# THE CHRONIC AND ACUTE EFFECTS OF WHOLE BODY VIBRATION TRAINING

By

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**Signature**………………………………………………

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The journal review process has been robust and at times challenging with all of the publications, but it has been fair and has helped me develop my knowledge as well as provide direction to future projects in my academic career.

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## ABSTRACT

Whole body vibration training (WBVT) has gained a lot of interest for its proposed benefits across a range of populations both active and injured. The purpose of the present thesis was to test the efficacy of WBVT in terms of injury rehabilitation and performance enhancement amongst professional and amateur athletes. The five papers submitted for the degree of PhD by publication are grouped into two key themes relevant to the development of knowledge and evidence to advance a better understanding of the chronic and acute effects of WBVT. The themes encompass the efficacy of WBVT (Chronic) as a rehabilitation tool and as an addition to a warm-up routine (acute). The explanatory narrative provides a brief background to WBVT, a summary of each paper and what the paper has contributed to the field both in terms of knowledge and methodological development. The papers presented provide evidence that chronic WBVT is an effective method of improving balance and stability in athletes suffering functional ankle instability (FAI) (Paper 1). Even when compared to traditional methods of rehabilitation for FAI, the addition of WBVT enhances the benefits of traditional rehabilitation protocols (Paper 2). The use of acute WBVT enhances reactive strength, again showing a significant benefit as an addition to a more traditional warm-up (FIFA 11+) amongst amateur soccer players (Paper 3). When training status was considered (amateur *vs*. professional), high frequency acute WBVT stimulus significantly improved landing stability (DPSI) amongst professional players only (Paper 4). These differences between groups were also identified when examining knee extensor potentiation and force output with significant improvements amongst professional but not amateur soccer players. Professional players also reported significantly greater beliefs in the effectiveness of WBVT (Paper 5). In conclusion the body of work presented discusses the practical and methodological implications of the new knowledge presented and identifies a series of future lines of research.

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## Chapter One – Introduction to narrative

This submission for PhD by publication has investigated the use of whole body vibration training (WBVT) as a rehabilitation tool amongst athletes suffering functional ankle instability (FAI) and as an acute performance enhancement intervention in professional and amateur soccer players using a series of randomised control trials (RCT) (Figure 1). For each of these papers I was the lead author, preparing the first and subsequent drafts of the papers, developing the original research idea, refining the research question, developing an appropriate methodology, collecting the data and performing the analysis being reported within the paper (see Appendix 6 for co-author signatures confirming this).

The first two papers of the PhD examined chronic (six weeks) WBVT and its effect on balance in a balance deficit (FAI) population; in particular the additional benefit it can provide to traditional rehabilitation exercises alone. The methodological theme of the narrative looked to compare WBVT against sham conditions (exercises in the absence of WBVT) instead of a passive control, something recommend in the research to help in the critical evaluation of WBVT protocols (Colson *et al.*, 2009). **Paper 1** (Cloak *et al.*, 2010) investigated the effect of a six week WBVT intervention on improvements in static and dynamic balance and postural fatigue amongst athletes suffering FAI. The main outcome of this study was a significant improvement in static and dynamic balance amongst the WBVT group. One question raised by this paper was whether the addition of a vibration stimulus to traditional FAI rehabilitation protocols would have any additional benefits for improvements in balance and muscle function. This was the focus of **Paper 2** (Cloak *et al.*, 2013) where a combination of WBVT stimulus and traditional wobble board training was compared against wobble board training alone in improving static and dynamic balance (Cloak *et al.*, 2013). The participants were exposed to the combined WBVT and wobble board training had a significant improvement in static and dynamic balance compared to wobble board training alone.

The subsequent 3 papers examined the acute effects of WBVT on performance enhancement. The basis for this was the increasing numbers of researchers examining the acute application of WBVT for subsequent athletic performance enhancement (Cochrane, 2011a, Adams *et al.*, 2009, Bullock *et al.*, 2008, McBride *et al.*, 2010, Cochrane, 2013). The majority of research examining acute WBVT has examined the response in untrained participants (Adams *et al.*, 2009, Cochrane *et al.*, 2010, Fernandes *et al.*, 2013, McBride *et al.*, 2010, Nordlund and Thorstensson, 2007, Pollock *et al.*, 2012, Ritzmann *et al.*, 2011). Accordingly, the response of professional/elite athletes to WBVT requires further investigation since this will typically be the population who use such instrumentation due to cost and availability.

**Paper 3** (Cloak *et al.*, 2014a) was an initial investigation into whether the addition of an acute bout of WBVT stimulus to a well-established warm-up (FIFA 11+) would improve performance in healthy collegiate soccer players (Cloak *et al.*, 2014a). The results indicated that the combination of WBVT and the FIFA 11+ warm-up significantly improved reactive strength indices (RSI) compared to the warm-up alone; though neither intervention had any effect on agility scores. The paper discussed the possible benefits the addition of acute WBVT may have within a warm-up routine, in particular the possible neuromuscular benefits that are associated with characteristics of an effective warm-up.

Linked to performance enhancement are landing mechanics and any addition to a warm-up routine pre-competition should aim to improve performance and decrease fatigue/injury risk. **Paper 4** (Cloak *et al.*, 2014b) compared the effects of an acute WBVT stimulus on landing mechanics and included a comparison between professional and amateur soccer players. The main findings of the paper were that WBVT significantly improved dynamic stability on landing amongst professional soccer players and had a negative impact in the amateur players. The findings suggested that the high vibration frequency and load may be sufficient to produce a positive neuromuscular response in highly trained athletes but may be too great a stimulus and therefore detrimental in amateur athletes (Cloak *et al.*, 2014b). As previously reported professional/elite and amateur athletes respond differently to WBVT (Osawa and Oguma, 2013, Ronnestad, 2009, Issurin and Tenenbaum, 1999). The exact reasons for these neuromuscular differences between the two groups required further investigation.

The final paper, **Paper 5** (Cloak *et al*., 2016), was an interdisciplinary paper investigating the observed differences between professional and amateur soccer players using an electro-stimulation protocol to assess force output post-activation potentiation (PAP) and voluntary motor unit recruitment amongst participants. The study also examined the participants perceived benefit of using acute WBVT; a key component to compliance with any intervention in athlete populations (Soligard *et al.*, 2010). The results demonstrated an improvement in force output and post-activation potentiation in professional players compared to amateur players. It was speculated that this may be mediated by initial starting strength levels. What is clear is that the effectiveness of an acute WBVT protocol would appear to be one that is mediated by training status (professional *vs*. amateur); in particular the level of muscular strength seems to impact upon physiological indices as well as beliefs on the value of acute WBVT.

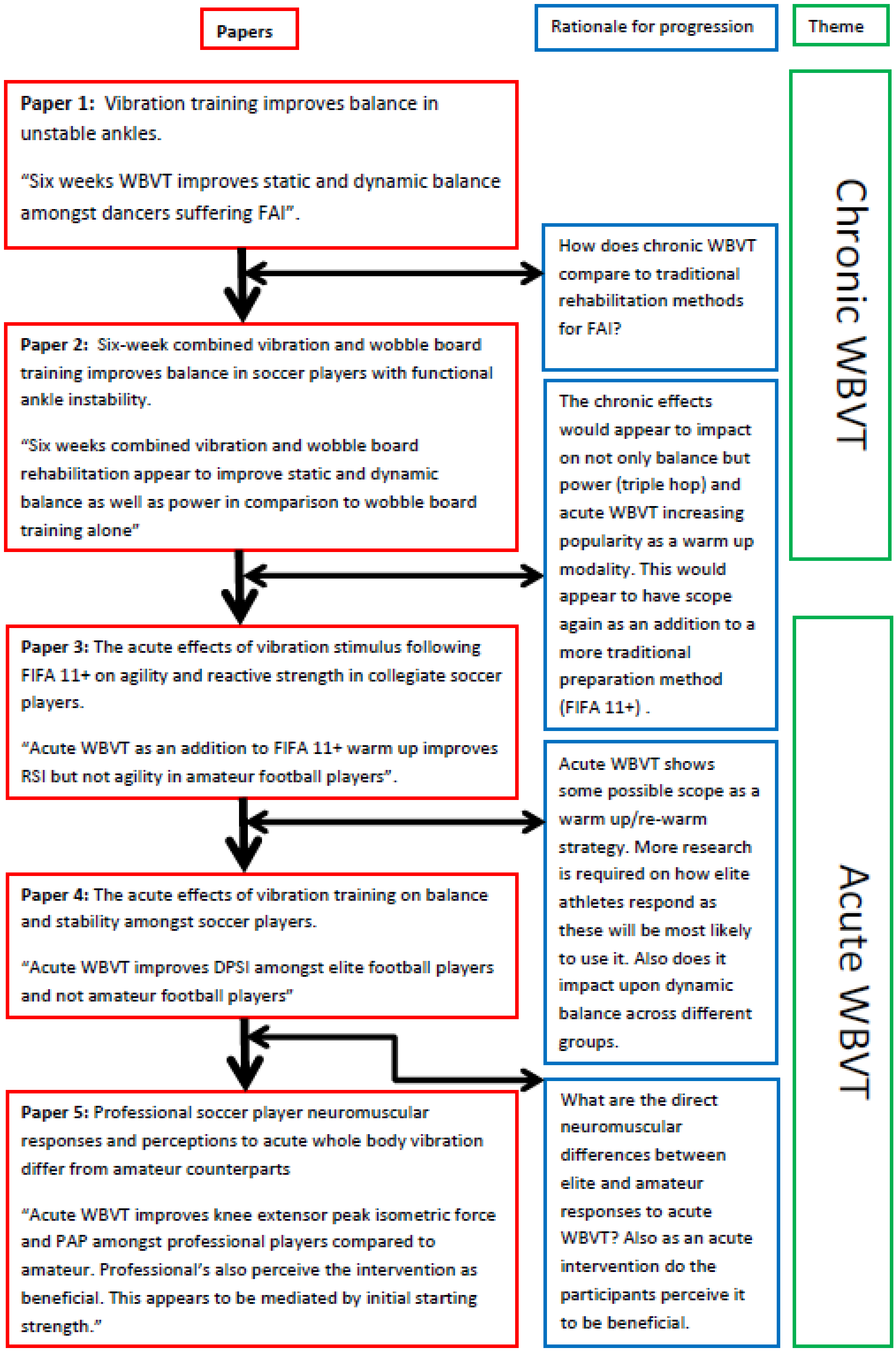


**Figure 1:** Synopsis of PhD by publication

## 1.1 Whole body vibration training (WBVT)

The scientific papers presented in this thesis focus upon the effect of WBVT in a range of settings and participants. Firstly as a rehabilitation tool, and then as an acute addition to a structured warm-up. The body of work examined explores some of the contemporary questions raised around the use of WBVT and each study presents a unique methodology to help answer these questions. During the course of work each study identified a future line of research which the proceeding study aimed to investigate. Therefore, the studies submitted for this PhD demonstrate a body of work that advances the knowledge around the use and efficacy of WBVT.

Vibration training over the past decade has become an increasingly popular training method amongst both professional/elite athletes and the general public with both chronic and acute environments. The notion that vibration can be beneficial is a new concept to some, as it has previously been associated with circulatory, neurological and joint damage associated with occupational exposure (Rittweger, 2010, Griffin, 1997). Initial research into the positive effects of vibration training with an oscillating bed, examined counteracting the effect of immobilisations following best rest on metabolic and physiological function (Toscani *et al.*, 1949, Sanders, 1936). The works of Nazarov and Spivak (1987) and Issurin *et al.* (1994) were some of the first to consider the use of vibration training in athletes as a means of improving strength and flexibility. It was reported that short bursts of superimposed vibration alongside traditional resistance exercise improved strength and flexibility compared to traditional resistance exercise alone (Issurin *et al.*, 1994). Rittweger (2010) recognised that these initial studies led to an increasing interest in the area and the potential for the WBVT to be used as a training modality across a range of applied settings. With key authors emerging in the field (Bosco *et al.*, 1999b, Cardinale and Bosco, 2003, Cochrane *et al.*, 2004, Issurin and Tenenbaum, 1999, Rittweger *et al.*, 2003), in combination with a growing commercial interest in the devices, there has been a substantial growth in research investigating WBVT applications and benefits.

Vibration is a mechanical oscillation, *i.e.* a periodic alteration of force, acceleration and displacement over time. Vibration exercise, in a physical sense, is a forced oscillation, where energy is transferred from an “actuator” (*i.e.* the vibration device) to a “resonator” (*i.e.* the human body) (Rittweger, 2010). The amplitude is determined by the oscillatory motion (peak to peak displacement in mm) of the device, and the repetition rate of the vibration cycles denotes the frequency of vibration (measured in Hertz) (Figure 2) (Cardinale and Bosco, 2003). During vibration exercise, the human body is accelerated, which causes a reactive force. Importantly, the peak acceleration in sinusoidal oscillation is as a result of the frequency (Hz) x Peak displacement (mm) of the vibration platform (Table 1) (Rauch *et al.*, 2010). The principle upon which it works lies within Newton’s second law of motion (force= mass x acceleration) and by either applying more mass (weights *etc.*) or more acceleration (altering frequency or peak to peak displacement) it is possible to alter forces acting on the body (Sá-Caputo *et al.*, 2015). Vibration exercise is mostly practised as whole body vibration, *i.e.* while standing on oscillating platforms, rather than locally applied to the muscle itself (Rittweger, 2010).

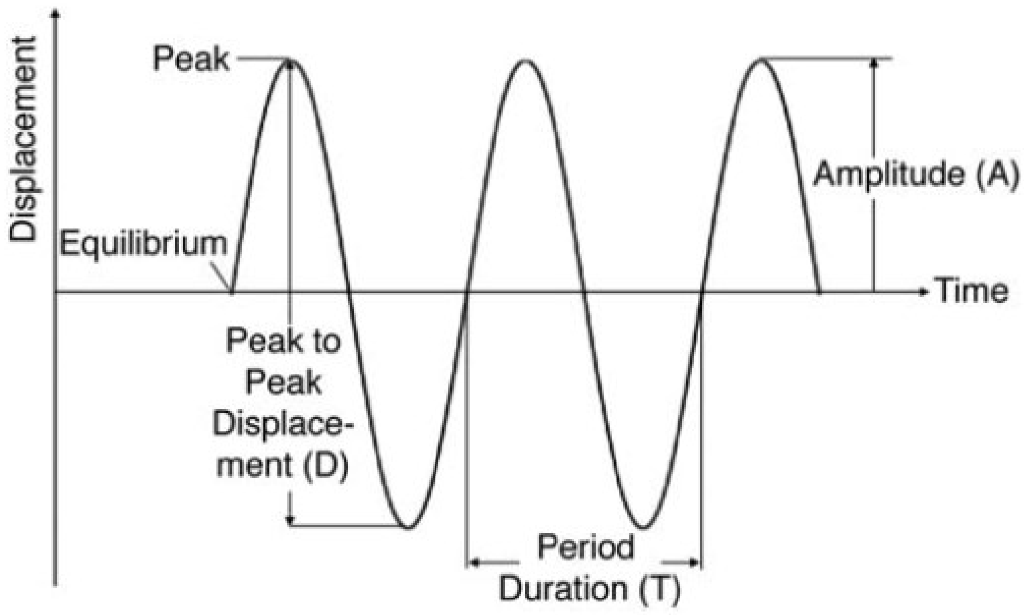


**Figure 2:** A plot of displacement against time in sinusoidal vibration. The definitions of the terms amplitude (A), peak-to-peak displacement (D) and period duration (T) are given in Table 1. The frequency (f) corresponding to the period duration is equal to: f = 1 / T (Hass *et al.*, 2010).

**Table 1:** Terms used to describe sinusoidal vibration (Rauch *et al.*, 2010)

| | Unit | Definition | Symbol | Formula |
|---|---|---|---|---|
| Period duration | s | Duration of one oscillation cycle | T | |
| Frequency | Hz, $s^{-1}$ | Repetition rate of the cycles of oscillation | f | f = 1/T |
| Peak-to-Peak Displacement | mm | Displacement from the lowest to the highest point of the total vibration excursion | D | $D = a_{Peak}/(2 \times \pi^2 \times f^2)$ |
| Amplitude | mm | Maximal displacement from equilibrium position | A | A = D/2 |
| Peak Acceleration | $ms^{-2}$ | Maximal rate of change in velocity during an oscillation cycle | $a_{Peak}$ | $a_{Peak} = 2 \times \pi^2 \times f^2 \times D$<br>$a_{Peak} \approx 20 \times f^2 \times D$ |

The neural adaptations that occur from traditional resistance/power training have been reported to be similar to those from WBVT (Bosco *et al.*, 1999a, Bosco *et al.*, 1999b, Cardinale and Bosco, 2003, Cochrane, 2011a, Cochrane, 2011b, Rittweger, 2010, Rittweger *et al.*, 2003). The human neuromuscular system is a specialised system which has the capability to respond to a variety of stimuli. Increasing the forces (peak acceleration) acting on the body has been suggested to promote muscle adaptation and force generating capacity (Cardinale and Bosco, 2003). The mechanical action of vibration produces a cyclic transition between involuntary eccentric and concentric muscle contractions (Rittweger, 2010). Vibration applied to the muscular tendon unit causes rapid change in the length of the muscle tendon complex and elicits a tonic vibration response via the tonic vibration reflex (TVR) (Hagbarth and Eklund, 1966). This rapid cyclic transition between eccentric and concentric contraction is seen to acutely enhance the efficiency of the neuromuscular system (Lienhard *et al.*, 2015c). Neuron excitability (monosynaptic and polysynaptic pathways) have also been shown to mediate TVR which may lead to adaptation to muscle spindle efficacy and adaptation to mechanoreceptors resulting in improved neuromuscular performance and muscle coordination (Lienhard *et al.*, 2015c, Rittweger, 2010, Nordlund and Thorstensson, 2007).

The neurological stimulation provided by WBVT has also been reported during tendon stretch reflex investigation. Rittweger *et al.* (2003) suggested α -motoneurons were stimulated by WBVT, which in turn recruited higher threshold/larger motor units leading to a reported increase in patellar tendon stretch reflex. Other chronic exposure adaptations suggested are mechanical dampening leading to absorption of energy and therefore generation of heat and increased muscle temperature (Rittweger, 2010). Evidence suggests that muscle has such dampening properties in response to vibration stimuli (Wakeling *et al.*, 2002) and muscle temperature has been associated with improvements in neuromuscular power output (Cochrane *et al.*, 2008). Also, “muscle tuning” is reported as the body’s ability to increase muscular activity to reduce the effect of vibration (Nigg and Wakeling, 2001). The exact mechanism of the tuning response remains unclear but would appear to rely heavily on muscle spindle response, sensitivity of joint and skin receptors and muscle tendon stiffness (Cochrane, 2011b). The efficacy of such a tuning response may be mediated by the condition of the corresponding muscle. Previous research suggests a positive neuromuscular response to WBVT may be due to higher sensitivity of muscle receptors and increased central nervous system (CNS) responses associated with well-trained participants (Issurin and Tenenbaum, 1999).

It is important to recognise that very few prolonged WBVT exposure studies suggest structural changes in the muscle size or architecture as the load is considered too low and any significant hypertrophy is deemed unlikely (Nordlund and Thorstensson, 2007). It is more likely neural adaptations occur, permitting gains in muscle strength and power in the absence of increases in cross-sectional area of the muscle as typically seen in those new to resistance training (Bosco *et al.*, 1999a). One reason why studies examining chronic interventions could lead to improvements in muscle function, as Cochrane (2011a) points out, is if the individual has an existing neuromuscular deficit such as balance or posture (Delecluse *et al.*, 2003, Moezy *et al.*, 2008, Trans *et al.*, 2009, Rees *et al.*, 2009, Melnyk *et al.*, 2008, Bogaerts *et al.*, 2007b, Torvinen *et al.*, 2002) or amongst older populations (Bogaerts *et al.*, 2007a, Rees *et al.*, 2009) . Amongst well trained individuals, chronic WBVT exposure would appear to have little benefit (Nordlund and Thorstensson, 2007) and WBVT would appear to need to be in combination with other traditional methods. Cardinale and Erskine (2008) agree it is unlikely that chronic WBVT alone, using the currently available frequency and amplitude settings on commercial devices would benefit healthy athletes to a greater extent than traditionally periodised resistance training methods.

The classic TVR theory is one that has been questioned over time (Nordlund and Thorstensson, 2007). Original TVR theory was based on vibration stimuli supplied directly to the muscle (Hagbarth and Eklund, 1966). Its applicability therefore to indirect WBVT is debatable (Nordlund and Thorstensson, 2007), however that is not to say that there is no muscle spindle activity (Cochrane, 2011b) and EMG analysis has previously reported a high level of vibration induced muscle stretch reflexes (Ritzmann *et al.*, 2010). The true extent to which WBVT effects the neuromuscular system cannot easily be assessed in terms of basic electromyography (EMG) activity (Nordlund and Thorstensson, 2007) as problems have been highlighted with the interference of motion artefact (Ritzmann *et al.*, 2010). Many studies examining EMG activity assume an increase in signal is a reflection of neuromuscular contribution due to not filtering motion artefact and this leads to large inter-study differences (Fratini *et al.*, 2009b, Fratini *et al.*, 2009a). A more pertinent question is how this vibration induced stretch reflex relates to functional outcomes for sports performers using WBVT interventions (Ritzmann *et al.*, 2010) . Nordlund and Thorstensson (2007) suggested if the neuromuscular effects of WBVT is to be correctly ascertained there should be a difference in voluntary and involuntary activation as assessed by interpolated twitch technique. The idea of non-neurogenic factors such as potentiation of muscle twitch force has been suggested previously following acute WBVT (Bosco *et al.*, 2000). Cochrane *et al.* (2010) identified that over the course of an acute vibration stimulus it is non-neurogenic twitch potentiation that induced improvements in power output and not neurogenic twitch potentiation. The success of acute interventions would therefore appear to be mediated by the initial fitness levels of the participants and their ability to tolerate vibration load without the detrimental effects of fatigue as reported by other studies examining muscle potentiation (Ebben, 2006, Hodgson *et al.*, 2005, Sale, 2002, Seitz *et al.*, 2014).

Increasingly, the literature has begun to examine the acute effects of WBVT in a sporting context either as part of a warm-up or re-warm-up strategy (Cochrane, 2013, Bullock *et al.*, 2008, Cardinale and Lim, 2003, Cochrane *et al.*, 2010, Da Silva-Grigoletto *et al.*, 2009, Jordan *et al.*, 2010, Lamont *et al.*, 2010, McBride *et al.*, 2010, Rittweger *et al.*, 2003, Ronnestad, 2009, Yeung *et al.*, 2014, Lovell *et al.*, 2013b). One of the unanswered questions in these studies is whether the addition of WBVT to an already well established warm-up routine provides additional benefit. Addressing this key question is something that would be particularly relevant for applied practitioners in the field. Also, despite the volume of research few studies have investigated professional/elite sport populations, with a few notable exceptions (Bullock *et al.*, 2008, Cochrane and Stannard, 2005, Despina *et al.*, 2013, Issurin and Tenenbaum, 1999, Lovell *et al.*, 2013b, Ronnestad, 2009). This is particularly relevant as amateur and professional/elite athletes have exhibited different responses to WBVT, which include power output and flexibility (Ronnestad, 2009, Despina *et al.*, 2013, Issurin and Tenenbaum, 1999).

Baseline fitness levels of the participants would more than likely have mitigating effects on the outcome measures employed in WBVT studies. Rieder *et al*. (2015) discussed this as a leading cause of inconsistencies amongst studies and remains one of the key criticisms of WBVT research. The acute effects have been shown to be a powerful tool in applied settings however with mixed results in various populations. One of the key questions for practitioners is whether the addition of WBVT has an additional benefit to performance. According to Cardinale and Erskine (2008), WBVT will never replace traditional rehabilitation methods or warm-up routines in athletic populations. Due to the expense and facility limitations it is important to provide empirical evidence of WBVT's additional benefits, as well as identifying those populations who would most benefit and who also may have a deep rooted belief in their established practices. With the increase in commercial availability and literature reporting improvements in strength, power, flexibility and balance (Rittweger, 2010), WBVT appears to be a viable option for rehabilitation and preparation for performance. The scope of the current papers presented in this thesis is to investigate some of the key applied questions surrounding the use of WBVT in athletic populations (particularly soccer) that could help inform future practice and add to the growing body of knowledge in the area.

Some key recurring themes continue to be raised throughout the WBVT literature which this thesis will look to investigate, generate new knowledge, and develop theories that will inform future research and practical applications.

i) Is chronic WBVT effective at improving balance and muscle function in physically active populations suffering a functional deficit such as FAI in comparison to an active control group?
ii) Does WBVT stimulus provide any additional benefit in comparison to traditional rehabilitation methods (wobble board) in injured populations?
iii) Does the addition of an acute WBVT to an already well established warm-up routine provide any additional benefit and what are these benefits?
iv) Do professional/elite and amateur populations differ in their responses to acute WBVT and what are the factors which may influence this?

### 1.2 Chronic WBVT and rehabilitation

**Paper 1:** Cloak, R., Nevill, A. M., Clarke, F., Day, S., & Wyon, M. A. (2010). Vibration training improves balance in unstable ankles. *International Journal of Sports Medicine,* 31(12), pp. 894-900

The purpose of the **paper 1** (Cloak *et al.*, 2010) was to assess the effect of a six week progressive WBVT intervention in collegiate dancers suffering FAI. Functional ankle instability is a condition characterised by repetitive episodes of the ankle "giving way" and/or incidence of recurrent ankle sprains (Tropp, 2002). While the cause of FAI remains unclear, it has been suggested that both passive structures such as ligaments, articular surface of the ankle and neurological structures (*i.e.* supporting musculature) are damaged at the time of an ankle sprain contributing to recurrent instability (Palmieri-Smith *et al.*, 2009). These neurological impairments effect postural control (Arnold *et al.*, 2009, Ross *et al.*, 2009a, Sefton *et al.*, 2009), dynamic balance (Eechaute *et al.*, 2009, McKeon *et al.*, 2008, Wikstrom *et al.*, 2007) and can contribute to muscle fatigue (Gribble and Hertel, 2004, Palmieri-Smith *et al.*, 2009, Powers *et al.*, 2004). Functional insufficiencies if not treated can lead to mechanical/structural insufficiencies and ultimately chronic ankle instability Figure 3**.**

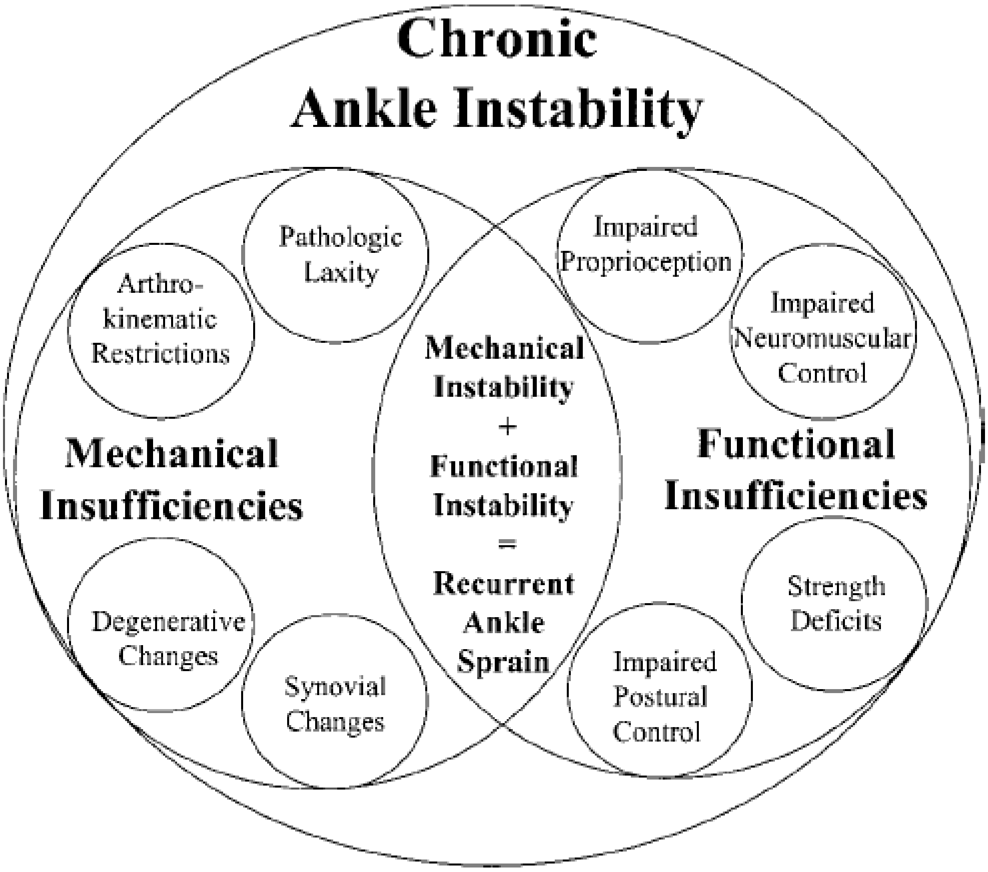


**Figure 3:** Paradigm of mechanical and functional deficits that contribute to recurrent ankle sprains (Hertel, 2002).

The rationale for the study was developed from an increasing body of knowledge reporting neuromuscular improvements from WBVT (Bosco *et al.*, 1999a, Cardinale and Bosco, 2003, Cochrane, 2011a, Rittweger, 2010, Rittweger *et al.*, 2003) . More recently this had encouraged the use of WBVT as a rehabilitation tool and method for improving stability and balance (Moezy *et al.*, 2008, Trans *et al.*, 2009, Rees *et al.*, 2009, Bogaerts *et al.*, 2007b, Torvinen *et al.*, 2002). With the reported large neuromuscular deficit associated with FAI (Palmieri-Smith *et al.*, 2009, Arnold *et al.*, 2009, Docherty *et al.*, 2005, Eechaute *et al.*, 2009) the inclusion of WBVT would appear to warrant further investigation. Cardinale and Erskine (2008) reported that, considering the recent findings in the literature of WBVT, more studies were required to evaluate the possibility of using such modalities in the rehabilitation of the most common athletic injuries of the lower limbs. However, there is a lack of research looking at physically active athletic populations in WBVT studies, with much of the early research focusing on elderly populations in rehabilitation (Arnold *et al.*, 2009). FAI is a prevalent condition amongst dance populations (Hiller *et al.*, 2004, Weigert and Erickson, 2007) so any new means of improving performance outcomes and subsequent injury risk reduction warrants investigation. Access to a population who place a high demand on balance and postural control on landing (Thacker *et al.*, 1999) provided an excellent opportunity to investigate the effect of chronic WBVT on both dynamic and static balance measures. Function of the peroneus longus muscle group (which is suggested as being compromised in those suffering FAI) and is a possible reason for subsequent repeated injury was also investigated. This is particularly prevalent among female ballet dancers due to the time they spend *en pointe* (balancing on the tips of their toes in ballet shoes) and can have an impact on performance and career progression (O'Loughlin *et al.*, 2008). A range of dependent variables were identified to assess both static and dynamic balance as well as muscle function, something that was highlighted as a requirement in the area of ankle instability research (Ross *et al.*, 2009b) as well as providing a number of lines of possible future enquiry.

