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The Immediate Influence of Whole Body Vibration on Proprioceptive Precision

Sean Madill
Utah State University

THE IMMEDIATE INFLUENCE OF WHOLE BODY VIBRATION ON PROPRIOCEPTIVE PRECISION

by

Sean Madill

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Approved:

Chris Dakin, Ph.D. Major Professor	David Bolton, Ph.D. Committee Member
Eadric Bressel, Ph.D. Committee Member	Mark R. McLellan, Ph.D. Vice President for Research and Dean of the School of Graduate Studies

UTAH STATE UNIVERSITY
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Abstract

As our bodies are exposed to whole-body vibration inertial and strain sensitive sensory receptors throughout our body are activated. The information relayed from these receptors to the central nervous system and brain is used to analyze our environment and coordinate movement. The aim of this study was to investigate whether extended duration whole-body vibration influences sensory adaptation and coordinated movement, specifically our joint position acuity immediately following vibration exposure. Twenty-five adults completed a between ankle joint matching task before and immediately following a 20-minute whole-body vibration session and a control session of 20 minutes of standing near, but not on the vibration plate. The joint matching task consisted of moving the participants left ankle to one of four selected angles (10°, 15°, 20°, 25°), having them hold it at that position and match the angle with their right ankle. The foot was positioned at each angle three times to total 12 trials to complete the matching task. The set joint angle and "matched" joint angles were measured using digital goniometers. There was a significant interaction and differences in baseline measurements between control and vibration sessions masking any joint matching acuity changes that may have arisen from whole body vibration exposure.

Introduction

We regularly expose our bodies to vibration through the activities of our daily life, which can have harmful consequences such as loss of balance, bowel problems and postural fatigue (Paschold & Mayton, 2011). Repeated exposures and prolonged periods of whole body vibration (WBV) are common to many occupations, such as operators of mining equipment, long haul truck drivers or other heavy construction equipment operators, and often with negative consequences to the employee's health (Paschold & Mayton, 2011). Workers in these occupations frequently report both low-back pain and loss of balance related to extended WBV exposure (Ahuja, Davis & Wade, 2005; Oullier et al., 2009). However, the effects of vibration may be circumstance dependent. In health clubs and clinics short bouts of artificial WBV from vibrating platforms are used as a physical training and rehabilitation tool, particularly in elderly and at-risk populations (Bruyere et al., 2005; Hiroshige, Mahbub & Harada, 2014). Several studies have shown that when WBV characteristics are carefully controlled (i.e., amplitude, frequency, and duration) an array of medium and long-term benefits including improved balance, increased muscle strength and increased bone density may be observed (Cardinale & Wakeling, 2005; Lam, Lau, Chung & Pang, 2012; Slatkovska, Alibhai, Beyene & Cheung, 2010).

During WBV, the mechanical stimulus propagates up from the vibrating surface through the feet or trunk of the person (Bressel, Smith & Branscomb, 2010). The stimulus radiates through the tissues and joints, stimulating inertial and strain sensitive sensory receptors present within the skin, muscles, joints, and, potentially, the inner ear (the vestibular system) (Cordo, Gurfinkel, Bevan & Kerr, 1995; Craske, 1977; Li, Lamis & Wilson, 2008). Since our brain uses this information to make inferences about our external and internal environment to coordinate movement, the prudent response of the brain may be to try to place less importance on the information arising from such noisy senses. Mechanistically, this could result in the brain 'tuning out' information arising from these receptors or adaptive reduction of the noisy receptor's responsiveness (Cardinale & Wakeling, 2005; Macefield, Hagbarth, Gorman, Gandevia & Burke, 1991; Pollock, Provan, Martin & Newham, 2011; Sonza, Maurer, Achaval, Zaro & Nigg, 2013).

