 0.71)	-0.09±1.16	0.03 (-0.66 to 0.72)
	INT	33.4±11.2	33.4±11.7	0%	0.0(-0.69 to 0.69)		
Time to Peak Torque	CON	0.41±0.29	0.32±0.09	-21.95%	-1.0 (-0.3 to 1.12)	-0.05±0.04	0.4 (-0.3 to 1.1)
	INT	0.34±0.15	0.34±0.14	0%	0.0 (-0.69 to 0.69)		
<b><i>Eccentric Flexion</i></b>							
Peak Torque	CON	103±51.4	95.1±28.9	-8.56%	0.19 (-0.51 to 0.88)	-4.53±4.41	0.26 (-0.44 to 0.95)
	INT	95.3±36	93.9±27.6	-1.47%	0.04 (-0.65 to 0.74)		
Power	CON	162±85.3	144±51.6	-11.11%	0.26 (-0.44 to 0.95)	-0.69±7.5	-0.50 (-1.21 to 0.2)
	INT	142±68.2	139±48	-2.11%	0.05 (-0.64 to 0.74)		
Angle of Peak Torque	CON	49.4±12	49.4±15.2	0%	0.0 (-0.69 to 0.69)	-0.1±1.16	-0.17 (-0.86 to 0.53)
	INT	53.6±13.2	52.4±13.4	-2.24%	0.09 (-0.6 to 0.78)		
Time to Peak Torque	CON	0.34±0.35	0.35±0.26	2.94%	0.03 (-0.73 to 0.66)	-0.05±0.04	-0.07 (-0.76 to 0.62)
	INT	0.28±0.11	0.27±0.1	-3.57%	0.10 (-0.6 to 0.79)		

CON = control group; INT = intervention group; CI = confidence intervals,  $\mu$  = mean; SD = standard deviation; SE = standard error; \* =  $p \leq 0$ .

**Table 7.** Concentric contraction results for extension and flexion conditions between control and intervention groups, including within-group changes from pre-intervention to post-intervention, and between groups differences in the mean changes.

<b>Concentric Contraction Results</b>							
<b>Concentric Extension</b>							
Variable	Group	Pre-intervention ( $\mu \pm SD$ )	Post-intervention ( $\mu \pm SD$ )	% Change	Post-Pre Training Effect Size (95% CI)	Difference INT - CON ( $\mu \pm SE$ )	INT – CON Effect Size (95% CI)
Peak Torque	CON	95.5±38.1	93.6±34.6	-1.99%	0.05(-0.64 to 0.74)	-4.03±2.88	-0.26(-0.95 to 0.44)
	INT	96.7±41.9	90.6±35.6	-6.31%	0.16(-0.54 to 0.85)		
Power	CON	165±63.3	161±66.2	-2.42%	0.06(-0.63 to 0.75)	-9.06±6.61	-0.32(-1.01 to 0.38)
	INT	165±70.7	150±57.1	-9.1%	0.23(-0.46 to 0.93)		
Angle of Peak Torque	CON	43.9±8.9	46.1±7.52	5.01%	0.27(-0.96 to 0.43)	1.34±0.97	-0.33(-1.03 to 0.37)
	INT	45.9±8.2	46.4±10.4	1.09%	0.05(-0.75 to 0.64)		
Time to Peak Torque	CON	0.22±0.05	0.22±0.05	0%	0.0(-0.69 to 0.69)	0.0±0.01	0.14(-0.56 to 0.83)
	INT	0.22±0.04	0.23±0.09	4.54%	0.14(-0.84 to 0.55)		
<b>Concentric Flexion</b>							
Peak Torque	CON	48.4±18.4	48.3±18	-0.21%	0.01(-0.69 to 0.69)	-1.34 ± 2.14	-0.19(-0.88 to 0.51)
	INT	48.1±23.3	45.6±18.5	-5.2%	0.12(-0.58 to 0.81)		
Power	CON	85.6±38.9	87.6±34.8	2.34%	0.05(-0.75 to 0.64)	-1.8 ± 4.51	-0.29(-0.99 to 0.41)
	INT	84.4±47.6	78.9±34.3	-6.52%	0.13(-0.56 to 0.83)		
Angle of Peak Torque	CON	39.1±8.3	37.1±5.4	-5.12%	0.29(-0.41 to 0.98)	-0.88 ± 1.31	0.32(-0.38 to 1.02)
	INT	40±9.39	40.3±8.07	0.75%	0.03(-0.73 to 0.66)		
Time to Peak Torque	CON	0.22±0.05	0.19±0.05	-13.64%	0.6(-0.11 to 1.3)	-0.01 ± 0.01	0.45(-0.25 to 1.16)
	INT	0.21±0.05	0.21±0.05	0%	0.0(-0.69 to 0.69)		

CON = control group; INT = intervention group; CI = confidence intervals,  $\mu$  = mean; SD = standard deviation; SE = standard error; \* =  $p \leq 0.05$

### 3.6 Discussion

The aim of the present study was to assess the acute effect of LV during an isometric exercise on the subsequent isokinetic peak torque, mean power, angle of peak torque and time to peak torque in the hamstrings and quadriceps muscles once the LV stimulus was removed. It was hypothesized that LV would induce an acute muscular strength and power enhancement within the vibrated muscle, and still be present once the stimulus was removed. To the best of the authors knowledge this is the first study that has investigated the acute effect of LV on strength and power in the hamstrings and quadriceps once LV is removed. However, acute application of LV failed to produce any significant improvements in the subsequent isokinetic peak torque, mean power, angle of peak torque and time to peak torque within intervention and control groups and between the intervention and control groups. The findings of our investigation are still relevant and important for the future use of LV on muscular strength and power enhancements for both practitioners and academics.

Peak torque is the highest torque output of a joint produced by muscular contractions as the limb moves through a range of motion. In the present study, peak torque yielded no significant results on the subsequent isokinetic strength of the hamstrings and quadriceps during eccentric and concentric contractions (Table 6 and Table 7). However, previous research has shown acute improvements in peak torque of other muscle groups during various exercise tasks. Cho et al, (2020) found significant increases (22.6 to 30.9%) in eccentric peak torque of the gastrocnemius muscles using an intermittent mode of local vibration (30 to 100 Hz frequency, 0 – 0.12 mm amplitude) and 10 minutes of exposure; interestingly this research group also utilized the same device the present study did. Another research group found increases of 13.5% in internal and external rotation peak torque of the shoulder muscles, utilizing 30 Hz frequency, 5 mm amplitude and 6 minutes of vibration exposure (Hong et al., 2010). A reason for the disparate findings between our research and those just mentioned could be due to the size of the muscle being stimulated. It is postulated that possibly larger muscles may require greater vibratory stimulus, either through larger amplitudes or greater frequencies. In saying this, it is possible that either the hamstrings muscles vibrated in the present study needed greater stimulation from the device in terms of higher frequency and amplitude, or that we needed to possibly utilise a different functional mode of vibration. This is because, the surface area of the hamstrings muscles are larger and may need more stimulus compared to the smaller biceps brachii that has been found to adapt well to LV when using two different modes

of vibration (Luo et al., 2009; Moran, McNamara and Luo, 2007). This posit is also supported by the following findings from previous research utilizing 30 and 60 Hz vibration frequency, 1.6 and 0.4 mm amplitude and 6 minutes of LV exposure did not statistically affect peak torque of the quadriceps muscles and tendon (Pamukoff et al., 2014). Although this research group returned a similar result to ours, their study did find greater muscle activation following LV at 30 Hz compared to 60 Hz vibration frequency, aligning their findings with previous studies (Pamukoff et al., 2014). This suggests that LV at 60 - 65 Hz frequency and an amplitude of 1 - 2 mm do not improve muscle function, and that this frequency range may be too high to stimulate neuromuscular output and the amplitude too small to induce adaptation within the muscle (Luo et al., 2008; Moran et al., 2007; Pamukoff et al., 2014). This makes sense, as past research has shown a greater neuromuscular output when the LV stimulation is similar to the natural frequency of the muscle, between 10 - 50 Hz in lower extremity musculature (Wakeling and Nigg, 2001). However, utilising a frequency range of 0 - 60 Hz within the present study returned no statistically significant results in relation to this. It is unclear as to why there were no strength adaptations seen in the results, and more specifically for peak torque adaptation within the hamstrings and quadriceps. Although, one reason for this could potentially be that even though past research demonstrates that a frequency range of 10 – 50 Hz is similar to the natural frequency of muscles, because the hamstrings are a larger muscle group, they would need an even greater frequency to stimulate and dissipate throughout the entire muscle group, and then only would strength adaptation occur. However, it is also important to note that the increases in hamstring strength could possibly be seen when there is an increased load overall either through an increased amplitude or duration of LV, and not only through frequency, and possibly an increase in all three loading parameters would allow for more adaptation.

