EFFECTS OF INSTRUMENT-ASSISTED SOFT TISSUE MOBILIZATION ON ISOKINETIC KNEE EXTENSOR STRENGTH AND FATIGUE

By

DANIEL ROMERO

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Sacramento State University

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Thesis Approved:

Matthew O'Brien

Thesis Adviser

Doug Smith

Aric Warren

Name: DANIEL ROMERO

Date of Degree: MAY, 2014

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Abstract: Strength is one characteristic that most athletes focus on improving as it is a critical element for success. It is believed that some micro-tearing of the muscle tissue occurs daily in routine activities and during regular exercise. Any restriction or imbalance within the musculoskeletal structure can affect optimal range of motion which then can affect the quality of force production, force application, and movement efficacy. Nontraditional treatments are beginning to be investigated to examine their effects on strength and a few techniques are slowly gaining popularity are the Graston Technique (GT) and Whole Body Vibration (WBV). Clinicians might apply the GT before practice or competition to break down adhesions to allow the muscle to function freely or use WBV to stimulate the neuromuscular system. However, the use of the GT or WBV may possibly leave the athlete susceptible to injury if strength is diminished in the process. PURPOSE: The purpose of this study is to address the potential acute effects of the GT and WBV on peak isokinetic torque and fatigue of the quadriceps during maximal voluntary contraction. The secondary purpose is to compare the individual effects between the GT and WBV on strength and fatigue following an acute exercise protocol. METHODS: Subjects were randomly selected into three groups: the GT, WBV and control. Each subject completed their group protocol a week after the pre-test. Peak isokinetic torque, total work and work fatigue values were collected pre-test and post-test using the Thorstennson protocol on the Biodex dynamometer 4.0. Following data collection, independent sample t-tests and a one-way ANOVA were performed on SPSS Statistics to analyze the data. RESULTS: Peak isokinetic torque and work fatigue decreased following each intervention. There was no significant difference between pre-test and post-test or between groups. Total work only increased in the GT but not significantly when compared to the WBV and control group. CONCLUSION: Based on the results, it is safe to assume that the GT and WBV is not better or worse than resting for 5 minutes before practice or competition when it comes to strength and fatigue.

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INTRODUCTION

A sports medicine team is continuously searching for methods to improve athletes' peak performance. Strength is one performance characteristic that most athletes focus on improving as it is an important factor in the normal function of joints and during strenuous activities.[1] The ability of the neuromuscular system to produce internal tension to overcome an external load is called strength.[2] Clinicians use various techniques to treat and prevent injuries in order to maintain certain performance such as strength.[3,4] These techniques have also been tested as exercise modalities to enhance strength and other performance characteristics.[5] Even though traditional treatments have proven to be effective, research is ongoing in an attempt to identify ways to improve factors of strength.[6] As stated, nontraditional treatments are beginning to be investigated to examine their benefits in strength gains and a modality that is slowly gaining popularity is the Graston Technique (GT).[7]

The GT is referred to as Instrument-Assisted Soft Tissue Mobilization (IASTM).[8] It is believed that some micro-tearing of the muscle tissue occurs daily in routine activities and during regular exercise.[9] Even though traditional treatments have proven to be effective, research is ongoing in an attempt to identify ways to improve factors of performance including strength.[10] Studies have shown the GT to be useful in breaking down scar tissue adhesions and relieving pain;[4,11,12] however, there is limited research on the effects of strength.[8] Clinicians trained in the GT might apply the technique before practice or competition to break down scar tissue to decrease pain and allow the muscle to function freely; yet, may unintentionally diminish the strength of an athlete because knowledge of whether the GT positively or negatively affects strength is limited.[13] The use of the GT may possibly leave the athlete susceptible to injury if strength is negatively affected.[2] It is the clinician's duty to prevent injury as well as to assist athletes in performing to their maximum capabilities.[14]

Besides the GT, another preventative technique in response to mechanical stress on tissue that is beginning to be utilized is Whole Body Vibration (WBV).[15,16] WBV has been suggested to improve performance such as vertical jump, power output and strength.[17] Even though there have been more controlled investigations on the effects of WBV as compared to the GT, these findings have reported both positive and inconclusive results in respect to strength.[17-19] WBV involves an oscillating platform that sends mild vibratory impulses through the feet and into the rest of the body.[20] Vibratory parameters such as frequency, amplitude and duration can be modified to increase or decrease intensity. It is thought that WBV can enhance performance through neural mechanisms, especially the tonic vibration reflex.[21] The tonic vibration reflex elicits a muscle contraction that if maintained long enough, can affect muscle tone and contraction.[17] As discussed with the GT, the use of WBV could possibly diminish strength leaving an athlete vulnerable to injury when implemented before activity.[22]

As the GT and WBV are continuing to be used as treatment modalities in rehabilitation, to our knowledge there is no research to conclude the acute effects of each treatment on strength. The purpose of this study is to address the potential acute effects of GT and WBV on peak isokinetic torque and fatigue of the quadriceps during maximal voluntary contraction. The secondary purpose is to compare the individual effects between the GT and WBV on strength and fatigue following an acute exercise protocol.

HYPOTHESIS

- H_1: There is no significant difference in peak isokinetic torque and fatigue of the knee extensors after one application of the GT or WBV.
- H_2: There is no significant difference in peak isokinetic torque and fatigue of the knee extensors between the GT and WBV group.