Indeed, prolonged stimulation can depress the responsiveness of sensory receptors throughout the body, reducing the information they convey to the CNS (Li et al., 2008; Oullier et al., 2008; Pierrot-Deseilligny & Burke 2005; Pollock et al., 2011). For example, cutaneous sensation in the lower limbs decreases following bouts of WBV as short as 10 minutes (Sonza et al., 2013) and muscle length receptor (muscle spindles) activity decreases as the duration of stimulation increases (Macefield et al., 1991). In addition, proprioceptive (body position sense) acuity decreases following the vibration of the whole body or localized vibration of muscle tendons (Craske, 1977; Cordo et al., 1995; Li et al., 2008). For example, Li et al. (2008) exposed subjects to 20 minutes of WBV and found increases in position sense errors of the trunk when compared to non-exposed subjects. They suggested that this sensory depression is due to an increase in the activation threshold of muscle spindles following periods of extended stimulation. More recently, Pollock et al. (2011) exposed subjects to five 1-minute bouts of WBV with 30 seconds of rest in-between and observed no differences in joint position sense in the lower limbs. The discrepancy between these results may indicate that the duration of the exposure to vibration plays an important role in the attenuation of position sense. If true, extended exposure to WBV may lead to a reduction in the responsiveness of our sensory receptors and those behaviors dependent on the information arising from them, such as joint position sense.

The aim of this study was to examine the sensory-motor impairment associated with an intermediate duration (between short < 10 minutes clinical type and long > 1hour occupational type) WBV exposure. To investigate this aim, pre- and post-treatment joint position sense was measured to determine if WBV had a detrimental effect. I hypothesized that adaptations resulting from extended duration WBV would reduce joint position sense acuity leading to greater error in the estimation of joint position.

Methods

Participants

Pilot data was gathered on 10 participants who completed a 20-minute vibration session with pre- and post-test measures of joint matching acuity. A power analysis was run on the absolute angle error scores combined across all angles which suggested that an experimental population of 25 subjects would be sufficient to reject the null hypothesis with 80% power (G*Power 3.1). Twenty-five subjects (11 male, 14 female; 24.2 ± 6.0 years; 171.3 ± 11.2 cm; 71.6 ± 17.0 kg) were recruited and participated in a within-subject experimental design with each subject participating in both the control and treatment groups, in order to compare pre- and post-treatment performance. Prior to testing, participants completed written informed consent as per the requirements of Utah State University's Institutional Review Board. The informed consent form detailed the study's methodology and any risks posed to the participant. Participants also completed a basic demographic information (age, gender, weight, height) questionnaire and the Physical Activity Readiness Questionnaire (PAR-Q). Any individuals with recent history of neurological impairment or musculoskeletal dysfunction were excluded. This study was approved by Utah State University's Institutional Review Board (Protocol # 7933).

Procedures

Participants completed a pre- and post-treatment joint matching task in order to determine the precision with which they could match the position of their limbs, before and after WBV. Prior to testing, participants were randomly assigned to complete either the control (no vibration) or treatment (vibration) protocol first. Participants completed the remaining protocol during their second visit. To perform the joint matching task, participants sat barefoot with their lower legs hanging freely and their vision occluded by a curtain to prevent visual feedback of the orientation of the feet during completion of the joint matching task. For these tasks, the researcher moved the participant’s left foot to one of four randomly selected angles (10°, 15°, 20°, 25°) from neutral position (0° dorsi flexion) after which the participant was asked to maintain the angle of their left foot while attempting to match it with their right foot. Each of the four angles was measured three times to complete the matching task.

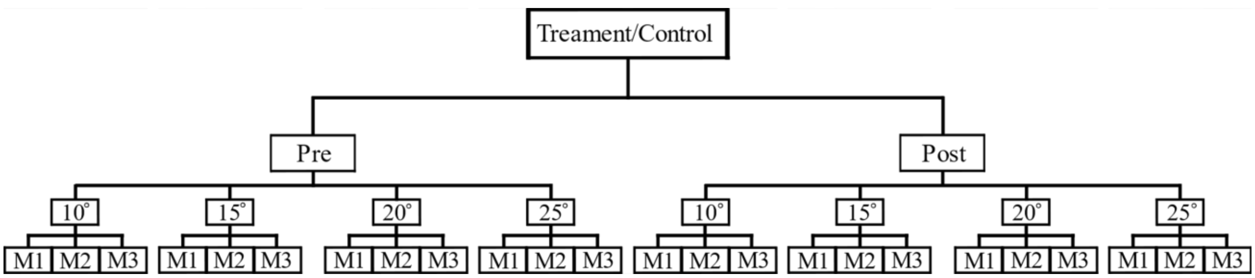

Figure 1. Flowchart showing the organization of the joint matching task procedure. The first second and third measurements taken at each angle are designated by M1, M2 & M3, respectively.