Muscular power is an important aspect of many activities, but it does have tendency to decline at a faster rate than other fitness parameters (Reid and Fielding, 2012), (i.e., muscular strength and endurance), and so enhancing the capabilities of muscles to produce power through the application of LV are important for both academic and clinical environments. Past research, similar to the present study, has found increases (0.6 – 10.7%) in the mean power of the biceps brachii, quadriceps, hamstrings, gluteal, and calves (Filipi et al., 2020; Issurin and Tenenbaum, 1999; Jacobson et al., 2017). However, our investigation resulted in no statistically significant increases in mean power in both the hamstrings and quadriceps during both concentric and eccentric exercises. Moran et

al. (2007), research group found no statistically significant differences in mean power of the biceps brachii during and after an elbow flexion exercise performed at 70% of the participants one repetition maximum (1RM). They concluded their findings were due to EMG measurements demonstrating no significant increases in muscle activity following 1.5 and 10 minutes of LV; however, it is stated that this phenomenon needs further investigation (Moran et al., 2007; Stewart et al., 2003). On the contrary, one research group found increases in quadriceps power during cycle tests with 10 minutes of LV applied before the cycle tests; exposing the quadriceps to a frequency of 100 Hz and an amplitude of 0.2 – 0.5mm (Filipi et al., 2020). The increases in quadriceps power was attributed to the relationship between muscular power and motor task velocity to reach an intensity level that would induce increases in power. As such, an adaptation within the central nervous system as a response to the LV stimulation before the cycling tests would be the root cause of muscle power increases within this research group's investigation (Filipi et al., 2020). Issurin and Tenenbaum (1999) research demonstrated an increase in mean power in the biceps brachii (10.2 to 10.7%) during an elbow flexion exercise with LV applied during the exercise sets (44 Hz frequency and 3 mm amplitude); they attributed the increase in power to the ability of a stretched muscle being more sensitive to vibratory stimulation as they contract more strongly (Eklund and Hagbarth, 1966; Johnston et al., 1970; Rohmert et al., 1989). Jacobson et al., (2017), research suggested that even though their vibration condition did not yield significant results, the vibration group did return a 0.6% increase in vertical jump height, which is a trivial finding and aligns with the changes seen in the present study. However, based on other studies, duration of localised vibration, intensity of the frequency and the amplitude value seem to have a greater effect on the results in mean power adaptation in the lower limb, mainly the gluteal, quadriceps, hamstrings and calf muscles, compared to other smaller musculature like the biceps brachii (Cochrane et al., 2004; Dabbs et al., 2011; Jacobson et al., 2017; Wheeler and Jacobson, 2013). Larger muscle groups have shown to respond better to vibration stimulations of longer durations and could potentially be more effective opposed to shorter (< 10 minutes). Germann et al. (2018), states that previous research has found positive effects when using higher frequencies of 100, 150 and 300 Hz alongside longer durations of LV stimulation of 15, 30 and 60 minutes, and the same positive results were achieved when using shorter durations alongside lower frequencies as well (Benedetti et al., 2017; Cochrane, 2016; Iodice et al., 2011; Pietrangelo et al., 2009; Souron et al., 2017; Souron et al., 2018). Thus, longer durations and greater frequencies and amplitudes of LV stimulation in larger musculature, like the quadriceps

and hamstrings, is important to induce greater power adaptations compared to smaller muscles, (i.e., the biceps brachii). The present study would not fall into this category, as a smaller amplitude (0 - 2 mm) and short duration (~8-12 minutes) were most likely the root cause of no power adaptations within the hamstrings and quadriceps. However, further investigations based on this theory are considered necessary for the future use of LV and power adaptation in larger musculature.

Angle of peak torque and time to peak torque are two variables that possess great test-retest reliability and both justify the ability of muscles to maximise the amount of torque they can generate at a given angle, and the time it takes to generate the greatest peak torque possible (Kannus, 1991). The hamstrings muscles are grouped together as a musculotendinous complex, making them more susceptible to stressors, and specifically during rapid changes between eccentric and concentric phases of contraction during exercises or playing sports (e.g., kicking a ball or sprinting) (Coratella et al., 2015). It has been found that the hamstrings have a greater angle of peak torque after they are fatigued from exercise or playing sport, and therefore have a relatively greater torque exerted against the quadriceps action which moves them to a shortened muscle length (Coratella et al., 2015). However, on the contrary, when the hamstrings are moved to a longer muscle length (closer to maximal knee extension), the ability to resist the quadriceps torque is impaired, and the susceptibility to injury is increased (Coratella et al., 2015). Thus, training the hamstrings to be relatively strong at longer muscle lengths (close to or at maximal knee extension) and exert a greater angle of peak torque during these movements is essential to reduce injury risk. In the present study, it was hypothesized that LV would alter the angle of peak torque to a longer length in the hamstrings, and that the time to peak torque would decrease, thus allowing the hamstrings to be trained at a longer length. However, our results demonstrated that the angle of peak torque and time to peak torque both yielded no statistically significant results for both eccentric and concentric conditions. But there were some small effect sizes for time to peak torque ( $g = 0.40$ ) in the eccentric extension condition between groups and for angle of peak torque ( $g = 0.32$ ) and time to peak torque ( $g = 0.45$ ) in the concentric flexion condition between groups. This demonstrates small changes occurred within our investigation for not only the angle of peak torque, but also that the muscles were able to produce peak torque faster at a given knee flexion angle of  $60^\circ$ . This essentially demonstrates a greater torque output of the joint during both eccentric and concentric muscular contractions. However, hamstring and quadriceps eccentric angle of peak torque is widely debated within the current

literature, with knee flexion angles of 30-40° being reported as the optimum angle of peak torque (Kellis and Blazevich, 2022), which was ultimately different to the present study. Past research has also shown that repeated eccentric contractions shift the angle of peak torque towards a longer muscle length (Coratella et al., 2015). During our investigation we utilised an angle of 60° knee flexion, which is a long muscle length for the hamstrings, but conversely, during the eccentric exercises angle of peak torque did not improve for both control and intervention conditions. The lack of observed changes to angle of peak torque could potentially be explained by the flexibility properties of the hamstring muscles themselves. For example, previous research has stated that hamstring flexibility and its angle-torque relationship can be explained by the effect of the muscle length on the sarcomere mechanics, (i.e., the length-tension relationship it possesses) (Alonso et al., 2009; Huxley and Peachey, 1961; Gordon et al., 1966; Rassier et al., 1999). Sarcomeres have an optimal length for production of force, and when this length is greater than their optimum, the force naturally decreases due to decreased cross-bridge formations; lengths shorter than optimum also result in decreased force (Alonso et al., 2009). Decreases in force during shorter muscle lengths are due to repulsive forces from thick filaments crimping against the Z-bands, the increased lateral distance between myosin and actin filaments, double overlapping of filaments and the increased fluid and osmotic pressures in the muscle (Alonso et al., 2009). On the contrary, previous research has found increases (28.15 to 33.57%) in isokinetic time to peak torque of the shoulder muscles when exposed to 30 Hz frequency, 5 mm amplitude and two 3 minute bouts of stimulation (Hong et al., 2010). This research group argued that the increases in time to peak torque were due to the connection between muscle stiffness and the role of muscular pre-activation (Riemann et al., 2002; Serpell et al., 2014), which has been addressed at the knee and ankle joints in the past (McNair et al., 1992; Serpell et al., 2014). As follows, during the present study it is plausible that the hamstrings and quadriceps were not activated sufficiently before the exercises were performed, and therefore there was insufficient stiffness within the muscles to induce an adaptation, increasing activation of the muscles and ultimately decreasing the time to peak torque (McNair et al., 1992; Serpell et al., 2014). As well as the fact that the hamstrings could possibly be positioned at too long a length, and thus decreased force output was present within the muscle due to increased sarcomere length (Alonso et al., 2009).

The findings of the present study provide new evidence relating to the utilisation of LV devices on larger muscle groups, and specifically relating to the acute effects after LV

application during isometric exercises at long muscle lengths. However, there are some limitations to be considered. For instance, our study population had a wide variety of previous sporting and exercise backgrounds, and were mostly recreationally active individuals; this could likely have influenced the results of the experimental protocol. The participants were not advanced in their sports/disciplines compared to similar studies that have compared elite athletes to recreationally active individuals (Issurin and Tenenbaum, 1999; Siegmund et al., 2014). Therefore, acute adaptation to strength and power would have naturally differed largely amongst the participants, especially since some had more resistance training experience than others. Additionally, the sample size was also relatively small and naturally larger effect sizes and significant differences were not likely to occur for an acute potentiation investigation. The third limitation to the present study was the actual design of the experiment conducted, and that it may have hindered post-activation potentiation as both vibration and non-vibration conditions were performed on the same day which could have induced greater fatigue hindering muscle performance overall. This is however speculation, and further research should focus on this point with larger muscle groups and LV stimulation. Alongside this, the vibration settings for larger muscle groups are still undefined within the literature and perhaps should be focused on more in the future, as our settings were utilised in previous research investigations that returned positive results on smaller muscle groups, (e.g., biceps brachii).

### 3.7 Conclusion

In conclusion, acute LV (frequency = 0 – 60 Hz, amplitude = 0 -2 mm) applied for 8 ~ 12 minutes to the hamstrings muscle group does not have an acute post-exercise effect on isokinetic peak torque, mean power, angle of peak torque or time to peak torque in both the hamstrings and quadriceps. It is postulated that the vibratory stimulus utilised in this research was not great enough to induce an acute post-exercise adaptation in the tested muscle groups once the LV was removed. However, there were some small increases in angle of peak torque and time to peak torque for both eccentric and concentric conditions. Future research should aim to implement a standardized approached to LV settings, study design and exercise choices that relate to the specific target muscle/s, as these seem to differ between larger and smaller muscular groups. Although past research has showed positive results in this area, more needs to be investigated and standardized to properly understand the post-exercise effects of muscular strength and power after the utilisation of LV.