ASSUMPTIONS

- We assume that the subjects will complete the health history questionnaire honestly.
- The subjects performed the Thorstennson protocol with full effort.
- Subjects will refrain from participation in any outside resistance training program, or any other recreational activity that may influence strength.
- Subjects will maintain their current level of activity by not increasing or starting a new exercise program.

LIMITATIONS

- Muscle activity should have been recorded.
- Subjects positioning on the Isokinetic Dynanometer 4.0 should have been recorded to be replicated during post-measurement visit during the testing bouts.
- The effort of the subjects during each testing bout may cause variability in the results.

DELIMITATIONS

Inclusion Criteria:

- Subjects must be healthy adults.
- Subjects must be able to give consent.
- Both sexes between the age of 18 and 35-years old.

- Subjects must be able to make it to both weeks of testing.
- Subjects must wear same socks for the WBV intervention.
- Subjects must go through a familiarization period before pre-measurement.
- Primary Investigator must apply the GT.

Exclusion Criteria:

- Subjects must not be infants, children or teenagers.
- Subjects must not have had previous treatment interventions with surgery and/or steroid injection.
- Subjects must not have a history of quadriceps trauma.
- Subjects must not have a history of musculoskeletal disorder (e.g. rheumatoid arthritis, fibromyalgia, myositis ossificans).
- Subjects must not have an acute inflammatory condition.
- Subjects must not have a vascular or metabolic disease.
- Subjects must not have any medications that could affect the musculoskeletal system.
- Subjects must not be pregnant or have any menstrual irregularities.
- Subjects must not have any open wounds in the area of treatment application.
- Subjects must not be prisoners.
- Subjects must not consume alcohol or participate in strenuous activity the day of testing.

DEFINITION OF TERMS

1. Algometer: A device for measuring sensitivity to pressure or to pain.[23]
2. Cross bridge: The interaction between myosin and actin filaments during contraction.[24]
3. Functional Rating Index: A self-reporting instrument consisting of 10 items, each with 5 possible responses that express graduating levels of disability.[11]

4. Numeric Pain Rating Scale: A verbal pain scale of 0 to 10 with 0 being no pain and 10 being the worst pain imaginable.[4]

5. Power Doppler: a handheld instrument that transmits reflected sound waves to determine blood flow through a blood vessel.[25]

6. QuickDASH Disability/Symptom Score: A questionnaire that assesses functional disability and symptoms of the arm, shoulder and hand.[26]

7. Spatial Recruitment: An increase in the number of active motor units.[24]

8. Tonic Vibration Reflex: A sustained contraction of a muscle while being exposed to vibration.[17]

9. Verbal Pain Rating Scale: A scale used to measure pain through verbal response.[12]

CHAPTER II

REVIEW OF LITERATURE

MUSCLE ANATOMY

Muscles have a significant role in the movement of joints as well as supporting the skeletal structures. A muscle must be tone enough to contribute to joint stability yet long enough to allow joint mobility.[27] Muscles are made up of bundles of fiber. The epimysium is the fibrous connective tissue that surrounds the entire muscle and the bundles of muscle fibers within a muscle are called fasciculus and are surrounded by the perimysium, another connective tissue layer. The muscle fibers within the fasciculus are separated by the connective tissue layer, endomysium. The cellular contents of the muscle fibers are enclosed by the sarcolemma[9] and inside the sarcolemma are hundreds to thousands of myofibrils that contain sarcomeres. Muscle fiber contraction results from the interaction of the myofilaments within the sarcomeres, called actin and myosin. Actin are thin filaments while myosin are thick filaments. Adenosine triphosphate, an energy substrate is required for contraction but the trigger is the uptake of calcium ions at the receptor sites. Troponin and tropomyosin are regulatory proteins present in thin filaments. The interaction between myosin and actin myofilaments are known as cross-bridge.[9] When calcium ions bind to troponin, tropomyosin slides uncovering binding sites for myosin and the actin myofilaments. The sarcomere length when in tension affects the efficiency of contraction. If the sarcomeres are too short, contraction can still occur but will not generate as much force. If the sarcomeres are stretched too far, the cross-bridge between the myosin head and actin tail are reduced causing functional weakness.[28] The force of muscle contraction transfers directly from the connective tissue attachment to the tendons.[9] Muscles adapt faster than connective tissues so it is important that connective tissues are strong enough in order for muscles to generate high levels of tension, which ultimately generates joint torque.[2]

NEURAL FACTORS

Each muscle fiber is controlled by a motor neuron; a group of the muscle fibers innervated by a single motor neuron are classified as a motor unit.[28] Different types of muscle fibers are innervated by small and larger motor neurons. Smaller motor neurons innervate slow-twitch fibers and these fibers are associated with low force levels for long periods of time. Larger motor neurons innervate fast-twitch fibers. Fast-twitch fibers have a high recruitment threshold and are associated with fast, rapid movements.[29] The difference between the two can be seen in Table 1.