The ankle angle of both limbs during the joint matching task was measured using a digital goniometer (Ergotest Innovation a.s., MuscleLab 4020e, Porsgrunn, Norway) placed on the back of the leg and heel, according to manufacturer’s recommendations. Those in the vibration session then completed 20 minutes of standing WBV, while those in the control session stood near the vibrator for 20 minutes. During both sessions participants were asked to stand barefoot with their feet hip-width apart with a slight bend in the knees and weight distributed evenly between their heels and toes. The vibration platform (NEMES DV-B, Boscosystem Technologies S.R.L., Rieti, Italy) was set to a vibration frequency of 30Hz with an amplitude of 1-2mm, which was verified using a tri-axial accelerometer (Model # 2460-050, Silicon Designs Inc., Kirkland, WA, USA).

This frequency setting was selected because previous works have shown that vibration frequencies between 20 and 40 Hz allow participants to remain in a moderate state of comfort while still eliciting proprioceptive alterations (Santos et al., 2008; Sonza et al., 2013). Immediately following the treatment period, participants were asked to sit on a bench placed just behind them to ensure that they did not take a step in the process of sitting. Once sitting they completed another set of 12 joint matching trials with their legs hanging freely and vision occluded. Since participants served as their own controls they were asked to return to the lab, no sooner than 24 hours, to complete either their control or treatment session, whichever was not done in the previous session.

Analysis

Bilateral ankle angle error (difference between left and right feet when "matched") was measured during the matching task to quantify the bias and variance observed between the pre-test and the post-test. Pre-test - post-test ankle angle at each of the set angles (10°, 15°, 20° & 25°) were compared to determine if there was a significant difference at any particular angle. The scores were then combined across all angles to provide a single pre or post-test bilateral error score. To assess within-subject differences a 2 x 2 (pre/post x treatment) repeated measures ANOVA was performed in SPSS 24.0 for Windows (IBM Corp., Armonk, NY). Significance levels were set at $p = 0.05$ for the ANOVA. The main effect of *treatment* was decomposed using pairwise comparison. To control for multiple comparisons Bonferroni corrections were made by multiplying the p-value by the number of comparisons, which meant the significance level for the pairwise comparisons was set at $p = 0.05$.

One participant (subject #22) was removed from all analyses because several of their scores fell into the outlier and extreme outlier categories based on the greater than 1.5 x interquartile range and greater than 3 x interquartile range method used by SPSS (Figure 2).

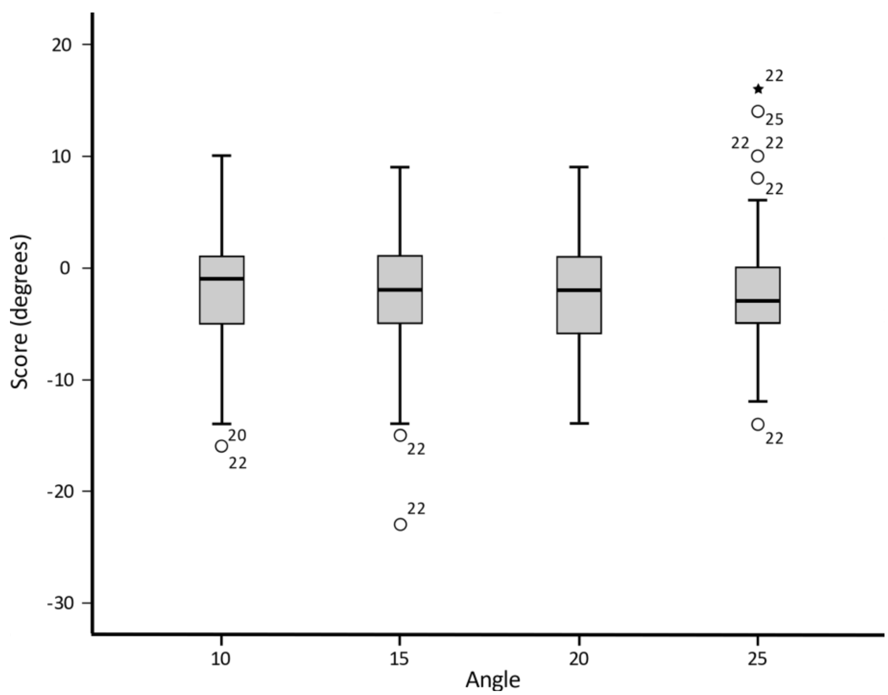

Figure 2. Shows the joint matching angle error scores for all subjects across pre and post conditions and vibration and control treatments. The x-axis represents the angles at which the ankles were set, and the y-axis represents the error score between ankles when “matched”. The box includes the interquartile range with the dark line representing the median. The whiskers extend to 1.5 times the interquartile range (height of the box) or to the minimum/maximum values. The numbers (20, 22 & 25) represent the participant identification number associated with the outlier (O) or extreme outlier (★) data points.