### 3.8 Conflicts of Interest

The author(s) disclosed receipt of the following financial support for the research conducted in this experimental study: This work was supported by a Callaghan Innovation, Research and Development Fellowship Grant 2022. The author(s) also declare that one individual involved in this work, Dr Dianne Jones, is employed by the company Myovolt (Christchurch, New Zealand), who provided the Myovolt wearable local vibration straps for the data collections conducted in this research. Dianne Jones was involved in the write-up of this experimental study. However, she was blinded from the initial study design, pilot testing protocols and the study design that was officially carried out, as well as all data collections, data analysis and interpretation of the results thereafter. She was purely involved from an academic position and as the secondary supervisor for this dissertation and experimental study. Other than this, there are no conflicts of interest in this work.

## **Chapter 4 Summary, Practical Applications, Limitations and Future Research**

### **4.0 Dissertation Summary**

Overall, this dissertation provides critical information regarding the acute effects of LV on strength and power outcomes that will be useful for practitioners to better prescribe and utilise LV to enhance performance and clinical outcomes. Based upon the literature review, consensus regarding the exact vibrational settings best utilised for strength and power improvement is still not fully known. However, in terms of strength enhancements, higher frequencies ( $> 100$  Hz), lower amplitudes ( $< 5$  mm) and longer durations ( $> 10$  minutes) of stimulation were most effective in eliciting the greatest strength increase, and in terms of power a lower frequency ( $< 100$  Hz) with a higher amplitude ( $> 5$  mm) and shorter duration of stimulation ( $< 10$  minutes) were most effective. Furthermore, it is important to be aware that larger muscles and/or muscle groups may require greater LV stimulus in order to achieve adaptations relative to smaller muscles and/or muscle groups (e.g., hamstrings versus biceps brachii) due to the nature of the muscles themselves; (i.e., muscle size and architecture). Based upon the review, it seems that a combination of localised vibrational frequencies, amplitudes, durations and rest periods do have an acute effect on muscle strength and power enhancements when applied to the desired muscle and/or muscle group directly via a LV portable device. However, due to the varying range in methodological approaches and device settings, it is problematic making direct comparisons between findings of various researchers.

The acute experimental cross-over pilot study also provided some critical findings for the future utilization of LV for strength and conditioning practice. The main findings from the experimental study were that an acute bout of LV stimulation (frequency =  $0 - 60$  Hz, amplitude =  $0 - 2$  mm) applied for  $8 \sim 12$  minutes to the hamstring muscles during an isometric hamstring contraction does not acutely affect the isokinetic strength of the hamstrings after the stimulus was removed. The potential reasoning for this non-significant finding is that even though the vibratory stimulus was set within a range to accommodate both strength and power outcomes as deduced from the literature review, the LV stimulus was possibly still not great enough to induce an immediate post-LV adaptation due to the fatiguing nature of the exercise testing. It was also postulated that because the hamstrings have a larger surface area compared to other muscles (e.g. biceps brachii), that it needed a greater vibratory stimulus with a higher frequency and larger

amplitude, applied for a longer duration to induce adaptation. However, this is not to say that LV stimulation applied during an isometric contraction, or any other muscular contraction for that matter, does not have any acute effect on the subsequent isokinetic strength of muscles, as this was a pilot study the findings are preliminary and alterations to the study design (i.e., exercise protocols) can be made so as to not overly fatigue the muscles.

#### 4.1 Practical Applications

This research has several important practical applications for not only strength and conditioning practices, but also for the emerging field of wearable resistance technologies.

1. The exact LV loading parameters for strength and power outcomes were yet to be defined before this research, however, based upon the literature review completed, it can be concluded that higher frequencies ( $> 100$  Hz), lower amplitudes ( $< 5$  mm) and longer durations ( $> 10$  minutes) seem to have more of an influence on muscular strength outcomes, and lower frequencies ( $< 100$  Hz), higher amplitudes ( $> 5$  mm) and shorter durations ( $< 10$  minutes) have greater influence on muscular power outcomes.
2. The future successful utilisation of LV will also depend on the muscle architecture and the size of muscle that is being vibrated – larger muscles, such as the hamstrings muscles, will require a larger vibratory stimulus, (i.e., greater frequency) ( $> 100$  Hz) and/or amplitude ( $\geq 5$  mm) and/or a longer duration ( $> 10$  minutes) of stimulation, whereas smaller muscles, like biceps brachii, will require less stimulation, (i.e., smaller frequencies) ( $< 100$  Hz) and amplitudes ( $< 5$  mm) and shorter durations ( $< 10$  minutes).
3. Placement of the LV device is also important for clinicians to consider as placing the device directly onto the target muscle, or inferior or superior to the muscle attachment will have implications to the vibration effectiveness. When a device is strapped directly onto the target muscle, compared to distributed through a gym machine cable, the vibratory stimulus has less time to dissipate its energy to the target muscle and more stimulation results enhancing the probability of strength and power adaptation to the muscle.

## 4.2 Research Limitations

1. The findings of the literature review provided a basic understanding of the loading parameters for both strength and power outcomes, however the exact loading parameters to be utilised alongside resistance training methods still require further investigation based on well-designed studies that standardize vibrational settings more strictly compared to past and current research.
2. The initial aim of this research was to recruit 30 participants, 15 male and 15 female, however due to the difficulty of recruiting participants and a limited time-frame to collect data, a smaller sample of  $n = 16$  participants, 9 male and 7 female, were recruited. This ultimately reduced the power of the study to detect a statistically significant result on the acute effect of LV applied to the hamstring on the subsequent isokinetic strength and power of the hamstrings and quadriceps. Therefore, the data of this research is considered preliminary and the study was considered a pilot study.
3. Participants in this research reflect varying demographics across many different recreational activities (e.g. Taekwondo versus football). Therefore, even though each participant was recreationally and/or resistance trained, the results cannot directly be extrapolated to just one demographic, population or sporting code.
4. The possibility of the testing protocol being too fatiguing was a potential concern in this study, as well as only the one testing session being completed. It is postulated that the methods of this research were problematic and even though this research was conducted to investigate the acute effects of LV, having one more testing session may have been beneficial so that not as much perceived fatigue was encountered.
5. Adherence to refraining from physical activity 24 hours prior to both the familiarisation and testing sessions was not strictly monitored, and was relied upon purely by participant's honesty. Training within 24 hours of the familiarisation and testing sessions may have had some latent fatiguing effects on participants, as well as recovering muscles having to work harder through the exercises, influencing the results negatively.
6. Time between the familiarisation and testing sessions was not strictly controlled, besides the fact that they occurred within 7 days of each other. Due to the difficulty in collating the different schedules of both the researcher, the participants and the laboratory availability, the sessions occurred randomly within 7 days of each other with some participants only receiving no more than one day apart to recover from

the familiarisation session. This may have induced some fatigue amongst participants as well, and impacted the results and findings of this research.

7. Diet was not controlled throughout this research, and with this neither was caffeine. The consumption of caffeine or any other ergogenic aid (e.g., pre-workout formula) prior to testing may have influenced the results of some participants compared to the others who may/may not have consumed caffeine or another ergogenic aid. However, this is not fully known and cannot be confirmed fully.

### 4.3 Final Recommendations and Future Research Directions

The findings of the literature review highlighted that LV stimulation has an acute effect on both strength and power outcomes. The results of the experimental study, however, indicate that a single bout of ~ 8 – 12 minutes of LV (frequency = 0 – 60 Hz, amplitude = 0 – 2mm) applied to the hamstrings during an isometric hamstring contraction does not have an effect on the subsequent isokinetic strength and power of the hamstrings and quadriceps once the LV stimulus is removed. However, this is not to say such acute adaptation is not possible, rather it is suggested that future research within the field of vibration utilise a less fatiguing exercise protocol when investigating this topic further. It is also suggested that once there is a clear understanding behind the mechanisms driving post-vibration adaptation to LV stimulation during isometric contraction, that LV stimulation be applied during both concentric and eccentric contractions to investigate those outcomes. Furthermore, applications of LV stimulation within an elite athlete population versus general population are undefined as the sample population within this research contained a varied mix of specialisations. Practically, it is important for future research to focus on these two populations as separate groups as the effectiveness of LV stimulation alongside resistance training methods may differ between groups that more resistance trained than those that are either new to resistance training or less resistance trained. Furthermore, it is imperative that future research includes more well-designed controlled experiments, so that the effectiveness of acute bouts of LV on muscular strength and power can be determined and utilized in further practice within academic and clinical environments. This research was an initial exploration of LV loading to improve strength and power of lower limb musculature. With a different methodology and more specific settings relating to either strength or power based upon the findings of the literature review, the potential for LV to improve strength and power of the lower limb musculature needs further consideration.