Characteristic	Slow Twitch	Fast Twitch
Contraction/relaxation rate	Slow	Fast
Type of contraction	Tonic	Phasic
Recruitment threshold	Low	High
Discharge type	Continuous	Bursts
Muscle function	Stabilizer	Mobilizer
Fatigue	Resistant	Fast
Mitochondria	Many	Few
Metabolism	Oxidative	Glycolytic

Table 1. Characteristics of different types of muscle fibers.[29,30]

The amount of tension produced by a skeletal muscle during a contraction in response to generating more resistance depends on the frequency of impulse stimulus and the number of motor units involved. A steady increase in muscular tension produced by increasing the number of active motor units is called recruitment.[28] Muscle spindles are specialized cells that monitor changes in length of skeletal muscles and participate in stretch reflexes. Muscle spindles have sensory nerve endings that surround specialized muscle fibers called intrafusal muscle fibers. Prolonged stretch of the intrafusal fibers stimulates the sensory nerve endings and the input from the muscle spindles contributes to the response by the central nervous system to contract the muscle fiber. The muscle spindles also contain motor neurons called gamma motor neurons. The gamma motor neurons adjust the tension of a muscle spindle to the variation of lengths of a muscle to keep the muscle spindle taut.

Extrafusal muscle fibers are ordinary skeletal muscle fibers. These fibers surround the muscle spindles and are innervated by alpha motor neurons. The alpha motor neurons can respond during a stretch reflex and can cause contraction of an entire skeletal muscle.[24] The tonic vibration reflex can also elicit a contraction as it is thought to activate the muscle spindles and extrafusal muscle fibers through Ia afferents and alpha motor neurons.[18] The tonic vibration is elicited through vibration and cause neurological adaptations.[21] The primary endings of the muscle spindles respond to the stimulation of vibration. Depending on the frequency of vibration, motor recruitment and synchronization can be altered.[31] The GT[8,13] and WBV[17,18] have been reported to alter muscle physiology and cause neurological adaptations leading to effects on strength.

GRASTON TECHNIQUE

GT involves several stainless steel hand-held instruments that are designed to configure around the contour of muscles (Figure 1).[8] The instruments are intended to act as a tuning fork when fibrous tissues are contacted to provide tactile feedback in the form of vibration to the clinician.[7,13] The GT increases tactile feedback to both the clinician and patient in this manner.[8] This enhances the clinician's ability identify soft tissue lesions and to perform soft tissue mobilization.[4] The instruments vary in size and shape due to the different structural composition and direction of soft tissue throughout the body.[32]

Figure 1. Stainless steel GT instruments.

The instruments are used to detect scar tissue adhesions throughout the muscle. Multi-directional strokes ranging from an angle of 30° to 60° are applied to the treatment site. These angles can adjust the intensity applied while still being able to detect muscle irregularities in the soft tissue texture through the undulation of the gliding instruments.[4] Once an adhesion is identified, a more specific instrument based on the size and shape of the muscle is used to effectively break up the scar tissue to allow the muscle to function normally.[8] Unlike the fat pads of the fingers during a massage, the instruments do not compress the tissue allowing the instruments to reach deeper restrictions or adhesions in the muscle rather than just superficial.[7] This results in deeper restrictions or adhesions being able to treat. It is hypothesized that the GT re-initiates the inflammatory process by inducing micro-trauma in a controlled manner to bring healing nutrients, blood and fibroblasts to the region.[32] However, the GT has the potential to cause excessive tissue damage if not applied appropriately. It is strongly encouraged to combine the GT with motion and strengthening exercises to promote tissue adaptation and remodeling.[13]

EFFECTS OF THE GRASTON TECHNIQUE

It is theorized that the GT introduces controlled micro-trauma and breaks down existing scar tissue and begins the formation of new scar tissue, realigning it in a parallel fashion rather than in a random manner.[4,11,12] In addition to breaking down scar tissue, the GT is believed to enhance the proliferation of extracellular matrix fibroblasts, decrease cell matrix adhesions and improve ion transport.[26,33,34] Predominately, the studies conducted had an improvement in pain, function and range of motion.[13,26,32-35] Some form of warm-ups activities are also used prior to the GT which consists of warming up the area in attempt to restore the proper blood supply to the muscle and assist in the resolution of edema and chemical exudates.[34-36] The additions of stretching and eccentric training are believed to stimulate the remodeling of collagen.[26,33,35] Even though there is little evidence in the enhancement of strength provided by the GT, an increase in function can relate to strength with the improvement of muscle-tendon stiffness and a reduction in tendon volume.[36]

The GT is used on athletes and patients to mobilize soft tissue adhesions and improve their athletic and daily abilities.[32] One way of achieving this is by improving musculoskeletal function. Most of the GT research available is case study based and not a controlled investigation. In one case study, a 32-year old female with De Quervain's stenosing tenosynovitis reported an improvement in her activities of daily living after treatment with the GT. Her QuickDASH Disability/Symptom Score improved from 80 out of 100 before the GT treatment to 0 out of 100 after the GT treatment. The protocol consisted of 2 treatments per week for 12-weeks. The QuickDASH Disability/Symptom Score evaluates the disability of the arm, shoulder and their impact on functional activities. A higher score suggests a reduction in functional levels.[26]