The WBVT protocol consisted of two sessions per week over a progressive six week protocol, systematically increasing in both frequency and duration, and therefore overall load (Rauch *et al.*, 2010). The protocol had the specific aim of focusing on lower body function and maintained a very basic set of lower limb exercises. The manipulation of the duration and frequency of the WBVT was done with the aim of providing a progressive overload to participants. The results of the study showed significant improvements in the Star Excursion Balance Test (SEBT) scores and static balance in comparison to control groups, both of which have been identified as key indicators of neuromuscular deficit in conditions such as

FAI (Arnold *et al.*, 2009). Single leg exercises with WBVT have previously demonstrated improvements in balance, however, only over a longer period with more exposures per week (Moezy *et al.*, 2008, Trans *et al.*, 2009, Rees *et al.*, 2009). Thus the research produced a method of reducing rehabilitation time for clinicians using a simple set of exercises. There was no significant change in the fatigue of the peroneal longus muscle, which may have been contributed to by the complexity of the assessment task. The results clearly demonstrated that WBVT had the ability to improve certain aspects of balance; however, any change in peroneus longus activity was not apparent, one possible reason discussed was the difficulty of the task not being sufficient to establish appropriate levels of fatigue. Dance movements, such as *demi-pointe*, may be too technical or cause too much discomfort to allow for prolonged periods of activity to achieve this level of fatigue (Hiller *et al.*, 2004) during EMG analysis.

Overall **paper 1** (Cloak *et al.*, 2010) introduced new knowledge into the body of work around WBVT and rehabilitation with some interesting results and avenues for future studies both in terms of the population and improving and refining the methodologies used. One limitation of **paper 1** (Cloak *et al.*, 2010) was the lack of a comparison with a more traditional rehabilitation method as well as the lack of an activity for the control group. The first point refers to the fact that although the results show positive findings amongst dancers, the cost of the equipment used would raise the question amongst practitioners of how the more traditional means of rehabilitation to improve balance and muscle function fare in comparison. The economic consideration of rehabilitation intervention is something that needs to be considered before implementation (Verhagen *et al.*, 2005b, Gianotti and Hume, 2007). This “cost-benefit” ratio should be something all applied research considers in an exercise science setting where funding for squads needs to be considered rather than just individuals (Sitler and Horodyski, 1995, Verhagen *et al.*, 2005b). In particular, what is the effect size of the intervention (something not reported in **paper 1**), and how it compares to traditional rehabilitation methods is required. Hopkins *et al*. (2009) discusses the importance of analyzing effect size particularly in studies examining the effectiveness of treatment protocols in sports medicine. Many quantitative studies are described as having statistically significant results when they are in fact trivially small and clinically unimportant (Carver, 1993). For the reader to appreciate the magnitude or importance of a study's findings, the results sections should include some measure of effect size in the results section (Fan, 2001). Effect size is a term used to describe a group of indices that measure the magnitude of a treatment effect (Kotrlik and Williams, 2003). Effect size is different from traditional significance tests because these measures focus on the meaningfulness of the results and allow the ability of researchers to judge practical significance of results presented (Kotrlik and Williams, 2003).

The SEBT may be also considered a limitation of the study as it is not a particularly challenging dynamic balance assessment. The SEBT, although defined in the literature as a dynamic balance task, does not replicate the demands of many sports or the environments where ankle injury will occur (Bressel *et al.*, 2007). Postural sway variables from a force platform are often considered the "gold standard" for measuring balance, and in particular dynamic postural stability index (DPSI) (Bressel *et al.*, 2007, Wikstrom *et al.*, 2005). However, the availability of a force plate in field settings may be limited. Therefore, a more dynamic balance test that requires minimal equipment and has a single leg landing component needs to be considered. This is type of dynamic stability task would be a better replication of when injury occurs, going from a unloaded to loaded condition; one of the most common playing scenarios preceding a non-contact injury to the lower extremities is landing from a jump (Fauno and Jakobsen, 2006, Fong *et al.*, 2007).

**Paper 2:** Cloak, R., Nevill, A., Day, S., & Wyon, M. (2013). Six-Week Combined Vibration and Wobble Board Training on Balance and Stability in Footballers with Functional Ankle Instability. *Clinical Journal of Sport Medicine*, 23(5), pp. 384-391

Following on from **paper 1** (Cloak *et al.*, 2010) the main focus of **paper 2** (Cloak *et al.*, 2013) was to investigate the effects of combined WBVT and wobble board training against wobble board training alone in a group of amateur soccer players. The comparison of WBVT to a more traditional means of rehabilitation (wobble board) was something highlighted for future research in **paper 1** (Cloak *et al.*, 2010). The introduction of a new piece of equipment onto the market (Vibrosphere; ProMedvi) which incorporated vibration stimulus in a wobble board provided an opportunity to investigate the exact effects of the vibration stimulus. This equipment had previously been used in a limited number of studies (Trans *et al.*, 2009, Beaudart *et al.*, 2013) in elderly populations, showing some success in improving proprioception (Trans *et al.*, 2009). The study focused on participants suffering FAI, a common complication following ankle injury (Suda *et al.*, 2009), however the population was changed to soccer players. The reason for this was twofold. Firstly, ankle sprains make up one of the most common injuries in soccer (Woods *et al.*, 2003) and therefore improving outcome results following injury could have a big beneficial impact on a large number of participants. Especially when reported soccer is responsible for a third of all sport related injuries in Europe (Høy *et al.*, 1992, Inklaar *et al.*, 1996). Secondly, the long-term implications of recurrent ankle injury are well documented in soccer (Kuijt *et al.*, 2012, Drawer and Fuller, 2001, Cloke *et al.*, 2009) , with an increased prevalence of osteoarthritis of the ankle in this group compared to the general population in later life (Kuijt *et al.*, 2012).

Traditional wobble board training has been a popular method for rehabilitation of ankle injuries (Holmes and Delahunt, 2009), although results have sometimes been equivocal as to its effectiveness (Powers *et al.*, 2004, Verhagen *et al.*, 2005a). Van der Wees *et al's*. (2006) systematic review considers wobble board training a clinically relevant means of improving balance and function in injured ankles. The rationale behind the proposed benefits is the combination of improving proprioception through increased mechanoreceptor feedback and restoring neuromuscular feedback to the participant (Rozzi *et al.*, 1999). EMG analysis has also shown that wobble board training has the ability to stimulate muscles of the lower leg (tibialis anterior/posterior, peroneus longus and flexor digitorum longus) and subsequently may have the ability to improve muscle responses to rapid changes in ankle permutations to maintain stability (Osborne *et al.*, 2001). Cimadoro *et al*. (2013) highlights that active control of the centre of mass (COM) on unstable surfaces is coupled with a significant increase in lower limb muscle activity, concluding that athletes should incorporate wobble board exercises into both training and rehabilitation to improve sensorimotor function, ankle strength and joint stability. Interestingly the proposed CNS proprioceptive and neuromuscular control systems (Figure 4) of wobble board training would appear to have similar patterns to the ones stimulated by WBVT (higher brain function and feedback loop, muscle spindles/ type 1a afferent motor neurons and mechanoreceptors) (Figure 5)**.** This coupled with the fact contraction of the muscle during WBVT (as would be present when controlling COM on an unstable surface), appears to increase overall activity of that muscle (Ritzmann *et al.*, 2013, Di Giminiani *et al.*, 2012). Thus, it would suggest a mutual benefit from the combination of WBVT and unstable surface training in rehabilitation settings.

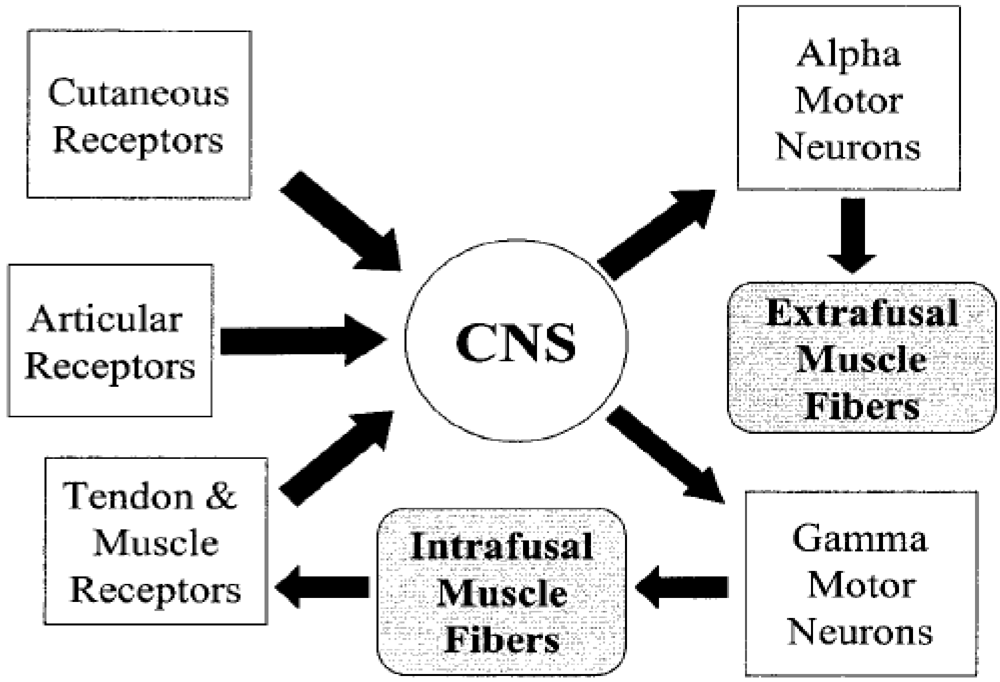


**Figure 4:** Paradigm of central nervous system (CNS) proprioceptive and neuromuscular control (Hertel, 2002).

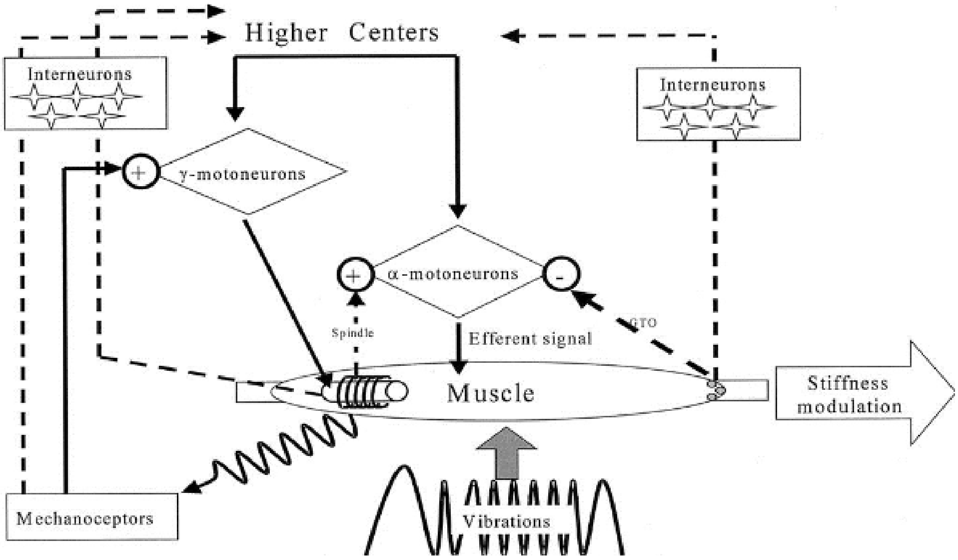


**Figure 5:** The effects of vibration stimulus on humans. The figure illustrates stiffness regulation during vibration stimulation. The quick change in muscle length and the joint rotation caused by vibration trigger both alpha (a) and beta (y) motor neurons to fire to modulate muscle stiffness (Cardinale and Bosco, 2003).

As identified in **paper 1** (Cloak *et al.*, 2010) the addition of a dynamic balance task was required to better replicate the demands of the sport and provide sufficient functional challenge to the participant. Single leg triple hop for distance (SLTHD) is a clinically valid tool for assessing strength and power characteristics in healthy athletes, while tasking balance (Hamilton *et al.*, 2008). The SLTHD not only provides a valid and reliable outcome measure of an intervention (Reid *et al.*, 2007), but provides valuable baseline data for any future return from injury and is field based requiring little equipment to administer (Reid *et al.*, 2007). More importantly, the participants' ability to maintain stability when dealing with the permutations of landing are highly correlated with their ability to control ankle position and reduce injury risk (Osborne *et al.*, 2001). The theme of easily administered, quick and reliable field based tests was also continued with the use of the Y balance test, a modification of the SEBT test used in **paper 1** (Cloak *et al.*, 2010). Performance of all eight reach directions however was seen as unnecessary when evaluating deficits related to FAI because of considerable redundancy among some of the reach directions reported (Hertel *et al.*, 2006). The modified SEBT test or Y balance test (Plisky *et al.*, 2006) has 3 rather than 8 directions, anterior (Ant), posterior medial (PM), and posterior lateral (PL) SEBT directions and has been shown to be the most effective assessment of balance in participants with FAI (Hertel *et al.*, 2006, Plisky *et al.*, 2006).

The protocol used in **paper 2** (Cloak *et al.*, 2013) for the combined vibration and wobble board training continued the theme of progressive volume overload across a six week period (twice per week). The increment in WBVT frequency was similar to **paper 1** (Cloak *et al.*, 2010) ranging from 30-40 Hz (4mm), however the total exposure time was less per week due to the fact the complexity of exercise was increased. Task difficulty of each exercise was manipulated as recommended by Ergen and Ulkar (2008) under supervision of a qualified instructor. These recommendations included a progressive increase in task difficulty and volume of exercises by manipulating exposure time, resistance (with the addition of an external load) and finally a sport specific component in the final weeks of the intervention. The wobble board only training group did the same exercises on the specialised wobble board (Vibrosphere, ProMedvi) but in the absence of any vibration stimulus and the control group continued normal activity. The results were similar to **paper 1** (Cloak *et al.*, 2010) with static balance and control of COM significantly improved for the vibration intervention in comparison to no vibration. In addition, anterior and posterior lateral reach distances (Y-balance) were significantly greater in the vibration group. **Paper 2** (Cloak *et al.*, 2013) highlighted a large effect size (Partial $Eta^2 = 0.66$) in COM distribution improvement and a small effect size in modified SEBT improvement (Partial $Eta^2 = <0.30$). Interestingly SLTHD (an indication of power and landing competency) showed that the addition of vibration provided significant improvement in performance. This was the first indication in the thesis of the neuromuscular adaptations in strength and power that had previously been suggested (Bosco *et al.*, 1999a, Bosco *et al.*, 1999b, Cardinale and Bosco, 2003, Cochrane, 2011a, Cochrane, 2011b, Rittweger, 2010, Rittweger *et al.*, 2003).

**Paper 2** (Cloak *et al.*, 2013) provided new evidence that the addition of vibration stimulus had further benefit to wobble board training alone. This study developed and presented an original and effective six-week rehabilitation protocol with practical significance to practitioners. In particular, this was the first study to examine a new piece of equipment entering the market (Vibrosphere, ProMedvi) on an athletic population. One of the main criticisms of the research touched on in the discussion is the clinical significance of the findings. The standard of clinical significance addresses the question of whether as a group the treated individuals are distinguishable from others following treatment (Kendall *et al.*, 1999). The more pertinent question therefore, is the effect size of these results and longitudinal epidemiological evidence on injury occurrence post treatment. Although moderate effects sizes were reported in static balance this needs to be tempered with the relatively small sample sizes (commonly an issue when looking at populations of injured athletes) (Knowles *et al.*, 2006) and the lack of follow-up information on re-injury. The cost benefit ratio mentioned in the paper's discussion is also an important consideration. Rittweger (2010) identified a flood of marketing and commercial drivers in the WBVT area that need investigation to substantiate claims. In comparison to relatively cheap wobble boards (or other unstable surface devices) the Vibrosphere (ProMedvi) and its addition of vibration stimulus to traditional rehabilitation methods would appear to be a particularly expensive option and possibly lacks practicality in large squad settings.

The results of **Paper 2** (Cloak *et al*., 2013) added new knowledge on the positive effect the addition of WBVT has on balance, neuromuscular function and flexibility using rigorous methods which enabled comparison to more traditional interventions. The scope and practicality for it to be used as a rehabilitation intervention has some issues in particular cost benefit ratio and practicality. However, the combined results of **paper 1** (Cloak *et al.*, 2010) and **paper 2** (Cloak *et al.*, 2013) indicate a set of positive adaptations from WBVT that could be considered desirable in preparation for performance (Bishop, 2003, Soligard *et al.*, 2010, Zois *et al.*, 2011), all be it these results were seen in an injured population. Cardinale and Erskine (2008) highlighted the need for more research in acute WBVT and warm-up settings. The review paper by Cochrane (2013) following the publication of **paper 2** (Cloak *et al.*, 2013) suggests the scope for WBVT to impact on performance may be best suited in a warm-up/acute capacity in healthy active participants. With the results and knowledge gained in **papers 1** (Cloak *et al.*, 2010**) and 2** (Cloak *et al.*, 2013) this appeared to be an avenue of investigation that warranted further analysis in a systematic and precise manner to contribute to knowledge in the area.

### 1.3 Acute WBVT in amateur soccer players

**Paper 3:** Cloak, R., Nevill, A., Smith, J., & Wyon, M. (2014). The acute effects of vibration stimulus following FIFA 11+ on agility and reactive strength in collegiate soccer players. *Journal of Sport and Health Science, 3*(4), pp. 293-298.

The purpose of **paper 3** (Cloak *et al.*, 2014a) was to investigate the acute effects of adding a high frequency WBVT exposure to a well-established warm-up routine, to see if some of the positive neuromuscular attributes discussed in **paper 2** (Cloak *et al.*, 2013) could be replicated. **Paper 2** (Cloak *et al.*, 2013) demonstrated improvements in postural control and power production; two very important characteristics when preparing for an effective warm-up routine (Bishop, 2003). This is particularly true in soccer, a sport that encourages these positive physiological abilities in players prior to competition or training (Arnason *et al.*, 2004). When discussing intervention protocols with participants during **papers 1** (Cloak *et al.*, 2010) **and 2** (Cloak *et al.*, 2013) they would report feelings of "freshness" and "being energetic" immediately post WBVT. Although this is acknowledged as anecdotal and may have been largely down to increased peripheral blood flow following WBVT (Rittweger *et al.*, 2000, Kerschan-Schindl *et al.*, 2001), this warranted further investigation. My own applied work had also begun to look more at preparation for performance amongst professional/elite soccer players and although parts of **paper** 1 (Cloak *et al.*, 2010) **and 2** (Cloak *et al.*, 2013) had been implemented amongst injured players there seemed greater scope for the effective use of acute WBVT in a club setting prior to performance.

The literature for WBVT had begun to change focus from chronic WBVT in athletic populations due to some of the reasons previously discussed relating to practicality and effectiveness (Cardinale and Erskine, 2008, Preatoni *et al.*, 2012, Rittweger, 2010) and had begun to investigate acute WBVT prior to/or during breaks in competition or performance (Bullock *et al.*, 2008, Despina *et al.*, 2013, Lovell *et al.*, 2013b, Ronnestad, 2009, Cochrane, 2013). A number of publications had reported the positive benefits of acute WBVT on a number of physiological variables. For example Cochrane (2013) suggested a number of positive benefits acute WBVT could have as part of an athlete's warm-up such as power output, sprint speed, flexibility and muscle temperature. Due to its low metabolic cost and time efficient nature, acute WBVT could offer some substantial benefits to coaches in a warm-up setting. However, more research is required on the exact mechanisms and how it works in combination with other warm-up practices (Cochrane, 2013). The time efficient nature of WBVT is particularly relevant in soccer, with Towlson *et al*. (2013) reporting that time constraints were one of the biggest considerations for practitioners when performing a warm-up or half-time re-warm-up amongst professional soccer players. Therefore, it would appear that acute WBVT could have a place in this setting. Cardinale and Bosco's (2003) summary of the potential mechanisms determining an increase in neuromuscular performance following acute WBVT is illustrated in Figure 6. WBVT stimulates the neuromuscular system to produce reflex muscle activation. If the vibratory stimulus is acute, it subsequently creates the potential for a more powerful and effective voluntary muscle activation (Cardinale and Bosco, 2003).

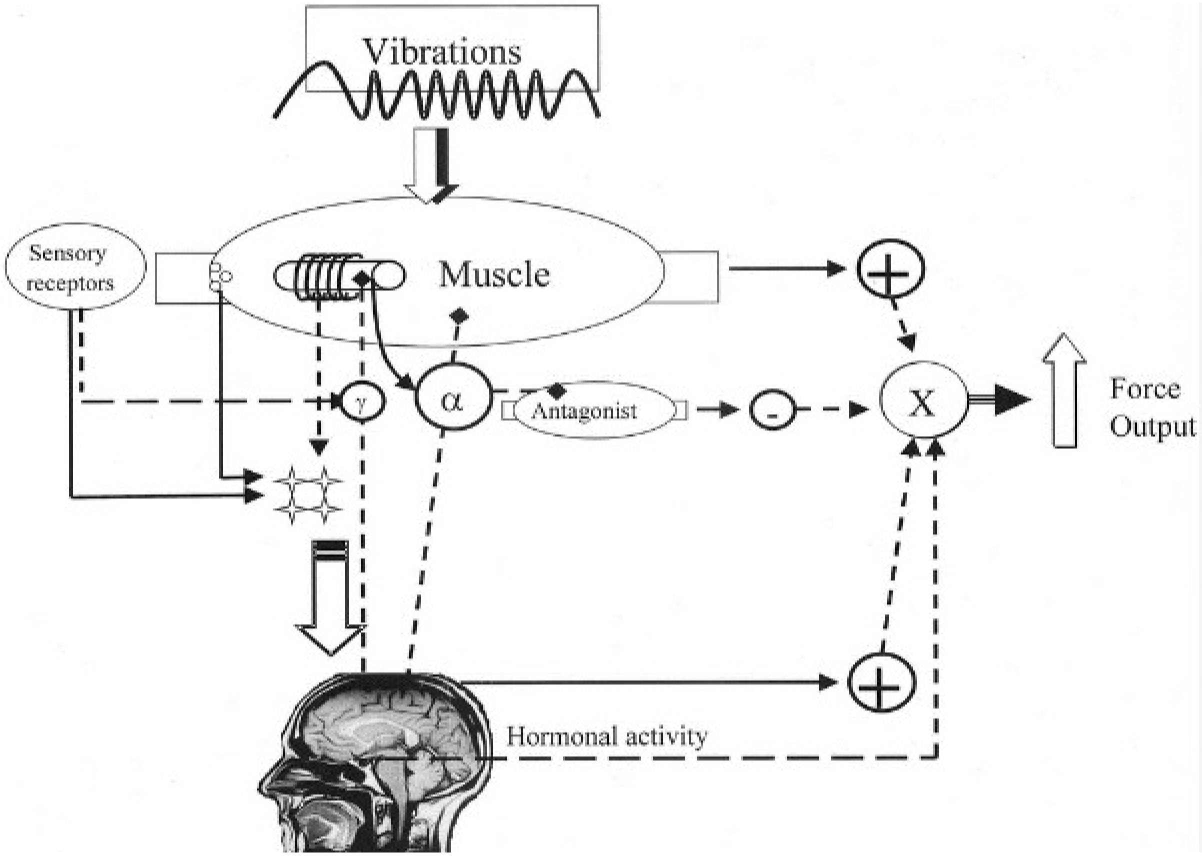


**Figure 6:** Diagram illustrating the potential mechanisms that mediate the enhancement of force-generating capacity after acute WBVT (Cardinale and Bosco, 2003).

The initial aim of **paper 3** (Cloak *et al.*, 2014a) were to assess whether acute WBVT would have any additional benefit to an already well established warm-up routine.

Research which examines physical preparation strategies, every attempt must be made to control as many confounding factors as possible to provide accurate results. It is of little value to compare interventions to a passive control group as difference in muscle temperature alone will impact upon results and provide practitioners with little relevant applied information (MacIntosh *et al.*, 2012). The FIFA 11+ was chosen due to its popularity and reported effectiveness as a warm-up protocol in soccer (Steffen *et al.*, 2013). FIFA 11+ was developed in 2006 in cooperation with the Santa Monica Sports Medicine Foundation (SMSMF), and the Oslo Sports Trauma and Research Centre (OSTRC), as a complete warm-up programme to prevent injuries in amateur soccer players (Bizzini *et al.*, 2013). The injury prevention programme (FIFA 11+), developed by FIFA with the aim of incorporating an effective warm-up and reducing intrinsic injury risk factors in soccer has been validated in soccer populations (Steffen *et al.*, 2008b, Tegnander *et al.*, 2008). However, the FIFA 11+ warm-up, although well established as a means of reducing injuries, has been questioned as having minimal effect on physical performance outcomes in soccer players (Lindblom *et al.*, 2012, Steffen *et al.*, 2008a, Impellizzeri *et al.*, 2013). Vescovi and Van Heest (2010) suggested that developing warm-up protocols with not only injury prevention benefits but also performance benefits, would make it easier to convince coaches to implement such programmes. Researchers have discussed additions to the FIFA 11+ warm-up protocol to help realise performance enhancements (Impellizzeri *et al.*, 2013). Impellizzeri *et al*. (2013) however, points out that any such additions to the FIFA 11+ need to consider fatigue (worsening of performance) and time efficiency.

**Paper 2** (Cloak *et al.*, 2013) discussed that one of the key factors in the use of WBVT in athletic populations is it should complement other methods. On its own, the evidence for chronic WBVT having any meaningful effect on performance is questionable amongst trained populations with no underlying neuromuscular disorder/injury (Hortobágyi *et al.*, 2015, Osawa and Oguma, 2013, Preatoni *et al.*, 2012, Rehn *et al.*, 2007, Yeung *et al.*, 2014, Cardinale and Erskine, 2008). This was confirmed recently by Hortobágyi *et al*. (2015) whose systematic review of the effects of chronic WBVT alone in healthy athletic populations showed relatively small and inconsistent effects on athletic performance and advocated more proven traditional means (e.g., resistance training). The acute effects of WBVT as an addition to a warm-up in conjunction with more traditional training methods would appear to have more scope for benefits amongst healthy/trained individuals with a training history (Bullock *et al.*, 2008, Cochrane, 2013, Despina *et al.*, 2013, Lamont *et al.*, 2010, Osawa *et al.*, 2011, Rønnestad *et al.*, 2013, Ronnestad, 2009). However, **paper 3** (Cloak *et al.*, 2014a) was the first in the literature to investigate whether the addition of WBVT to a standardised warm-up routine has any additional benefit in comparison to an active control group, thereby answering one of the key criticisms of most previous acute WBVT studies that a passive control group is unrealistic (Nordlund and Thorstensson, 2007). **Paper 3** (Cloak *et al.*, 2014a) provided an original exploratory paper into the effects of acute WBVT combined with a well-established warm-up protocol (FIFA 11+). The combination had never previously been investigated and the effect of acute WBVT in healthy athletic populations was a significant change in focus of the thesis. Balance and injury risk were not a focus of the outcome measures used in **paper 3** (Cloak *et al.*, 2014a). The initial focus was to identify any neuromuscular effects (RSI) and performance outcomes related to a key determinant of soccer performance (agility) (Bloomfield *et al.*, 2007). **Paper 3** (Cloak *et al.*, 2014a) was also a move away from the chronic progressive overload model used in **paper 1** (Cloak *et al.*, 2010) **and 2** (Cloak *et al.*, 2013) and instead used a high frequency acute load (40hz + 4mm). One of the easiest ways to increase overall load is to increase frequency (Ritzmann *et al.*, 2013) and as previously identified the larger the muscle displacement (due to increases in frequency or amplitude) the greater muscle activation during the acute WBVT stimulus (Fratini *et al.*, 2009b).