The following recommendations should be considered for future research investigating the acute effects of LV in the lower limbs alongside resistance training:

1. A more specific approach to the vibration settings based upon the desired outcomes indicated in the literature review (i.e., either strength or power) and methodology should be tested.
2. Utilizing a device that emits a higher vibration frequency and amplitude for larger musculature like the hamstrings and quadriceps.
3. Ensuring the study population demographic is fairly similar, or relates to the sports activity or athlete profile, so the results are not potentially influenced by the heterogeneity of the sample.
4. Ensuring the exercise protocols are not overly fatiguing the muscles, and thus pilot testing be done more vigorously to ensure this is not the case.
5. Once the post-vibration acute effects of LV stimulation during isometric contraction are known, it is imperative to investigate the acute effects during other muscular contractions, (i.e., concentric and eccentric muscular contractions), as the findings may be similar or different and this would be crucial for the future of LV training alongside resistance training.

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## Appendices

### Appendix 1: Chapter 2 Abstract

“The effects of localised wearable vibration on muscular strength and power: a systematic review”

The objective of this systematic review was to investigate the acute effects on local wearable vibration on muscle strength and power in various muscle groups. The electronic databases Google Scholar, EBSCO, SPORTdiscus and PubMed were searched using a combination of the following keywords: wearable vibration, local vibration, localized vibration, focal vibration, acute effects, immediate effects, acute bouts, muscular strength, muscular power, strength, power, vibration therapy, punctual vibration therapy, and vibration training. The search was limited to articles published in English. Trials that evaluated the acute effects of localised vibration on muscle strength and power were included in this review. In total, 28 full-text studies were assessed for eligibility, with 5 being excluded and therefore 23 full-text studies were included in this review. Most of the studies reported significant improvements in muscular strength and/or power after the application of localised vibration, however there was considerable variation in the vibration settings, strength and power outcome measures and target muscle locations. The use of localised vibration on a target muscle can enhance muscular strength and power. However, further well-designed and standardized studies are required to confirm the vibration settings for both muscular strength and power as these seem to differ slightly.

## Appendix 2

Table 5. The acute effects of localised vibration on strength and power outcomes in various musculature adapted from chapter 3 systematic literature review

The acute effects of localised vibration on strength and power outcomes in various musculature						
Study	Participant demographics	Location of vibration & device	Vibration settings	Training Protocols	Outcomes	
<i>Bosco et al., 1999</i> <i>Influence of vibration on mechanical power and electromyogram activity in human arm flexor muscles</i> <i>Randomised control trial</i>	12 international level boxers	Biceps brachii of experimental arm GALILEO 2000 device	30Hz 6mm 60 seconds x 5 with 60 seconds rest between	5 x maximal dynamic elbow flexion with 1-min interval between each for 3 sets on one arm Rest for 5-min and then test another arm Receive vibration treatment on one arm Retest arms as above	SD, 13.33% increase in power in experimental arm NSD for control arm power (pre versus post-test values)	
<i>Cho et al., 2020</i> <i>The immediate effects of local vibration on ankle plantar flexor muscle activation and peak torque in healthy adults</i> <i>Cross-sectional design</i>	16M 20F 22.3 years	Right Gastrocnemius muscle Myovolt wearable vibration strap	30 -100Hz 0-0.12mm 10 minutes	Concentric & eccentric peak torque and muscle activity of gastrocnemius were collected using isokinetic device for pre-test values Vibration was applied for 10-min Repeat concentric and eccentric peak torque & muscle activity procedures for post-test values Trial was implemented 4 times with submaximal contraction and then another 4 times for maximal contraction	SD in muscle activity and eccentric peak torque ( $p < 0.05$ ) Concentric peak torque had NSD pre and post-tests	

				60-seconds of rest between every experiment	
<i>Cochrane, 2007</i> <i>Effects of acute upper-body vibration on strength and power variables in climbers</i> <i>Randomised cross-sectional design</i>	5F 7M 22.9 ± 6.5 years 168.6 ± 9.4m 62.1 ± 15.3 kgs	Shoulders and arms through dumbbell  Commercialised electric-powered dumbbell with rotating axis delivering oscillatory movements	26Hz  3mm  5 minutes	Performed various exercises to determine strength and power:  Medicine ball throw (cm), handgrip strength (N) and campus distance test (cm)	NSD found for medicine ball throw (1.67% increase), hand grip strength (1.69% increase) and campus distance performance  No gender differences observed
<i>Cochrane, 2016</i> <i>The acute effect of direct vibration on muscular power performance in master athletes</i> <i>Randomised control trial</i>	10M 43.5 ± 1.7 years 1.80 ± 0.04m 84.5 ± 6.7kg	Biceps Brachii muscles  Myovolt wearable vibration strap	0 – 170Hz  0 – 0.12mm  10 minutes	2 consecutive reps of dumbbell bicep curls at 50% 1RM with 2 min recovery between testing of each limb (1 arm = experimental and 1 arm = control)  10 minutes vibration  Repeat dumbbell bicep curls and mechanical peak power and mean concentric power during concentric phase	PP increased between pre and post-test values for vibration versus control group  MCP increased in vibration versus control group

<i>Cochrane, 2017</i>	13M 21.7 ± 2.6 years 1.81 ± 0.07m 82.0 ± 8.3 kg	Biceps Brachii and forearm region Myovolt wearable vibration strap	120Hz 1.2mm 15 minutes	10 sets of 6 maximal elbow flexor voluntary eccentric repetitions performed on isokinetic dynamometer (Biodex) 15 minutes of VT was applied immediately, 24, 48 and 72 hours after eccentric exercise, and contralateral arm performed no VT.	NSD for both ISO and CON strength ( $p > 0.05$ ) over time between VT and control
<i>Effectiveness of using wearable vibration therapy to alleviate muscle soreness</i> <i>Repeated measures design</i>					
<i>Couto et al., 2013</i>	32 M 26.0 ± 3.46 years 71.3 ± 4.2 kg	Latissimus dorsi and biceps brachii muscles Tri-phase induction motor attached to lat pulldown machine	60Hz 12mm During exercise	4 sets of lat pulldown x max reps each set Reps performed at 55% of MVC. 2 min rest periods Rhythm controlled via metronome Max reps determined when rhythm out of sync with metronome	NSD between control and vibration conditions
<i>To verify the acute effects of the application of local vibration on upper limbs during resistance training on the number of maximum repetitions, metabolic and hormonal responses</i> <i>Randomised control design</i>					
<i>Custer et al., 2017</i>	10M and 9F 27.21 ± 5.78 years 174.30 ± 7.84 cm 80.67 ± 17.17 kg Moderately active	Triceps surae, quadriceps, hamstrings and gluteal muscles Swissing (Swiss TTP, Twinsburg, OH)	20Hz 2mm Immediately after exercise protocol	Baseline testing 5 repeated cycles of inclined treadmill walking at 4.8 – 5.6km/h and 1 minute of jumping exercises (10 tuck jumps and 20 lateral jumps). Incline increased by 1% each minute until 15% achieved RPE: 14 – 17 using Borg RPE Scale	Vertical jump: No significant interaction between treatment and time ( $F = .656, P = .480$ ) No significant main effect for time ( $F = .112, P = .894$ )
<i>The effects of local vibration on balance, power and self-reported pain after exercise</i> <i>Single-blind crossover study</i>					

<i>Dickerson et al., 2012</i>	19F and 11M 22-32 years	Right hamstrings muscle group	30Hz  6mm	Intervention (Vibration or sham vibration)	NSD in means between vibration and sham treatment on either leg R SLH: p = .412 L SLH: p = .666 R Quad: p = .971 L Quad: p = .730 R Ham: p = .480 L Ham: p = .840
<i>Immediate effects of localized vibration on hamstring and quadricep muscle performance</i>		Thumper Versa Pro Massager	Before exercise testing	Isometric testing of quadriceps and hamstring peak strength and then a single leg hop test for distance  Peak quadriceps strength was tested first and then peak hamstrings strength	
<i>A repeated measures cross-over design</i>					
<i>Filipi et al., 2020</i>	28M (healthy) 24 ± 3 years	Quadriceps muscles	100Hz	Vibration or placebo took place before tests 1 and tests 2 for both vibration and control group	SD between vibration and control group: PP: 11.4% increase aP: 6.6% increase TW: 5.7% increase
<i>Effects of focal vibration on power and work in multiple Wingate tests</i>	172 ± 9.6m 72 ± 12.5kg	Electromagnetic vibrator	0.2 -0.5mm  10 minutes over 3 consecutive days	Cycle test: series of 5 bouts of WAnT lasting 10s, separated by 50s of active recovery at 30W on a constant brake ergometer	
<i>A double-blind study</i>					
<i>Hong et al., 2010</i>	22M 19.45± 1.78 years	Shoulder muscles	30Hz	Baseline tests: - Seated in isokinetic dynamometer with arm in 90° abduction and 90° elbow flexion with neutral rotation in scapular plane - Concentric internal rotation and external rotation peak torques were measured using 5 maximal testing repetitions at 60°/sec	SD for IR peak torque (p = 0.042) and ER peak torque increased by 13.5% (p = 0.058)  SD for time to peak torque for IR (p = 0.037) (33.57%) and ER (p = 0.045) (28.15%)
<i>Acute effects of whole-body vibration on shoulder muscular strength and joint position sense</i>	175.68 ± 9.21cm 73.82 ± 8.5 kg  18F 20.23 ± 1.69 years	Whole body vibration platform placed onto hands	5mm  3 minutes x 2	Participants held a plank position with hands on whole body vibrating platform for 1 minutes with a 1 min rest in between for 3 sets Baseline tests repeated	
<i>A mixed design between subjects</i>	167.14 ± 6.24cm 66.33 ± 10.15kg				
<i>Iodice et al., 2011</i>	36M □ 2 groups – 1 cV	Quadriceps, gluteal and calf muscles	300Hz	cV group:	NSD to jump height, F <sub>mean</sub> , P <sub>mean</sub> and P <sub>power</sub>