Hammer reported an increase in function for two separate subjects suffering from two different muscular pathologies. One subject with symptoms of supraspinatus tendinosis was discharged after two visits per week for 5-weeks of the GT treatment. After the treatment the subject had normal functional testing and pain relief. Another subject with symptoms of Achilles tendinosis was released after 6-weeks of the GT treatment with decreased thickness in the central portion of the tendon indicating tissue mobilization and pain free functional testing.[32] In a different case study, a subject diagnosed with a 1st degree tibialis posterior strain had an improvement in stiffness and motion after two weeks of treatment with the GT.[34] Black reported an improvement in a subject's function of daily living after a patellar tendon repair 10-weeks prior. Passive and active range of motion improved by the fifth treatment of the GT and their Lower Extremity Functional Scale score improved by 21% compared to the original evaluation.[13] Aspegren et al. found an improvement in the Functional Rating Index of a 21-year old female collegiate volleyball player with costochondritis. The Functional Rating Index is a self-reporting instrument that consists of responses that express graduating levels of disability. A higher score suggest more pain and disability. Her initial Functional Rating Index was 22 and improved to a score of 5 by the sixteenth treatment. Treatment consisted of high-velocity, low-amplitude spinal manipulation, GT and Kinesio taping.[11]

Improvement in range of motion has also been observed in athletes and patients after the application of the GT.[35] In Burke et al., subjects under the age of 50 years old who were experiencing clinical signs, symptoms, and functional impairments of Carpal Tunnel Syndrome reported improvement in wrist range of motion. Wrist extension improved from $38.1^{o} \pm 9.98^{o}$ (mean ± SD) to $45.8^{o} \pm 0.69^{o}$ and wrist flexion improved from $44.8^{o} \pm 8.91^{o}$ to $52.0^{o} \pm 7.59^{o}$. Treatment was delivered 2 times a week for a total of 4 weeks.[8] In the lower extremity, Hammer observed an improvement in dorsiflexion range of motion in an athlete with plantar fasciitis after applying the GT. The subject received 12 treatments over a 6-week period and improvement was observed in dorsiflexion of the foot with plantar fasciitis with the asymptomatic foot.[32] Similar results were concluded in a subject with subacute lumbar compartment syndrome. After 6 visits 2 per week, the subject was able to passively and actively flex his trunk fully in all directions. The functional flexion test improved to normal and the patient reported not feeling any spinal restrictions or pain.[35]

Pain can limit an athlete's performance; however, the GT has been suggested to relieve discomfort and soreness associated with musculoskeletal trauma and limitations.[33] In a physically active male with bilateral Achilles tendinopathy, pain was reported to have improved by approximately 50% compared to the original evaluation by the sixth visit with the use of the GT.[36] Two subjects with lateral epicondylopathy indicated complete pain relief after the tenth visit and twelfth visit, respectively.[12] Similar findings were seen in the case study of Howiit et al., a 42-year-old male with trigger thumb received 8 treatments over a 4-week period. Initially, he complained of moderate pain with restrictions but reported full pain free range of motion by the sixth visit.[37] Another case study reported improvement in pain in a 32-year-old female diagnosed with De Quervain's stenosing tenosynovitis. Papa reported an improvement in Verbal Pain Rating Scale after 8-weeks of GT treatment. At baseline, the Verbal Pain Rating Scale was 3 out of 10 at rest and 8 out of 10 during activity and after treatment it was 0 out of 10 and 1 out of 10, respectively. When reported as 0, the scale refers to "no pain" while 10 refers to the "worst pain possible".[26] In further support of improvement in pain, Black reported an improvement in a subject who had a patellar tendon repair 10-weeks prior. After 4 visits of treatment with the GT, the numeric pain scale improved from 5 out of 10 at worse to 0 out of 10.[13] Mixed results were observed in treating plantar heel pain with the GT. Looney et al. observed subjects having a significant improvement after 8 treatments of the GT; however, there were three out of ten subjects with little to no improvement in pain. An 11-point Numeric Pain Rating Scale was used to measure the subject's level of pain and in fact, 10% reported significant worsening after the application of the GT.[4]

In addition to function, range of motion and pain, several studies have reported improved strength after applying the GT.[8] Burke et al. found an improvement in grip and pinch strength of subjects with Carpal Tunnel Syndrome. The treatment group improved their pinch strength by 18% as grip strength improved from 20.2 ± 8.79 kg to 25.7 ± 10.56 kg immediately post-intervention. Although, there were little change to the control wrists after the application of the GT. Grip strength changed from 24.4 ± 9.27 kg to 24.6 ± 9.56 kg.[8] In another study, a subject following a patellar tendon repair 10-weeks prior reported an improvement in strength following the application of the GT. This was noted from an improvement in functional activity.[13] Although many of these individual case studies reported strength increases in subjects with muscular pathologies, research is still needed to investigate the acute effects of the GT on strength in a controlled manner. Table 2 summarizes the results of the GT studies discussed in this section.

Table 2. The results of different GT studies.

	Number of Treatments	Region of GT Application	Combination	Results
Aspegren et al.[11] 2007	16 treatments.	Chondrosternal joint and fifth costochondral segment.	In combination with high-velocity, low-amplitude spinal manipulation and Kinesio taping.	FRI improved from 22 to 5. Numeric Pain Scale score improved from7 to 0.25. DPQ improved; daily activities from 60 to 6 and work/leisure reduced from 70 to 10.
Black.[13] 2010	5 visits over a 4-week period.	Distal quadriceps and patellar tendon.	Joint mobilization and strengthening activities included.	Pain fully resolved. LEFS score improved from 23% to 44%. AROM improved from 93 degrees to110 degrees.