Results

Twenty-four participants completed both treatment sessions. The control group's period of prolonged standing elicited a decrease in bilateral error from 4.36° ± 2.59° to 3.52° ± 2.31° from pre- to post-test, respectively. Whilst in the treatment group, vibration led to joint angle error increases from the pre- to post-test conditions, 3.12° ± 2.02° and 3.78° ± 2.01°, respectively. A pairwise comparison indicated a significant *treatment* effect from pre- to post-test in the control group ($t_{(23)} = 2.24$, $p = 0.0$), but not in the treatment group ($t_{(23)} = -1.98$, $p = 0.06$). Further, the Cohen's effect size values for these were $d = .34$ and $d = .32$, respectively, suggesting a low to moderate significance.

Table 1. Pre- & post-test absolute error angle means and standard deviations for all participants at each testing angle across the vibration and control sessions. Significant differences ($p < 0.05$) between vibration and control are identified by * and between pre/post conditions by **†**, with subscripts designating the values being compared (e.g. the condition indicated by subscript 1 was compared with the other condition with the same subscript).

		10°	15°	20°	25°	Average
Vibration	Pre	3.35 ± 2.41	2.94 ± 1.87	3.24 ± 2.14*$_{1,2}$	2.97 ± 1.66*$_{4}$	3.12 ± 2.02
	Post	3.87 ± 2.31	3.90 ± 2.42	4.08 ± 1.92**†**$_{2}$	3.26 ± 1.39	3.78 ± 2.01
Control	Pre	3.87 ± 2.32	4.00 ± 2.70	4.92 ± 2.80$_{1,3}$	4.68 ± 2.56$_{4,5}$	4.36 ± 2.59
	Post	3.43 ± 2.65	3.36 ± 2.46	3.96 ± 1.98**†**$_{3}$	3.32 ± 2.18**†**$_{5}$	3.52 ± 2.31

Freely standing for 20 minutes significantly decreased the average between limb error score in the control session, while 20 minutes of vibration had a non-significant tendency to increase the average between limb error scores from pre- to post-test conditions in the vibration session (Figure 3). The differences at baseline and oppositely directed responses to standing and vibration resulted in a significant *treatment* by *condition* interaction ($F_{(1,1125)} = 20.80$, $p < .001$) (see Figure 3) with the control group's error decreasing and the treatment group's error increasing. There was also a statistically significant difference between subjects pre-test absolute angle error scores when comparing the control session to the treatment session ($t_{(23)} = 2.32$, $p = .01$).