<p><i>Acute and cumulative effects of focused high frequency vibrations on the endocrine system and muscle strength</i></p> <p><i>Randomised crossover design</i></p>	<p>(n = 18) and 1 cR (n = 18)</p> <p>cV: 21 ± 1.4 years 176.0 ± 4.3 cm 78.3 ± 4.5 kg 14.1 ± 1.6 %BF</p> <p>cR: 22 ± 0.7 years 172 ± 3.8 cm 73.4 ± 4.3 kg 12.5 ± 1.1 %BF</p>	<p>VISSMAN device</p>	<p>2mm</p> <p>3 sessions/week for 30 minutes</p>	<ul style="list-style-type: none"> <li>- exposed to HLV for 4-weeks, 3 sessions/week</li> <li>- 8:00am blood sample 1 taken, 8:30am performed CMJ and MVC tests for leg extensor muscles with 2min rest between jumps and 9:00am received HLV treatment for 30min at 300Hz.</li> <li>- Then blood sample 2 taken, CMJ and MVC tests performed again.</li> <li>- One hour after blood sample 2 taken, blood sample 3 was taken</li> </ul> <p>cR group:</p> <ul style="list-style-type: none"> <li>- underwent resistance training protocol – leg extensions for 4-weeks, 3 sessions/week.</li> <li>- 8:00am blood sample 1 taken, CMJ and MVC tests done, 9:00am 30min lying position, 9:30am blood sample 2 taken, CMJ and MVC tests, 10:30am blood sample 3 taken</li> </ul>	<p>Increase in bilateral MVC – 32.5 ± 11.5% in cV group, 18.6 ± 5.4% in cR group</p> <p>Increase in strength of quadriceps muscle (<math>P &lt; 0.05</math>):</p> <p>cV group: Pf increase of 41% and T1 (<math>P &lt; 0.05</math>) and 33% at T2 (<math>P &lt; 0.05</math>)</p> <p>cR group: Pf increase in dominant leg of 37% (<math>P &lt; 0.05</math>) at T1 and 30% at T2 (<math>P &lt; 0.05</math>)</p>
<p><i>Issurin and Tenenbaum, 1999</i></p> <p><i>Acute and residual effects of vibratory stimulation on explosive strength in elite and amateur athletes</i></p> <p><i>A repeated-measures analysis of variance with group between-participants design</i></p>	<p>28M</p> <p>2 groups: elite and amateur</p> <p>Elite group: 14M 21.3 ± 4.1 years 74.0 ± 9.3 kg 175 ± 6 cm 35.5 ± 2.3 mid-upper arm circumference (cm)</p>	<p>Biceps brachii muscles</p> <p>Electromotor with a speed reduction and eccentric wheel</p>	<p>44Hz</p> <p>3mm</p> <p>During exercise set</p>	<p>General warm-up 5-7 mins including indoor running (2-3min), general calisthenics (1-2min) and exercises for the upper extremities (2min)</p> <p>Then 8-10 reps of biceps curls with a low to medium (20-40% of body weight) weight.</p> <p>3-5 attempts performed at increasing weight to determine 1RM.</p> <p>Rest for 15 min.</p> <p>Weight equivalent to 65-70% of 1RM was selected.</p> <p>Two series of exercises were performed, with 8-15min rest in between.</p>	<p>Maximal power (W) without VS: Elite = 295 ± 75.1 Amateur = 254 ± 85.6</p> <p>Maximal power (W) with VS: Elite = 295 ± 71.9 (10.4% gain in max power) Amateur = 254 ± 86.8 (7.9% gain in max power)</p> <p>Mean power (W) without VS: Elite = 286 ± 76.6 Amateur = 243 ± 88.3</p> <p>Mean power (W) with VS: Elite = 281 ± 76.5 (10.2% gain in power)</p>

	Amateur group: 14M 25.8 ± 7.3 years 78.5 ± 9.6 kg 179 ± 7cm 34.4 ± 3.1 mid-upper arm circumference (cm)			Exercise rate within a set was approximately 1 rep every 2s Rest period = 2-3min between sets	Amateur = 241 ± 89.6 (10.7% gain in mean power Significant effect for with versus without vibration stimulation for mean power ( $F_{1,26} = 59.2$ , $p < 0.001$ ) and for maximal power ( $F_{1,26} = 56.3$ , $p < 0.001$ ) Elite vs amateur resulted in a significant effect of maximal power ( $F_{1,26} = 4.42$ , $p < 0.04$ )
<i>Issurin et al., 2010</i> <i>Acute effects of strength exercises with superimposed vibration: Impact of frequency and amplitude of oscillations</i> <i>Repeated measures within subjects design</i>	8M 33.5 ± 3.8 years 177 ± 4 cm 75.5 ± 3.5kg	Biceps Brachii muscles 3kW 3-phase electromotor with speed reduction and regulation	17, 27 or 38Hz 2, 4 or 8mm During exercise set	Two days training: General warm up (5-7min) and task specific warm-up using experimental equipment 3 consecutive series of exercises of 10-12 reps with LV amplitude of vibration set at 2, 4 and 8mm respectively, no vibration during first series (control) and 17, 27 and 38Hz during 2 <sup>nd</sup> , 3 <sup>rd</sup> and 4 <sup>th</sup> series Rest: 12-15 minutes between each series Maximal voluntary contractions at start of each series with 5-8s interval's in between	Power gain increased by 13.60%, 19.03% and 25.67% for 17, 27 and 38Hz respectively Dynamic power associated with 2mm, 4mm and 8mm was 12.07%, 20.10% and 25.63% respectively Frequency by amplitude interaction = SE on dynamic power gain, GG = 536.23 8mm amplitude: Dynamic power increased by 15.14%, 29.34% and 38.33% following 17Hz, 27Hz and 38Hz 4mm amplitude: Dynamic power increase = 16.81%, 20.56% and 25.94% following 17Hz, 27Hz and 38Hz 2mm amplitude: Dynamic power increase = 9.88%, 16.39% and 19.67% following 17Hz, 27Hz and 38Hz Monotonic increase in force gains:

					3.68% with 17Hz 4.76% with 27Hz 3.80% with 38Hz
<i>Jacobson et al., 2017</i> <i>Acute effects of biomechanical muscle stimulation on the counter-movement vertical jump power in division 1 football players</i> <i>A randomised crossover design</i>	21 participants 20.33 ± 1.28 years 89.95 ± 10.84 kg 82.08 ± 7.35 cm	Gluteal, quadriceps, hamstrings and calf muscles  Swissing TTP Model	30Hz  No defined amplitude  4 minutes	8 min standardised warm-up 3 consecutive counter-movement VJ (assessed for peak and average power [watts], and peak and average velocity [m.sec <sup>-1</sup> ]) using a TENDO Power and Speed Analyzer linear velocity transducer Vibration applied for 4 minutes Repeat above protocols	Vibration condition increased peak power by 0.6%, bike condition decreased by -0.5% VJ height: Increased by 1.55% on average in vibration group VJ velocity: Vibration group showed greater peak velocity sequentially each jump, 2.4% increase, p ≤ 0.05
<i>Maeda et al., 2020</i> <i>Acute effects of local vibration stretching on ankle range of motion, vertical jump performance and dynamic balance after landing</i>  <i>Repeated measures, crossover design</i>	15M 23.5 ± 2.3 years 172.1 ± 6.4cm 67.2 ± 9.9kg	Gastrocnemius muscle belly  Myovolt wearable vibration strap	0 – 170Hz  0 – 0.12mm  5 minutes	Warm-up: 5 min cycling exercise with ergometer air resistance set to 75W and cadence set to 60rpm followed by 3min rest before beginning tests. Measurement of degree of max ankle dorsiflexion ROM before and after stretching in the SS, V + S and control protocols. Each subject performed a maximal voluntary vertical jump on the floor with non-dominant limb in 2 conditions: 1) from a semi-squatting position (squatting jump) and 2) an upright standing position (CMJ). Jump height was determined using a jump gauge, 2min recovery between jumps.	Jump performance parameters: SJ: SD CMJ: control, V + S > SS (P < 0.05 for control and V + S) (1.72% change) V + S proved to have a superior effect on jumping performance when compared to SS