From the findings of **Paper 3** (Cloak *et al.*, 2014a) it is suggested that the addition of 30 seconds of an isometric squat WBVT at 40Hz + 4mm improved some characteristics of RSI but not agility. One initial reason for the improvements in RSI discussed is due to increased efficiency in the stretch shortening cycle (SSC)(Fernandes *et al.*, 2013). In particular an improvement in the short-latency stretch reflex would mean a significant reduction in contact time (CT), as this corresponds to the reflex after ground contact (Komi, 2000). The above suggestion of an increase in short-latency stretch reflex is questionable as such neuromuscular changes could also benefit the 505 agility test scores, but this was not the case. An alternative explanation for the results may have to do with the acute suppression of muscle spindle activity. Rittman *et al*. (2011) discussed the idea that vibration stimulus has been linked to suppression of Ia afferent pathways caused by pre-activation (Crone and Nielsen, 1989). However, as the SSC is a combination of Ia afferent inputs and cortical contribution (Taube *et al.*, 2012b), the current results may suggest that an increase in cortical contribution (via supraspinal centres) compensates for a reduction in Ia afferent transmission following acute WBVT. This proposes that supraspinal centres not only initiate jumping and landing movements but also pre-programme at least part of the muscular activation pattern to support a lack of afferent input (Taube *et al.*, 2012a). This may explain the difference in improvements between RSI and 505 agility time. Ritzmann *et al*. (2011) suggested that depending on the complexity of the motor task there was a greater cortical contribution and a reduction in Ia afferent recovery time. Therefore it could be argued that the motor complexity of the drop jump protocol during the RSI protocol was greater than that of the 505 agility protocol and therefore benefited from this (Ritzmann *et al.*, 2011). Figure 7 illustrates the complex nature of SSC movements in which the CNS has to coordinate and adjust the contribution of anticipated (feedforward controlled) and feedback controlled neuromuscular activity incorporating cortical, subcortical, and spinal levels (Taube *et al.*, 2012a).

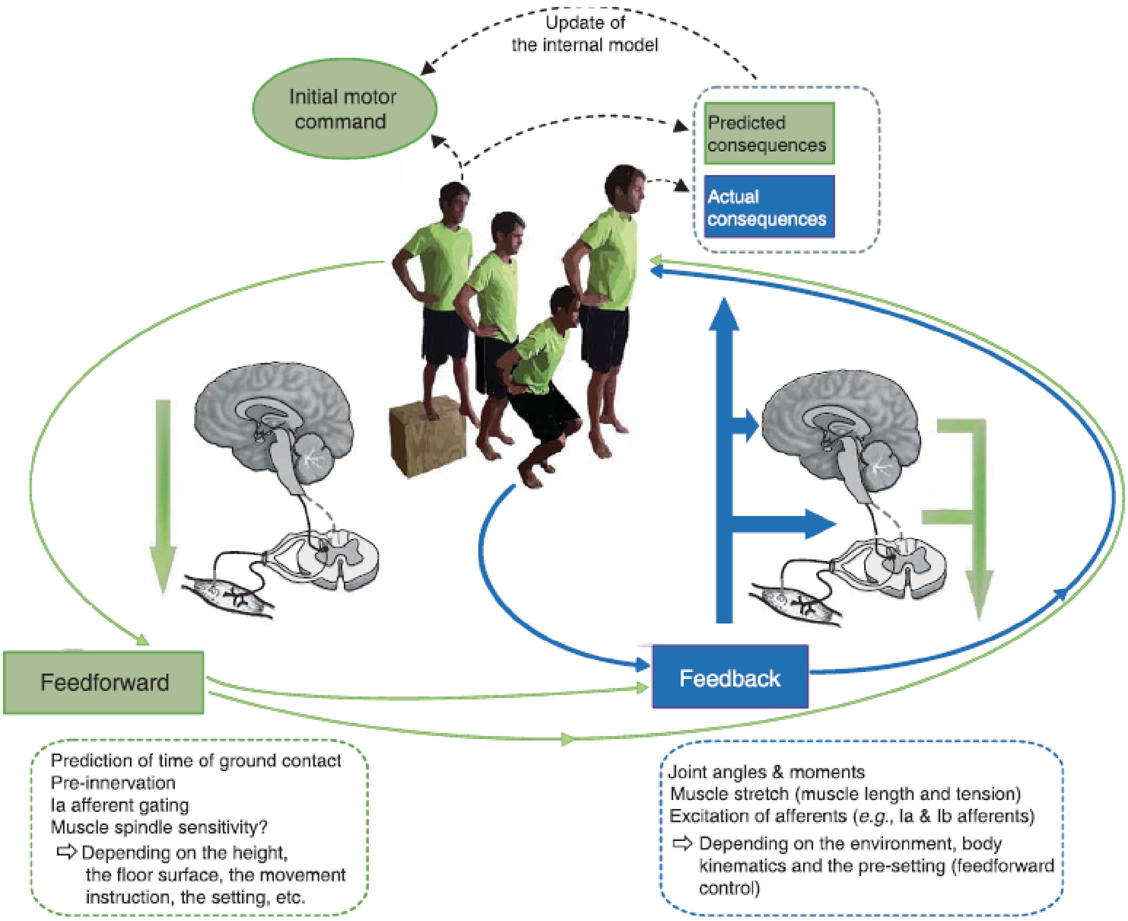


**Figure 7:** Interaction of feedforward and feedback control during stretch-shortening cycle movement (Taube *et al.*, 2012a)

A decrease in the recruitment threshold of motor units could also be suggested as a factor for the decreases in CT (Pollock *et al.*, 2012), with an increase in spindle sensitivity improving detection on landing and a lowering of recruitment threshold meaning an increase in the velocity of contraction (Pollock *et al.*, 2012). The 505 agility time results were discussed from a number of viewpoints: the complexity of the skill, a fatigue effect or alternately, it was just a case of the overall limited exposure (30 seconds). Although this exposure time has been seen as sufficient for simple tasks like jumping (Turner *et al.*, 2011), it might not be for more complex skills (Cochrane *et al.*, 2004). Although not significant, a negative trend in 505 agility was discussed, so any increase in exposure may have accelerated this worsening in performance due to fatigue and needs to be considered. Therefore agility results may raise the questions about possible fatiguing nature of acute high frequency WBVT. The interaction of all the technical factors on agility makes it difficult to identify the components that ultimately influence performance when looking at acute WBVT (Cochrane *et al.*, 2004). Agility may therefore not be the most sensitive or valid performance measure of neuromuscular responses following acute WBVT but does hold ecological validity.

Overall **paper 3** (Cloak *et al.*, 2014a) provided new evidence that a relativity short duration of WBVT in combination with a well-established warm-up protocol can provide some immediate neuromuscular benefits. This work also contributed to the body of work on the FIFA 11+ as well as acute WBVT. The paper was an introduction to the topic of acute WBVT in soccer players and raised some important applied questions. Firstly, the key to any addition to a warm-up protocol is to enhance performance and any additions to an athlete's warm-up should not cause fatigue or worsening of performance which may result in injury (Impellizzeri *et al.*, 2013). Although not significant, **paper 3** (Cloak *et al.*, 2014a) does suggest that an increase in acute WBVT exposure may have an negative impact on agility performance and needs further investigation. More relevant however is the suggestion of possible suppression of Ia afferent feedback caused by acute WBVT, which may impact on balance and postural control or cause fatigue to the musculature involved in these tasks. Results from **Papers 1 and 2** suggest those systems which effect balance are stimulated during chronic WBVT exposure so it could be assumed that this may be true during acute WBVT.

A test that specifically looks at complex tasks such as landing stability and is a sensitive and reliable measure that can detect changes following acute WBVT would help in investigating suggestions of fatigue and worsening of balance. One of the most common injury mechanisms amongst soccer players is to the lower extremity during jump/landing scenarios (Wong and Hong, 2005). Therefore, the potential for positive benefits following acute WBVT is large. However, before acute WBVT can be advocated for safety reasons this should be investigated. The issue of safety around WBVT has mainly focused on industrial risk (Rittweger, 2010, Griffin, 1997) however, the possible safety implication that acute exposure may have on different groups may also be warranted if we are to advocate acute WBVT across various populations/levels of expertise. The second key finding of **paper 3** (Cloak et al., 2014a) is that acute WBVT could be a time efficient addition to a warm-up or more likely a re-warm-up strategy in soccer. If considered as a re-warm-up strategy playing facilitates would need to be considered and realistically professional/elite players would be the population that would have the resources to implement such a protocol (Towlson *et al.*, 2013). Therefore, it is important to look at how professional/elite players respond to acute WBVT, firstly to assess the potential effect it may have on landing stability and as the conclusion of **paper 3** (Cloak *et al.*, 2014a) suggest more acute WBVT studies are needed to be conducted amongst various populations. In particular professional/elite groups, those most likely to be users and those where potential for injury/worsening in performance would have the biggest impact.

## 1.4 Professional and amateur responses to acute WBVT

**Paper 4:** Cloak, R., Nevill, A., & Wyon, M. (2014). The acute effects of vibration training on balance and stability amongst soccer players. *European Journal of Sport Science*, 14, pp1-7.

Seiler and Kjerland (2006) were two of the first authors to recognise that data from professional/elite athletes subjected to specific interventions in traditional experimental designs were scarce. This population rarely wishes to alter their training in the interest of research and access can be difficult (Seiler and Kjerland, 2006). Central to this observation was the recognition that studies based on untrained, or moderately trained individuals should not be uncritically used as evidence for prescription to professional/elite athletes (Seiler and Kjerland, 2006). Even in the early work of Issurin and Tenenbaum (1999), professional/elite and amateur athletes were recognised as responding differently to WBVT stimulus. The research proposed the reason for this being increased sensitivity of muscle receptors and differences in CNS responses amongst professional/elite athletes, and there was also a significant difference in peak power output between groups post-WBVT. As previously reported, WBVT as a substitution for a well-designed resistance training programme has limited effectiveness amongst professional/elite athletes (Preatoni *et al.*, 2012, Cardinale and Erskine, 2008). More recently, Hortobágyi *et al*. (2015) suggested not enough has been done to investigate the effects of WBVT amongst professional/elite athletes despite the immense popularity of the topic reflected in the large numbers of whole body vibration studies published annually (Hortobágyi *et al.*, 2015).

Amongst well trained athletes who have reported stiffer muscle-tendon units (Kubo *et al.*, 2002) and the ability to produce higher force outputs, WBVT may have the capability of increasing muscle output immediately prior to exercise however, further research is recommended to investigate WBVT as a warm-up activity (Cochrane, 2013). **Paper 1** (Cloak *et al.*, 2010) suggested that physically active participants may respond faster to WBVT than sedentary populations (6 weeks not 8 weeks as a rehabilitation protocol). Another important consideration when programming acute WBVT for trained participants is that a well-developed muscle-tendon unit allows for increased vibration dampening capacity, and therefore vibration frequency needs to be a sufficiently high load (>30 Hz, 4mm, >60sec) to elicit a positive response amongst trained populations (Bullock *et al.*, 2008, Issurin and Tenenbaum, 1999, Lovell *et al.*, 2013b, Padulo *et al.*, 2014, Ronnestad, 2009). In contrast, Bullock *et al*. (2008) suggested that a possible trade off with increasing WBVT load is a distribution in proprioceptive ability, in their case joint position sense. As discussed in **paper 3** (Cloak *et al.*, 2014a)**,** Impellizzeri *et al*. (2013) points out that any additions to a warm-up routine need to consider fatigue (worsening of performance) and should not increase the risk of injury. With the prevalence of knee and ankle injuries in soccer due to non-contact means such as landing (Wong and Hong, 2005) any alteration in proprioceptive feedback or fatigue needs to be investigated. The discussion from **paper 3** (Cloak *et al.*, 2014a) indicates an improvement in the short-latency stretch reflex would mean a significant reduction in CT, as this corresponds to the reflex after ground contact (Komi, 2000). Also, increased muscle spindle sensitivity and a decrease in recruitment threshold of motor units are also suggested as a key factor for the decreases in CT (Pollock *et al.*, 2012), with an increase in spindle sensitivity improving detection on landing and a lowering of recruitment threshold meaning an increase in the velocity of contraction (Pollock *et al.*, 2012). Ritzmann *et al*. (2011) however suggests suppression of Ia afferent pathways caused by pre-activation following acute WBVT. As SSC is a combination of Ia afferent inputs and cortical contribution (Taube *et al.*, 2012b) this may suggest that an increase in cortical contribution (via supraspinal centres) compensates for a reduction in Ia afferent transmission following acute WBVT. These are theoretical assumptions based on the literature and suggest acute WBVT has the possibility to impact positively on performance when preparing for competition. In particular, the ability to produce rapid contractions to deal with the changing permutations on landing. However, it's also suggested that afferent feedback (crucial to stability and balance; see Figure 4) may also be influenced by WBVT.

**Paper 3** (Cloak *et al.*, 2014a) had examined possible mechanisms of acute WBVT as an addition to a well-established pre-performance warm-up amongst amateur soccer players. In applied soccer settings however, it would be more likely in acute settings it would be used during breaks in play. Towlson *et al*. (2013) examined the importance of active re-warm-up activities highlighting its importance but also the typical time available to practitioners being limited (3-5minutes). Taking the work of Towlson *et al.* (2013) into consideration and from applied experiences, due to time constraints the optimal use of acute WBVT would be during the half time interval and timings should try and replicate this. This was recently confirmed as a crucial period  by the recommendations for half time strategies in teams sports from Russell *et al*. (2015) and colleagues (Figure 8).  Re-warm-up strategies in sport as a whole have begun to gain more attention in team sports (Lovell *et al.*, 2013a, Russell *et al.*, 2015, Towlson *et al.*, 2013, Weston *et al.*, 2011) . A growing body of evidence has demonstrated reduced high-speed running (HSR) activities immediately after the half-time interval (Weston *et al.*, 2011, Russell *et al.*, 2015).  Lovell *et al.* (2013b) highlighted that a passive half-time interval reduced sprint, jump and dynamic strength performance in semi-professional soccer players. Alternatively, the addition of acute WBVT during half time attenuated these performance decrements (Lovell *et al.*, 2013b).

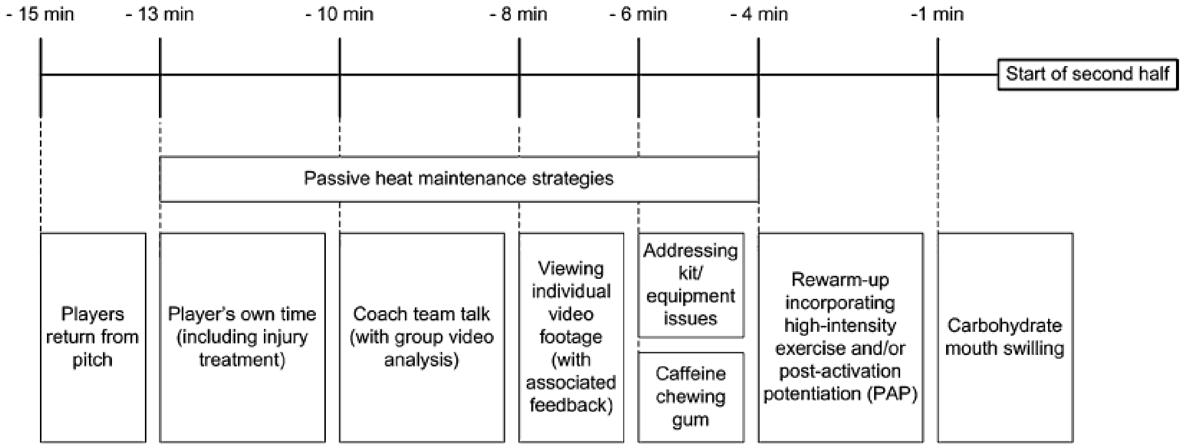


**Figure 8:** Theoretical model of strategies suggested during 15 minute half time period (Russell *et al.*, 2015).

Laboratory-based research in the applied sports sciences is conducted based on the assumption of ecological validity. Specifically, recommendations are made to the athletic population based upon laboratory findings (Jobson *et al.*, 2007). **Paper 4** (Cloak *et al.*, 2014b) was specifically interested in further examining some of the themes raised in **paper 3** (Cloak *et al.*, 2014a) and in other published studies around neuromuscular responses to acute WBVT and how professional/elite and amateur athletes respond. To increase the ecological validity of the study the stability test was a single leg landing task (Fauno and Jakobsen, 2006) and time allowed for intervention was 15 minutes (corresponding to a half-time scenario) (Towlson *et al.*, 2013, Russell *et al.*, 2015) were incorporated into the methodology. Also **paper 4** (Cloak *et al.*, 2014b) employed an active control group for comparison as one of the criticisms of acute WBVT research is the comparison of results to a passive control group (Nordlund and Thorstensson, 2007). A true control group in applied research suffers a conflict between internal and external validity (Page, 2012) . Internal validity requires rigorous control of variables; however, internal validity does not support real-world generalisability (external validity).  In some situations, a true control group is not possible or ethical; therefore, "quasi-experimental" designs are often used in applied research where the control group receives a standard treatment (Page, 2012). More recently, Rieder *et al*. (2015) highlighted only a handful of WBVT publications that indicate significant gains in lower limb muscle strength when protocols include an active control group performing the same exercises required from the group exposed to WBVT. This is vital when the acute WBVT takes place during isometric conditions such as an isometric squat where the isometric contraction alone may be the cause of any neuromuscular effect observed (Rixon *et al.*, 2007) and is a vital methodological consideration for all WBVT research.

The complexity of the stability tasks needed to be improved from those used in previous **papers 1** (Cloak *et al.*, 2010) **and 2** (Cloak *et al.*, 2013). Required was something which increased the ecological validity of the research and better replicated the stability demands of the sport, while sensitive enough to identify changes in balance following acute WBVT. Postural sway variables from a force platform have often been considered the "gold standard" for measuring dynamic balance and although no gold standard has been defined for dynamic balance, more sophisticated techniques, such as the DPSI (Wikstrom *et al.*, 2005)(Figure 9) has been identified as a highly valid and reliable technique for detecting postural changes in athletic populations (Bressel *et al.*, 2007). The Y balance test was also included in **paper 4** (Cloak *et al.*, 2014b), although not as sensitive as DPSI, practically, it requires minimal equipment and is considered clinically "friendly," particularly when conducted with other field tests and also provides valuable comparative data other practitioners can use (Bressel *et al.*, 2007). Another important consideration with the Y balance test is its ability to detect changes in flexibility. The anterior reach direction of the Y balance test has previously been suggested as requiring the greatest amount of dorsiflexion (Gribble *et al.*, 2009). The protocol used had an increase in overall WBVT training exposure (3x 60 sec) at the same loading of **paper 3** (Cloak *et al.*, 2014a)(40hz + 4mm), this was chosen as sufficient stimulus for acute settings as previously described (Issurin and Tenenbaum, 1999, Lovell *et al.*, 2013b, Padulo *et al.*, 2014, Ronnestad, 2009) and also to fit into a realistic time frame for a re-warm-up strategy (Russell *et al.*, 2015, Towlson *et al.*, 2013). Before acute WBVT all participants completed a basic warm-up on a cycle ergometer, another traditional means of maintaining muscle temperature during half-time (Mohr *et al.*, 2004, Lovell *et al.*, 2007), again to give a comparison to the active control group as opposed to a passive control.

**Figure 9:** Dynamic postural stability index (DPSI) procedure (Sell, 2012). Participants started 70 cm from the centre of the force plate and jumped over a hurdle placed at 50% of each participants maximal jump height with both legs before landing on the force plate on the dominant leg, stabilizing as quickly as possible, and maintaining this position for 3 seconds.

Results indicated that amongst professional players DPSI improved in comparison to amateur soccer players. These differences between professional and amateur player responses were in contrast to previous research that found acute WBVT had little effect on balance (Despina *et* *al.*, 2013). However, Despina *et al*. (2013) used a static single leg balance task, which as previously mentioned lacks sensitivity (Bressel *et al.*, 2007), as well as the fact the population examined had a highly developed balance skill set (elite gymnasts) so the balance task would not be a sufficient challenge for them (Aydin *et al.*, 2002). The findings of **paper 4** (Cloak *et al.*, 2014b), in comparison to previous research between professional/elite and amateur players (Ronnestad, 2009), also highlights some key differences in methodological issues when comparing acute WBVT studies. Landing is characterised by a very specialist set of motor programmes including pre-activation, eccentric contraction followed by concentric contraction (Komi, 1983). The motor output in the pre-activation phase just prior to touch-down in drop-jumps, as well as part of the muscular activation after touch-down (in the eccentric phase), is anticipatory (Zuur *et al.*, 2010). The muscular activation after touch-down is reactive to the permutations of the landing because spinal reflexes (short latency response, SLR) are elicited at touch-down and contribute to the motor output (Zuur *et al.*, 2010) and was previously reported in relation to contact times during RSI scores in **paper 3** (Cloak *et al.*, 2014a). Increases in the short-latency stretch reflex response of the stretch shortening cycle have been identified as a possible factor in the increase in power production post-vibration stimulus at higher vibration protocols >40Hz (Fernandes *et al.*, 2013). In particular an improvement in the short-latency stretch reflex would mean a significant reduction in contact time permutations, as this corresponds to the reflex after ground contact (Komi, 2000). Any such reductions in landing permutations could contribute to a reduction in DPSI amongst professional soccer players. The results of the study introduced new theoretical concepts about how different populations respond to acute WBVT as well as a rigorous methodology (DPSI) on how to accurately assess stability in future WBVT research using athletic populations.

The few studies that have reported improvements in balance using basic force platform data from landing tasks following acute WBVT amongst healthy amateur participants have used a lower vibration frequency (<30hz and 4mm) (Sanudo *et al.*, 2012, Despina *et al.*, 2013). This was in contrast to the higher stimulus (40hz and +4mm) used in **paper 4** (Cloak *et al.*, 2014b), which was chosen due to its popularity amongst the few studies using professional/elite athletes or highly trained male participants (Issurin and Tenenbaum, 1999, Ronnestad, 2009, Lovell *et al.*, 2013b, Padulo *et al.*, 2014). However, as previously reported there may be a trade-off between vibration intensity and proprioception (Bullock *et al.*, 2008) and previous research on locally applied vibration stimulus has reported disruption to proprioceptive function of foot and ankle (Pollock *et al.*, 2011, Weerakkody *et al.*, 2009). With previous research recognising differences between neuromuscular response to WBVT due to higher sensitivity to muscle receptors and increased CNS responses (Issurin and Tenenbaum, 1999) it is suggested by the present findings that higher WBVT intensities (>40hz 4mm) may be acceptable for professional/elite trained individuals and not amateur athletes. Although not significant, DPSI increased (got worse) following acute WBVT amongst amateur participants. This supports some of the suggestions in **paper 3** (Cloak *et al.*, 2014a) and the work of (Impellizzeri *et al.*, 2013) that the effective warm-up should not cause fatigue prior to performance, particularly when this could affect postural stability, something consistently linked with increase in injury risk (Wikstrom *et al.*, 2007). The paper therefore provides a cautionary note for practitioners to consider the training level of the population and the subsequent tasks they will be performing post-treatment when considering the use of acute WBVT at this intensity.

**Paper 5:** Cloak, R., Lane, A. and Wyon, M. (2016) Professional soccer player neuromuscular responses and perceptions to acute whole body vibration differ from amateur counterparts. *Journal of Sports Science and Medicine*, 15, pp.57-64

Methodologically the research had begun to investigate the acute effects of WBVT with a more sensitive set of measures. **Paper 4** (Cloak *et al.*, 2014b) had identified significant postural stability differences between professional and amateur soccer players as well as an increase in ROM. Although the main findings identify a significant difference between groups (amateur *vs.* professional), and provides coaches/sports scientists with some practical considerations as well as increasing the knowledge within the area, the neuromuscular differences that may have mediated these factors were beyond the scope of **paper 4** (Cloak *et al.*, 2014b)**.** Further research was recommended to investigate how training status (amateur *vs.* professional) effects neuromuscular responses to acute WBVT (Cloak *et al.*, 2014b).

The literature has hypothesised about various neuromuscular factors which occur due to WBVT such as increased excitability, recruitment and PAP (Cochrane, 2013, Bullock *et al.*, 2008, Cardinale and Lim, 2003, Da Silva-Grigoletto *et al.*, 2009, Lamont *et al.*, 2010, Ronnestad, 2009, Lovell *et al.*, 2013b) without specifically examining the direct neuromuscular effects on these variables, even those that have failed to compare effects on different populations (those most likely to use such an intervention) or considered timings and structure as part of a warm-up or half-time intervention (Cochrane *et al.*, 2010, Jordan *et al.*, 2010, McBride *et al.*, 2010, Rittweger *et al.*, 2003, Yeung *et al.*, 2014). MacIntosh et al. (2012) states that to firstly identify the role of PAP during a structured warm-up it must be clearly identified with muscle twitch potentiation measurements. Once the methodology acknowledges this and other factors are controlled such as an active control group, then the effect PAP has on performance outcomes can be accurately assessed post warm-up (MacIntosh *et al.*, 2012). The literature on acute WBVT had begun, as previously mentioned, to focus more on performance routines and half-time interventions (Cochrane, 2013, Lovell *et al.*, 2013b, Russell *et al.*, 2015), the thesis has added new knowledge in terms of looking at possible injury prevention mechanisms **paper 4** (Cloak *et al.*, 2014b). However, for a complete and effective acute warm-up/re-warm-up strategy Russell *et al*. (2015) suggested a PAP type activity is crucial before play in team sports or in the final stages of re-warming-up prior to the second half (Figure 8). Time efficient methods of warming-up in soccer and creating a PAP stimulus is an increasingly popular topic area for those preparing players for competition (Zois *et al.*, 2015).

Throughout the data collection of this body of work the perceptions athletes held for WBVT as a training method were noted in discussions with participants. The nature of the intervention means that participants in the control group would conduct the exercises on the platform in the absence of vibration. Depending on the participants' beliefs on WBVT this may have affected the participants' belief as to whether they were receiving a beneficial treatment or not. The theoretical contribution to the literature is that a significant difference appears between amateur and professional athletes, and Yeung *et al*. (2014) speculates that the groups may also perceive the effects of acute WBVT in very different ways, with highly trained participants responding to the sensations of acute training stimulus with subsequent improved effort in comparison to amateur participants who just feel tired after acute WBVT stimulus. Until **paper 5** (Cloak *et al.*, 2016) beliefs and perceptions of how/if the WBVT has impacted upon performance had not been assessed. Therefore, the perception/beliefs each of the groups had in the intervention itself and whether there is a significant difference between amateur and professional players was recorded. Beliefs in the likely effectiveness of an intervention or ergogenic aid have been found to have an incremental effect on performance (Beedie and Foad, 2009). Individuals who positively believed that an intervention will be effective appear to gain greater benefits than participants who do not. Results from Beedie and Foad (2009) suggests that a belief effect could shape the efficacy of an intervention. **Paper 3** (Cloak *et al.*, 2014a) discussed the importance of coach and player buy-in when prescribing an intervention and the work of Soligard *et al*. (2010) indicates compliance is crucial for any intervention to be successful was highlighted. Finch (2011) discusses the need for the effectiveness of injury prevention interventions to include information from stakeholders (participants) on how they perceive the effectiveness of the intervention, and not just physical outcome measures. A research design that includes a multidisciplinary design to evaluate the physical performance outcomes (*i.e.* Strength, PAP etc.) as well as the behaviour changes and perceptions of intervention (beliefs) are also highly recommended by Finch (2011). Assessing this difference in beliefs may provide new knowledge and also a possible theoretical framework for future acute intervention studies.

All the previous papers had assumed the participants perceived the benefits of WBVT alongside a positive neuromuscular response (Cloak *et al.*, 2013, Cloak *et al.*, 2014a, Cloak *et al.*, 2014b, Cloak *et al.*, 2010). **Paper 5** (Cloak *et al.*, 2016) examined these two phenomena on professional and amateur participants by incorporating a muscle twitch interpolation technique and a questionnaire on the participants' perceptions of the WBVT intervention. The twitch interpolation method would also allow confirmation of actual voluntary and involuntary neuromuscular responses (Jordan *et al.*, 2010). The introduction of a twitch interpolation tests was a highly sensitive test to look at neuromuscular responses, in particular those non-neurogenic in nature such as PAP (Jordan *et al.*, 2010). **Paper 3** (Cloak *et al.*, 2014a) **and 4** (Cloak *et al.*, 2014b) had discussed the fact that agility and single-leg landing have a large skill component that requires a very specialist set of efficient movement patterns and improvement in it has many other factors contributing to success (*i.e.* skill level, technique, learned behaviours etc.)(Cochrane *et al.*, 2004). This could be particularly influential in a group where skill levels represent a discrete difference between professional and amateur soccer players (Rebelo *et al.*, 2013). An interpolated twitch technique in the methodology allowed for the skill element to be removed, and a more sophisticated look at the neuromuscular responses (Cochrane *et al.*, 2010, Jordan *et al.*, 2010, Yeung *et al.*, 2014) as well as a quick performance outcome to be fed back to participants (knee extensor peak isometric force). The introduction of twitch interpolation methods was one of the most invasive used in all the projects and it took a period of time to establish this project. Establishing these projects with professional/elite athletes takes time and trust (Seiler and Kjerland, 2006) and was a key consideration when conducting the research.