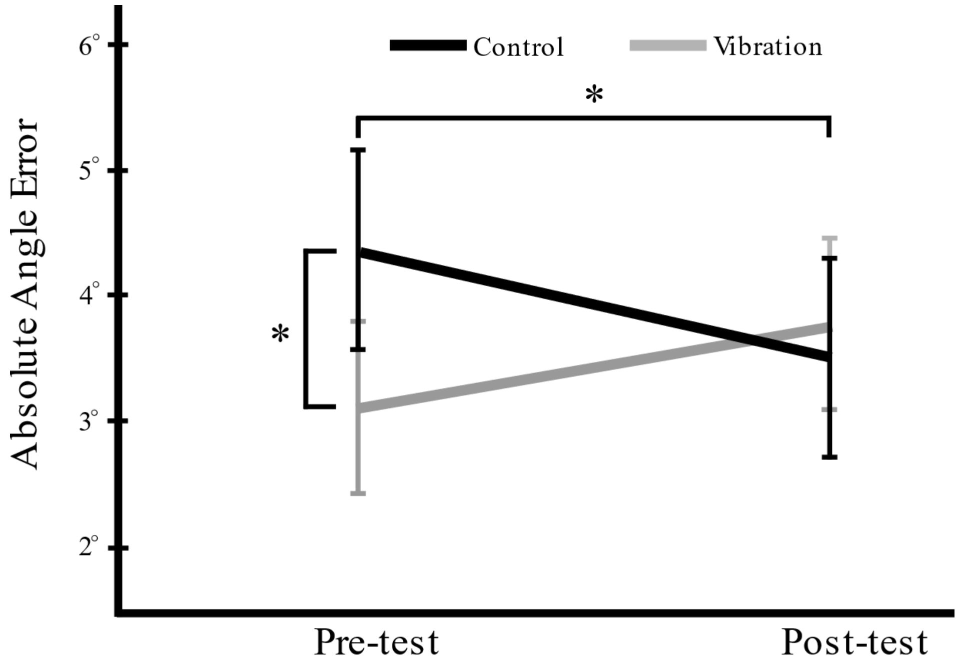

Figure 3. The average absolute angle error scores for all subjects averaged across the four test angles of the pre- and post-test during the control and vibration sessions. The error bars represent 95% confidence intervals for each condition centered on the condition's mean. The * represents statistical significance with the p-value set at $p < 0.05$.

Discussion

The purpose of the present study was to examine whether WBV exposure for an intermediate duration of 20-minutes would alter proprioceptive precision during an ankle joint matching task. The differences in the baseline data and the criss-cross *interaction* from pre- to post-tests in the vibration and standing sessions make it difficult to draw any conclusions as to whether vibration influenced joint position sense.

Previous studies have suggested that WBV exposure has adverse effects on proprioceptive precision and sensory acuity (Ahuja et al., 2005; Cordo et al., 1995; Oullier et al., 2009). However, several studies have also reported no change in proprioceptive precision following WBV exposure (Pollock et al., 2011; Santos et al., 2008). These inconsistencies may be explained by differences in the parameters of the vibratory stimuli used during these studies. Cornelius et al. (1994) suggested that with changes in the duration and/or direction/pattern of the stimuli there is potential that the bodies sensory-motor systems would produce different results. Additionally, a single acute bout of vibration exposure may elicit changes in postural sway, cutaneous sensation or joint position sense that may be different from those elicited by one extended bout or several exposures over time (Cornelius et al., 1994; Ahuja et al., 2005). These observations suggest several factors, such as vibration duration and direction, may be responsible for the different changes in motor behavior reported following WBV.

Previous studies evaluating the effects of WBV on proprioceptive precision have yet to clarify whether the duration of exposure to WBV contributes to transient alterations in the function of the central nervous system. Long duration exposure is common to many occupations such as operators of buses, forklifts, tractors, mining equipment and other construction vehicles. It has been suggested that extended vibration exposure can lead to a loss of balance or motor coordination errors (Ahuja et al, 2005; Oullier et al., 2009) which increases the likelihood of incurring a fall-related injury or fatality during egress from non-moving vehicles (Ahuja et al., 2005; Paschold, 2008). Several studies simulating occupation related vibration exposure have confirmed this theory, reporting larger center-of-pressure or postural sway areas following extended duration WBV (Ahuja et al., 2005; Oullier et al., 2009). Ahuja et al. (2005) exposed subjects to three driving sessions of 2.5-hours each, simulating long-haul truck driving, and reported cumulative increases in postural sway area following each session. Their results suggest that not only is duration of the exposure a factor in sensory-motor impairment, but repetition of exposure. In a similar study, bulldozer trainees were reported as having greater postural sway area following a single 2-hour work session (Oullier et al., 2009). While the current study did not investigate postural sway measures, joint position sense, particularly in the lower limbs, plays an important role in postural sway (Hansson, Beckman & Hakansson, 2010), as a loss in joint position sense may lead to changes in postural sway (van Deursen, Sanchez, Ulbrecht & Cavanagh, 1998). With the much shorter exposure time (20-minutes) in the current study, the vibration treatment showed to have little or no difference from the standing control when comparing post-test joint position sense errors. Similarly, Hiroshige and colleagues, found no change in joint position sense or postural sway following an 8-week program with 3-minutes of vibration exposure 2 x/week. Pollock et al. (2011) also confirmed that shorter duration exposure had little to no effect on joint position sense or postural sway with a total vibration exposure time of 5 minutes. These reports suggest that there may be a threshold somewhere between 20-minutes and 2-hours of vibration exposure where sensory-motor impairment deficits begin to manifest.