<i>Mileva et al., 2006</i> <i>Acute effects of a vibration-like stimulus during knee extension exercise</i> <i>Randomized control trial</i>	9M 21 ± 3 years 177 ± 7 cm 70 ± 8kg	Knee extensors (quadriceps) Vibrex, Exoscience device	10 Hz No amplitude given During both pre-and-post-exercise 1RM tests and during each contraction of Vb+ protocols	Familiarisation session Warm up: 5-minutes cycling at 90 Q on LODE ergometer Then Isometric (MVC) and dynamic strength 1RM) of knee extensors was tested Four trials on knee extension machine with either (Vb+) or without (Vb-) superimposed vibration at low (35% 1RM, LVb+ and LVb-) and high (70% 1RM, HVb+ and HVb-) contraction intensities with 3 days recovery between trials	Dynamic strength ( $P = 0.02$ ) SD during vibrated compared to non-vibrated trials SD in power between vibrated and non-vibrated trials Strength significantly higher post- than pre-exercise ( $P=0.002$ ) SD in muscle performance during knee extension exercises at low contraction intensity (10Hz)
<i>Moran et al., 2007</i> <i>Effect of vibration training in maximal effort (70% 1RM) dynamic bicep curls</i> <i>Randomized control trial</i>	14M 26.3 ± 6.6 years 77.8 ± 12.6 kg 177.3 ± 6.8cm	Biceps brachii A portable muscle-tendon vibrator (made in house)	65Hz 1.2mm During exercise set (~30 seconds)	Four training conditions: 1) exercise with superimposed vibration, 2) exercise with sham vibration, 3) no exercise with vibration and 4) no exercise with sham vibration Exercise protocol: 3 sets of 10 bicep curls with a load of 70% 1RM performed by dominant arm while sitting on preacher-curl bench with 3min rest between sets	NSD in the following: Angular velocity ( $P = 0.86$ ) Peak angular velocity ( $P = 0.90$ ) Mean moment ( $P = 0.83$ ) Mean power ( $P = 0.53$ ) Peak Power ( $P = 0.77$ ) Bicep EMG <sub>rms</sub> ( $P = 0.78$ )
<i>Pamukoff et al., 2014</i> <i>The acute effects of local muscle vibration frequency on peak torque, rate of torque development, and EMG activity</i>	20: 9M and 11F 20.4 ± 1.4 years 68.1 ± 11.0kg 170.1 ± 8.8cm	Quadriceps and quadriceps tendon Custom built local muscle vibration device (single-axis electromagnetic oscillator)	30Hz and 60Hz 1.6mm and 0.4mm 6 minutes	3 testing sessions (30Hz, 60Hz, control) separated by 1 week intervals 5 min warm up on cycle ergometer Baseline PT, RTD and surface EMG during 5s knee extension MVIC. Quadriceps MVIC were assessed immediately, 5 min, 15 min and 30 min post-intervention Subjects positioned in isokinetic dynamometer with knee in 60° flexion	Condition X time interaction = SD for EMG amplitude ( $p = 0.001$ ), but not for PT ( $p = 0.324$ ) or RTD ( $p = 0.425$ ) Increase in EMG amplitude following 30Hz LMV = Significantly greater than 60Hz LMV and control

<i>A single group, repeated measures, crossover design</i>					and instructed to extend knee as fast and hard as possible I response to visual stimulus 2 trials recorded at each time point and averaged for analysis 1 min rest between trials	
<i>Rongsawad and Ratanapinunchai, 2018</i> <i>Effects of Very High Frequency and Wide-Pulse Duration on Stimulated force and Fatigue of Quadriceps in healthy Participants</i>	34: 3M and 31F 18-35 years	Quadriceps of the right leg  ENDOMED device	50, 150 and 200Hz  Pulsed current of 0.9ms  2 seconds on and 4 seconds off for 15 minutes	3 sessions in total: Session 1 – MVIC of knee extensors and familiarization with fatigue test protocol Session 2 & 3 – other stimulation frequencies were used Each session was separated by 48 hours	High stimulation frequencies (150 and 200Hz) showed more decline in normalized stimulated force during fatigue test compared to 50Hz (low stimulation) However, NSD found for either intervention (high versus low stimulation)	
<i>Sagiroglu, 2017</i> <i>Acute effects of applied local vibration during foam roller exercises on lower extremity explosive strength and flexibility performance</i> <i>Randomized crossover design</i>	22M 22.13 ± 2.47 years 178 ± 4.92cm 74.9 ± 3.93kg	Hamstrings, quadriceps, gluteal and gastrocnemius muscles Foam roller vibration apparatus	38Hz No amplitude given 30 second intervals for 10 repetitions	Warm-up on a vertical bike Foam Roller application: Jumping test for 2 minutes (3 CMJ @ 15s intervals), 30s after completed 3-sit-and-reach tests with 15s intervals of rest between then Foam roller exercises completed immediately after preliminary tests. Foam roller + LV application: same as above with vibration characteristic open at 38Hz during foam rolling exercises. 30s after FR and FR+LV the same protocol was carried out once again.	VJ & FR +LV: $p < 0.05$ Flexibility & FR+LV: $p < 0.05$ VJ & FR: $p < 0.05$ Flexibility & FR: $p < 0.05$  VJ % change = 3.8%	

<i>Siegmund et al., 2014</i>	CANA: 6M, 22.8 ± 2.0 years	Gluteal, hamstrings and erector spinae group muscles	20Hz  No amplitude given	Participants leant against the padded surface of the BMS drum. Then procedure repeated on a seated stool to contract desired muscle group. 1 minute rest between each BMS position = 11 min per participant	Sit and reach test SD between pre-and-post-BMS CAA: 4.3% sit and reach increase CANA: 10.2% sit and reach increase OA: sit and reach 8.2% increase Perceived stiffness: CAA: improved by 1.8 units CANA: improved. By 2.0 units OA: improved by 1.7 units
<i>Acute effects of local vibration with biomechanical muscle stimulation on low-back flexibility and perceived stiffness</i>	174 ± 5.6 cm 74 ± 15.3 kg 13F 23.1 ± 1.4 years 169.9 ± 5.5 cm 66.7 ± 8.8 kg	Swissing segmental BMS device	2 minutes		
<i>Mixed methods with time points as within participants variable</i>	CAA: 3M 19.7 ± 0.5 years 170.0 ± 11.4 cm 77.0 ± 30 kg 7F 19.4 ± 1.1 years 160.4 ± 21. cm 52.4 ± 3.3 kg OA: 9M 76.8 ± 7.0 years 172.6 ± 7.6 cm 79.9 ± 7.4 kg 6F 73.3 ± 10.2 years 161.8 ± 5.9 cm 66.0 ± 4.2 kg				

<i>Souron et al., 2018</i> <i>Neural adaptations in quadriceps muscle after 4 weeks of local vibration training in young versus older subjects</i> <i>Acute cross-sectional design</i>	21 – 16M & 5F 24 ± 3 years 177 ± 9 cm 74 ± 15 kg	Rectus femoris muscle and mid-portion of the infrapatellar tendon VB 115, Techno Concept device	100Hz 1mm ~ 80 seconds (during exercise set)	Series of 10 TMS and 2 PNS pulses delivered on relaxed muscle during no vibration (Control), muscle vibration (VIB <sub>MU</sub> ) and tendon vibration (VIB <sub>TD</sub> ) performed at 60, 120 and 180° knee extension on isometric dynamometer 1 min rest period between series (10 min in total during testing session)	SD, muscle strength (P < 0.001) MVC increase: 9.67% between pre-and-post-test values MEP was higher at 120° compared to 60 and 180°
<i>Wang et al., 2022</i> <i>Acute effects of vibration foam rolling and local vibration during warm-up on athletic performance in tennis players</i> <i>Randomized block design</i>	27M 20.4 ± 1.3 years 71.6 ± 7.8 kg 1.81 ± 0.63m	VFR and PVPD groups: Lower back, gluteus, quadriceps, lateral thigh muscles, hamstrings and calf muscles groups Vibration foam roller: VYPER and a Portable Vibrational Percussion device (OUTSO)	60Hz No amplitude given ~ 30 seconds	Jog at self-selected pace for 5 minutes VFR group: roll lower back, gluteal, quadriceps, lateral thigh muscles, hamstrings and calf muscle groups (7 minutes in total) PVPD group: placed on lower back, gluteal, quadriceps, lateral thigh muscles, hamstrings and calf muscle groups (7 minutes in total) Then immediately performed CMJ, drop jump, hexagon, 2.5m lateral acceleration test and Y-balance tests with 3 minutes rest between each test	SD for all interventions (p = 0.007) VFR SD in CMJ (p = 0.03) and HT time (p = 0.03) (8.06% change) Reactive strength index SD after VFR (p = 0.012) and PVPD (p = 0.025)

\*SD = significant difference, NSD = no significant difference, Hz = Hertz, mm = millimetres, PP = Peak Power, MCP = mean concentric power, ISO = isometric, CON = concentric, VT = vibration therapy, min = minutes, MVC = maximal voluntary contraction, RPE = rate of perceived exertion, SLH = single leg hop, Quad = quadricep, Ham = hamstring, R = right, L = left, aP = average power, TW = total work, IR = internal rotation, ER = external rotation, CMJ = counter movement jump, HLV = high intensity vibration, V = vibration, f = force, VS = vibratory stimulation, IRM = one repetition maximum, LV = local vibration, SE = significant effect, VJ = vertical jump, ROM = range of motion, SJ = squat jump, SS = static stretching, V + S = vibration and stretching, PT = peak torque, RTD = rate of torque development, MVIC = maximal voluntary isometric contraction, LMV = local muscle vibration, FR = foam roller, PNS = peripheral nerve stimulation, TMS = transcranial magnetic stimulation, VIB = vibration, MEP = motor evoked potential, VFR = vibration foam roller, PVPD = portable vibration percussion device.