Burke et al.[8] 2007	10 treatments over 6-weeks.	Forearm-wrist-hand.	Stretching and strengthening.	VAS improved from 61.5 ± 26.56 mm to 9.8 ±12.54 mm. Grip strength improved in the GT group from 20.2 ± 8.79 kg to 25.7 ± 10.56 kg. Wrist extension and flexion improved.
Crothers et al.[7] 2008	10 treatments over 4-weeks.	Thoracic spine musculature.	N/A	Conclusion was that there was enough evidence to support the protocol.
Hammer.[32] 2008	Supraspinatus tendinosis: 10 treatments Achilles tendinosis: 12 treatments; plantar fasciitis: 12 treatments.	Supraspinatus tendinosis: scapular region and dorsal axillary shoulder fascia; Achilles tendinosis: gastrocnemius, soleus and hamstrings; plantar fasciitis: calcaneal fascial origin.	Stretching and strengthening.	Resulted in elimination of pain and normalization of the positive functional tests in subjects with supraspinatus tendinosis, Achilles tendinosis and plantar fasciitis.
Hammer and Pfefer.[35] 2005	6 visits at 2 weeks per week.	Lumbar region, hamstrings and hip lateral rotators.	N/A	Able to actively and passively flex in all directions. Hamstring flexibility and flexibility of the right external rotators showed significant improvement.
Howitt et al.[34] 2009	6-weeks.	Gastrocnemius, soleus and tibialis posterior.	Acupuncture, electrical stimulation, ultrasound and ART of gastrocnemius, soleus and tibialis posterior.	Relief of symptoms and able to return to training. By the third and fourth visit, right lower leg girth improved from 29 cm to 27 cm and pain improved to "two or three" out of ten.
Looney et al.[4] 2010	8 treatments.	Triceps surae, soleus, plantar fascia and medial calcaneal tubercle.	Static stretching.	In the GRC, 7 out of 10 subjects had meaningful improvement. 1 out of 10 reported significant worsening. NPRS and LEFS showed significant improvement.
Miners and Bougie[36] 2011	By the 6th visit.	Achilles tendon.	ART, stretching and specific exercise.	A 50% improvement in pain level was noted and minimal discomfort.

Papa.[33] 2012	12 treatments.	Gastrocnemius-soleus complex.	Acupuncture with electrical stimulation, stretching and eccentric exercise.	At week 9, VPRS score improved from 6-7 out of 10 during activity to 0 out of 10. LEFS score improved from 48 to 80.
Papa.[26] 2012	2 visits a week for 4-weeks and then 1 visit per week for 4 weeks.	Thenar muscle group and forearm extensors/flexors.	Stretching and eccentric exercise.	VPRS score improved from 3 to 0 out of 10 at rest and from 8 to 1-2 out of 10 with functional activity. QDDSS improved from 80 to 0 out of 100.
Papa.[12] 2012	Case 1: 10 treatments. Case 2: 12 treatments.	Forearm and elbow.	Acupuncture with electrical stimulation, stretching and eccentric exercise.	Case 1: VPRS score improved from 7 to 0 out of 10 and QDWMS improved from 95 to 0 out of 100. Case 2: VPRS improved from 5 to 0 out of 10 and QDWMS improved from 62.5 to 0 out of 100.

WHOLE BODY VIBRATION

Vibration is a mechanical stimulus that elicits repeated eccentric-concentric contraction of the muscles to stabilize the body's joints.[38] A form of vibration that is gaining attention is WBV (Figure 2).[17,39] WBV is a platform that an athlete or patient can stand on that sends mild vibratory impulses through the feet and into the rest of the body.[20] There are four variables that the vibratory load is dependent on: amplitude (A), frequency (f), duration (t), and acceleration (α). Amplitude is the maximal displacement of the oscillatory motion (mm). Frequency is determined by the number of cycles of oscillation (Hz). Duration is the overall exposure time (min or s) and acceleration is the change of velocity with time ($m \cdot s^{-2}$ or g).[38,40,41] There are three types of oscillations depending on the model. Vertical displacement produces an up and down movement. Triplanar displacement produces a forward and back, up and down, and side-to-side movement while centrally pivoting displacement produces a side-altering oscillation movement similar to a see-saw.[20] WBV machines typically have a frequency ranging from 0-50 Hz and amplitude ranging from 0-10 mm.[38] Originally, WBV was developed to increase power and strength in athletes.[42,43] WBV is thought to activate muscles by increasing neuromuscular activity; in fact, recent studies have shown WBV to have similar neuromuscular adaptations as traditional strengthening exercises.[15,18,38,43] Although, the effects of WBV on performance have been inconclusive as both beneficial and insignificant results have been found. Despite the mix results, WBV is capable of altering performance in athletes.[44]

Figure 2. Whole Body Vibration (VT100).