Current studies have been inconclusive as to whether the direction of the vibratory stimulus also plays a role in altering proprioceptive precision. Two studies examined random pattern tri-axial WBV in simulated long-haul truck driving and bulldozer operating settings and found alterations in postural sway (Ahuja et al., 2005; Oullier et al., 2008). While, a third study, with similar tri-axial vibration, showed no significant differences in postural stability after vibration exposure (Cornelius et al., 1994). Two studies using a different seesaw-like vibration pattern reported no change in postural sway or joint position sense (Hiroshige et al., 2014), though Pollock et al. (2011) did report long-lasting reductions in cutaneous sensation of the plantar surface of the foot, which also plays an important role in postural stability (Roll, Kavounoudias & Roll, 2002). The direction of vibration in the current study was primarily in the horizontal plane, making comparisons to previous works difficult.

One of the primary mechanisms that vibration could potentially alter proprioceptive precision is through stimulation of the muscle spindles (Burke, Hagbarth, Lofstedt & Wallin, 1976). Muscle spindle's Ia afferents relay information about imposed changes in length of their parent muscle to the central nervous system. Because changes in muscle length are associated with changes in joint angle, muscle spindles can also relay limb position sense to the CNS (Kandel, Schwartz, & Jessell, 2000). Muscle spindle Ia afferents can be strongly influenced by vibration stimuli, with some firing at a rate of up to a 1:1 ratio with the stimuli (Cordo et al., 1995; Burke et al., 1976; Fallon & Macefield, 2007). When the afferent discharge is driven by the vibration stimuli muscle length changes may be masked or biased, leading to proprioceptive errors (Ribot-Ciscar, Roll, Tardy-Gervet & Harlay, 1996; Wierzbicka et al. 1998). Another potential mechanism for joint position accuracy is in the activity of cutaneous receptors relaying information regarding touch sensitivity or stretch imposed on the skin. Long-lasting (up to 60 minutes) reductions in cutaneous sensitivity were reported following a relatively short (5-10 minutes) WBV exposure (Pollock et al., 2011; Sonza et al., 2013). Muller & Brandes (2015) reported throwing accuracy deficits in amateur handball players with the application of kinesiotape when compared to controls with no tape application, suggesting altered cutaneous stimulation, resulting from the application of tape, may alter limb position sense.

There are a few limitations that should be considered when evaluating the results of the current study. First, in some individuals, the between-limb joint matching task accuracy could be reduced because of our choice to compare between limbs rather than within. The errors we observed at trial onset may be due to poor bilateral motor accuracy (accuracy between limbs) rather than vibration-induced sensory errors (McCormick, Zalucki, Hudson & Moseley, 2007; Sousa, Leite, Costa & Santos, 2017). Second, the treatment was known to the participants prior to the administration of the joint matching pre-test, which may have led to psychological or anxiety related performance differences (Eysenck, Derakshan, Santos & Calvo, 2007; Lawrence, Khan & Hardy, 2013). In a study by Hjortskov and colleagues (2005), stretch reflex responsiveness was shown to be enhanced during activities (handgrip exercise, post-handgrip ischemia, & mental arithmetic) that activated sympathetic outflow. This enhancement in stretch reflex responsiveness with increased sympathetic drive may help explain why the vibration treatment group had smaller errors in the pre-test joint matching task compared to the control, in the current study. Third, the joint matching task involves both sensory input and motor output, therefore, it is difficult to distinguish whether alterations in proprioceptive precision are a result of sensory input or motor output impairments.

In conclusion, because of the large difference between control and treatment groups at baseline and the presence of an interaction it is difficult to say whether vibration altered proprioceptive precision as a result of the WBV exposure. For future works it would be suggested to do a within-limb joint matching task to reduce both subject and equipment error associated with between-limb measurements. Additionally, ensuring that the participants are blinded to the treatment until after the completion of the baseline measurements or completing baseline measurements during a separate visit will aid in reducing anxiety related performance differences. Finally, pairing the joint matching task with a sensory task (i.e., monofilament test) would allow for distinguishing whether WBV related changes took place within the sensory input or motor output systems.

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