\*Significant difference at  $p \leq 0.05$ , no significant difference at  $p \geq 0.05$

### Appendix 3: Chapter 3 Abstract

“Integrating local vibration training into an isometric strength protocol: acute effects on lower-body isokinetic strength in healthy, active individuals”

*Purpose:* To investigate the acute effect of local vibration during an isometric hamstring contraction on the subsequent isokinetic strength and power of the hamstrings and quadriceps muscles once the local vibration stimulus is removed.

*Methods:* Recreationally active females ( $n = 7$ ) and males ( $n = 9$ ) performed an isokinetic dynamometry strength protocol and then a series of isometric hamstring contractions with local vibration stimulus and then repeated the protocol without, the order of this was randomised between participants. Local vibration was applied for ~ 8-12 minutes at a frequency range of 0 to 60 Hz and an amplitude of 0 to 2mm. Peak torque, mean power, angle of peak torque and time to peak torque were measured using the Humac Norm isokinetic dynamometer to assess the pre-and-post-vibration isokinetic strength and power of the hamstrings and quadriceps.

*Results:* There were no significant differences found for all measures between and within groups for all variables ( $p > 0.05$ ).

*Conclusions:* Acute localised vibration during an isometric hamstring contraction does not affect peak torque, mean power, angle of peak torque and time to peak torque of both the hamstrings and quadriceps. Further well-designed studies should be utilized in future research to determine the exact protocols to follow when utilizing local vibration alongside different muscular contractions during resistance training.

## Appendix 4: Ethics approval Letter



### Auckland University of Technology Ethics Committee (AUTEC)

Auckland University of Technology  
D-88, Private Bag 92006, Auckland 1142, NZ  
T: +64 9 921 9999 ext. 8316  
E: [ethics@aut.ac.nz](mailto:ethics@aut.ac.nz)  
[www.aut.ac.nz/researchethics](http://www.aut.ac.nz/researchethics)

5 September 2022

Aaron Uthoff  
Faculty of Health and Environmental Sciences

Dear Aaron

Re Ethics Application: **22/217 Integrating local vibration training into strength protocols: acute effects on lower-body isokinetic strength in healthy, active individuals**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 30 August 2025.

#### Standard Conditions of Approval

1. The research is to be undertaken in accordance with the [Auckland University of Technology Code of Conduct for Research](#) and as approved by AUTEC in this application.
2. A progress report is due annually on the anniversary of the approval date, using the EA2 form.
3. A final report is due at the expiration of the approval period, or, upon completion of project, using the EA3 form.
4. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form.
5. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
6. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.
7. It is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard and that all the dates on the documents are updated.
8. AUTEC grants ethical approval only. You are responsible for obtaining management approval for access for your research from any institution or organisation at which your research is being conducted and you need to meet all ethical, legal, public health, and locality obligations or requirements for the jurisdictions in which the research is being undertaken.

Please quote the application number and title on all future correspondence related to this project.

For any enquiries please contact [ethics@aut.ac.nz](mailto:ethics@aut.ac.nz). The forms mentioned above are available online through <http://www.aut.ac.nz/research/researchethics>

(This is a computer-generated letter for which no signature is required)

The AUTEC Secretariat  
**Auckland University of Technology Ethics Committee**

Cc: [ycy4963@autuni.ac.nz](mailto:ycy4963@autuni.ac.nz); [john.cronin@aut.ac.nz](mailto:john.cronin@aut.ac.nz)

## Appendix 5: Participant Information Sheet



**AUT SPORTS PERFORMANCE  
RESEARCH INSTITUTE NEW ZEALAND**

### **Participant Information Sheet**

**Date Information Sheet Produced:** 01/09/2022

### **Project Title**

Integrating local vibration training into strength protocols: acute effects on lower-body isokinetic strength in healthy, active females and males.

### **Invitation**

My name is Hannah Tiedt, a Master of Sport, Exercise and Health student at the Auckland University of Technology, based at the Sports Performance Research Institute New Zealand (SPRINZ). My supervisor, Dr. Aaron Uthoff, and I invite you to participate in my Master's dissertation project. I currently hold a Callaghan Innovation R&D Fellowship grant which has been provided to me to fund this research alongside the company Myovolt, a New Zealand based wearable vibration therapy company.

This project will be aimed at investigating the lower-body muscular strength in healthy, active females and males with a focus on the potential immediate effects of local vibration training devices. The project will be assessing whether applying one of these vibration devices to a specific part of the body can lead to an immediate effect on lower-body strength, namely within the quadriceps and hamstrings muscles using Myovolt wearable vibration sleeves (see Figure 1). Participants will be completing the project while sitting on and using the Humac Norm Isokinetic Dynamometer machine (see Figure 2), which will be measuring your lower-body strength parameters (muscular force production).



**Figure 1.** Myovolt wearable vibration sleeve by itself (A) and applied around the thigh (B).



**Figure 2.** Participant strapped into the seat of the Humac Norm machine(A) and an image of the full apparatus(B).

### **What is the purpose of the study?**

The purpose of this study is to investigate the potential immediate effects of local vibration training on lower-body muscular strength with the integration of Myovolt wearable vibration sleeves. The muscles involved in this project will be the quadriceps and hamstrings muscles, two of the most important lower-limb muscles in relation to common injuries of the knee joint. The relationship between these two muscles is important as they both affect the functioning of the knee joint, and the risk of injury opposed upon the knee joint. One of the leading causes of knee injuries is the strength imbalances between the major muscles around the knee joint, two of the main contributors being the quadriceps and hamstrings muscles. If any present strength imbalances between these two muscles can be restored, then knee injury incidence could feasibly decrease.

While there is early evidence that applying vibration directly to a muscle or muscle groups enhances the immediate force production, most of the current research on this topic has aimed their applications on the muscles of the arms or front of the shin. Therefore, little is known about the effects of the vibration on the force production and strength capabilities of the major thigh muscles. Furthermore, it is unknown whether immediate strength improvements associated with localised vibration application are present once the wearable vibration device is removed, nor whether localised vibration therapy can help shift peak forces produced in a muscle during exercise to longer muscle lengths.

An exploration of this information may shed light on the utility of using localised vibration training to induce strength adaptations to the critical knee joint muscles deemed favourable in both academic and applied environments. The outcomes of the study will be useful for both the sports technology and rehabilitation fields and it is important to investigate the topic in relation to these two fields.

### **How are people chosen to be asked to be part of the project?**

You are most likely receiving this information sheet as you contacted me via email because you saw the physical or online advertisement, were interested in the research, and believed you met the required inclusion criteria for this research project.

People will be chosen to participate on a first come first serve basis. This will also depend on the following criteria (1) if you are healthy and keep active regularly, such as gym workouts, Cross Fit, running, walking 3 – 4 times a week (2) are aged between 18-50 years of age, (3) are in relatively good health with no adverse health conditions, (i.e., hypertension, heart disease), (4) don't have lower-limbs injuries within the last 6-months,

and (5) don't have any significant injuries that could prevent you from performing the required exercises (leg extensions, leg curls and isometric leg curl holds). Unfortunately clients of the researchers (Hannah Tiedt and Dr. Aaron Uthoff) are excluded from taking part in the research.

### **How do I agree to participate in this research?**

Your participation in this research will be agreed upon by signing the consent form given to you along with this information sheet and returning it to Hannah Tiedt either via her email address provided or in a hard copy format. Once the forms have been returned, Hannah Tiedt will be in contact with you to arrange a time to meet at AUT Millennium SPRINZ and run through your first familiarisation session of the testing procedures. Please note that your participation is fully voluntary (it is your choice) for the entire duration of the project and you can withdraw from the study at any time point with no consequences.

In order to participate in this research you will need to arrange the times and days you travel to AUT Millennium SPRINZ with Hannah Tiedt, and she will liaise with you according to both your schedules.

### **What happens in the project?**

You will be required to travel to the AUT Millennium SPRINZ and meet with Hannah Tiedt at the Strength and Conditioning laboratory who will take you through the testing procedures so that you can participate in the study. You will be required to be available for two 1,5 hour sessions. This will comprise of a familiarisation session and a data collection session performed on different days. During both the familiarisation and data collection sessions you will be required to supply your demographic data – namely your age, gender, height, weight and exercise experience level. This is for the purposes of gaining background information of the participants involved and this will be de-identified along with your other data collected during the sessions. During each session you will perform a standardised warm up consisting of leg swings, body weight lunges, body weight squats and counter movement jumps. You will then perform four sets of 3 repetitions of leg extensions and leg curls exercises and 2 sets of 3 repetitions of isometric hamstring holds on the Humac Norm Isokinetic Dynamometer machine. This machine is similar to the leg extension and leg curl machines found in most gyms (see Figure 2 above). This will likely be a familiar movement for you if you have/do use the gym regularly, if not you will be able to practice the movements during the familiarisation session. You will be performing isometric hamstring holds while wearing the Myovolt wearable vibration sleeves after the first and third sets of leg extensions and leg curls. The first session will take 1,5 hours and the second session will also take 1,5 hours, this includes the standardised warm-up, data collection and cool down afterwards for both. The first session will be a familiarisation session so that you can become familiar and comfortable with the Humac Norm machine, we will run through the entire protocol and make sure you are comfortable with all the movements required of you. This is a chance to ask as many questions and try the exercises as many times as possible within the allocated time to ensure you are ready for your next session, which will be the official data collection. The second session will be the actual data collection session. The data collection session will follow the same process as the familiarisation session and we will run through the entire protocol outlined above in one go. After the data collection protocol is complete you will perform a cool down, no longer than 10 minutes. This will be a series of stretches and a 5 minute walk on the treadmill performed at a speed of 4km/h, to ensure your muscles are properly cooled down. No data will be used from the familiarisation sessions, only data collected from the second session will be used for the study's results.