Results indicated that acute WBVT significantly improved knee extensor force output amongst professional players in comparison to amateur players. In particular this appeared to be mediated by non-neurogenic means in terms of improvements in PAP as previously reported (Cochrane *et al.*, 2010, Jordan *et al.*, 2010). Interestingly, there were also significant differences in the perceptions of the benefits of acute WBVT, with professional athletes perceiving the intervention as beneficial to subsequent performance in comparison to amateur players. These findings provided a new body of knowledge to the literature in how amateur and professional soccer players respond to acute WBVT. A substantial body of work exists which has examined the effect of training status on responses to traditional PAP type conditioning exercises which has been proposed as a major factor in differences in potentiation effect between stronger and weaker athletes (Seitz *et al.*, 2014, Chiu *et al.*, 2003, Seitz and Haff, 2015). The evidence from the current findings suggests a similar theoretical model should be examined in how acute WBVT effects subsequent performance based upon the training level of the participants and rest periods prescribed. This initial exploration of the neuromuscular differences in response to acute WBVT provides a number of new themes that warrant further investigation such as muscular strength levels of the participants, rest periods and optimal dose response. These findings also provide support for McCall *et al*. (2015), that more intervention studies, specifically within professional/elite soccer, are required as making assumptions based on amateur participants' data may be misleading. The large body of work in WBVT using amateur participants which was one of the key drivers for investigating professional and amateur differences in **Paper 4** (Cloak *et al.*, 2014b) **and 5** (Cloak *et al.*, 2016) has highlighted a particular need for this in WBVT as well. Professional and amateur player differences have further reaching implications for practitioners if the results are mediated by the initial starting strength of the players. The addition of acute WBVT could be seen as an advanced training tool and not to be used on younger or less experienced players.

Overall **paper 5** (Cloak *et al*., 2016) provides some key new knowledge with regards to acute WBVT differences between professional and amateur soccer players and beliefs around the intervention. In particular, a larger body of knowledge on how professional/elite and amateur athletes respond to WBVT is required to understand its effectiveness and what may influence its efficacy (Cardinale and Erskine, 2008). It also raises some key theoretical points that warrant further investigation such as whether the effectiveness of the acute WBVT is mediated by the condition or strength levels of the participant to dissipate fatigue following acute WBVT conditioning exercise (Figure 10).

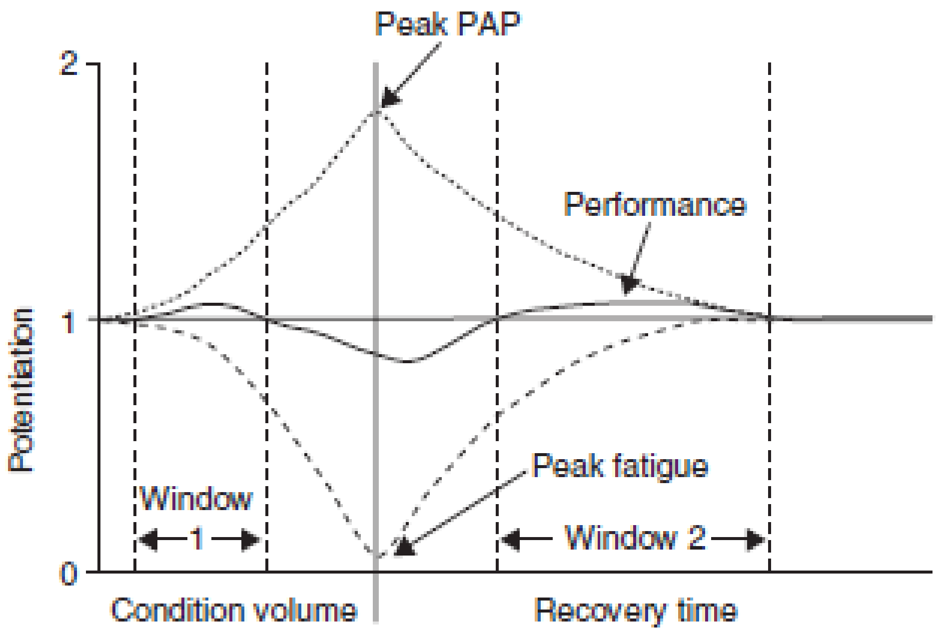


**Figure 10:** A hypothetical model presented by (Tillin and Bishop, 2009) of the relationship between PAP and fatigue following pre-conditioning exercise (window 1). Following the conditioning exercise fatigue dissipates at a faster rate than PAP, and a potentiation of subsequent explosive performance is realised during recovery (window 2).

As previously mentioned, this PAP benefit tends to be seen in muscularly stronger athletes who can deal with the conditioning stimulus and dissipate fatigue quicker to gain maximal PAP benefits (Chiu *et al.*, 2003, Seitz *et al.*, 2014, Seitz and Haff, 2015). This was previously seen with more traditional conditioning exercises (*i.e.* % of 1RM resistance exercise) however, the present results would suggest that this is also a contributing factor to the success of acute WBVT and needs to be considered before prescribing. Although this is the first paper to look at the effect of training level of neuromuscular responses in soccer some key hypotheses are also raised that require further enquiry. These include the time course of the PAP; this is particularly pertinent with regards team sports like soccer. Zois *et al.* (2015) indicated that a high intensity warm-up that included PAP inducing conditioning exercises can provide performance benefits to soccer players which can last for up to 30 minutes.

MacIntosh *et al*. (2012) would question the theoretical model (Figure 8) (Russell *et al.*, 2015) on PAP forming part of a warm-up protocol due to its limited duration in long duration events (*i.e.* match play). The duration and practical performance implications on soccer performance on the key determinants of performance (*i.e.* speed, agility, distance covered, repeated sprint ability, and jump ability) requires further analysis.

A greater battery of strength diagnostic information is also required. Isometric contraction is a good indicator of muscle potential (Keogh *et al.*, 1999) and in particular isometric contraction provides a high amount of muscle activation of the quadriceps muscle groups during twitch interpolation technique (Babault *et al.*, 2001). However, this type of diagnostic testing is difficult and expensive; more field based tests of strength and power (*i.e.* 1RM, CMJ or RSI) would provide an easier guide for coaches to use when prescribing WBVT, and more importantly, deciding who will gain the greatest benefit. Amongst active amateur populations a load of < 20Hz and 2mm amplitude is considered sufficient to produce positive neuromuscular effects (Lienhard *et al.*, 2015b), higher loads, such as the ones used in the current paper (40Hz and 4mm) should maybe only be considered for professional athletes who have the physical characteristics to deal with such a load. More research examining optimal loading on WBVT is needed across a range of frequencies and amplitudes is required (Lienhard *et al.*, 2015b). Lienhard *et al*. (2015a) argues that higher WBVT loads benefit highly active individuals due to stiffer muscle-tendon units. However, a cautionary note is required in that these same muscle-tendon units may also put highly trained individuals at a higher risk of vibration induced injury. It is important not to just keep increasing load with the view that neuromuscular performance will improve in a linear fashion.

The beliefs surrounding the perceived benefits of acute WBVT requires further exploration of which the exact mechanism as to how professional and amateur players rationalise acute WBVT differently. As previously mentioned the belief the participant has in the intervention, particularly an acute intervention prior to performance, has implications for success and adherence. One possible reason is that WBVT with high frequencies and amplitudes produces higher ratings of perceived exertion (RPE), as there appears to be a correlation between frequency and RPE (Marin *et al.*, 2015, Bertucci *et al.*, 2015). The acute WBVT as a preconditioning exercise does produce fatigue as our PAP results would suggest and as presented in Figure 10. The differences in how the professional and amateur athletes perceive this fatigue could explain the differences in belief in the intervention, as physical fitness in soccer players appears to influence session RPE (Milanez *et al.*, 2011, Rabelo *et al.*, 2016). Amateur players may have perceived the WBVT as much harder than professional athletes and therefore not seen it as beneficial. Whichever, the reasoning behind the differences in beliefs surrounding acute WBVT requires further investigation: what is clear is there is a difference. In professional soccer where the biggest barriers to warm-ups and half time re-warm-ups are players having their own set routines (which they do not want to disrupt) and a unwillingness from coaching staff to incorporate new methods (Towlson *et al.*, 2013), additional information on player beliefs concerning the intervention may offer particular scope for influencing some of these factors and remains to be addressed.

**Chapter Two - Thesis Conclusions and Directions for Future Studies**

With regards the use of WBVT the thesis presented has examined some of the key questions around its effectiveness and presented a new body of evidence on its efficacy in chronic and acute settings as well as introducing new theoretical concepts which may suggest its benefits to an athlete or team.

In conclusion:

- A simple progressive overload of WBVT improves balance of FAI amongst injured dancers **(Paper1)**.
- The addition of WBVT to a traditional progressive rehabilitation protocol provides a significant benefit to soccer players suffering FAI in comparison to traditional rehabilitation methods alone **(Paper 2)**.
- Acute WBVT as an addition to a well-established warm-up routine in soccer (FIFA 11+) improves aspects of RSI but not agility in amateur soccer players **(Paper 3)**.
- Professional soccer players show significant improvements in DPSI following cycling combined with acute WBVT in comparison to amateur players. Both groups show an improvement in flexibility **(Paper 4)**.
- Professional soccer players show significant improvements in knee extensor force output and PAP in comparison to amateur players when acute WBVT is combined with cycling. Professional players also perceive the intervention as beneficial compared to amateur players **(Paper 5)**.

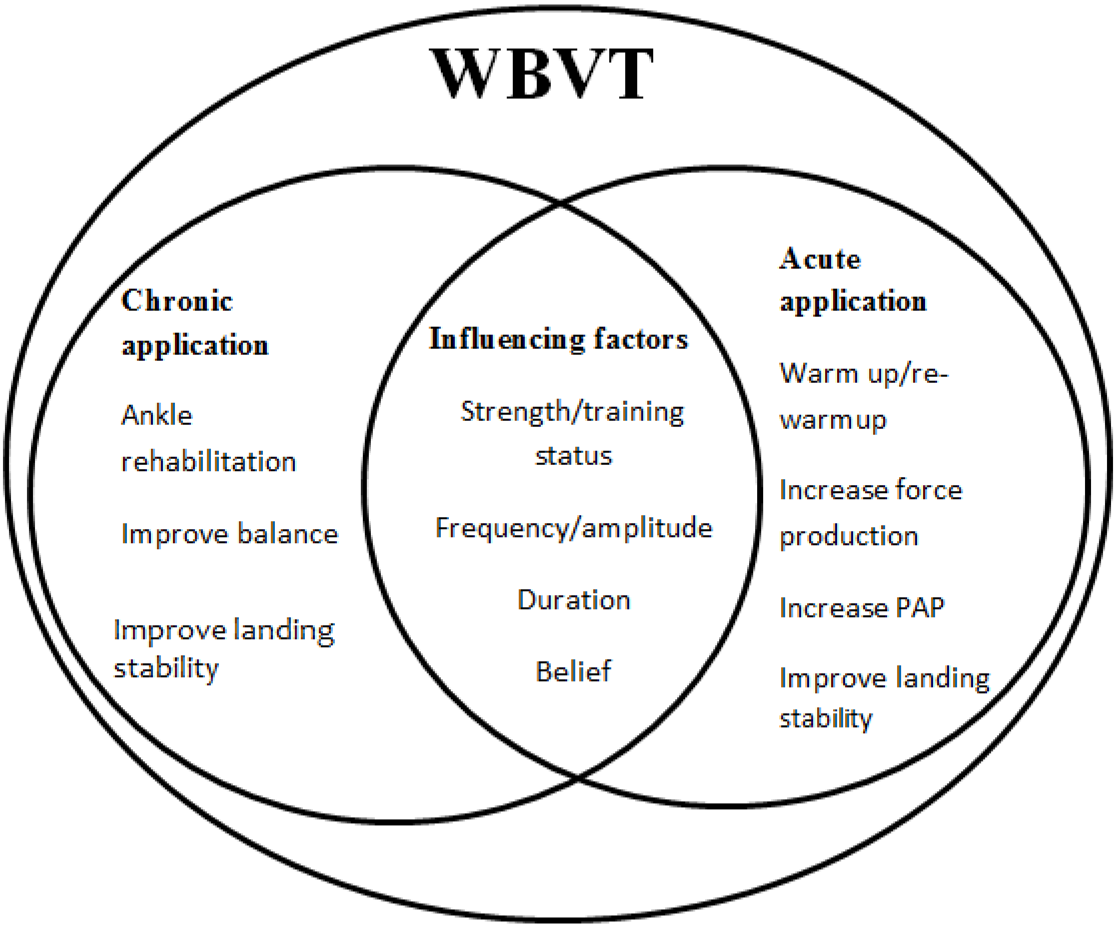


**Figure 11:** Paradigm of the benefits of acute and chronic WBVT and the factors which may influence its effectiveness.

The thesis has identified a number of areas for future research and factors which may influence WBVT effectiveness (Figure 11). The chronic application of WBVT presented in **papers 1** (Cloak *et al.*, 2010) **and 2** (Cloak *et al.*, 2013) have shown balance and strength improvements amongst athletic populations suffering FAI. Future studies employing large cohorts of participants and evaluating longitudinal injury epidemiology data post WBVT are required, to understand the long term impact WBVT has at reducing injury incidence in comparison to other methods. The results show particular scope for other clinical populations who also suffer with a loss in balance and muscle function which could increase injury risk or those suffering long term conditions such as Cerebral Palsy or Multiple Sclerosis. It is important to also consider adherence and practicality of such interventions to truly evaluate their feasibility as a rehabilitation tool.

The acute application of WBVT shows particular capacity to positively influence warm-ups or re-warm-ups in team sports. However, **papers 3** (Cloak *et al.*, 2014a)**, 4** (Cloak *et al.*, 2014b) **and 5** (Cloak *et al.*, 2016) have identified a number of possible mediating factors that require further investigation such as optimal intensity and duration of WBVT, the efficacy of the intervention to actual match performance and the training status of the participant. Future studies should also consider using more sophisticated in vivo techniques to examine changes muscle and tendon function. These should include transcranial magnetic stimulation (TMS) to assess afferent and cortical signals post WBVT and electromyography during WBVT with the appropriate filtering of mechanical noise would also provide superior information on how participants respond to WBVT. Individual differences and optimal intensities and durations for each user will exist as with any training intervention. Information from the above suggestions could help to individualise WBVT to fully maximise the benefits. Finally, the difference in beliefs between populations requires further investigation and is a model that could be used across other interdisciplinary projects investigating acute performance enhancement interventions.

**APPENDIX**

Appendix 1

Paper 1: Cloak, R., Day, S., Nevill, A., and Wyon, M. (2010) Vibration training improves balance in unstable ankles. *International Journal of Sports Medicine*, 31, pp. 894-900.

# Vibration Training Improves Balance in Unstable Ankles

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Key words
- ankle
- vibration
- balance
- injury

## Abstract

Functional ankle instability (FAI) is a common condition following ankle injury characterised by increased risk of injury. Ankle sprains are a common acute form of injury suffered in dancing and loss of balance can affect not only risk of injury risk but also performance aesthetics. Whole body vibration training (WBVT) is a new rehabilitation method that has been linked with improving balance and muscle function. 38 female dancers with self reported unilateral FAI were randomly assigned in 2 groups; WBVT and Control. Absolute centre of mass (COM) distribution during single leg stance, SEBT normalised research distances and Peroneus longus mean power frequency ($f_{med}$) where measured pre and post 6-week intervention. There was a significant improvement in COM distribution over the 6 weeks from 1.05±0.57 to 0.33±0.42 cm2 ($P<0.05$), and 4 of the 8 planes of direction in the SEBT Ant, Antlat, Med and Antmed from 77.5±7.1 to 84.1±5.8% ($P<0.05$) compared to control groups during the course of the 6 week training intervention. There was no evidence of improvement in peroneus longus ($f_{med}$) over time ($P=0.915$) in either group. WBVT improved static balance and SEBT scores amongst dancers exhibiting ankle instability but did not affect peroneus longus muscle fatigue.

## Introduction

Recent research has found the ankle to be the second most commonly injured body site in sport, with ankle sprain being the most common type of ankle injury particularly prevalent among dance populations due to the nature of the activity [15,38]. Dance requires its participants to frequently jump and land on 1 leg, as well as performance of specific aesthetic movement patterns of the foot, all of which presents a higher risk for ankle sprains [54]. A functional instability in the ankle may persist after initial injury leading to an increased risk of recurrent ankle injury and subsequent time loss and distress to the athlete [4,23,30,44,45].

Functional ankle instability (FAI) is a condition characterised by repetitive episodes of "giving way" and/or incidence of recurrent ankle sprains [58]. While the cause of FAI remains unclear, it has been suggested that both passive structures such as ligaments, articular surface of the ankle and neurological structures are damaged at the time of an ankle sprain contributing to recurrent instability [40]. These neurological impairments include postural control [2,29,46,48–50], dynamic balance [13,21,24,34,39,63] and muscle fatigue [1,17,19,31,36,40,42,52,59]. Therefore exercises that increase static/dynamic balance and fatigue resistance should be routinely performed following ankle injury to allow a safe return to sporting activity. This is particularly prevalent among female ballet dancers due to the time they spend *en pointe* (balancing on the tips of their toes in specially made shoes) and can have an impact on performance and career progression [38].

Whole body vibration training (WBVT) is a training method which has been recently introduced as a rehabilitative tool among clinicians [5,11,35,37,43,55,57]. It has been hypothesised that the transmission of mechanical oscillations from the vibrating platform may lead to physiological changes in muscle spindles, joint mechanoreceptors, higher brain activity and strength and power properties [37]. WBVT has also been reported as improving balance scores within certain populations. Recent research conducted by Rees et al. [43] identified that 8 weeks of WBVT significantly improved single leg static balance. Other clinical

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research has concurred that WBVT improves balance capabilities [6]. However it should be noted that these studies have all been conducted within elderly populations and thus comparison with younger sporting populations is difficult. Moezy et al. [37] identified that WBVT training significantly improved balance and joint position sense in anterior cruciate ligament reconstruction patients allowing them to return to full activity as well as giving them an increased satisfaction with the rehabilitation process. Although there is support for the use of WBVT as a rehabilitation method, other studies have reported equivocal improvement in balance with vibration training within young healthy populations [55,56]. However it should be noted the researchers identified improvements in lower limb strength and power performance which were acknowledged as important components of lower limb function and injury prevention [55]. Other investigators have also identified the need for more than one dependent variable to be investigated when examining ankle injury, with a combination of static and dynamic measures as well as muscle function [46].

Consequently, there is little scientific evidence with regard to the effects of WBVT as a rehabilitation tool for those suffering FAI symptoms. Accordingly the aim of this study is to investigate the effect of 6 weeks progressive WBVT on static and dynamic balance as well as muscle fatigue of the peroneus longus within dancers reporting FAI.

## Methods

▼

### Participants

38 female dancers (age 19±1.1 years, height 163.6±7.3 cm, weight 60.3±6.3 kg) from a university dance department volunteered to take part in the study. The inclusion criteria for participation in this study were self reported unilateral chronic ankle instability, including a history of more than 1 lateral ankle sprain within the past 2 years and recurrent feeling of "giving way". The study gained ethical approval [22] from the School of Sport, Performing Arts and Leisure, University of Wolverhampton Ethics Committee. Subjects completed a Cumberland Ankle Instability Tool questionnaire (CAIT) to determine their inclusion. The tool is a questionnaire with 9 scale questions that generates a score between 0 and 30 and has high reliability and discriminative validity [27]. Scores of ≤23 indicate functional ankle instability. Exclusion criteria for all patients included an ankle injury during the previous 6 weeks, any balance or vestibular disorder, any history of lower limb breaks or fractures, previous ankle, knee or hip surgery and/or current head injury. All participants gave informed consent and the study was approved by the local ethics committee. According to the results of the CAIT (◉ Table 1), 19 subjects were assigned to the vibration training group and 19 were assigned to the control group. 32 reported functional instability in their right ankle and 6 in the left.

### Testing Procedures

#### Single leg balance test

Participants were asked to remain as motionless as possible whilst standing on their test leg, on the RSscan® pressure mat (RSscan, Ipswich) as the inability to maintain quite stance during single leg standing has consistently been associated with ankle instability [2,46]. Participants performed all tests with their eyes open, hands on hips, and their non-weight bearing leg flexed at the knee (◉ Fig. 1). All subjects performed the test bare foot to eliminate the effect of shoe type [33]. Participants performed one 10 s practice trial, followed by two 30 s testing trials. Subjects rested 20 s between trials as suggested in previous research [46]. Trials were repeated if participants lost balance, hopped or touched down on the non-weight bearing leg. The centre of pressure (COP) area was recorded which represented the maximum anterior, posterior, medial, and lateral sway during the given time [46]. The average of both trials was recorded. Increased values in the mean radius of the COP suggest decreased postural control, whereas a decreased value suggests increased postural stability [32].

#### Star excursion balance test (SEBT)

The Star Excursion Balance Test (SEBT) has been shown to have a strong intra-test and inter-tester reliability [25,28]. The participants performed the SEBT while standing barefoot on their unstable ankle in a grid laid on the floor with 8 lines extending at 45 degree increments from the centre of the grid (◉ Fig. 2). As in previous studies, the length and width of the foot was measured and meticulously placed so that the geometric centre of the foot was aligned to the centre of the 8 line star [24]. Participants maintained a single leg stance while reaching with their non-weight bearing leg as far as possible along a chosen line, with the aim of touching the furthest point with the most distal part of the foot. A mark was made by the investigator at the point of touchdown of the reaching leg. Reach distances were measured from the centre of the grid and divided by leg length and multiplied by 100 to calculate reach distance as a percentage of leg length (%MAXD) normalising data [18]. Leg length was measured, with the participant lying supine, as the distance from the anterior superior iliac spine to the centre of the ipsilateral medial malleolus using a anthropometric tape measure [18]. If at any point the participant used their reaching leg for substantial support, removed their foot from the centre of the grid or lost balance during the trial, the trial was discarded and repeated. The order of reaching directions was randomized by the investigator and repeated in this order for the post treatment trials. The average of 3 trials was taken.

#### Mean power frequency ($f_{med}$) of the peroneus longus

It has also been shown that muscle fatigue can significantly impair postural control [9,17,19]. Thus it is likely that improvements in muscle strength and endurance through training would improve stability. Generally, fatigue is considered a failure to maintain a required or expected force output. It is well accepted that the inability to maintain this force is associated with changes in muscle electrical activity [62]. Because of this, electromyography (EMG) is commonly used to assess fatigue [42]. As a muscle fatigues, changes in EMG frequency characteristics (e.g., median power frequency) can be used to quantify the rate at which fatigue occurs [12]. Whereas EMG amplitude increases during

| Group | N | Age (yr) | Mass (kg) | Height (cm) | Limb Dominance | CAIT Score |
|---|---|---|---|---|---|---|
| vibration | 19 | 19±0.8 | 60.3±5.7 | 164.5+8.7 | R 19 L0 | 18.4±1.3 |
| control | 19 | 19±1.3 | 60.2±6.9 | 162.6±5.5 | R 13 L6 | 18±1.5 |

**Table 1** Subjects' characteristics (mean+SD) and right (R) and left (L) limb dominance.

**Fig. 1** Single leg static balance on RSscan® pressure mat.

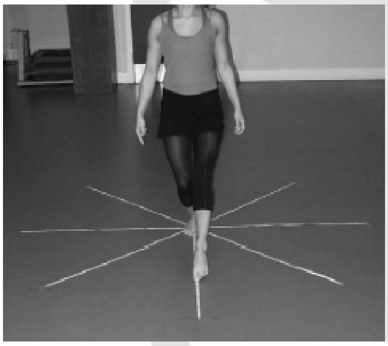

**Fig. 2** SEBT anterior view, illustrating anterior reach direction.

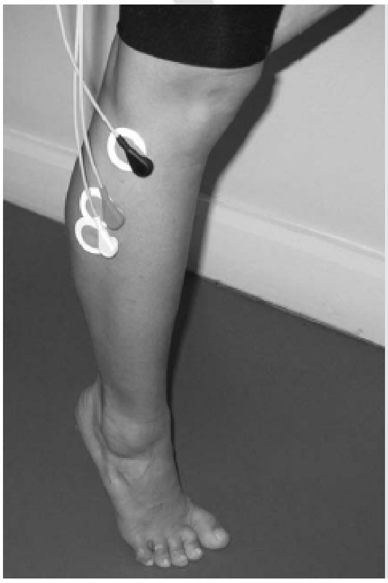

**Fig. 3** EMG recording of peroneus longus during demi-pointe.

fatigue, the median power frequency actually decreases, reflecting decreases in muscle-fibre conduction velocity [12].
Before testing, each participant's shin area was shaved (if necessary), debrided, and cleaned with isopropyl alcohol for placement of the EMG electrodes using 1 cm diameter circular Ag/AgCl electrodes. The electrodes were placed distal to the caput fibulae, one-quarter of the distance between the caput fibulae and the lateral malleolus along the line connecting these anatomical landmarks. Electrodes were placed longitudinally along this line with a 2 cm inter-electrode distance and a reference electrode was placed on the head of the fibula [20]. Proper positioning of the electrodes over the corresponding muscle bellies was verified by inspection during maximal voluntary contractions in an upright standing position (◉ **Fig. 3**). Surface EMG measurements were collected using a commercial data acquisition system (Powerlab, AD instruments, UK). Signals were amplified and fed into a personal computer after analogue-to-digital conversion. The EMG signals were band-pass filtered at 10 and 500 Hz and sampled at 2000 Hz using data acquisition Software (Chart v 5.1, AD Instruments, UK).
Although ankle muscular activity has been widely studied in individuals with FAI [10,16,40,51,60], those studies have been performed in extremely controlled conditions and few focused on actual conditions, present in dance, as proposed in this study [53]. *Demi-pointe* is a ballet position in which the subject stands on the toes, that is, with the weight of the body resting on the metatarsals [26]. Subjects were allowed to use a barre to stabilise themselves during the *demi-pointe* stance for 30 s as it was deemed too difficult by participants to maintain balance for 30 s unsupported, as reported in previous research [26], and as the aim of the testing was to examine the mean power frequency of the peroneus longus during the task and not the balance of the participant. The same examiner was used during all testing to access correct height for *demi-pointe* and support for the *demi-pointe* was restricted to a single finger on ballet barre. For the current investigation, the mean power frequency of the first 5-s interval, which we considered the non-fatigued, or baseline was normalised. Thus, the data for the final 25–30 s interval was calculated relative to the first 5-s interval as a percentage drop in mean power frequency and used for statistical analysis [42].

## Intervention

### Whole Body Vibration Training

All participants in the treatment group followed a structured 6 week progressive vibration programme consisting of single leg exercises increasing in duration and vibration frequency as the training progressed. At the beginning of 6 weeks, participants were randomly assigned in 2 groups (WBVT and Control groups). The WBVT group did exercises on vibration platform (Bosco, Greece) while bare foot. ◉ **Table 2** shows the details of the WBVT program. The participants in the Control group refrained from any ankle specific strength/balance training during the 6-week period and continued their normal training regime.

## Statistical analysis

The dependent variables were the normalised reach distance expressed as a percentage of subject's leg length, mean power frequency ($f_{med}$) and centre of mass distribution (COM). All data were analysed using a 2-way ANOVA with repeated measures, with one between-subjects factor (Treatment group; WBVT vs. Control) and one within-subjects factor (Time; Pre- vs. Post-training). An alternative method of analysis (ANOCOVA) was

**Table 2** 6 week WBVT training plan.

| | Day 1 | Day 2 |
|---|---|---|
| week 1 | single leg heel raises 50 s x 3 each leg @ 30 Hz | single leg heel raises 50 s x 3 each leg @ 30 Hz |
| | single leg squats 50 s x 3 each leg @ 30 Hz | single leg squats 50 s x 3 each leg @ 30 Hz |
| WBV duration (min) | 10 min | 10 min |
| week 2 | single leg heel raises 50 s x 3 each leg @ 30 Hz | single leg heel raises 50 s x 3 each leg @ 30 Hz |
| | single leg squats 50 s x 3 each leg @ 30 Hz | single leg squats 50 s x 3 each leg @ 30 Hz |
| WBV duration (min) | 10 min | 10 min |
| week 3 | single leg heel raises 60 s x 3 each leg @ 35 Hz | single leg heel raises 60 s x 3 each leg @ 35 Hz |
| | single leg squats 60 s x 3 each leg @ 35 Hz | single leg squats 60 s x 3 each leg @ 35 Hz |
| WBV duration (min) | 12 min | 12 min |
| week 4 | single leg heel raises 60 s x 3 each leg @ 35 Hz | single leg heel raises 60 s x 3 each leg @ 35 Hz |
| | single leg squats 60 s x 3 each leg @ 35 Hz | single leg squats 60 s x 3 each leg @ 35 Hz |
| WBV duration (min) | 12 min | 12 min |
| week 5 | single leg heel raises 70 s x 3 each leg @ 40 Hz | single leg heel raises 70 s x 3 each leg @ 40 Hz |
| | single leg squats 70 s x 3 each leg @ 40 Hz | single leg squats 70 s x 3 each leg @ 40 Hz |
| WBV duration (min) | 14 min | 14 min |
| week 6 | single leg heel raises 70 s x 3 each leg @ 40 Hz | single leg heel raises 70 s x 3 each leg @ 40 Hz |
| | single leg squats 70 s x 3 each leg @ 40 Hz | single leg squats 70 s x 3 each leg @ 40 Hz |
| WBV duration (min) | 14 min | 14 min |

**Table 3** Means and standard deviations of normalized reach distances (reach distance is cm/leg length in cm). All testing was conducted on a previously identified unstable ankle.

| | Vibration (n19) | | Control (n19) | | |
|---|---|---|---|---|---|
| | Pre Intervention (%MAXD) | Post Intervention (%MAXD) | Pre Intervention (%MAXD) | Post Intervention (%MAXD) | Group Min Effect (P-value) |
| ANT* | 75.5±7.1 | 80.2±7.2 | 74.7±6 | 74.9±6.1 | 0.036* |
| AM* | 81±5.5 | 85±9.2 | 79. 1±6 | 78.1±7.7 | 0.038* |
| MD* | 84.8±8 | 92±12.5 | 82.4±6.6 | 83.7±7.8 | 0.047* |
| PM | 88.9±9.3 | 97±13.5 | 84.9±9 | 87.5±10.3 | 0.23 |
| PO | 87.6±10 | 93.9±14.2 | 86.3±11.3 | 89.9±12.2 | 0.58 |
| PL | 85.4±10.8 | 93.8±11.6 | 82.6±14.4 | 86.2±13.4 | 0.23 |
| LAT | 78.9±11.6 | 91.1±12.3 | 74.4±15.6 | 80.4±15.7 | 0.19 |
| AL* | 68.5±9.4 | 79.4±8.5 | 70.5±8.9 | 74.7±9.7 | 0.015* |

Abbreviations: AL, anterolateral; AM, anteromedial; ANT, anterior; LAT; lateral; MD, medial; PL, posterolateral; PM, posteromedial; PO, posterior. (* indicates significance $P<0.05$)

performed using post-intervention data as the dependent variable and pre-intervention values as the covariates to confirm/reinforce the findings of the repeated measures ANOVAs [61]. Data was analysed using SPSS for Windows, Version 16.0 (SPSS Inc, IL). An alpha level of $P<0.05$ was determined to be significant for all statistical comparisons.