EFFECTS OF WHOLE BODY VIBRATION

Since WBV is linked to neuromuscular adaptations, researchers have been investigating the use of this modality to improve sports performance and injury prevention.[21] Flexibility is one performance measurement that has shown positive outcomes from WBV.[23,42,45-47] Van Den Tillaar concluded that WBV training can significantly increase hamstring flexibility of subjects in one week with three sessions of WBV. These results stayed consistent after 2 weeks of training. In the study, WBV was paired along with the proprioceptive neuromuscular facilitation contract-release method of stretching. The treatment group exhibited a 14.4° greater ROM improvement than the proprioception neuromuscular facilitation contract-release method group alone.[45] Another study found an increase of approximately 35° in ten college-aged subjects' hamstrings after being treated with WBV. The treatment consisted of six repetitions of 30 seconds for 6-weeks.[46] Similar results were reported in a study involving eighteen healthy female elite field hockey players. Immediately following one intervention of WBV, flexibility measurements of the hamstrings increased by 8.2%.[42] Fagnani et al. also had similar results when examining the hamstrings. After 8-weeks of implementing the WBV modality three times a week, significant improvement was observed as measured by the sit-and-reach test.[48] Sands et al. further supported similar findings as range of motion increased in the side split of ten male gymnasts.[23] However, flexibility in the ankle joint after WBV has also been found to not have the same significant success as in the hamstrings. Apple et al. examined fourteen healthy volunteers and the effect of one bout of WBV for three minutes on dorsiflexion range of motion. There were no significant differences in dorsiflexion range of motion across time as well as pre and post-test as all changes were less than 5°.[47]

Another outcome measure investigated after the application of WBV was pressure-to-pain perception. Pressure-to-pain perception is the application of enough pressure by a handheld device such as an algometer[23] or syringe[43] to a certain region of the body to elicit pain. In the Sands et al. study, they found no significant differences in pressure-to-pain perception in ten male gymnasts after 45 seconds of WBV.[23] In fact, a study that focused on attenuating the effects of delayed-onset muscle soreness, found that the control group had a greater increase of pressure-to-pain perception than WBV. Delayed–onset muscle soreness is pain and stiffness felt in a muscle hours to days after a sudden increase in training. Results showed a decrease in pressure-to-pain threshold of 38.11% after 24 hours and 25.58% after 48 hours of initiating delayed-onset muscle soreness for the WBV group. The control group had a decrease in pressure-to-pain threshold of 74.56% after 24 hours and 71.62% after 48 hours of initiating delayed-onset muscle soreness, respectively.[43] In a more recent study, the findings supported the results of Sands et al. on WBV and its effects on pressure-to-pain perception. In the study, Apple et al. concluded WBV does not create a suppression of the central nervous system and suppression is not the cause of greater gains in range of motion after observing the Hoffmann reflex in their study. The Hoffmann reflex can be used to assess the response of the nervous system to various neurologic conditions, application of therapeutic modalities, pain, and exercise training. In their study, the Hoffmann reflex decreased significantly in both control and WBV groups when compared to the pre-test. Since there was no difference between the control and WBV group, WBV alone does not cause a suppression in the central nervous system.[47]

The effects of WBV have also been investigated in relation to power.[18,40] Power is the ability to generate the greatest amount of force in the shortest period of time.[2] Vertical jump is one outcome measure indicative of leg power. WBV showed mixed results in the study by Cardinale and Lim.[49] The two jumps performed were countermovement jumps and squat jumps. The countermovement jump allows the subject to perform a counter movement with the lower limbs before the jump such as bending the knees followed by fully extending them. The squat jump involves the subject jumping from a semi-squatted position. Five (5) minutes of low frequency WBV produced greater improvement in jump height after intervention compared to 5 minutes of high frequency WBV. In this study, high frequency WBV actually reduced squat jump and countermovement jump but was not statistically significant. In the low frequency WBV group, only the squat jump resulted in a significant increase while countermovement showed slight improvement. The study suggested that the use of high frequencies on untrained individuals could impair force generating capacities and diminish performance.[50] Another study found an increase in vertical jump after the use of WBV. Eighteen female elite hockey players showed an improvement in arm countermovement vertical jump after 90 seconds of WBV. The result was an 8.1% increase compared to cycling and the control group.[42] Dabbs et al. measured vertical jump at different rest intervals after the exposure of WBV. Thirty active subjects were exposed to WBV for 4 bouts of 30 seconds with 30 seconds of rest between each bout. Immediately after WBV, subjects showed an increase in vertical jump height. In light of these results Dabbs et al. reported the ideal time of rest before performing a vertical jump was based on the individual.[40]

Acute WBV has also been shown to effect blood flow. Lythgo et al. found WBV to increase blood cell velocity after one minute intervention. Nine healthy, college aged subjects were instructed to stand on the WBV platform at 6 different frequencies and 2 different amplitudes. This protocol resulted in 12 different vibration bouts. In the study, each bout lasted one minute. Measurements were taken after each bout. The increase in frequency and amplitude revealed a greater increase in blood cell velocity.[51] Another study further supported the findings of Lythgo et al. with results showing significantly greater mean blood flow in the popliteal artery following 9 minutes of WBV in three different stances. Furthermore, a significant increase in the relative moving blood volume in the quadriceps and gastrocnemius was observed through a Power Doppler Index. The Power Doppler determines how well blood flows through blood vessels by detecting sound waves and uses an index to assess it.[25]