It is to be noted that no form of exercise training can take place on the day of your data collection prior to your collection; training afterwards is acceptable.

### **What are the discomforts and risks?**

There are no major risks involved in this project. Since you will be performing a few leg extensions and leg curls, you might be at a small chance of experiencing a muscle strain or some delayed onset muscle soreness. You might also experience some slight discomfort if you have not spent much time in a sports science laboratory. However, we will try to limit that by making sure you are warmed up and cooled down properly. You will however be required to wear shorts for the data collections, and this may be uncomfortable for some. If you do feel you need extra support or have questions regarding this, it can be discussed further with the project co-ordinator and supervisor (contact details below).

### **How will these discomforts and risks be alleviated?**

We will try to limit any chance of a muscle strain and mitigate delayed muscle soreness by ensuring that you are warmed up and cooled down properly. To try and minimise any discomfort being seen doing your testing in the lab, a curtain will be used to block off the area where the Humac Norm machine is placed. This will ensure privacy of the participant and make them feel more comfortable during the exercise process.

Participants are advised to talk to the project co-ordinator (Hannah Tiedt) if issues do arise during a data collection or during the duration of the study, so that she can handle the situation as best she can to ensure the participant feels comfortable throughout the process.

### **What are the benefits of participating in the project?**

The benefits to participating in this study for the community and participants are listed below:

- Be involved in new, exciting research taking place at SPRINZ
- Be informed of your very own lower-body strength capabilities (quadriceps and hamstrings muscles)
- Learn more about local vibration training, a new avenue within sport science and rehabilitation setting
- Exposed to a new concept and training mechanism within the sports technology and rehabilitation fields
- Be part of ground-breaking research within the scope of wearable vibration training and the sports science field.
- A new technology could potentially provide a solution to common knee injuries the community are facing within the sports setting
- The community will be part of something new, and never done before within AUT Millennium SPRINZ facility

The benefits to the researchers if you decide to participate in the study:

Researchers will be able to:

- Have a better understanding on how vibration training can immediately effect the strength properties of a muscle, namely the hamstrings and quadriceps
- Understand how vibration training can be used within the rehabilitation setting for muscle injuries and return to play protocols

- Exposed to new research taking place within the sports science field
- Engage with participants from all areas of sport and recreation
- Determine the longitudinal effects this technology could potentially have for future training studies

#### **What compensation is available for injury or negligence?**

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

#### **How will my privacy be protected?**

- We will take a number of measures to protect your privacy as much as possible and to ensure your personal details (name and contact details) remain confidential.
- You will be given a unique participant number for the duration of the project attached to their name, e.g., P1 (Participant 1), and all participants will be de-identified because of this.
- No data files will have your name on them but will have your unique participant number on them instead.
- All de-identified electronic data collected during the study will be stored on a secure server (network drive with restricted user access) with built-in redundancy housed within the AUT City Campus. Your privacy and confidentiality will be of primary concern while handling the data.
- Your data will not be shared with any third party.
- All of your data will be de-identified and all of the results from this project will be averaged. Therefore, none of your individual data will be presented and nobody except for Hannah and Dr. Aaron Uthoff will have access to your individual results.
- Each participant and person within the research team involved in the study will abide by the privacy rules of AUT and in accordance with the requirements of the New Zealand Privacy Act (1993).
- Only the project researcher (Hannah Tiedt) and her primary supervisor (Dr. Aaron Uthoff) will have access to participant's personal information such as their email addresses and phone numbers. These will be stored securely on the AUT premises under the supervisor's control and separate from the consent forms.

#### **What are the costs of participating in the project, including time?**

There are no monetary costs involved by participating in the project. However, will be required to spend 3 hours at AUT Millennium for the two sessions explained above (familiarisation and data collection sessions). The parking is free to you for the first 1,5 hours of your visit in the main parking lot outside the AUT Millennium buildings as long as you insert your car's number plate into the car parking pay machine.

#### **What opportunity do I have to consider this invitation?**

You have two weeks to consider if you would like to participate in this research. Within those two weeks you will need to indicate to Hannah via email if you wish to participate or not, remember your participation is completely voluntary and your choice.

#### **Participant Concerns**

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor who will pass on the information to the Project Co-ordinator.

Project Co-ordinator Contact Details:

Hannah Tiedt

Phone number: 021 086 97932

Email address: [ycy4963@autuni.ac.nz](mailto:ycy4963@autuni.ac.nz)

Project Supervisor Contact Details:

Dr Aaron Uthoff

Email address: [aaron.uthoff@aut.ac.nz](mailto:aaron.uthoff@aut.ac.nz)

*Approved by the Auckland University of Technology Ethics Committee on 5<sup>th</sup>  
September 2022 AUTEK Reference number 22/217*

## Appendix 6: Participant Consent Form



**AUT SPORTS PERFORMANCE  
RESEARCH INSTITUTE NEW ZEALAND**

### **Consent to Participation in Masters Project**

*For use when laboratory or field testing is involved.*

**Project Title:** Integrating local vibration training into strength protocols: acute effects on lower-body isokinetic strength in healthy, active females and males.

**Project Supervisor:** Dr. Aaron Uthoff

**Researcher:** Miss Hannah Tiedt

### **By signing this form, you agree to the following statements:**

- I have read and understood the information sheet provided and fully comprehend what it says dated 1<sup>st</sup> September 2022.
- I have read and understood the inclusion criteria and agree to the following statements below:
  - I am healthy and keep active regularly by participating in activities such as gym workouts, CrossFit, running, walking 3 -4 times a week,
  - I am aged between 18-50 years of age,
  - I am in relatively good health with no adverse health conditions, e.g., hypertension, heart disease, etc.,
  - I do not currently have or in the past 6 months had any lower limb injuries,
  - I do not currently have any significant injuries that could prevent me from performing the required exercises (leg extensions, leg curls and isometric leg curl holds),
  - I am also not a client/student of the researcher (Hannah Tiedt) nor the supervisor (Dr. Aaron Uthoff)
- I have had an opportunity to ask questions and to have them answered by the research team involved. I am also satisfied with the answers I have been given regarding the study and I have a copy of the consent form and information sheet.
- I have been given sufficient time to consider whether or not to participate in this study.
- I have had the opportunity to consult with friends, family, whanau support to help me ask questions and understand the study.
- I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.

- I understand that if I withdraw from the study then I will be offered the choice between having data that is identifiable as belonging to me removed or allowing it to continue to be used. However, once the findings have been produced, removal of my data may not be possible.
- I am a healthy, active female or male between the ages of 18 and 50 years who participates in regular exercise training 3-4 times weekly (e.g., running, CrossFit, Gym workouts, sports, hiking, etc.).
- I have not had a lower limb injury within the past 6 months that could affect my performance within the data collection of the study. I also have no other major injuries that could influence my results or my performance in the study.
- I am not suffering from heart disease, high blood pressure, any respiratory condition (excluding mild asthma), any illness or infection that could impair my physical performance.
- I understand that my participation in this study is confidential and that no material, which could identify me personally, will be used in any reports on this study.
- I agree to take part in this research.
- I wish to receive a summary of the overall research findings. Please tick one:  
Yes          No
- I wish to receive a copy of my individual results from the study. Please tick one:  
Yes          No
- I wish to have my performance results stored indefinitely. Please tick one:  
Yes          No

Participant Signature:

Participant Name:

Participant Contact Details (if appropriate)

Email:

Phone Number:

Date:

*Approved by the Auckland University of Technology Ethics Committee on 5<sup>th</sup>  
September 2022 AUTEK Reference number 22/217*

*Note: The participant should retain a copy of this form*

## Appendix 7: Participant Recruitment Advertisement



# Participants needed for new study using wearable vibration training!



My name is Hannah, and I am a Master of Sport, Exercise and Health student at AUT. I am looking for healthy, active volunteers who wish to participate in a research study for my Master's dissertation.

This study is going to be investigating the potential acute effects of local vibration training on lower-body isokinetic strength with the integration of Myovolt wearable vibration sleeves. Participants will be included in the study on a voluntary basis.

### What is the purpose of the study?

To investigate the potential acute effects of local vibration training on lower-body muscular strength using Myovolt wearable vibration sleeves. This will be of great benefit to both the sports technology and rehabilitation fields.

### Who can participate?

Healthy active males and females who meet the following criteria can participate:

- are aged between 18 - 50 years
- are healthy and active, regularly exercising between 3-4 times a week, e.g., running, gym, CrossFit, walking etc.
- in relatively good health with no adverse health conditions, e.g. hypertension, heart disease etc. no
- lower-limb injuries within the past 6-months
- no significant injuries that could prevent you from performing the required exercises (leg extensions, leg curls and isometric hamstring holds)

Unfortunately, clients of the researchers are not allowed to participate.

**If you meet the above criteria and wish to participate please contact me using the contact details below for more information.**

### Contact details:

Name: Hannah Tiedt

Phone number: +64 2108697932

Email address: [ycy4963@autuni.ac.nz](mailto:ycy4963@autuni.ac.nz)