## Results

### Star excursion balance test results

There were significant improvements in anterior ($P=0.036$), anterior medial ($P=0.038$), medial ($P=0.047$) and anterior lateral ($P=0.015$) amongst the WBVT group in comparison to the control group (◎ **Table 3**) as identified by a significant group-by-time interaction. There were no significant differences/interactions between groups in the planes of posterior medial ($P=0.23$), posterior ($P=0.58$), posterior lateral ($P=0.23$) and lateral ($P=0.19$). These findings were confirmed using ANCOVA with significant main effects for the WBVT group compared with the control group for the anterior, anterior medial, medial and anterior lateral variables (all $P<0.05$). No significant differences were found between groups in the posterior medial, posterior, posterior lateral and lateral (all $P>0.05$).

### Mean power frequency ($f_{med}$) and centre of pressure distribution results

There was no significant difference in percentage decrease in MPF between groups over the 30 s period that the participants were on *demi-pointe* ($P=0.915$). Though a significant difference in COP between the WBVT and control group ($P=0.04$) was noted (◎ **Table 4**).

## Discussion

As far as we are aware, this is the first randomised control trial investigating the effect of WBVT on balance and muscle function in dancers suffering FAI. For this investigation we hypothesised that peroneus longus fatigue would be reduced and static and SEBT excursion balance would improve after 6 weeks of progressive WBVT in comparison to those in the control group. The results of this study suggest that while static and dynamic balance significantly improved over certain planes of motion in those undertaking WBVT, muscle fatigue did not significantly differ between groups.

WBVT has been used by a limited number of researchers as a method of rehabilitation [5, 11, 35, 37, 43, 55, 57]. However little has been done amongst young active participants suffering FAI. As with previous research [43] single leg static balance improved

**Table 4** Means and standard deviation of percentage decrease in MPF (MPF Dif %) calculated from 0–5 s MPF and 25–30 s MPF during the course of 30 s on *demi-pointe*. The values are shown as percentages of Hertz difference in values during 0–5 s and 25–30 s in MPF over the course of the 30 s and Centre of Pressure distribution (COP) shown as cm2.

| Vibration (n19) | | Control (n19) | | |
|---|---|---|---|---|
| **Pre** | **Post** | **Pre** | **Post** | **Significance*** |
| **MPF Dif %** | **MPF Dif %** | **MPF Dif %** | **MPF Dif %** | **group main effect (P-value)** |
| 6.2 ± 3.6 | 6.6 ± 3.6 | 7.1 ± 3.9 | 7.3 ± 2.3 | 0.915 |
| **COP distribution (cm2)** | **COP distribution (cm2)** | **COP distribution (cm2)** | **COP distribution (cm2)** | **group main effect (P-value)** |
| 1.05 ± 0.57 | 0.33 ± 0.42 | 1.01 ± 0.44 | 0.82 ± 0.46 | 0.04* |

* Indicates significance $P < 0.05$)

with the implementation of WBVT, however this improvement was demonstrated over a 6 week training period, twice a week, whereas previous research had gone for a longer > 8 week period with > 3 sessions a week. This supports Arnold et al.'s [2] suggestion that more research is needed in both sedentary and athletic populations to identify optimum rehabilitation duration for improving and monitoring static balance.

Interestingly, the initial centre of mass distribution score were less than those identified in previous research within FAI populations [2]. Explanations for this could be the relatively high CAIT scores reported by participants indicating that the severity of instability was less than those in previous research [50] or a more likely reason could be in line with Aydin et al. [3], who identified female gymnasts as having a greater joint position sense and kinaesthetic awareness due to the activity they compete in being largely focused on balance and correct form. Dance also has similar components to competitive gymnastics and may warrant, as a population, further investigation to identify differences in general university populations used in previous FAI research.

Dance requires both static and dynamic balance as key components to successful performance [38] therefore the improved SEBT score of those in the WBVT group compared to the control group may be of greater significance to clinicians looking at successful rehabilitation methods than static balance tests alone. Although it should be noted that there was only an improvement over 4 planes of motion (anterior, anterior medial, medial and anterior lateral) and there is debate on the significance of these planes of motion in identifying stability improvements in those suffering balance deficits [14, 41].

The Star Excursion Balance test consists of complex closed kinetic chain motions of the stance leg. The subject has to flex his/her hip, knee, and dorsiflex the foot while balancing on the sprained ankle. Concentric and eccentric muscle contractions, proprioception, as well as postural control are simultaneously involved [7]. With this in mind, STAR excursion training itself may have caused an improvement in scores as reported previously by Chaiwanichsiri [7]. However this is unlikely in this study considering the relatively low number of repetitions but may explain some of the improvements seen among the control groups and warrant further investigation of the test as a training intervention alone. As we did not assess ankle dorsiflexion flexibility it is impossible to say whether an increase in flexibility due to WBVT improved SEBT scores. However vibration training has been reported as improving flexibility [8] and may require future investigation.

Peroneus longus ($f_{med}$) was not affected in either the WBVT group or the control group. South and George [52] reported fatigue of the peroneus muscles did not affect ankle join position sense, suggesting that either proprioception is fatigue resistant in the peroneus muscles or other structures in the ankle (e.g. ligaments, capsule) may play a significant proprioceptive role. Powers et al. [42] also found that 6 weeks strength and proprioception training had no effect on peroneus fatigue in those suffering FAI. The present research agrees with Powers et al. [42], that one reason for this may be the training stimulus of 6 weeks WBVT may not have been sufficient enough to instigate appropriate changes in peroneus longus activity, or the task itself on *demi-pointe* was not tasking enough to establish appropriate levels of fatigue. However, it is felt that further research is required to identify appropriate dance specific fatiguing exercises. As noted by previous research, dance movements such as *demi-pointe* are perceived by the investigators as being too difficult to maintain for significant periods without failure which is not necessarily due to fatigue [26].

It was also difficult in this study to objectively format the rehabilitation protocol due to the lack of evidence based research for young FAI populations and WBVT. Therefore we chose to adapt previous models of balance training and vibration [6, 47]. However these were often based around fall prevention populations and often limited to sit and stand performance [47], something that has little relevance to athletic performance. Therefore one of the greatest difficulties that were encountered in developing the training protocol was the lack of objective evidence to support the use of WBVT in FAI populations.

When interpreting the results of the current study one has to remember that the WBVT group participants also did dynamic exercise movements during vibration exposure (single leg squats and heel raises), and thus, one could suspect that the improvements may be attributed to these exercises [55]. However, it remains unlikely that these exercises alone were behind the improvement in static and dynamic balance without some contribution from the vibration component. Further research is required to assess the effectiveness of WBVT against classical methods of rehabilitation amongst functionally unstable populations.

In conclusion it appears that WBVT improves single leg balance and SEBT performance in dancers with unilateral FAI. The positive effect of WBVT, its short time of training and adherence rate in the present study supports the need for future research on this type of training as new method of ankle injury prevention in dance populations. Further research is needed to compare WBVT to classical methods of rehabilitation.

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Appendix 2

Paper 2: Cloak, R., Day, S., Nevill, A., and Wyon, M. (2013) Six-week combined vibration and wobble board training improves balance in soccer players with functional ankle instability. *Clinical Journal of Sports Medicine*, 23 (5), pp. 384-391.

# Six-Week Combined Vibration and Wobble Board Training on Balance and Stability in Footballers With Functional Ankle Instability

*Ross Cloak, MPhil,* Matthew Wyon, PhD,† Alan Nevill, PhD,‡ and Stephen Day, PhD§*

**Objective:** To compare the effectiveness of a combination of vibration and wobble board training against wobble board training alone in footballers suffering from functional ankle instability (FAI).

**Design:** A 2 × 3 prefactorial–postfactorial design.

**Setting:** University research laboratory.

**Participants:** Thirty-three male semiprofessional footballers with self-reported unilateral FAI were randomly assigned in 3 groups: vibration and wobble board (mean age 22.2 years), wobble board (mean age 22.7 years), and control (mean age 23.1 years).

**Interventions:** Participants in each intervention group performed a 6-week progressive rehabilitation program using a wobble board, either with or without the addition of vibration stimulus.

**Main Outcome Measures:** Absolute center of mass (COM) distribution during single-leg stance, modified star excursion balance test (SEBT) reach distances, and single-leg triple hop for distance (SLTHD) were measured before and after 6-week intervention.

**Results:** Combined vibration and wobble board training resulted in reduced COM distribution [$P \leq 0.001$, effect size (ES) = 0.66], increased SEBT reach distances ($P \leq 0.01$ and $P \leq 0.002$, ES = 0.19 and 0.29, respectively), and increased SLTHD ($P \leq 0.001$, ES = 0.33) compared with wobble board training alone during the course of the 6-week training intervention.

**Conclusions:** Combined vibration and wobble board training improves COM distribution, modified SEBT scores and SLTHD among footballers suffering FAI, compared with wobble board training alone.

**Key Words:** vibration, functional instability, balance, injury

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## INTRODUCTION

Ankle inversion sprain is a common injury in both sportsmen and physically active individuals, with recurrence rates for this type of injury being reported to be as high as 80%.[1] Football is a complex contact sport associated with high levels of injury risk.[2] Of these, ankle injuries are commonly reported accounting for between 11% and 18% of all injuries, the majority of which are sprains.[3]

The most common complication after ankle sprain is functional instability,[4] which is a condition characterized by repetitive episodes of "giving way" and/or incidence of recurrent ankle sprain.[5] Functional ankle instability (FAI) can be considered as a multifactorial condition involving neurological, muscular, and sensorimotor factors, all contributing to a deficit in balance and muscle function.[6] These impairments have been shown to include postural control,[7] dynamic balance,[8] and muscle function.[9] Arnason et al[10] identified that previously sprained ankles in footballers had as much as a 5-fold increase in injury risk in comparison with their uninjured counterparts, indicating not only significant instability after ankle sprain but also the necessity for a more effective rehabilitation program.

Rehabilitation using wobble board techniques has been popular among clinicians for a number of years,[11] particularly among football populations.[12] Although research suggests an improvement in symptoms of ankle instability with the intervention of wobble board training,[13] others contradict this claim indicating no significant improvement in balance or muscle function.[14,15] A meta-analysis by Van der Wees et al[16] indicated that rehabilitation programs based on wobble board proprioceptive exercises could be considered clinically effective in ankle rehabilitation. This assumption, however, has been challenged on the basis that wobble board training alone does not actually target ankle proprioception deficits.[17] Kiers et al[17] proposed that training on unstable surface was alone not sufficient to stimulate ankle proprioceptors but did highlight the sensitivity of ankle muscle spindles to vibration stimulus and suggest that muscle spindles are key to ankle proprioception and overall body orientation. These results suggest that clinicians need to consider more effective exercises in ankle rehabilitation and warrant further investigation into the inclusion of vibration stimulus.

Whole-body vibration training (WBVT) is a method that has been recently introduced as a rehabilitative tool among clinicians.[18–20] It has been hypothesized that the transmission of mechanical oscillations from the vibrating platform may lead to physiological changes in muscle spindles, joint mechanoreceptors, higher brain activity, and hence strength and power properties.[18] The proposed physiological reasons behind these changes have been attributed to stimulation of primary afferent (Ia, IIa) endings of the muscle spindles as identified with the reflex muscle contraction known as tonic vibration reflex.[21] A reduction in motor unit recruitment thresholds and altered motor neuron excitability have also been suggested as mechanisms for the above physiological improvements.[22] Whole-body vibration training has typically taken place on a stable platform; recently, however, a vibration system has been incorporated into a wobble board (Vibrosphere; ProMedvi, Sweden), which claims to incorporate the benefits of traditional vibration therapy with the added advantage of increased postural demand. This method of training has been shown to be successful in improving certain balance parameters in elderly populations.[19] There was, however, no direct comparison with wobble board exercise alone, therefore the true contribution of the vibration component is difficult to ascertain.

The purpose of the present research therefore was to examine the effect of 6-week combined vibration and wobble board training (Vibrosphere; ProMedvi) against wobble board training alone on absolute center of mass (COM) distribution during single-leg stance, modified star excursion balance test (SEBT), and single-leg triple hop for distance (SLTHD) in footballers suffering from FAI. We hypothesize an improvement in balance with use of a combination of vibration and wobble board training based on previous literature,[19] although it is unclear whether this will be of greater effect than wobble board training alone.

## METHODS

### Participants

Thirty-three male amateur football players volunteered to take part in the study (Table 1). The inclusion criteria for participation in this study were self-reported unilateral chronic ankle instability, including a history of more than 1 lateral ankle sprain within the past 2 years, and recurrent feeling of "giving way." Participants were eligible for the study if their Cumberland ankle instability tool score (CAIT) was greater than 23. The tool is a questionnaire with 9 adjectival scale questions that generates a score between 0 and 30 and has high reliability and discriminative validity.[23] Scores ≤23 indicate FAI. Exclusion criteria for all participants included an ankle injury during the previous 6 weeks, any balance or vestibular disorder, any history of lower limb breaks or fractures, previous ankle, knee, or hip surgery, and/or current head injury. Participants also presented negative results in the anterior drawer test, which assesses the integrity of the anterior talofibular ligament and of talar tilt test that assess the calcaneofibular ligament integrity.[24]

All participants gave written informed consent, and the study was approved by the local ethics committee. According to the results of the CAIT (Table 1), participants were randomly assigned (using the closed envelope technique) to the vibration and wobble board training group (Vibrosphere; ProMedvi), wobble board training alone, or the control group. The latter were asked to continue normal activity.

### Data Collection

#### Centre of Mass Distribution

Participants were asked to remain as motionless as possible while standing on their test leg, on the RSscan pressure mat (RSscan, Ipswich, United Kingdom) as the inability to maintain quiet stance during single-leg standing has been associated with ankle instability.[25] The use of a pressure mat to assess changes in COM distribution had been previously suggested as a valid and reliable assessment tool.[26] Participants performed all tests with their eyes open, hands on hips, and their non–weight-bearing leg flexed at 90-degree angle at the knee. All participants performed the test barefoot to eliminate the effect of the shoe type.[27] Participants performed one 10-second practice trial, followed by three 30-second testing trials. Participants rested 20 seconds between trials as suggested in previous research.[7] Trials were repeated if the participants lost balance, hopped, or touched down on the non–weight-bearing leg. The investigators recorded the number of retrials, and no statistical significance was shown between groups. Center of mass distribution represented the maximum distance of sway area (in square centimeters) of the participants COM during the given time.[7] The average of 3 trials was recorded.

### Modified Star Excursion Balance Test

The SEBT has been shown to have a strong intratester and intertester reliability.[28] Performance of all 8 reach directions, however, was seen as unnecessary when evaluating deficits related to FAI because of considerable redundancy among the reach directions reported.[8] Therefore, the participants performed the anterior, posterior medial, and posterior lateral SEBT directions that have been shown to be the most effective in assessing dynamic balance in participants with FAI.[8,29] Each subject performed 3 practice trials in each of the 3 directions on identified leg followed by 5 minutes of rest before recording began. Participants then performed 3 trials in each direction. Ten seconds of rest were provided between individual reach trials.[30]

TABLE 1. Participant Characteristics

| Group | N | Age, yr Mean (SD) | Mass, kg Mean (SD) | Height, cm Mean (SD) | Affected Limb | | CAIT Score |
|---|---|---|---|---|---|---|---|
| | | | | | Right | Left | |
| Vibration and wobble board | 11 | 22.2 (0.7) | 78.3 (7.7) | 174.5 (7.8) | 6 | 5 | 18.1 (0.9) |
| Wobble board | 11 | 22.7 (1.2) | 73.9 (4.7) | 171.2 (5.4) | 7 | 4 | 17.4 (1.4) |
| Control | 11 | 23.1 (1.1) | 77.5 (7.0) | 176.5 (9.0) | 7 | 4 | 17.9 (1.3) |

The participants performed the SEBT while standing barefoot on their unstable ankle in a grid laid on the floor with 3 lines extending at 45-degree increments from the center of the grid. Reach distances were measured from the center of the grid, divided by leg length, and multiplied by 100 to calculate reach distance as a percentage of leg length (% MAXD) to normalize data.[31]

## Single-Leg Triple Hop for Distance

Triple hop for distance is a valid clinical tool for assessing strength and power characteristics in healthy athletes, while tasking balance components.[32] A standard cloth tape measure was fixed to the ground, perpendicular to a starting line. Participants stood on the designated testing leg, with the great toe on the starting line. They performed 3 consecutive maximal hops forward on the affected limb (arm swing was allowed). The investigator measured the distance hopped from the starting line to the point where the heel struck the ground upon completing the third hop.[33]

All participants were allowed 1 to 3 practice trials (self-selected). A test trial was repeated if the participant was unable to complete a triple hop without losing balance and contacting the ground with the opposite leg. Number of practice trials and failed trails were recorded by the investigators, and no statistical relationship was highlighted, either in relation to performance or differences between groups. The maximum distance achieved during the 3 trials was recorded in centimeters and used for analysis. All participants wore low-cut athletic footwear during the test.[32]

## Combined Vibration and Wobble Board Training

The training methodology was based on the recommendation by Ergen and Ulkar[12] for rehabilitation training in football players suffering from functional deficits after ankle injury. Both training groups exercised twice a week for 6 weeks. Each training session was supervised by one of the members of the research team. Table 2 indicates the training undertaken over the 6-week duration. To ensure comparability between VibroSphere and wobble board training groups, the Vibrosphere (ProMedvi) was used by both the training groups. The researchers took this view to maintain validity when comparing both groups, so any differences could not be associated with using a different wobble board or training protocol. The function pads, which are designed to reduce stability and increase difficulty while on the Vibrosphere (ProMedvi), were also used for both groups (Figure 1). Hertz and time progression was used to provide progressive overload as with previous research advocating these frequencies.[34] Rittweger[35] identified time under tension, or in the case of vibration training time under exposure, as key to progressive overload as well are frequency. Task difficulty of each exercise was manipulated as recommended by Ergen and Ulkar.[12] These recommendations included a progressive increase in task difficulty and volume of exercises by manipulating exposure time, external resistance (with the addition of an external load), and finally a sport-specific component in the final weeks of the intervention.

## Data Analysis

The 3 dependent variables were the COM distribution, SLTHD, and SEBT, the latter of which was normalized as a percentage of subject's leg length (including anterior, posterior medial, and posterior lateral distances). All data were analyzed using a 2-way analysis of variance (ANOVA) with repeated measures, with one between-subject factor [treatment group (3 levels); combined wobble board and vibration vs wobble board vs control] and one within-subjects factor (time; pretraining vs posttraining). Bonferroni post hoc tests and pairwise multiple comparisons were used to determine which change values (difference between pretraining and posttraining) differed between the treatment groups. These change values were analyzed using a 1-way ANOVA, with change values as the dependent variable and the 3 treatment groups as the grouping factor in the ANOVA. An alpha level of $P < 0.05$ was determined to be significant for all statistical comparisons.

# RESULTS

## Center of Mass Distribution and Single-Leg Triple Hop for Distance Results

There was a significant difference in COM distribution because of the main effect "time" [$F(1, 30) = 57.99$, $P = 0.001$] with a large effect size (ES) (partial eta squared = 0.66). Overall differences in COM distribution because of the main effect "treatment group" were not significant [$F(2, 30) = 2.57$, $P = 0.094$]. However, a significant group-by-time interaction was observed [$F(2, 30) = 6.74$, $P = 0.004$], indicating that the changes in COM distribution from preintervention to postintervention varied significantly between the 3 groups. This interaction effect is illustrated in Figure 2, which includes standard error bars. Post hoc comparisons using Bonferroni test indicated that the changes in COM distribution preintervention to postintervention of the control group differed significantly from the combined vibration and wobble board group ($P < 0.001$) (Table 2). There was a significant difference in SLTHD because of the main effect "time" [$F(1, 30) = 15.02$, $P = 0.001$] with a medium ES (partial eta squared = 0.33).

Overall differences in SLTHD because of the main effect "treatment group" were not significant [$F(2, 30) = 1.13$, $P = 0.336$]. However, a significant group-by-time interaction was observed [$F(2, 30) = 10.52$, $P = 0.001$], indicating that the changes in SLTHD from preintervention to postintervention varied significantly between the 3 groups. This interaction effect is illustrated in Figure 3, which includes SE bars. Post hoc comparisons using Bonferroni test indicated that the changes in SLTHD preintervention to postintervention of the control group differed significantly from the combined vibration and wobble board group ($P < 0.001$) (Table 3).

## Modified Star Excursion Balance Test Results

There was a significant difference in SEBT anterior and posterior lateral reach distances (%MAXD) distribution because of the main effect "time" [$F(1, 30) = 6.97$, $P = 0.01$ and $F(1, 30) = 11.99$, $P = 0.002$] with a small ES (partial eta squared = 0.19 and 0.29, respectively). Overall differences in SEBT anterior and posterior lateral reach distances (%MAXD)

TABLE 2. Six-Week Training Program for VibroSphere and Wobble Group

| Exercise | Difficulty | Function Pad | Time | Hertz |
|---|---|---|---|---|
| Week 1 | | | | |
| Standing on one leg | Static hands on hips | Dark blue-soft 2-intermediate | 2 × 45 each leg | 30 |
| Heel raises on one leg | Isometric with support | Dark blue-soft 2-intermediate | 2 × 45 each leg | 30 |
| Single-leg step ups | Hands on hips | Dark blue-soft 2-intermediate | 2 × 45 each leg | 30 |
| Single-leg straight leg dead lifts | Hands on hips | Dark blue-soft 2-intermediate | 2 × 45 each leg | 30 |
| Week 2 | | | | |
| Standing on one leg | Static hands on hips | Dark blue-soft 2-intermediate | 2 × 45 each leg | 30 |
| Heel raises on one leg | Isometric with support | Dark blue-soft 2-intermediate | 2 × 45 each leg | 30 |
| Single-leg step ups | Hands on hips | Dark blue-soft 2-intermediate | 2 × 45 each leg | 30 |
| Single-leg straight leg dead lifts | Hands on hips | Dark blue-soft 2-intermediate | 2 × 45 each leg | 30 |
| Week 3 | | | | |
| Standing on one leg | 3-kg medicine ball above head | Red-soft 3-difficult | 2 × 60 each leg | 35 |
| Heel raises on one leg | Isometric with support | Red-soft 3-difficult | 2 × 60 each leg | 35 |
| Single-leg step ups | 3-kg medicine ball above head | Red-soft 3-difficult | 2 × 60 each leg | 35 |
| Single-leg straight leg dead lifts | 3-kg medicine ball in hands | Red-soft 3-difficult | 2 × 60 each leg | 35 |
| Week 4 | | | | |
| Standing on one leg | 3-kg medicine ball above head | Red-soft 3-difficult | 2 × 60 each leg | 35 |
| Heel raises on one leg | Isometric with support | Red-soft 3-difficult | 2 × 60 each leg | 35 |
| Single-leg step ups | 3-kg medicine ball above head | Red-soft 3-difficult | 2 × 60 each leg | 35 |
| Single-leg straight leg dead lifts | 3-kg medicine ball in hands | Red-soft 3-difficult | 2 × 60 each leg | 35 |
| Week 5 | | | | |
| Standing on one leg | Volley ball back to partner | Blue-challenging fitness pad | 2 × 75 each leg | 40 |
| Heel raises on one leg | Isometric with support | Blue-challenging fitness pad | 2 × 75 each leg | 40 |
| Single-leg step ups | 3-kg medicine ball above head | Blue-challenging fitness pad | 2 × 75 each leg | 40 |
| Single-leg straight leg dead lifts | 3-kg medicine ball in hands | Blue-challenging fitness pad | 2 × 75 each leg | 40 |
| Week 6 | | | | |
| Standing on one leg | Volley ball back to partner | Blue-challenging fitness pad | 2 × 75 each leg | 40 |
| Heel raises on one leg | Isometric with support | Blue-challenging fitness pad | 2 × 75 each leg | 40 |
| Single-leg step ups | 3-kg medicine ball above head | Blue-challenging fitness pad | 2 × 75 each leg | 40 |
| Single-leg straight leg dead lifts | 3-kg medicine ball in hands | Blue-challenging fitness pad | 2 × 75 each leg | 40 |

Wobble board group completed exercises in the absence of vibration.

because of the main effect "treatment group" were not significant [$F(2, 30) = 0.62$, $P = 0.545$ and $F(2,30) = 4.937$, $P = 0.140$]. However, a significant group-by-time interaction was observed for SEBT anterior reach distance [$F(2, 30) = 8.05$, $P = 0.002$] and SEBT posterior lateral reach distance [$F(2,30) = 5.78$, $P = 0.008$], indicating that the changes in SEBT anterior and posterior lateral reach distances from preintervention to postintervention varied significantly between the 3 groups. This interaction effect is illustrated in Figures 4 and 5, which include SE bars. Post hoc comparisons using Bonferroni test

FIGURE 1. Vibrosphere (ProMedvi) training device and function pads.

indicated that the changes in SEBT anterior and posterior lateral reach distances preintervention to postintervention of the control group differed significantly from the combined vibration and wobble group ($P < 0.001$) (Table 4). There was no significant group-by-time interaction reported between treatment groups for posterior medial reach distance (Table 4).

## DISCUSSION

When interpreting the results of the present study, it should be remembered that both Vibrosphere (ProMedvi) and wobble board groups did identical exercises on identical apparatus with the addition of vibration in the former. With this in mind, the results suggest that the addition of vibration provided extra benefit in SLTHD, COM distribution, and SEBT anterior/posterior scores. Vibration training has previously been suggested as a rehabilitation method among researchers; however, none of these studies have looked at the treatment of FAI within athletic populations, concentrating more on fall prevention strategies among the elderly and ACL reconstruction patients.[18–20,36,37] The use of a combination of a vibration device built into a wobble board has been

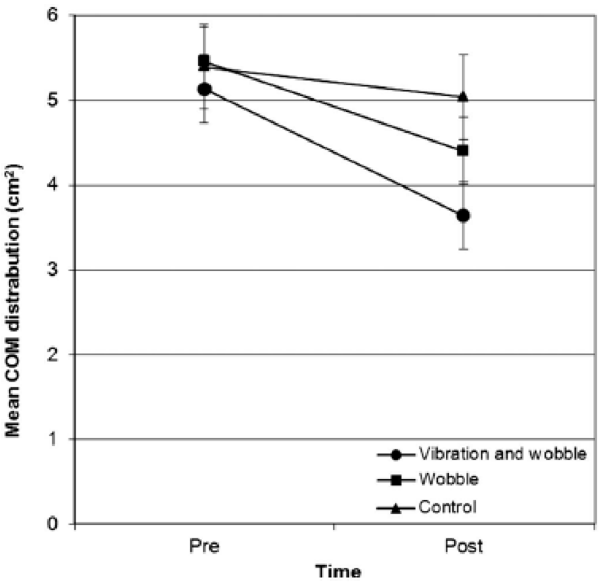


FIGURE 2. Center of mass distributions between treatment groups over time.