Strength is an outcome measure that has exhibited inconclusive findings following exposure of WBV. A McBride et al. study showed an increase in muscle force after 6 sets of 30 seconds of WBV at 30 Hz and 3.5 mm. Although there was a significant increase in peak force immediately post WBV (9.4%) motor neuron excitability and muscle activation resulted in no significant change.[22] Muscle activity did in increase from the range of 0.6%-6.7% in ten active subjects after 30 seconds of WBV exposure. The higher frequency and amplitude combination of 30 seconds of WBV resulted in statistically significant increases in muscle activity for the vastus lateralis. In addition, Hazell et al. found that static and dynamic contractions during the exposure of WBV improved muscle activity in the vastus lateralis.[52] Fagnani et al. found positive results in strength after exposure to WBV. Thirteen female athletes had significant improvement of bilateral knee extensor strength following 8-weeks of WBV training which included 3 sessions per week.[48] In another study, strength increases were observed in postmenopausal women ranging from the ages of 58-74 years old. Compared to resistance training, WBV caused similar increases in isometric strength in postmenopausal women. After 6 months of training, knee extensor strength increased by 15% in the WBV group and 16% in the resistance training group, respectively.[53]

When looking at the rehabilitation benefits of WBV, Johnson et al. concluded that WBV has similar strength gains as a traditional strengthening treatment. Knee extensor strength improved 84.3% in the WBV group compared to 77.3% in the traditional progressive resistance exercise group for subjects recovering from total knee arthroplasty. Voluntary muscle activation also significantly increased in the WBV group but did not significantly differentiate from the traditional progressive resistance exercise group.[15] Besides using WBV post-surgery to strengthen the muscles, WBV can be used to attenuate the effects of delayed-onset muscle soreness. According to Aminian-Far, before eccentric exercise, implementing 60 seconds of WBV can reduce the amount of strength lost from delayed-onset muscle soreness. Immediately post exercise, the control group torque decreased by 42.70% while the WBV group torque decreased by 7.50%. Similar results were seen 24 hours and 48 hours. Torque decreased in the control group at 24 hours by 51.75% and at 48 hours by 55.44%, respectively and 12.21% and 13.45% at 24 and 48 hours, respectively, in the WBV group.[43]

Despite the aforementioned positive effects of WBV on strength, there have been negative effects on strength recorded after exposure to WBV. After 30 seconds of WBV at 30 Hz and 2.5 mm in a half-squat position, nine males had a slight decrease in peak force during an isometric squat. In addition, jump height and peak power decreased after implementing WBV for 30 seconds. These measurements decreased immediately after WBV, 5-minutes post intervention and 15-minutes post intervention.[18] It was noted in another study conducted by Torvinen et al., sixteen young healthy volunteers who were exposed to WBV for 4 minutes had a decrease in mean power frequency. Even though isometric knee extension increased after the bout, a decrease in mean power frequency was statistically significant in the soleus and gastrocnemius as well as a non-significant decrease in mean power frequency in the vastus lateralis.[19] Jordan et al. found a decrease in resting muscle twitch torque, voluntary muscle activation and peak isometric torque during muscle voluntary contraction of the knee extensors. Twenty-four healthy active subjects were treated with WBV while standing in a semi-squat position. An immediate decrease resulted after each subject completed 3 bouts of 60 seconds of WBV. Peak isometric torque decreased by -4.4 ± 3.9 Nm (mean ± SE).[17]

The cause of improvement in performance when adding WBV has been connected to neuromuscular adaptation. Bosco et al. theorized that vibration causes the skeletal muscle to undergo changes in muscle length.[6] In addition, vibration assists in the excitability of the spinal reflex. This results in reflex activation of motor neurons with increased spatial recruitments, which is the amount of muscular tissue being stimulated.[6,42] The preponderance of studies has concluded that WBV elicits greater gamma motor neuron input, which leads to an increase in sensitivity of the primary endings causing an enhanced stretch-reflex pathway.[20,42,43,50,51,54] The increase in sensory stimulation might result in a more efficient positive proprioceptive feedback loop in the generation of isometric force. Furthermore, additional motor unit activity, slow-twitch fiber and motor unit synchronization can be recruited by the tonic vibration reflex via muscle spindle and polysynaptic activation.[42,43,55] As well as lowering the threshold for fast-twitch fibers.[21] Nevertheless, studies have also found muscle activity and peak isometric torque to decrease after exposure to WBV because of fatigue.[17-19] It is theorized that fatigue could affect force generating capacities and cause soreness.[41,50] The WBV research investigations have shown different effects in certain performances and measurements which is why it is important to examine the acute effects of WBV and the GT so that clinicians can make informed decisions on when to incorporate these techniques. Table 3 summarizes the results of the different WBV studies discussed in this section.

Table 3. The results of different WBV studies.

	Number of treatments	Frequency/Time	Combination	Results
Aminian-Far et al.[43] 2011	1 treatment.	35 Hz/1 bout of 60 seconds before eccentric exercise.	Eccentric exercise.	Control group decrease 24 & 48 hours after eccentric exercise were 74.56% & 71.62%, respectively. WBV group decrease 24 & 48 hours after eccentric exercise were 38.11% & 25.58%, respectively.
Apple et al.[47] 2010	1 treatment.	40 Hz/1 bout of 3 minutes.	N/A	No significant difference in H-reflex between control and WBV. Both groups had a decrease in H-reflex amplitude. Increase in dorsiflexion; however, less than 5 degrees.
Cardinale and Lim.[49] 2003	1 treatment.	20 Hz/1 bout of 5 minutes. 40 Hz/1 bout of 5 minutes.	N/A	Low frequency of WBV increased squat jump by 4%. High frequency of WBV decreased squat jump (-3.8%) and counter movement jump (-3.6%).
Cochrane and Stannard.[42] 2005	1 treatment.	26 Hz/1 bout of 2 minutes.	6 different exercises during WBV.	Significantly greater hamstring range of motion after WBV (increased by 8.2%). WBV produced an 8.1 ± 5.8% increase in arm countermovement vertical jump.
Cormie et al.[18] 2006	1 treatment.	30 Hz/1 bout of 30 seconds.	N/A	Peak force during the isometric squat slightly decreased from baseline following vibration. Subjects jumped higher following exposure to WBV.
Dabbs et al.[40] 2011	1 treatment.	30 Hz/4 bouts of 30 seconds.	N/A	Within each rest interval, WBV had a significantly greater vertical jump height compared to the control.