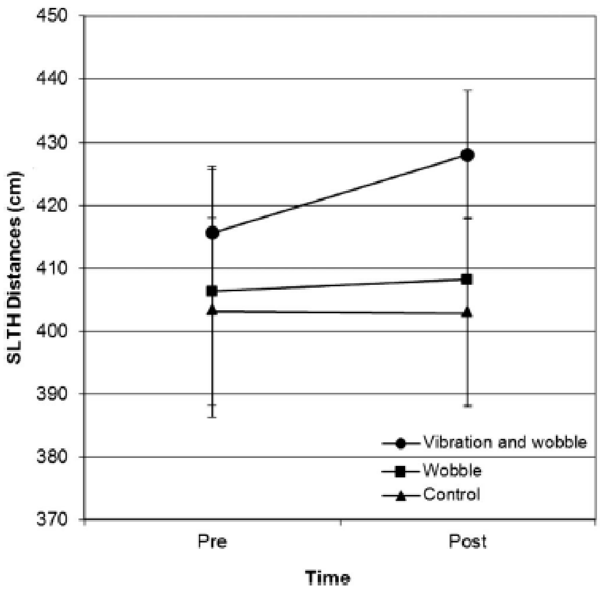


FIGURE 3. Single-leg triple hop for distance between groups over time.

TABLE 3. Center of Mass Distribution and SLTHD Results

| Treatment Group | Treatment Group | Mean Difference | Significance | 95% Confidence Interval | |
|---|---|---|---|---|---|
| | | | | Lower | Upper |
| Pairwise comparisons COM distribution (cm²) | | | | | |
| 1. Control | 2. Vibration and wobble | −1.14 | 0.001* | −1.93 | −0.35 |
| | 3. Wobble | −0.70 | 0.09 | −1.49 | 0.09 |
| Pairwise comparisons SLTH distance (cm) | | | | | |
| 1. Control | 2. Vibration and wobble | −12.73 | 0.001* | −20.25 | −5.20 |
| | 3. Wobble | −2.18 | 1.00 | −9.71 | 5.35 |

Bonferroni post hoc test was performed, and the results were compared with the control group.
*Significance $P < 0.05$.

investigated previously.[19] Trans et al[19] used an 8-week training cycle on a Vibrosphere (ProMedvi) to assess strength and proprioception in elderly females suffering knee osteoarthritis. An improvement was shown for proprioception; however, no significant strength gains were reported. Although comparisons are difficult because of the participant pool, the reasoning behind differing effects in terms of strength increases may be due to the exercise routines being static knee flexion holds and the participants being a sedentary elderly population.[19] Both the current research and the study by Trans et al,[19] however, do conclude that the training device improves balance and strength indices over a relatively short period and number of sessions.

The COM distribution and SEBT improvements may also be associated with the benefits of vibration training. It has been well documented that the input of proprioceptive pathways (Ia, IIa, and IIb) are used in the production of isometric forceful contractions.[38] During WBVT, it has been reported that these pathways are strongly stimulated.[39] The vibratory stimulus activates the sensory receptors that result in muscle contraction. The increase in SLTHD after 6 weeks of training, and thus after extensive sensory stimulation, might be as a result of a more efficient use of the positive proprioceptive feedback loop in the generation of intramuscular force production and isometric control.[39] The present study suggests that the combination of wobble board and vibration training may target not only the local muscles, such as tibialis anterior, peroneus longus, and gastrocnemius, but also possibly the core muscle groups leading to improved movement efficiency and coping with the demands of the balance tasks.[40] This could explain the improvement seen in COM distribution and SEBT. This theory has also been supported by previous research, which indicates that improvements in SEBT may be achieved through increased abdominal activation,[41] highlighting the importance of rehabilitation within unstable ankle populations concentrating on a whole kinetic chain exercises, not just the

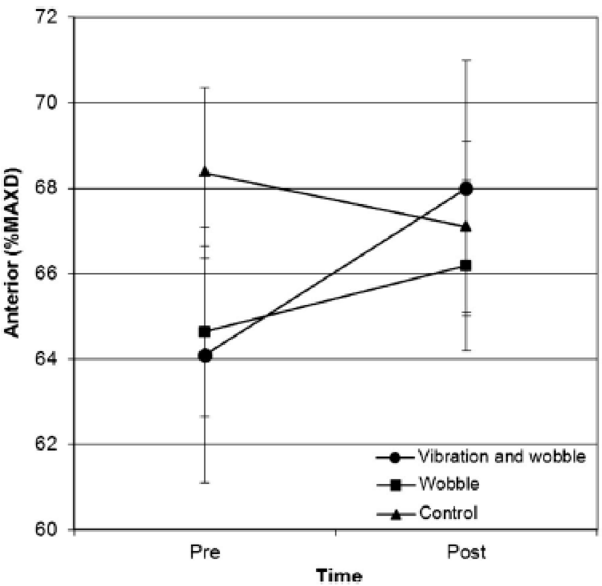


FIGURE 4. Star excursion balance test anterior %MAXD reach distance between groups over time.

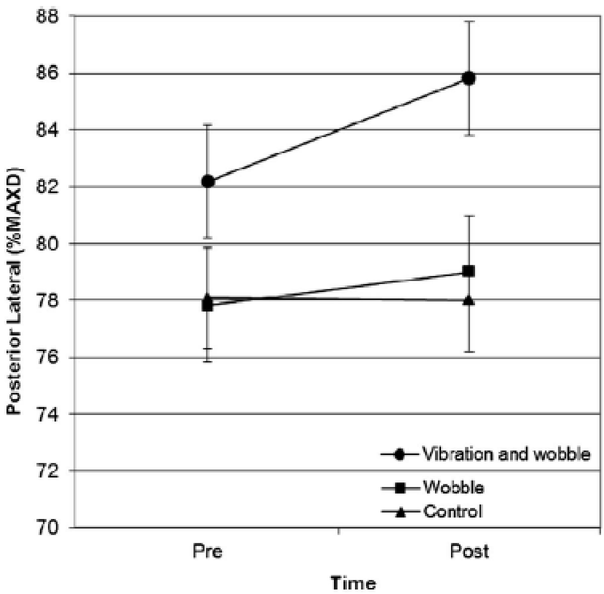


FIGURE 5. Star excursion balance test posterior lateral % MAXD reach distance between groups over time.

TABLE 4. Modified SEBT Mean and SD of Normalized Reach Distances

| Treatment Group | Treatment Group | Mean Difference | Significance | 95% Confidence Interval | |
|---|---|---|---|---|---|
| | | | | Lower | Upper |
| Pairwise comparisons of anterior reach distance | | | | | |
| 1. Control | 2. Vibration and Wobble | 5.18 | 0.001* | 1.90 | 8.46 |
| | 3. Wobble | 2.81 | 0.11 | −0.46 | 6.10 |
| Pairwise comparisons of posterior medial reach distance | | | | | |
| 1. Control | 2. Vibration and Wobble | 1.55 | 0.26 | −0.69 | 3.78 |
| | 3. Wobble | 0.73 | 1.00 | −1.51 | 2.96 |
| Pairwise comparisons of posterior lateral reach distance | | | | | |
| 1. Control | 2. Vibration and Wobble | 3.73 | 0.001* | −0.69 | 3.78 |
| | 3. Wobble | 1.27 | 0.78 | −1.51 | 2.96 |

Reach distance is centimeter per leg length in centimeters.
Bonferroni post hoc test was performed, and the results were compared with the control group.
*Indicates significance $P < 0.05$.

peripheral site of the injury,[42] such as balance/vibration stimulation, mediated by a progressive set of exercises used in the present research. The current research, however, acknowledges that any such assumptions from the present results would need confirmation through future research using electromyography and motion analysis.

Vibration training has been well documented as a training method for improving neuromuscular properties of skeletal muscle, such as strength and power indices.[39,43–45] Such structural changes are not only mediated by acute intramuscular factors by increasing muscle size and structure through hypertrophy.[46] But given the duration of the present study, the more likely reason behind the improvement in muscle function was neural adaptation to primary afferent (Ia, IIa) endings of the muscle spindles,[21] a reduction in motor unit recruitment thresholds, and altered motor neuron excitability,[22] thus allowing for a more co-ordinated and forceful activation during different permutations of movement.[47] This knowledge of vibration training and neuromuscular adaptation may help us to understand the above findings among the Vibrosphere (ProMedvi) training group, particularly among the SLTHD; however, as with previous studies,[47] the absence of EMG profiling or muscle biopsies means any such conclusion are difficult. However, on the basis of the evidence set forth above, it could be assumed that such adaptations have occurred.

The current research acknowledges that the present variables are not sole predicators of injury, and future longitudinal studies are needed to assess how long these positive results continue and whether this information correlates with reinjury risk. This is particularly important for footballers as by assessing if the intervention itself has reduced injury occurrence, we can begin to reduce one of the main contributory factors to injury risk in football, that of a previous or recurrent history of ankle injury.[10] The researchers also acknowledge that in the current cost–benefit ratio environment, many clinicians face with any new equipment. The relatively small ES (partial eta squared = 0.19 and 0.29) among the SEBT anterior and posterior scores highlights the need for further research. It is recommended this future research is completed using the Vibrosphere (ProMedvi) in a multi-intervention setting, before the clinical significance of the device can be fully ascertained.

## CONCLUSIONS

Six weeks of progressive wobble board and vibration training significantly improved COM distribution, SEBT, and SLTHD in comparison with wobble board training alone. Combined wobble board and vibration training would seem to be beneficial in football players suffering FAI.

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Appendix 3

Paper 3: Cloak, R., A. Nevill, J. Smith and M. Wyon. (2014) The acute effects of vibration stimulus following FIFA 11+ on agility and reactive strength in collegiate soccer players. *Journal of Sport and Health Science*, 3(4), pp. 293-298

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# The acute effects of vibration stimulus following FIFA 11+ on agility and reactive strength in collegiate soccer players

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**Abstract**

*Purpose*: The aim of this study was to assess the effects of combining the FIFA 11+ and acute vibration training on reactive strength index (RSI) and 505 agility.

*Methods*: Seventy-four male collegiate soccer players took part in the study and were randomly assigned to FIFA 11+ with acute vibration group (FIFA + WBV), FIFA 11+ with isometric squat group (FIFA + IS) or a control group consisting of the FIFA 11+ alone (Con). The warm-up consisted of the FIFA 11+ and was administered to all participants. The participants in the acute vibration group were exposed to 30 s whole body vibration in squat position immediately post warm-up. The isometric group completed an isometric squat for 30 s immediately post warm-up.

*Results*: RSI significantly improved pre- to post- intervention amongst FIFA + WBV ($p < 0.001$) due to a decrease in contact time ($p < 0.001$) in comparison to FIFA + IS and Con, but 505 agility was not affected.

*Conclusion*: The results of this study suggest the inclusion of an acute bout of WBV post FIFA 11+ warm-up produces a neuromuscular response leading to an improvement in RSI. Future research is required to examine the exact mechanisms behind these improvements amongst other populations and over time course of the performance.


*Keywords:* Agility; FIFA 11+; Reactive strength; Soccer; Vibration

## 1. Introduction

Soccer is one of the most popular sports worldwide; it is a contact sport and challenges physical fitness by requiring a variety of skills at different intensities. Running is the predominant activity, and explosive efforts during sprints, duels, jumps, and changes of direction are important performance factors, requiring maximal strength and anaerobic power of the neuromuscular system.[1−4] The physiological and technical demands of the sport lead coaches and clinicians to continually look for the best methods of preparation for the athletes to perform at their optimum.

The completion of an active warm-up before training or physical competition has typically been shown to have a positive impact on athletic performance with improvement in power, speed, and agility.[5−7] Contemporary research has identified the importance of a dynamic warm-up on improving reactive strength and jumping ability in soccer.[7] An effective warm-up, however, should not just be seen as essential to performance but also as a mechanism to reduce incidence of injury amongst players. Compliance with specific dynamic warm-up protocols, such as the FIFA 11+, have been shown to decrease injury risk amongst youth soccer players.[8] However, the FIFA 11+ warm-up, although well established as a means of reducing injuries, has been reported as not having an effect on performance outcomes in soccer players.[1,9,10] Vescovi and

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VanHeest[11] suggested that developing warm-up protocols with not only injury prevention benefits but also performance benefits, would make it easier to convince coaches to implement such programmes. Some researchers have discussed additions to the FIFA 11+ warm-up protocol to help realise performance enhancements.[10] Impellizzeri et al.,[10] however, pointed out that any such additions to the FIFA 11+ need to consider fatigue (worsening of performance) and time efficiency to the soccer player. Although the FIFA 11+ has been traditionally investigated over a longer period of time, Zois et al.[12] has encouraged researchers to challenge traditional warm-up routines in soccer and how they subsequently effect acute physical qualities of the players.

Soligard et al.[8] raised some important issues when it comes to successful warm-up programme to improve performance and reduce injury risk; what is crucial is compliance from the athlete and the coach. Time constraints are seen as a perceived barrier for many coaches to the implementation of a specific warm-up protocol and the perceived increase in workload.[8] As such whole body vibration (WBV) exercise is an acute application that can easily be administered and has been previously identified as an ideal dressing-room based intervention in soccer. It has also been identified as a possible counter to any cool down period between pitch based warm-up and performance, or as a useful addition during tactical discussions.[13]

Recent investigation has identified acute WBV as a viable method of improving speed in soccer.[14,15] Turner et al.[16] found that an exposure of 30 s at 40 Hz was sufficient to elicit a positive change in explosive power amongst recreationally trained males. Their findings are particularly attractive to coaches and players due to the short time frame required to elicit a positive response. In particular the acute effects of WBV training have become a popular area of research amongst strength and conditioning coaches and sports scientists due to its time efficiency and other potential benefits.[17–20] McBride et al.[20] asked participants to complete six acute sets of bilateral/unilateral squats at a frequency of 30 Hz (3.5 mm amplitude) and identified an increase in peak force of the triceps surae during maximal voluntary contractions. Bullock et al.[19] reported the addition of 3 × 60 s WBV at a frequency of 30 Hz post warm-up amongst elite skeleton athletes as being beneficial to subsequent sprint and maximal jump performances.

The above research highlights the possible contribution of post activation potentiation (PAP) as a possible mechanism for the improvements in performance and highlighted its possible benefits as a pre- competition routine.[20] PAP is a proposed condition where pre-exercise muscle stimulation leads to an increase in motor neuron excitability and/or increased phosphorylation of myosin light chains.[21–24] It also has been reported as being elicited by WBV.[25] More recently this has been questioned, particularly when looking at acute vibration studies. Increases in the short-latency stretch reflex response of the stretch shortening cycle have been identified as a possible factor in the increase in power production post vibration stimulus at higher vibration stimulus >40 Hz.[24] The benefit of this to soccer would be that the initial PAP following WBV would help prepare the player for the intense engagement and that high tempo play associated with the first 15 min of the match;[26] this in turn is also identified as a period of the game with a high injury occurrence.[26] Towlson et al.[27] reported pressuring opponents, establishing match tempo and asserting superiority as key priorities in this period. When implementing a warm-up or half-time warm-up in professional soccer these are the main factors considered by practitioners for the first 15 min of each half.[27]

The positive impact of a well-structured dynamic warm-up (FIFA 11+) on reducing injury risk has been reported. The effect this protocol has had on subsequent performance has, however, been questioned, with some researchers recommending additions to the programme to improve performance gains.[10] The present study aims to identify if vibration stimulus added any extra performance benefit to a dynamic warm-up or was a standard dynamic warm-up protocol sufficient to elicit a positive acute response in performance in collegiate soccer players. The study examines whether adding acute WBV or isometric exercise to the FIFA 11+ has an effect on reactive strength index or 505 agility performance.

## 2. Methods

### 2.1. Participants

Seventy-four male collegiate amateur soccer players volunteered for the study (20.0 ± 1.2 years, 74.1 ± 14.8 kg, and 174.5 ± 7.9 cm). All participants completed a Physical Activity Readiness Questionnaire (PARQ) and informed consent form prior to the commencement, and any participant that reported a lower limb injury in the previous 3 months was excluded from the study. Institutional ethical approval (University of Wolverhampton, UK) was granted prior to recruiting volunteers. All participants partook in 2–3 training sessions per week plus one match. All participants were familiar with tests as they were routinely used for both training and to monitor fitness.

### 2.2. Reactive strength and 505 agility

Participants were randomly assigned to three groups, FIFA 11+ WBV (FIFA + WBV), FIFA 11+ isometric squat (FIFA + IS), and Control (Con) using a sealed envelope method. The tests consisted of a reactive strength index measure (RSI), which includes measurement of jump height and contact time, which have previously demonstrated excellent reliability.[28] And a 505 agility test which has also reported good validity and reliability when assessing change of direction speed.[29,30] The RSI involved the participant performing a maximal counter movement jump following a drop jump from a 30 cm plyometric box. Drop jump height (DJH) and contact time (CT) were recorded using the Opto-jump system (Microgate, Bolzano, Italy) which is considered a valid and reliable alternative to a force platform when assessing jumps.[31] RSI was calculated by dividing the height jumped by the contact time prior to take-off.[32] For the 505 agility test timing gates were placed 5 m from designated turning point.

The participants assumed a starting position 10 m from the timing gates (and therefore 15 m from the turning point). Participants were instructed to accelerate as quickly as possible through the timing gates, pivot on the 15 m line, and return as quickly as possible through the timing gates.[29] Times were recorded for each trial using a light gate system (Smartspeed; Fusion Sport, Queensland, Australia). Thomas et al.[33] indicated that the test provided a good indicator of the player's deceleration and change of direction capacity. Each participant completed a familiarisation session the day prior to testing before the mean scores of three trials of each test were recorded pre- and post- intervention on the day of testing.

### 2.3. FIFA 11+ and vibration intervention

Each group then completed their allocated intervention, and the warm-up consisted of the FIFA 11+. The FIFA 11+ programme consisted of 15 single exercises, divided into three parts including initial and final running exercises with a focus on cutting, jumping, and landing techniques (parts 1 and 3) and strength, plyometric, agility, and field balance components (part 2). For each of the six conditioning exercises in part 2, the 11+ programme offered three levels of variation and progression.[1] For all groups the warm-up was conducted by the same researcher who was experienced in the delivery of the FIFA 11+. Participants were also briefed on all aspects of the warm-up in order to confirm their understanding using material and videos provided online at the 11+ programme website (http://f-marc.com/11plus/).

Each group following the FIFA 11+ immediately carried out their allocated intervention (FIFA + WBV, FIFA + IS, and Con). The FIFA + WBV group performed a 100-degree squat (as verified with a clinical goniometer) with their heels elevated and slightly leaning forward to maximise vibration stimulus.[34] Participants were exposed to a vertical sinusoidal WBV of 40 Hz with a ±4 mm amplitude (NEMES Bosco System, Rieti, Italy). The FIFA + IS group completed a 30-s isometric squat with a 100-degree flexion at the knees on the platform (without vibration), and the Control group only completed the FIFA 11+. Participants then completed the RSI test immediately (<15 s) post intervention and the 505 agility 4 min after so as not to effect the results.[19]

### 2.4. Statistical analysis

Descriptive statistics (mean ± SD) were calculated for DJH, CT, RSI, and 505 agility. A mixed-model repeated-measures ANOVA (group × time) and Scheffe *post hoc* tests were used to analyse the intervention effect on DJH, CT, RSI, and 505 agility. Statistical significance was set at $p < 0.05$. In addition, to further interpret any differences between means, effect sizes (Partial Eta$^2$) were calculated and interpreted based on the criteria of Cohen[35] where 0.1 is a small effect, 0.25 is a medium effect, and 0.4 is a large effect. The reliability of sprint 505 agility and RSI measures between testing sessions was assessed by intra-class correlation coefficients (ICCs). An ICC value of 0.75 or greater was considered acceptable for reliability.[36] ICC between testing sessions (familiarisation and testing) revealed RSI (0.90 and 3.9%) within that contact time (0.92 and 2.3%), drop jump height (0.88 and 1.92%). Finally 505 agility was reported as 0.88 (1.3%). Statistical analysis was done with SPSS software version 19.0 (SPSS, Chicago, IL, USA).

## 3. Results

Following random allocation of participants no significant baseline differences were identified between treatment groups. Descriptive statistics (mean ± SD) for the pre- and post- DJH, CT, RSI, and 505 agility of the intervention and control groups are shown in Table 1. There were no main effects due to group or time ($p > 0.05$) for DJH, CT, RSI, or 505 agility, although a number of these dependent variables revealed significant time × group interactions.

The counter-movement jump data reported no time × group interaction, although there was a trend ($p = 0.06$) towards the vibration intervention having a greater effect on DJH than the other interventions (Fig. 1). CT reported a significant time × group interaction ($F(2, 71) = 5.529$; $p = 0.006$, Partial Eta$^2$ = 0.2) with the vibration group significantly decreasing CT compared to the other two groups ($p < 0.05$) (Fig. 2). Despite the lack of a significant DJH effect, the RSI, a measurement based on DJH and CT, reported a significant time × group interaction ($F(2, 71) = 8.869$; $p < 0.001$, Partial Eta$^2$ = 0.2) with *post hoc* tests indicating a significant increase in the vibration group ($p < 0.05$) (Fig. 3).

There was no time × group interaction for the 505 agility test ($p > 0.05$) although, similar to the DJH data, there was a trend towards the vibration intervention having a greater negative effect on agility (increased time) than the other interventions.

## 4. Discussion

The current study is the first to look at the effects that the addition of WBV to the FIFA 11+ has on RSI and 505 agility. The aim of the present research was to investigate the benefits

Table 1
Drop jump height (DJH), contact time (CT), reactive strength index (RSI), and 505 agility (505) descriptive statistics (mean ± SD) for each treatment group (FIFA + WBV ($n = 25$), FIFA + IS ($n = 25$), and Control ($n = 24$)).

| Parameters | FIFA + WBV | FIFA + IS | Control |
|---|---|---|---|
| Pre- DJH (mm) | 101.6 ± 25.1 | 99.1 ± 27.9 | 106.1 ± 21.4 |
| Post- DJH (mm) | 109.1 ± 26.9 | 98.1 ± 32.4 | 105.3 ± 21.0 |
| Pre- CT (ms) | 211.6 ± 55.9 | 217.4 ± 85.1 | 209.6 ± 66.6 |
| Post- CT (ms)[a] | 189.0 ± 46.5 | 223.4 ± 81.4 | 211.6 ± 61.5 |
| Pre- RSI | 0.5 ± 0.2 | 0.5 ± 0.2 | 0.5 ± 0.2 |
| Post- RSI[a] | 0.6 ± 0.2 | 0.5 ± 0.2 | 0.5 ± 0.1 |
| Pre- 505 (s) | 2.8 ± 0.3 | 2.9 ± 0.3 | 2.8 ± 0.3 |
| Post- 505 (s) | 2.8 ± 0.3 | 2.9 ± 0.3 | 2.9 ± 0.3 |

Abbreviations: WBV = whole body vibration; IS = isometric squat; RSI = reactive strength index.
[a] indicates a significant time × group interaction ($p < 0.05$) and a significant difference between groups ($p < 0.05$).

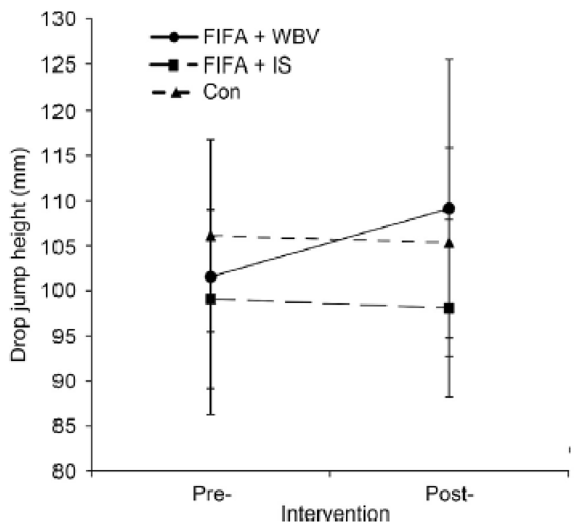


Fig. 1. Change in drop jump height pre- and post- intervention. FIFA 11+ whole-body vibration (FIFA + WBV), FIFA 11+ isometric squat (FIFA + IS), and FIFA 11+ alone (Con). Values are means and error bars are standard deviations. Time × group interaction ($F(2,71) = 2.123$: $p = 0.127$), with no significant difference between groups ($p > 0.05$).

of including an acute bout of vibration stimulus following the FIFA 11+ in collegiate soccer players. A well established and successful warm-up has not only benefits to subsequent performance,[5–7] but also injury prevention.[8] The FIFA 11+ has been recognised as a well-established tool for reducing injury rates amongst soccer players, however performance improvements following its intervention have not been reported as clearly.[1,9,10] From the present results the addition of acute vibration to well-established warm-up has shown positive results in RSI through a decrease in CT, however there was no

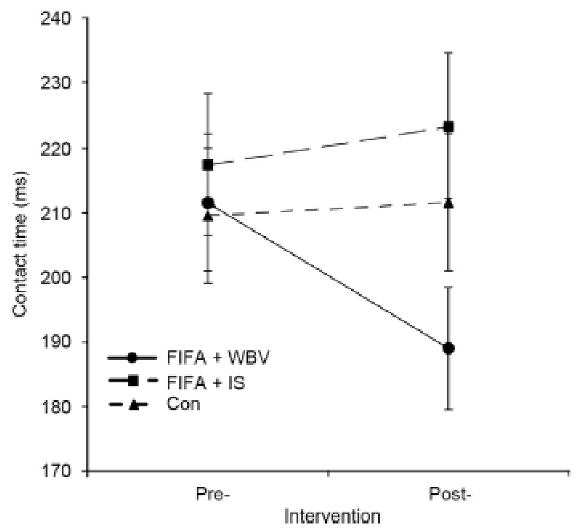


Fig. 2. Change in contact time pre- and post- intervention. FIFA 11+ whole-body vibration (FIFA + WBV), FIFA 11+ isometric squat (FIFA + IS), and FIFA 11+ alone (Con). Values are means and error bars are standard deviations. Time × group interaction ($F(2,71) = 5.529$: $p = 0.006$, Partial $Eta^2 = 0.2$), with a significant difference between groups ($p < 0.05$).

improvement in 505 agility amongst participants. Factors such as reactive strength have been strongly correlated to change of direction efficiency and speed,[37] as well as a key distinguishing characteristic between elite and non-elite soccer players.[38] Such acute improvements in these characteristics should therefore welcomed by players and coaches.

The determination of physiological mechanisms responsible for the significant acute changes that took place following different warm-up protocols is beyond its scope of the present study as no direct neuromuscular responses were measured. The changes in RSI however indicate that there has been a neuromuscular response due to WBV which will be discussed and suggestions made to why this may have occurred. As identified in previous research one potential explanation for the improvements in RSI (through a reduction in contact time) is due to increased efficiency in the stretch shortening cycle (SSC).[24] In particular an improvement in the short-latency stretch reflex would mean a significant reduction in CT, as this corresponds to the reflex after ground contact.[39] Vibration training as a mechanical stimulus has been linked to an improvement in latency stretch reflex post vibration.[40,41] Increased muscle spindle sensitivity and a decrease in recruitment threshold of motor units could also be suggested as a key factor for the decreases in CT,[42] with an increase in spindle sensitivity improving detection on landing and a lowering of recruitment threshold meaning an increase in the velocity of contraction.[42]

The above argument however, of an increase in short-latency stretch reflex and a decrease in recruitment threshold are questioned by the current findings. Such neuromuscular changes could also benefit the 505 agility time but this was not the case. An alternative explanation for the present results may have to do with the suppression of muscle spindle activity. Ritzmann et al.[43] suggested that an increase in muscle stiffness (and thus reflex response) in the muscles involved during jumping was due to the suppression of Ia afferent transmissions from muscle spindles following vibration stimulus by the supraspinal centres. Ritzmann et al.[43] discussed the idea that vibration stimulus has been linked to suppression of Ia afferent pathways caused by pre activation.[44] However, as the SSC is a combination of Ia afferent inputs and cortical contribution,[45] the current results may suggest that an increase in cortical contribution (via supraspinal centres) compensates for a reduction in Ia afferent transmission. More importantly, for the current research this may explain the difference in improvements between RSI and 505 agility time. Ritzmann et al.[43] suggested that depending on the complexity of the motor task there was a greater cortical contribution and a reduction in Ia afferent recovery time. Therefore it could be argued that the motor complexity of the drop jump protocol during the RSI protocol was greater than that of the 505 agility protocol and therefore benefited from this.[43] Although positive results have been seen in 30 s WBV exposure[16] in power and jump ability the relatively small exposure could be the reason for no increase in 505 agility as previously reported.[30] An increase in vibration exposure may have improved these agility values. However, although not significant, a negative

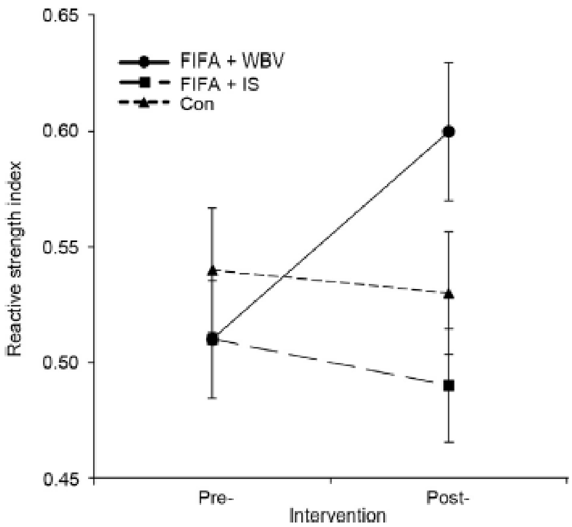


Fig. 3. Change in reactive strength index pre- and post- intervention. FIFA 11+ whole-body vibration (FIFA + WBV), FIFA 11+ isometric squat (FIFA + IS), and FIFA 11+ alone (Con). Values are means and error bars are standard deviation. Time × group interaction ($F(2,71) = 8.869$: $p < 0.001$, Partial Eta$^2 = 0.2$), with a significant difference between groups ($p < 0.05$).

trend in 505 agility was recognised. So any increase in exposure may have accelerated this worsening in performance due to fatigue.[46]

The primary aim of the present study was to investigate the effects of acute vibration stimulus on a well-established warm-up routine (FIFA 11+). The results presented show that the addition of 30 s of vibration training immediately (<90 s) post FIFA 11+ had significant effect on CT and RSI, however no overall change in DJH or 505 agility. This is the first study to combine the two interventions to test performance outcomes amongst soccer players and future research should investigate (1) the exact mechanism behind such improvements amongst different abilities as clear differences exist between trained and untrained athletes and responses to WBV,[47] and (2) the time span of any improvements over the course of the athlete's chosen activity to improve ecological validity. What is clear is that the neuromuscular response to acute vibration stimulus following a dynamic warm-up needs further investigation, in particular amongst a range of populations and performance outcomes.

## 5. Conclusion

Much debate still surrounds the acute effects of WBV on subsequent performance enhancement. Amongst collegiate soccer players 30 s WBV at 40 Hz following FIFA 11+ improves RSI and has no negative effects on 505 agility. These positive trends suggest that the inclusion of WBV plates may be a useful addition to a post warm-up area either pitch side or training room based, to provide additional benefits to the FIFA 11+. A note of caution is recommended, however, further investigation is warranted into the time course of such benefits and the exact mechanism behind such improvements. Also, the apparent negative trend in agility needs further investigation, as one of the key criticisms for the additions of exercises to the FIFA 11+ is the risk of fatigue leading to a worsening in performance.[10] Although the increase in agility time was not significant, from a practical perspective this requires further investigation. What is clear is that WBV provides real scope as a beneficial addition to an already well-established warm-up routine, with strength and conditioning coaches using the novelty of such equipment as a factor for increased adherence and compliance.

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Appendix 4

Paper 4: Cloak, R., Nevill, A., and Wyon, M. (2014) The acute effects of vibration training on balance and stability amongst soccer players. *European Journal of Sport Science*, 14, pp. 1-7.

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ORIGINAL ARTICLE

# The acute effects of vibration training on balance and stability amongst soccer players

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**Abstract**

Acute whole body vibration training (WBVT) is a tool used amongst coaches to improve performance prior to activity. Its effects on other fitness components, such as balance and stability, along with how different populations respond are less well understood. The aim of the current research is to determine the effect of acute WBVT on balance and stability amongst elite and amateur soccer players. Forty-four healthy male soccer players (22 elite and 22 amateur) were assigned to a treatment or control group. The intervention group then performed 3 × 60 seconds static squat on vibration platform at 40 Hz (±4 mm) with Y balance test (YBT) scores and dynamic postural stability index (DPSI) measured pre and post. DPSI was significantly lower in the elite players in the acute WBVT compared to amateur players ($F_{1,\ 40} = 6.80$; $P = 0.013$). YBT anterior reach distance showed a significant improvement in both amateur and elite players in the acute WBVT group ($F_{1,\ 40} = 32.36$; $P < 0.001$). The improvement in DPSI amongst the elite players indicates a difference in responses to acute high frequency vibration between elite and amateur players during a landing stability task. The results indicate that acute WBVT improves anterior YBT reach distances through a possible improvement in flexibility amongst both elite and amateur players. In conclusion, acute WBVT training appears to improve stability amongst elite soccer players in comparison to amateur players, the exact reasoning behind this difference requires further investigation.

**Keywords:** *Whole-body vibration, balance, stability, elite, soccer*

## Introduction

Soccer is one of the most popular games in the world with approximately 2,00,000 elite and 2.4 millon amateur players (Junge & Dvorak, 2004). It is characterised as an intermittent sport with bouts of walking, running, sprinting and numerous changes of direction and jumps. Soccer at all levels has a well-reported incidence of lower extremity injuries (Junge & Dvorak, 2004). Poor landing mechanics is a well-established cause of lower extremity injury to the knee and ankle in soccer (Alentorn-Geli et al., 2009). One of the most common playing scenarios preceding a non-contact knee injury is landing from a jump at or near full extension (Fauno & Jakobsen, 2006) and similarly other loaded to unload transitions contribute to ankle injuries, one of the most common injury sites in soccer (Woods, Hawkins, Hulse, & Hodson, 2003). Dynamic postural stability is the maintenance of a centre of mass over a base of support when moving or when an external perturbation is applied to the body (Brown & Mynark, 2007). The relationship between postural stability and injury risk is well established amongst researchers (Wikstrom, Tillman, Chmielewski, Cauraugh, & Borsa, 2007). Elite and amateur players exhibit differences in balance performance (Butler, Southers, Gorman, Kiesel, & Plisky, 2012), with more experienced players having greater neuromuscular characteristics of balance such as rate of force of development, motor unit firing rate and tendon stiffness than their untrained counterparts (Sundstrup et al., 2011).

Whole body vibration training (WBVT) has become a popular area for researchers and applied practitioners, particularly with its reported benefits in improving strength and power output (Cochrane, 2011). More recently, it has been suggested as a way of preparing athletes for the subsequent performance incorporating it in warm-up routines (Cochrane, 2013; Lovell, Midgley, Barrett, Carter, & Small, 2013). Bullock et al. (2008) identified a single bout of 3 × 60 sec acute WBVT at 30 Hz had a beneficial effect on some aspects of jump and sprint performance amongst elite skeleton athletes. The authors note that more investigation is

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required into the effects of using higher WBVT frequencies amongst elite athletes as well as the effects such acute bouts have on balance and proprioception (Bullock et al., 2008). The acute effects of vibration exposure have been investigated with positive results in time to stabilisation following an acute bout of WBVT amongst healthy participants (Sanudo et al., 2012). The authors commented that this may have been due to improved motor unit synchronisation and possible remodelling of the central balance motor programmes (Sanudo et al., 2012). However, not all authors have found such positive effects following acute vibration; for instance Pollock, Provan, Martin, and Newham (2011) reported no change in balance or joint position sense following acute WBVT. What is acknowledged is that more research is required into the effects of acute WBVT before it can be considered for inclusion as part of a well-developed pre-competition warm-up routine. The benefit of this to soccer would be the initial neuromuscular response following WBVT which would help prepare the player for the intense engagement and high tempo play associated with the first 15 minutes of a match (Rahnama, Reilly, & Lees, 2002). However, any additions to a soccer warm-up routine should be carefully selected as these could contribute to an increased risk of fatigue leading to a worsening in performance or increased injury risk (Impellizzeri et al., 2013).

One criticism the current research team has of a large proportion of the current WBVT studies is the lack of elite populations under investigation, with a few notable exceptions (Bullock et al., 2008; Cochrane & Stannard, 2005). As previously mentioned not only do amateur and elite soccer players show differences in dynamic balance during single leg tasks and reactions to changes in posture (Butler et al., 2012; Sundstrup et al., 2011), but amateur and elite athletes also show different responses to WBVT, which include power output, muscle sensitivity to stimulus and flexibility (Despina et al., 2013; Issurin & Tenenbaum, 1999; Ronnestad, 2009). It is therefore important to examine the acute effects of WBVT on balance and the effect that playing level has on the effectiveness of the intervention. The aim of the present research is to assess the effect of acute vibration stimulus on balance amongst soccer players of differing abilities.

## Methods

### *Participants*

A total of 44 male soccer players (age = 22.1 ± 2.1 years, body mass = 77.1 ± 8.2 kg and height 175.3 ± 6.9 cm) volunteered to take part in this study during their pre-season. The 22 elite players (8 defenders, 10 midfielders and 4 forwards) on average trained 12–14 hours per week and played one or two games a week for the previous 3–5 years. The 22 amateur players (8 defenders, 10 midfielders and 4 forwards) on average trained between 3 and 6 hours per week and played up to one game per week over the previous season. This classification of player ability has previously been used (Cometti, Maffiuletti, Pousson, Chatard, & Maffulli, 2001). All players were free from injury, including concussion or mild head injury within the last year and no reported musculoskeletal injury within the last three months prior to the study. The study was approved by the institution's ethical committee, the testing procedure was explained to the players and a written informed consent was obtained from the players prior to commencement. All participants were randomly assigned to either a control or WBVT group. The restricted randomization (blocking and stratification) of the participants was performed as follows. First, five matrices (Playing level, elite or amateur; playing position, defence, midfield or forward) were created to stratify the participants, in an attempt to avoid imbalance between the groups of playing positions. The final groups were made up of 22 elite players (11 treatment and 11 control) and 22 amateur players (11 treatment and 11 control). This research protocol was approved by the University Ethics Institutional Review Board.

### *WBVT*

All participants began with 10 minutes on a cycle ergometer at between 65% and 85% of age-predicted maximum heart rate. An effort was made to achieve the specified heart rate ranges within 2 minutes of initiating exercise. The revolutions per minute were kept between 60 and 80 rpm. After 10 minutes, the WBVT group performed a 100-degree squat (as verified with a clinical goniometer) with their heels elevated and slightly leaning forward to maximise vibration stimulus (Di Giminiani, Masedu, Tihanyi, Scrimaglio, & Valenti, 2012). Participants were exposed to a vertical sinusoidal WBV of 40 Hz with a ±4 mm amplitude (NEMES-Bosco, Italy). The WBVT group completed 3 × 60 seconds (Bullock et al., 2008) with 60 seconds rest between trials, and the control group performed an identical warm up, however the squat was performed in the absence of vibration. Participants then completed the dynamic postural stability index (DPSI) test 2 minutes post-vibration and the Y balance test (YBT) 4 minutes after final DPSI trial so as not to affect the results (Bullock et al., 2008). All testing was completed within 15 minutes as previously used in acute WBVT with elite athletes (Despina et al., 2013) and replicates the 15-minute time frame highlighted as important to initial periods of competition in soccer (Rahnama et al., 2002).

### *DPSI*

Participants reported to a research laboratory for a single test session. DPSI was assessed using a single-leg jump landing in the anterior direction, which has demonstrated good intersession reliability (Sell, 2012). The single-leg jump landing task was only conducted on the dominant limb. Limb dominance was defined as the limb the participant would use to kick a ball maximally.

Ground reaction force data were collected during each single-leg jump stabilisation test to measure dynamic postural control as described by Wikstrom et al. (2010). Specifically, a triaxial force plate (model 4060; Bertec Corporation, Columbus, OH) sampling at a rate of 200 Hz captured the required ground reaction force data. To complete this test, participants started 70 cm from the centre of the force plate and jumped over a hurdle placed at 50% of each participants' maximal jump height with both legs before landing on the force plate on the dominant leg, stabilising as quickly as possible and maintaining this position for 3 seconds. As within the context of previous protocols and data analysis, a higher DPSI represents worse postural stability (Sell, 2012). Force plate data were analysed to calculate the DPSI and directional indices as described previously (Wikstrom et al., 2010). These indices assess the standard deviations of fluctuations around a zero point that are then divided by the number of data points in a trial so that higher scores indicate greater variability. The medial–lateral stability index (MLSI), anterior–posterior stability index (APSI) and vertical stability index (VSI) correspond, respectively, with the frontal (y), sagittal (x) and transverse (z) axes, respectively, of the force plate. The DPSI is a composite of the ground reaction forces in all planes and thus is sensitive to force changes in each direction (Wikstrom et al., 2010; Table I).

A custom MATLAB (v7.0.4, Natick, Massachusetts) script file was used to process the ground reaction force data for calculating the DPSI. Ground reaction force data were passed through a zero-lag fourth-order low-pass Butterworth filter with a frequency cut-off of 20 Hz. The DPSI is a composite of the anterior/posterior, medial/lateral and vertical ground reaction forces. The DPSI was calculated using the first 3 seconds of the ground reaction forces immediately following initial contact identified the instant the vertical ground reaction force exceeded 5% body weight. This method of calculating DPSI has demonstrated good test–retest reliability (Wikstrom, Tillman, Smith, & Borsa, 2005). The average of three successful trials was recorded.

Table I. Calculation for DPSI

| Variable | Equation |
|---|---|
| MLSI | $\left(\sqrt{\frac{\sum(0-GRFx)^2}{number\ of\ data\ points}}\right) \div BW$ |
| APSI | $\left(\sqrt{\frac{\sum(0-GRFy)^2}{number\ of\ data\ points}}\right) \div BW$ |
| VSI | $\left(\sqrt{\frac{\sum(BW-GRFz)^2}{number\ of\ data\ points}}\right) \div BW$ |
| DPSI | $\left(\sqrt{\frac{\sum(0-GRFx)^2+\sum(0-GRFy)^2+\sum(BW-GRFz)^2}{(number\ of\ data\ points)}}\right) \div BW$ |

BW, body weight; Σ, Sum; $GRF_x$, medio-lateral ground reaction force; GRFy, anterior–posterior ground reaction force; MLSI, medial–lateral stability index; APSI, anterior–posterior stability index; VSI, vertical stability index; DPSI, composite score.

### *Y balance test*

The YBT involved the individual standing on an elevated central plastic footplate 2.54 cm off the ground and pushing a rectangular reach indicator block with the foot along a 1.5-m length of plastic tubing on an anterior (Ant), posterior lateral (Lat) and posterior medial (Med) reach distances (Plisky, Rauh, Kaminski, & Underwood, 2006). The reach distance was recorded as the point at which the reach indicator block is pushed furthest from the stance leg (Figure 1). Participants then performed three trials in each direction. Ten seconds of rest were provided between individual reach. Reach distances were divided by leg length and multiplied by 100 to calculate reach distance as a percentage of leg length (%MAXD) in order to normalise data. This protocol demonstrated higher inter-rater (0.99–1.00) and intra-rater reliability (0.85–0.91) amongst investigators (Plisky et al., 2009).

### *Statistical analysis*

Data were presented as means (±SD). The DPSI, anterior reach distance, posterior medial and posterior lateral reach distances were all analysed using a three-way analysis of variance (ANOVA) with repeated measures. The two between-subject factors were "playing level" (elite vs. amateur) and "treatment" (vibration vs. control) whilst the within-subject factor was "time" (pre- vs. post-intervention). Statistical significance was set at $P < 0.05$. In addition, to further interpret any differences between means, effect sizes ($\eta_p^2$) were calculated and interpreted based on the criteria of Cohen (1992) where 0.1 is a small effect, 0.25 is a medium effect and 0.4 is a large effect. An intraclass correlation coefficient (ICC) was employed to determine the inter-session reliability (Shrout & Fleiss, 1979). ICC assessed the test–retest

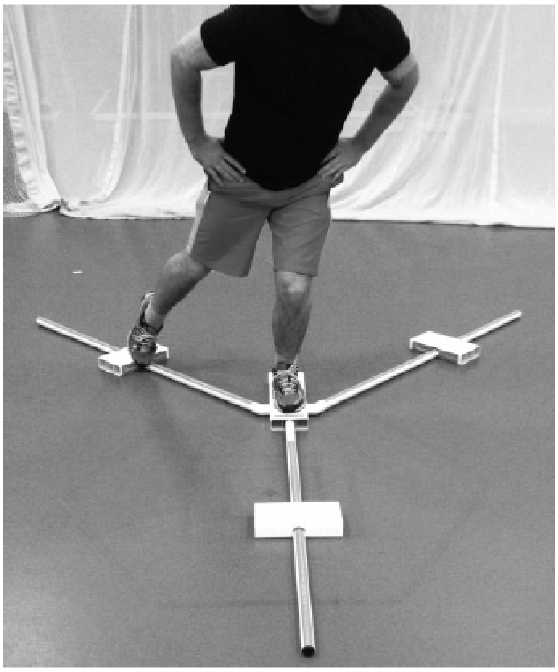

Figure 1. Y balance test.

reliability of comparing the mean of the dependent variables between testing sessions. The ICC test–retest reliability of DPSI ($r$ = 0.950) and YBT ($r$ = 0.830) was significant ($p$ < 0.001), indicating little variability and thus a high degree of consistency attained between testing sessions. The Shapiro–Wilk statistic for each condition confirmed that the data were normally distributed. Differences in the pre-test values between groups were assessed using a two-way ANOVA looking at treatment (WBVT/control) and status (elite/amateur). The significance level was set at $P$ < 0.05 for all the comparisons. All statistical procedures were conducted using SPSS 19.0 (SPSS Inc., Chicago, IL, USA).

## Results

First, it should be noted that at baseline, no significant differences were found between groups. Both DPSI and YBT raw scores were used to identify differences in playing level (elite vs. amateur) and treatment-by-time interaction (WBVT vs. Control) Table II. Repeated ANOVA of DPSI identified a three-way "playing level"-by-"treatment"-by-"time interaction" ($F_{1,\,40}$ = 6.80; $P$ = 0.013, $\eta_p^2$ = 0.145). As can be seen in Figure 2, DPSI decreased from pre-test to post-test (−7.9%) in the elite WBVT group, whereas there was a slight increase in the amateur WBVT group (2.8%). Therefore, WBVT had a significant effect on DPSI amongst elite players only. There were no significant main or interaction effects of the three composites that make up the DPSI (VSI, APSI and MLSI) identified by the ANOVAs.

Repeated ANOVA of anterior (Ant) reach distance identified a main effect of "time" ($F_{1,\,40}$ = 30.48; $P$ < 0.001, $\eta_p^2$ = 0.432) and a two-way "treatment"-by-"time" interaction effect ($F_{1,\,40}$ = 32.36; $P$ < 0.001, $\eta_p^2$ = 0.447), with no significant "playing level" effect, indicating both elite and amateur player improved in the WBVT group (Table II). There were no significant main or interaction effects of posterior medial and posterior lateral reach distances identified by the ANOVAs.

## Discussion

WBVT has gained a lot of attention over the past decade; however to the best of our knowledge, the current research is the first to examine the acute effects on balance amongst elite and amateur soccer players. The main findings were acute WBVT significantly improved DPSI amongst elite players, with no change in DPSI amongst amateur players. Neither control group (elite or amateur) showed any change in DPSI. Anterior YBT reach distances improved in both elite and amateur players who received acute WBVT. These results indicate that acute WBVT has a positive effect on DPSI amongst elite soccer players, but not amongst amateur players. In contrast, Despina et al. (2013) found no improvement in balance amongst elite gymnasts with the inclusion of acute vibration stimulus. The test was limited with a static single-leg balance task and a lower vibration exposure time at a lower frequency (30 Hz to 2 mm). The balance task used may not have been sufficient to challenge an elite gymnastics population because gymnasts have a high level of proprioception due to the nature of their training (Aydin, Yildiz, Yildiz, & Kalyon, 2002) and therefore any improvement would be difficult to ascertain.

This raises a key issue with the methodology used in acute whole body vibration amongst elite and amateur athletes. Ronnestad (2009) found that maximum power output was achieved amongst both trained and untrained individuals, with untrained individuals showing the higher gains in jump performance post WBVT. Although amongst amateur athletes this may be seen during explosive movements, stabilisation of body weight jumping over an obstacle requires a specialist set of movement patterns and this may explain the lack of improvement amongst amateur athletes in the current research. Landing is characterised by (1) a pre-activation phase, (2) an eccentric phase followed immediately by (3) a concentric muscular action (Komi, 1983). The motor output in the pre-activation phase just prior to touch-down in drop-jumps, as well as part of the muscular activation

Table II. Descriptive statistics and statistical results for the variables on the YBT and DPSI across the different levels of playing level and treatment groups

| | WBVT | | Control | | |
|---|---|---|---|---|---|
| | Elite | Amateur | Elite | Amateur | |
| | Mean ± SD | Mean ± SD | Mean ± SD | Mean ± SD | *P* value |
| Pre-MLSI | 0.0156 ± 0.0020 | 0.0233 ± 0.0023 | 0.0151 ± 0.0020 | 0.0163 ± 0.0020 | |
| Post-MLSI | 0.0127 ± 0.0017 | 0.0224 ± 0.0017 | 0.0153 ± 0.0017 | 0.0165 ± 0.0017 | |
| Pre-APSI | 0.0529 ± 0.0023 | 0.0565 ± 0.0023 | 0.0537 ± 0.0023 | 0.0548 ± 0.0023 | |
| Post-APSI | 0.0531 ± 0.0023 | 0.0565 ± 0.0023 | 0.0535 ± 0.0023 | 0.0559 ± 0.0023 | |
| Pre-VSI | 0.1421 ± 0.0109 | 0.1602 ± 0.0109 | 0.1448 ± 0.0109 | 0.1470 ± 0.0109 | |
| Post-VSI | 0.1304 ± 0.0088 | 0.1756 ± 0.0088 | 0.1437 ± 0.0088 | 0.1498 ± 0.0088 | |
| Pre-DPSI | 0.1528 ± 0.0091 | 0.1809 ± 0.0091 | 0.1545 ± 0.0091 | 0.1581 ± 0.0091 | $P = 0.013$* |
| Post-DPSI | 0.1409 ± 0.0087 | 0.1862 ± 0.0087 | 0.1545 ± 0.0087 | 0.1604 ± 0.0087 | |
| Pre-Ant | 66.4 ± 1.5 | 66.2 ± 1.5 | 68 ± 1.5 | 67.9 ± 1.5 | $P < 0.001$* |
| Post-Ant | 71.5 ± 1.7 | 73.3 ± 1.7 | 67.9 ± 1.7 | 67.8 ± 1.7 | |
| Pre-Med | 88.8 ± 1.5 | 94 ± 1.5 | 94.2 ± 1.5 | 92.5 ± 1.5 | |
| Post-Med | 88.4 ± 1.7 | 92.7 ± 1.7 | 93.5 ± 1.7 | 92.8 ± 1.7 | |
| Pre-Lat | 95.8 ± 1.8 | 95.8 ± 1.8 | 99.2 ± 1.8 | 98.3 ± 1.8 | |
| Post-Lat | 95.8 ± 1.7 | 95.6 ± 1.7 | 99.3 ± 1.8 | 98.3 ± 1.7 | |

*Significant difference in "playing level" × "treatment-by-time" interactions.
MLSI, medial–lateral stability index; APSI, anterior–posterior stability index; VSI, vertical stability index; DPSI, composite score; Ant, anterior; Lat, posterior lateral; Med, posterior medial.

after touch-down (in the eccentric phase), is anticipatory (Zuur et al., 2010). The muscular activation after touch-down is reactive to the permutations of the landing because spinal reflexes [short-latency response (SLR)] are elicited at touch-down and contribute to the motor output (Zuur et al., 2010). Increases in the short-latency stretch reflex response of the stretch shortening cycle have been identified as a possible factor in the increase in power production post vibration stimulus at higher vibration protocols >40 Hz (Fernandes, Kawchuk, Bhambhani, & Gomes, 2013). In particular, an improvement in the short-latency stretch reflex would mean a significant reduction in contact time permutations, as this corresponds to the reflex after ground contact (Komi, 2000). Any such reductions in landing permutations could contribute to a reduction in DPSI,

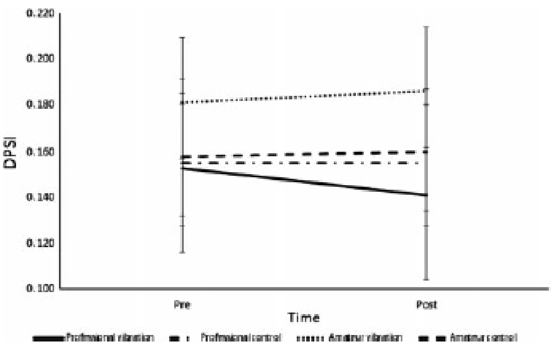


Figure 2. "Playing level"-by-"treatment-by-time" interaction DPSI results for elite and amateur players ($F_{1,\ 40} = 6.80$; $P = 0.013$, $\eta_p^2 = 0.145$).

and vibration training as a mechanical stimulus has been linked to an improvement in latency stretch reflex post-vibration (Shinohara, Moritz, Pascoe, & Enoka, 2005); however, it should be noted that this was reported during locally applied vibration stimulus as the same response is still to be confirmed during WBVT. These neuromuscular changes may be more exaggerated in the elite population due to their response to higher vibration stimulus. Issurin and Tenenbaum (1999) speculate that higher sensitivity of muscle receptors and increased central nervous system response to vibration stimulus. However, the current research did not measure reflex activity and future research is required to establish the exact mechanisms underlying the improvement in DPSI amongst elite populations.

In contrast to the current research, Sanudo et al. (2012) identified an improvement balance amongst amateur athletes with acute WBVT. One explanation for this disparity between the current results is the difference in frequency used in both studies. The current research went for a vibration frequency of 40 Hz ± 4 mm due to its popularity amongst elite populations (Issurin & Tenenbaum, 1999; Ronnestad, 2009), which may have resulted in too high a vibration stimulus for the amateur players to gain any performance benefit. A high vibration stimulus (>300 Hz) applied locally has been previously reported as negatively effecting proprioception in humans, in particular cutaneous receptors, which provide proprioceptive information that is integrated with that from muscle spindles to provide a judgement of joint position and movement (Weerakkody, Taylor, & Gandevia, 2009). Direct comparisons with the WBVT in the current research are difficult; however, previous research has questioned the effect of high-amplitude (8 mm) WBVT on proprioceptive function of the foot and ankle of recreationally trained adults (Pollock et al., 2011). Although not significant, results did illustrate an increase in DPSI scores amongst amateur athletes. As previously discussed, the idea of any good pre-performance routine is to sufficiently warm up the participant without fatiguing and leading to a worsening in performance or injury (Impellizzeri et al., 2013). Although the authors accept that lower limb injury is multifactorial, the present results question the efficacy of acute WBVT as a warm-up strategy amongst amateur athletes as poor postural stability has been linked with injury risk (Wikstrom et al., 2007).

The results from the current study on the YBT report similar improvements between both amateur and elite players though significant changes only occurred on the anterior reach distance. It could be argued that a functional test such as the YBT did not have the sensitivity to distinguish changes after acute WBVT that a force plate test like the DPSI can. WBVT has previously been suggested as a way of improving flexibility (Cochrane & Stannard, 2005; Gerodimos et al., 2010). This may be due to acute vibration exposure increasing muscle temperature (Cochrane, Stannard, Firth, & Rittweger, 2010) or a reduction in pain sensation in the affected muscles and tendons possibly allowing for a greater tolerance of the following stretch (Cochrane & Stannard, 2005). These flexibility benefits have been previously reported as lasting up to 15 minutes (Gerodimos et al., 2010) which may be beneficial in a warm-up capacity in soccer as the first 15 minutes of either half tends to be a key period for injuries (Rahnama et al., 2002). The anterior reach direction has previously been suggested as requiring the greatest amount of dorsiflexion (Gribble, Robinson, Hertel, & Denegar, 2009). In the long term, an improvement in dorsiflexion range of motion may also help to reduce potential long-term problems, such as patella tendinopathy, one of the most common reasons for sport-induced pain in the knee, particularly prevalent in sports with explosive jumping movements (Backman & Danielson, 2011).

## Conclusions

The findings of the present research are that there appears to be a difference in response to acute WBVT between elite and amateur soccer players. The improvement in DPSI amongst elite players seems to indicate elite players respond positively to the high frequency and short intermittent duration of the vibration stimulus, whereas it appears not to have the same response amongst amateur players. The improvements in anterior reach distances appear to indicate an improvement in flexibility which has benefits to both elite and amateur players. The differences in neuromuscular responses are speculative and based on level of training each group undertakes; future research will need to identify neuromuscular responses between levels. Also, careful consideration should be given to developing warm-up protocols using acute WBVT as a better understanding of how different athletic populations respond to different protocols is required.

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Appendix 5

Paper 5: Cloak, R., Lane, A., and Wyon, M. (2016) Professional soccer player neuromuscular responses and perceptions to acute whole body vibration differ from amateur counterparts. *Journal of Sports Science and Medicine*, 15, pp.57-64

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**Research article**

# Professional Soccer Player Neuromuscular Responses and Perceptions to Acute Whole Body Vibration Differ from Amateur Counterparts

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**Abstract**
Acute whole body vibration (WBV) is an increasingly popular training technique amongst athletes immediately prior to performance and during scheduled breaks in play. Despite its growing popularity, evidence to demonstrate its effectiveness on acute neuromuscular responses is unclear, and suggestions that athlete ability impacts effectiveness warrant further investigation. The purpose of this study was to compare the neuromuscular effects of acute WBV and perceptions of whether WBV is an effective intervention between amateur and professional soccer players. Participants were 44 male soccer players (22 professional and 22 amateur; age: 23.1 ± 3.7 years, body mass: 75.6 ± 8.8 kg and height: 1.77 ± 0.05 m). Participants in each group were randomly assigned to either an intervention of 3 x 60 s of WBV at 40 Hz (8mm peak-to-peak displacement) or control group. Peak knee isometric force, muscle activation and post activation potentiation (PAP) of the knee extensors along with self-report questionnaire of the perceived benefits of using the intervention were collected. A three-way ANOVA with repeated measures revealed professional players demonstrated a significant 10.6% increase ($p < 0.01$, *Partial* $Eta^2 = 0.22$) in peak knee isometric force following acute WBV with no significant differences among amateur players. A significant difference ($p < 0.01$, *Partial* $Eta^2 = 0.16$) in PAP amongst professional players following acute WBVT was also reported. No significant differences amongst amateur players were reported across measurements. Results also indicated professional players reported significantly stronger positive beliefs in the effectiveness of the WBV intervention ($p < 0.01$, *Partial* $Eta^2 = 0.27$) compared to amateur players. Acute WBV elicited a positive neuromuscular response amongst professional players identified by PAP and improvements in knee isometric peak force as well as perceived benefits of the intervention, benefits not found among amateur players.

**Key words:** Potentiation, power, strength, perceptions.

## Introduction

Whole body vibration (WBV) has been suggested as an attractive and time efficient complement to traditional forms of exercise for an athlete prior to performance (Cochrane, 2011, 2013; Ronnestad and Ellefsen, 2011). WBV evokes muscle contractions via tonic vibration reflex (TVR) through tendon vibration (Rittweger, 2010). The change in muscle length during vibration is detected by muscle spindles and induces a non-voluntary muscular contraction (Rittweger, 2010). An enhancement of the stretch-reflex, proposed improvements in neuron excitability and motor unit recruitment of the muscle are cited as reasons for improvements in strength and power output (Bosco et al., 1999). However, other mechanisms such as muscle temperature (Cochrane et al., 2008), blood flow (Kerschan-Schindl et al., 2001) and post activation potentiation (PAP) (Cochrane et al., 2010) have also been suggested as contributing factors. Yeung et al. (2014) suggest that these mechanisms are seldom investigated in acute WBV settings and suggest that if immediate muscle facilitation is the result of homonymous α -motoneurons activation, the effect should be seen in force output and motor unit recruitment. An observation not detected by Yeung et al. (2014) who reported no change in quadriceps stretch-induced reflex or peak force, findings consistent with other researchers who have also questioned the effectiveness of acute WBV (Hannah et al., 2013).

Acute WBV has been investigated as a potential ergogenic aid amongst coaches to induce immediate performance benefits prior to performance (Bullock et al., 2008) or during half-time rest periods in soccer to help prepare for the second half performance (Lovell et al., 2013). Towlson et al. (2013) discuss how 58% of Premier League/Championship football team practitioners incorporated half-time re-warm up strategies and Russell et al. (2015) suggest a PAP activity should be incorporated during the final 5 minutes of a half-time scenario in team sports. Any additions to a warm up routine should be carefully selected as these could contribute to an increased risk of fatigue leading to a decrease in performance or increased injury risk (Impellizzeri et al., 2013). Level of conditioning of the athlete should also be considered when implementing an acute conditioning exercise with the aim of PAP due to initial strength levels being dependent on the success of the intervention (Chiu et al., 2003; Seitz et al., 2014; Seitz and Haff, 2015). Depending on the extent of the pre-conditioning activity, the muscle's impending activation can either be impaired by fatigue or enhanced by a phenomenon known as PAP (Sale, 2002), through a combination of neurogenic and non-neurogenic responses (Sale, 2002). This is seen by coaches as a particularly positive quality when preparing athletes for competition. Rittweger et al. (2003) identified increases in mean power frequency during sustained isometric contraction of the vastus lateralis after acute WBV. The authors suggest a central nervous recruitment of predominantly large motor units to maintain force output following acute WBV (Rittweger et al., 2003). Torvinen et al. (2002) identified that an acute bout of WBV improvements in strength and power of the lower extremities suggesting neural adaptations may have occurred, the authors note that the acute WBV was long enough (4 minutes) to stimulate without fatiguing the muscle.

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The idea of non-neurogenic factors such as potentiation of muscle twitch force has been suggested with electromyography (EMG) (Bosco et al., 2000), and Cochrane et al. (2010) identified that acute WBV induces PAP via non-neurogenic twitch potentiation and not neurogenic twitch potentiation. Jordan et al. (2010) however questions the influence of PAP following bouts of acute WBV, indicating an attenuation in knee extensor peak force values, not an improvement. These findings suggest further investigation is warranted into twitch potentiation and non-neurogenic factors following acute WBV. Knee extensor twitch potentiation has been correlated with improved performance in sprint and counter movement jump in elite soccer players (Requena et al., 2011).

A large amount of the current WBV research has used non-elite/moderately trained or sedentary populations as participants, with a few notable exceptions (Bullock et al., 2008; Cochrane and Stannard, 2005; Despina et al., 2013; Issurin and Tenenbaum, 1999; Lovell et al., 2013; Ronnestad, 2009). This has highlighted the need to investigate the different responses amongst different groups and possibly sub-groups and the underpinning neuromuscular effects (Ronnestad and Ellefsen, 2011). One specific group of interest is the difference between amateur and elite athletes. Evidence demonstrates that amateur and elite athletes differ in responses to WBV, with elite athletes showing greater increases in force output, muscle sensitivity to stimulus and balance (Cloak et al., 2014; Ronnestad, 2009). Further, Cloak et al. (2014) suggested acute WBV may impair balance and landing stability amongst amateur soccer players due to fatigue, in comparison to elite soccer players' balance and landing stability. Cloak et al. (2014) speculated differences between groups were attributed to differences in strength levels and neuromuscular responses to WBV. Isometric peak force output of the knee extensors has been identified as a distinguishing strength characteristic between professional and amateur soccer players, with professional players producing significantly higher values then amateurs (Gissis et al., 2006).

Few studies have compared perceptions of benefits of acute WBV between trained and untrained individuals. Belief effects are typically studied under the rubric of examining a placebo effect, defined as positive outcome arising from the belief that a beneficial treatment has been received (Beedie and Foad, 2009). Rønnestad et al. (2013) identified improved sprint performance related to perceived improvement in feeling of well-being in the legs following acute WBV in elite ice-hockey players. Marin et al. (2015) reported that untrained participants indicated a higher RPE when exposed to acute WBV at 50Hz compared to 30Hz and recommend 30Hz for untrained individuals. Beliefs in the likely effectiveness of an intervention or ergogenic aid have found to have an incremental effect on performance (Beedie and Foad, 2009). Individuals who positively believed that an intervention will be effective appear to gain greater benefits than participants who do not. Results of Beedie and Foad (2009) suggest that a belief effect could shape the efficacy of an intervention. Therefore, it seems prudent to assess beliefs in the effectiveness of an intervention during the evaluation. Assessing beliefs is becoming used more regularly in applied research. For example, Finch (2011) proposed monitoring athletes via self-report measures to try to identify perceived benefits on training interventions for injured athletes.

The aim of the present investigation, therefore, was to compare the acute effects of WBV amongst professional and amateur soccer players on muscle activation, PAP and peak isometric force of the knee extensors during a maximal voluntary contraction (MVC) and the perceptions of benefits of the intervention between groups.

## Methods

### Participants

Forty-four male soccer players (age 23.1 ± 3.7 yrs., body mass 75.6 ± 8.8 kg and height 1.77 ± 0.05 m) volunteered to take part in this study. The 22 professional players (English Football League 1) (age 24.1 ± 3.8 yrs., body mass 77.1 ± 7.4 kg and height 1.78 m ± 0.07 m) on average trained 12-14 hours per week and played one or two games a week for the previous 3-5 years. The 22 amateur players (age 22.1 ± 3.4 yrs., body mass 74.1 ± 9.9 kg and height 1.76 ± 0.06 m) on average trained between 3-6 hours per week and played up to one game per week over the previous season. All players reported to be free from injury, including concussion or mild head injury within the last year and no reported musculoskeletal injury within the last three months prior to the study. All participants had a minimum of 1 year's regular strength and power training and two days before familiarisation and testing days participants were instructed to minimize strength and power training involving the lower body and avoid adrenergic-enhancing substances, such as caffeine (Chiu et al., 2003). This research protocol was approved by the University Ethics Institutional Review Board of the University of Wolverhampton. All participants completed baseline measurements for peak isometric force, muscle twitch force and voluntary muscle activation during knee extension isometric MVC. Within each treatment group participants were randomly assigned using a sealed envelope method to either a control or WBV intervention. The final groups where made up of 22 professional players (11 WBV and 11 controls) and 22 amateur players (11 WBV and 11 controls). A 30-min rest interval separated the baseline measurements and the beginning of the intervention and subsequent post-intervention neuromuscular testing to allow for sufficient recovery (Jordan et al., 2010). An overview of the study design can be seen in Figure 1.

### Participant preparation and electrical stimulation

All participants were seated with hips and knees flexed at 90 degrees. Participants where strapped in to prevent unwanted movement using an adjustable waist and shoulder belt, and arms were across the chest. Participants were positioned in a custom made chair designed for isometric testing of the knee extensors, in a upright position with 85° hip flexion and knee at 90° flexion using full knee extension as 0° reference angle. Testing was only con-

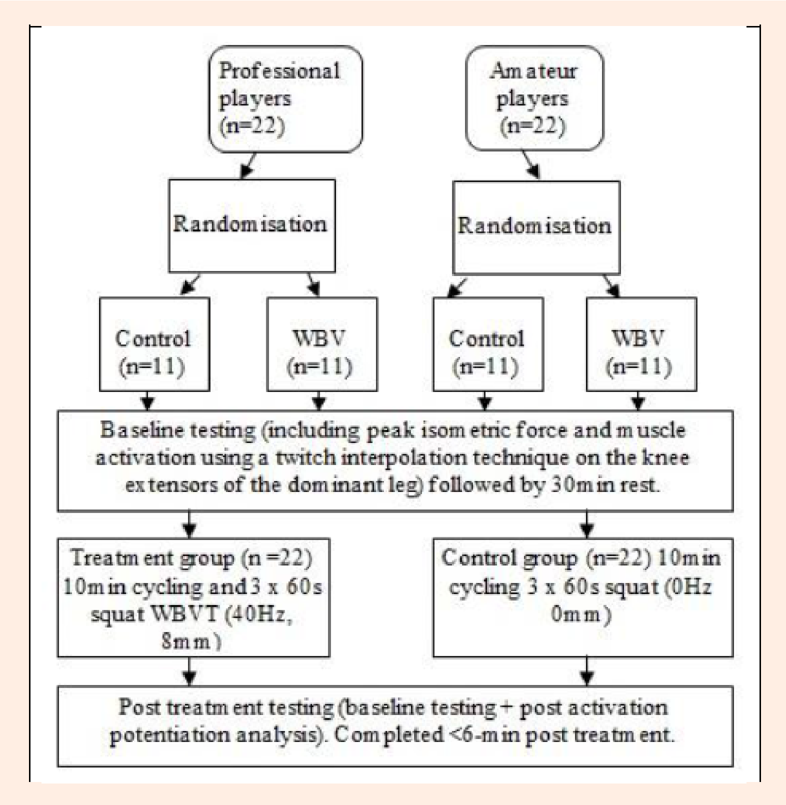


**Figure 1. Overview of study design.**

ducted on the participant's dominant leg. Their ankle was secured to an ankle holder attachment. The ankle holder was connected to a load cell (LCM Systems Ltd, UK) and DC amplifier. The load cell was calibrated before each testing session and secured to an anchor point behind the chair, with all forces recorded using a data acquisition system LabChart 7 Pro Software (PowerLab System, ADInstruments).

A familiarisation session took place the week prior to testing, participants were asked to abstain from any physical activity two days before each testing session (Jordan et al., 2010). The familiarisation included preparation of the participant's skin, fastening of the electrodes, and adjustments were made to the isometric chair which was recorded for future tests in preparation for the MVC. Two 5 x 8 cm self-adhesive surface electrodes (Valu-Trode electrodes, Axelgaard Manufacturing Co. Ltd., Fallbrook, CA) where placed on the distal and proximal areas of the quadriceps muscle group. Skin preparation involved shaving, gentle abrasion and cleaning with alcohol wipes. To ensure that electrode placement remained the same throughout, testing positions where marked on the participant using a marker pen (Cochrane, 2011). During the familiarisation session, participants were trained to perform MVCs with approximately 5-10 attempts taken to obtain a reliable MVCs (i.e., with no more than 5 % variation between the last trials) (Neyroud et al., 2014). Each received verbal encouragement (to ensure a maximal effort was given for the MVC) by the same member of the research team, and this was done throughout familiarisation and testing. Maximum twitch response was determined with a single 200us pulse generated by a high-voltage stimulator (DS7AH, Digitimer, Hertfordshire, UK). This involved increasing the twitch voltage in 50-100mA steps until a plateau in twitch force was reached. This value was noted and used during the subsequent testing (Cochrane et al., 2010).

### MVC of isometric knee extension and twitch interpolation technique

The twitch interpolation technique was used in this investigation to assess neuromuscular function. The higher the percentage score indicates a greater ability to voluntarily recruit motor units. Three doublet twitches were given to the relaxed quadriceps muscle through a set of electrodes attached to the muscle belly (DS7AH, Digitimer, Hertfordshire, UK). The mean force (measured by a load cell in a seated position) produced by these three twitches represented the resting twitch force (RTFpre). The participant then performed a MVC that was held for 7 seconds (Jordan et al., 2010). At the fourth second of the voluntary contraction, when a steady-state force had been reached, another doublet twitch was applied eliciting the interpolated twitch force (ITF). Following the MVC three additional doublet twitches were given to the relaxed muscle (RTFpost). The protocol used has been described elsewhere (Jordan et al., 2010; Suter et al., 1998). Voluntary muscle activation during the MVC was calculated as follows: Voluntary muscle activation% = [1-(ITF/RTFpre)] x 100.

The presence or absence of PAP following the treatment conditions was calculated by dividing the post-treatment resting muscle twitch force (RTFpost) by the pre-treatment resting muscle twitch force (RTFpre). This value was then multiplied by 100% and subtracted from 100. This process has also been used by Jordan et al., (2010) when examining the effects of acute WBV (PAP = (RTFpost/RTFpre x 100) – 100). Post intervention (<6min) the participants were returned to the isometric chair for retesting.

### Whole body vibration (WBV) protocol

All participants began with 10 minutes on a cycle ergometer between 65 and 85% of age-predicted maximum heart rate. An effort was made to achieve the specified heart rate range within 2 minutes of initiating exercise and revolutions per minute were kept between 60-80 rpm (Kelly et al., 2010). After 10 minutes the WBV group performed a 100-degree squat (as verified with a clinical goniometer) (Cloak et al., 2014). Once knee angle was fixed participants were asked to raise their heels as much as possible, once the position was standardised for each participant it was monitored using a clinical goniometer during trials to maximise vibration stimulus (Di Giminiani et al., 2012). Participants were exposed to a vertical sinusoidal WBV of 40Hz (8mm peak-to-peak displacement) (Cloak et al., 2014) (NEMES-Bosco, Italy). The WBV group completed 3 x 60 seconds with 60 seconds rest between trials as previously used in acute WBV setting in athletic populations to elicit high power output (Bullock et al., 2008), and the control group performed an identical warm up, however the squat was performed in the absence of vibration.

### Self-report measures of perceived benefit of treatment

A self-report measure was developed specifically to assess perceived benefits of the different treatments amongst players. Participants used a 9-point scale anchored by 1 "not at all" to 9 "very well" in response to the question "To what extent do you think your treatment helped you perform today?" post intervention. This approach to assessing self-reported measure of performance has been used in previous research (Lane et al., 2002) and offers a simple method of developing bespoke measure albeit one where the inherent subjectivity in responses represents a challenge. It is suggested that self-report measures be used as estimates of performance and should not be treated as directly observable concepts (Nisbett and Wilson, 1977).

### Statistical analysis

Independent sample t-tests were used to identify baseline knee isometric peak force differences between professional and amateur players. Knee isometric peak force (N) and muscle activation were analysed using a three-way ANOVA with repeated measures. The two between-subject factors were 'playing level' (professional vs. amateur) and 'treatment' (vibration vs. control) whilst the within-subject factor was 'time' (pre vs. post-intervention). A univariate ANOVA was used to investigate differences post treatments in PAP and perceived benefits of intervention amongst groups (between-subject factors were 'playing level' and 'treatment'). Statistical significance was set at $p < 0.05$. Further, effect sizes (Partial Eta$^2$ ) were calculated and interpreted based on the criteria of Cohen (1992) where 0.1 is a small effect, 0.25 is a medium effect and 0.4 is a large effect. An intraclass correlation (ICC), was employed to determine the inter-session reliability (Shrout and Fleiss, 1979). Test-retest reliability was assessed by comparing the mean of the dependent variables between testing sessions (familiarisation and test day). The ICC test—retest reliability of knee isometric peak force (r = 0.962) and muscle activation ($r$ = 0.943) was significant (p < 0.001), indicating little variability and thus a high degree of consistency attained between testing sessions. The Shapiro-Wilk statistic for each condition confirmed that the data were normally distributed. All statistical procedures were conducted using SPSS 20 (SPSS Inc., Chicago, IL, USA).

## Results

### Twitch interpolation analysis

Repeated ANOVA of knee isometric peak force identified a significant 3-way 'playing level'-by-'treatment'-by-'time interaction ($F_{1, 40}$=11.09; p = 0.002, *Partial Eta*$^2$ = 0.217), As can be seen in Table 1, knee isometric peak force increased (10.6%) from pre-test to post-test in the professional WBV group, whereas there was a slight decrease in the amateur WBV group (-3.8%). Therefore, as illustrated in Figure 2, WBV had a significant effect on knee isometric peak force amongst professional players only. There were no significant main or interaction effects of muscle activation identified by the repeated ANOVA's (p =0.259).

Univariate ANOVA of PAP identified a significant 'playing level'-by-'treatment' interaction ($F_{1, 43}$=7.69; p =0.008, *Partial Eta*$^2$ = 0.161), with PAP amongst WBV professional players being 8.1% (±5.4) and -4.2% (±4.2) amongst amateur players (Table 1). An independent sample t-test indicated a significant (p = 0.02) difference in pre knee isometric peak force (N) between all professional (427.2 ± 197.4) and amateur players (317.1 ± 38.7). Finally, a univariate ANOVA of perception of benefit of intervention used on the day identified a significant 'playing level'-by-'treatment' interaction ($F_{1, 43}$=14.56; p < 0.001, *Partial Eta*$^2$ = 0.267). With perceived benefits of intervention amongst WBV professional players being mean scores of 8 ± 1.2 and 5.9 ± 1.1 amongst amateur players.

## Discussion

The aim of this study was to compare the effect of acute WBV on peak isometric force, muscle activation and PAP between professional and amateur soccer players. We also looked to investigate the perceived benefits of acute WBV across the different populations (professional and amateur). The results of the present investigation indicate acute WBV significantly improves peak knee isometric force with the presence of PAP amongst professional players in comparison to amateur counterparts; the latter

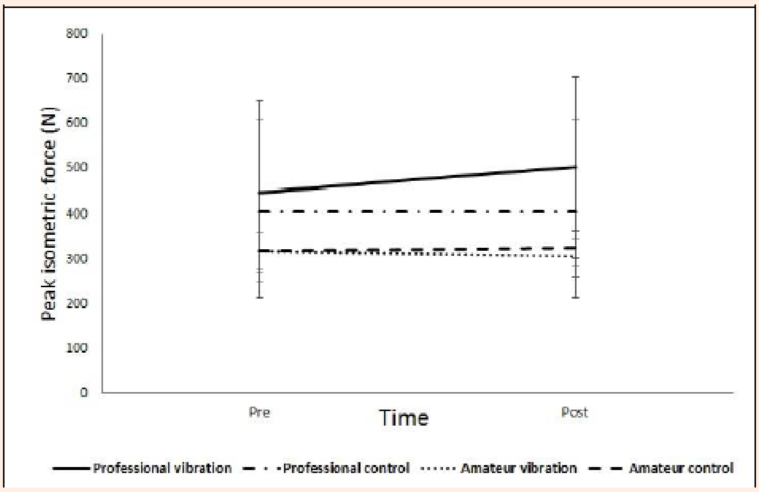


**Figure 2. Peak isometric force 'playing level'-by-'treatment'-by-'time interaction.**

showed no significant improvement in peak knee isometric force or the presence of PAP. The professional players reported a significantly more positive perception of acute WBV as a beneficial intervention in comparison to amateur players. Finally, neither professional nor amateur players showed any significant changes in muscle activation following acute WBV.

It has been previously reported that acute whole body vibration has a positive effect on performance with it being considered as a possible warm-up tool (Cochrane, 2013). One of the proposed mechanisms of improvement in performance is an increase in muscle activation via neurogenic potentiation based on the tonic vibration reflex (Rittweger et al., 2003). Our results showed improvements in knee isometric peak force and PAP amongst professional players following acute WBV compared to amateur players. The results suggest some key findings; firstly the increase in knee isometric peak force appears to be related to PAP rather than increased muscle activation. The results are in line with the findings of Cochrane et al. (2010), who also reported peak knee isometric force improvements following acute WBV. It would appear that the improvement in muscle RTF suggests phosphorylation of myosin regulatory light chains making contractile proteins more sensitive to the intracellular $Ca^{2+}$ signal (Sweeney et al., 1993). This would result in greater cross-bridge interaction for the same intracellular $Ca^{2+}$ concentration, which in turn increases the muscle tension for the same absolute level of neural stimulus (Szczesna et al., 2002). Although myosin light chain phosphorylation was not assessed the improved force output (with no change in overall muscle activation levels) does suggest a strong non-neurogenic component, as previously suggested by Cochrane et al. (2010).

Another possible reason for no significant change in overall muscle activation but an increase in knee isometric peak force, is the type of muscle fibres activated following acute WBV. Rittweger et al. (2003) suggests neuromuscular improvements after vibration exercise is most likely due to an enhanced excitability of fast twitch fibres and motor units. Pollock et al. (2012) suggests a combination of larger motor unit stimulation (and a reduction of fast-twitch fibre thresholds following WBV), an account that would explain no change in overall activation but a significant shift in fibre type recruitment within the current findings. The magnitude of the RTF after a conditioning contraction is a good representation of the activation of fast-twitch fibres during the conditioning contraction (Sasaki et al., 2012). The significant difference in pre-intervention knee isometric peak force score (N) between professional and amateur players illustrates the difference in strength profiles, with professional players displaying higher knee isometric force capabilities. It has been previously noted professional soccer players report significantly higher strength and speed characteristics (including isometric forces) compared to amateur players (Gissis et al., 2006). It has also been well documented that stronger individuals exhibit elevated myosin chain phosphorylation and tend to have larger/stronger type II fibres (Smith and Fry, 2007; Tillin and Bishop, 2009),

**Table 1. Mean (and ±SD) changes in isometric peak force, muscle activation, perceived benefits and PAP amongst playing level (professional v amateur) and treatment group (WBV v control).**

| | Pre isometric peak force (N) | Post isometric peak force (N) | Pre activation % | Post activation % | Perceived benefit | PAP % |
|---|---|---|---|---|---|---|
| **Professional WBV (n=11)** | 448.3 (202.3) | 501.3 (199.8) * | 84.6 (8.7) | 87.3 (5.0) | 8 (1.2) * | 8.1 (5.4) * |
| **Professional control (n=11)** | 406.2 (199.8) | 406.7 (193.2) | 86.5 (3.3) | 85.5 (4.6) | 6.3 (1.7) | 2.5 (5.3) |
| **Amateur WBV (n=11)** | 316.3 (41.4 | 304.8 (45.4) | 84.6 (8.7) | 84.3 (4.9) | 5.9 (1.1) | -4.2 (4.2) |
| **Amateur control (n=11)** | 318 (37.8) | 323.4 (40.2) | 82.1 (3.2) | 82.3 (2.3) | 7.1 (1.0) | -1.5 (4.6) |

* Indicates significant difference ($p < 0.05$)

which have been proposed as a major factor in differences in potentiation effect between stronger and weaker athletes following a conditioning activity (Chiu et al., 2003; Seitz et al., 2014; Seitz and Haff, 2015). The standardised rest period following treatment (<6 min) may also have not been long enough for residual fatigue to subside and potentiation to effect power output in amateur/weaker athletes (Chiu et al., 2003; Seitz et al., 2014). Seitz et al. (2014) suggest that given the relationship between strength, PAP and fatigue, the stronger/better conditioned individuals may dissipate the residual fatigue quicker following a conditioning activity and therefore express PAP earlier as our results suggest. In order to validate this hypothesis further research which assesses the athletes over multiple time points is warranted.

Population differences may help to explain the disparity within WBV research. Yeung et al. (2014) identified no significant change in potentiation or peak force output of the knee extensors following an acute bout of WBV. However, it is acknowledged by the researchers that over a third of their participants did no regular exercise (37% n = 10) with none of the participants training regularly with a team or club (Yeung et al., 2014). Hannah et al. (2013) also reported no improvements in thigh muscle neuromuscular responses following acute WBV in fourteen healthy, recreationally active males not involved in systematic strength or power training. As with other studies investigating PAP it would appear that starting strength is an important factor when performing pre-conditioning activity (Chiu et al., 2003; Seitz et al., 2014; Seitz and Haff, 2015). It could be argued from the present set of results that this is also true when the pre-conditioning activity is WBV and not just traditional resistance exercise. Bullock et al. (2008) discusses the idea that muscle tendon complex of professional athletes are conditioned to minimize changes in muscle length and to damp vibrations and resist high-impact load; therefore higher WBV loads (>40Hz 8mm peak-to-peak displacement) potentially elicit a more positive response amongst well trained individuals (Issurin and Tenenbaum, 1999; Lovell et al., 2013; Rønnestad et al., 20009; 2013). Knee extensor isometric peak force is one of a number of strength profiling tests that could be used to assess initial strength levels between playing levels (Gissis et al., 2006). However, comparisons within the literature are difficult due to differing methodologies and testing set-ups, and its relation to soccer performance has been questioned (Requena et al., 2009). For a clearer understanding of how initial strength level impacts upon the effects of acute WBV a number of strength diagnostic tests should be included in future.

In the present study, results show that amateur players reported significantly lower scores on the perceived benefit scale from the acute WBV than professional players. Rønnestad et al. (2013) used self-report measures following acute WBV and elite ice-hockey players reported their legs feeling "good" following treatment as opposed to "normal" amongst controls prior to a subsequent significant improvement in 10 and 20m on-ice sprint performance. However, a limitation of the approach used in the present study was that beliefs were not manipulated positively (placebo treatment) and negatively (placebo treatment)(Beedie and Foad, 2009). However, the order of treatment and the control conditions were randomised and no information about potential effects of the vibration treatment was given to the participants. What is clear is that the amateur athletes did not perceive the WBV as beneficial as cycling alone, whereas the professional players did. The findings for amateur players might be linked to current training status and subsequent fatigue. As would be expected, elite players trained for more hours than amateur players. Therefore, it is plausible that among amateur players the load may have been too high and caused sensations of fatigue, as previously suggested (Marin et al., 2015). However, this was not assessed through further questioning.

In contrast, professional players perceived acute WBV as beneficial; the athlete's perceived benefit, and convincing beliefs, can have an incremental effect on performance (Beedie and Foad, 2009). The incorporation of novel equipment to a task has also been seen to improve interest and enjoyment and motivation during training (Fitzgerald et al., 2010) . Marin et al., (2015) suggests lower frequencies (30Hz) may be perceived as more enjoyable amongst untrained and amateur athletes due to lower RPE and suggests it should be used to increase compliance and adherence. Perceptions of benefits of acute WBV interventions have received little attention in the literature. However, it would appear it may be an important issue when prescribing for different populations. If beliefs influence the initial success experience when using an intervention, this is likely to raise confidence and beliefs further that it is effective and, therefore, the intervention acts as a self-efficacy intervention (Beedie and Foad, 2009).

## Conclusion

The current research is the first to our knowledge to demonstrate a significant neuromuscular difference in responses to acute WBV between professional and amateur soccer players. Although the exact mechanism for the increase in PAP and knee extensor peak force amongst the professional players is yet to be confirmed, the effect appears to be mediated by initial strength levels and possibly vibration frequency used. One limitation of the present research is the time course of any neuromuscular benefit. MacIntosh et al. (2012) discusses the lack of research looking at how long the benefits of PAP last and the practical application to prolonged athletic activity such as game play. Future research should focus on how the current protocol impacts on ultimate match performance either as a warm-up or half-time strategy, and whether a more in depth strength profile of each player would provide more information to differentiate how players respond to WBV. The difference in perceived benefits between professional and amateur players also highlights the need for future research to investigate the role of athlete perceptions of WBV benefits, as there appears to be a significant difference between athletic populations.

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## Key points

- Acute WBV improves knee extensor peak isometric force output and PAP amongst professional and not amateur soccer players
- Professional players perceived acute WBV as more beneficial to performance than amateur players
- Isometric strength, vibration intensity and duration appear to influence results amongst players of different playing levels

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Appendix 6

**R. Cloak**, A. M. Nevill, F. Clarke, S. Day, M. A. Wyon (2010) Vibration Training Improves Balance in Unstable Ankles. *International Journal of Sports Medicine*, 31(12), pp. 894-900.

This is to declare that, as co-author of the above scientific paper, **Ross Cloak:**

- Initiated the project and has intellectual ownership

- Formulated the study's experimental design, aims and methodology

- Collected and compiled the data

- Performed the statistical analysis with cooperation from the co-authors

- Wrote up the manuscript, taking in to account comments from the co-authors

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**R. Cloak**, A. M. Nevill, S. Day, M. A. Wyon (2013) Six-Week Combined Vibration and Wobble Board Training on Balance and Stability in Footballers With Functional Ankle Instability. *Clinical Journal of Sport Medicine*, 23(5), pp. 384-391.

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**R. Cloak**, A. M. Nevill, J. Smith, M. A. Wyon (2014) The acute effects of vibration stimulus following FIFA 11+ on agility and reactive strength in collegiate soccer players. *Journal of Sport and Health Science,* 3(4), pp. 293-298

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