Dastmenash et al.[46] 2010	3 times per week for 4-weeks.	28 Hz/6 bouts of 30 seconds.	PNF contract-release before WBV.	WBV with PNF showed a greater increase in ROM than WBV or control alone.
Fagnani et al.[48] 2006	3 times per week for 8-weeks	35 Hz/3 bouts of 20 seconds (1st & 2nd week), 3 bouts of 30 seconds (3rd & 4th week), 3 bouts of 45 seconds (5th & 6th week), 4 bouts of 1 minute (7th & 8th week).	N/A	Significant improvement in bilateral knee extensor strength after WBV. The percentage increase in mean dynamic strength was 11.2%. Significant improvement in hamstring range of motion after WBV. 19.6 ± 5.5 cm improved to 22.6 ± 4.6 cm.
Hazell et al.[52] 2007	1 treatment.	5 frequencies ranging from 25-45 Hz/10 bouts of 30 seconds.	Two different amplitudes: 2 mm and 4 mm.	Muscle activity for vastus lateralis was 34.5% ± 3.9%. After WBV, there was an improvement ranging from 0.6%-6.7%
Jordan et al.[17] 2010	1 treatment.	30 Hz/3 bouts of 60 seconds.	N/A	Decrease in peak isometric torque (1.9%) and voluntary muscle activation (0.1 ± 1.5%).
Kerschan-Schmindl et al.[25] 2001	1 treatment.	26 Hz/1 bout of 9 minutes.	N/A	WBV produced increased the number of visualized vessels with a diameter of at least 2 mm.
Lythgo et al.[51] 2009	1 treatment.	6 frequencies ranging from 5 to 30 Hz/12 bouts of 1 minute.	Two different amplitudes: 2.5 mm and 4.5 mm.	WBV produced a four-fold increase in peak blood cell velocity and a two-fold increase in peak blood cell velocity.
McBride et al.[22] 2010	1 treatment.	30 Hz/6 bouts of 30 seconds.	Static squat with each leg during a set.	WBV produced an increase in peak force immediately post-intervention (9.4%). No change in EMG or rate of force development.
Melnyk et al.[39] 2009	3 times per week for 4-weeks.	30 Hz/1 bout of 3 minutes.	N/A	No significant changes in latencies and reflex activity in long peroneal and tibialis anterior muscle.
Pollack et al.[21] 2012	5 treatments,	30 Hz/5 bouts of 1 minute.	N/A	No overall effect of WBV on the recruitment threshold. Increases occurred in low-threshold motor units and decreases occurred in high-threshold motor units.

Sands et al.[23] 2008	1 treatment.	30 Hz/1 bout of 45 seconds.	N/A	WBV improved split range of motion by 7.9 ± 3 cm. No difference in pain-perception threshold.
Torvinen et al.[19] 2002	1 treatment.	15-35 Hz/1 bout of 4 minutes.	Vibration frequency increased by 5 Hz each minute.	Subjects had a 3.2% benefit in isometric knee extension strength; however, mean power frequency decreased in the gastrocnemius, soleus and vastus lateralis.
Van Den Tillaar.[40] 2006	3 times per week for 4-weeks.	28 Hz/6 bouts of 30 seconds.	PNF contract-release before WBV.	WBV significantly increased hamstring range of motion (increased by 30%).
Verschueren et al.[53] 2003	72 treatment sessions within a 24-week period.	35-40 Hz/ 1 bout of 30 minutes including warming up and cooling down.	Changes in amplitude, frequency or exercise.	WBV improved isometric and dynamic muscle strength (+15% and +16%).

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CHAPTER III

METHODS

Permission for the study was granted by the Oklahoma State University Institutional Review Board. Sixty healthy subjects provided written informed consent to participate in this investigation. Subjects were recruited through a convenience sampling method using University courses. A questionnaire was given to address the following exclusion criteria: (1) individuals who are not yet adults (infants, children, teenagers); (2) previous treatment interventions with surgery and/or steroid injection; (3) a history of quadriceps trauma; (4) a history of musculoskeletal disorder (e.g. rheumatoid arthritis, fibromyalgia, myositis ossificans); (5) acute inflammatory conditions; (6) vascular disease or metabolic disease; (7) medications affecting the musculoskeletal system; (8) pregnancy or menstrual irregularities; (9) open wounds; (10) adults unable to consent; and (11) prisoners.

PRE-TESTING PROCEDURE

The testing day was preceded by a day of familiarization. The purpose of the familiarization period was to limit the effect of subjects not familiar with the Biodex isokinetic dynamometer. A Biodex isokinetic dynamometer 4.0 was used in this study to measure strength and fatigue during isokinetic knee extension at 180^{o}/sec (Figure3). Two different preventative techniques were explained to the subjects. The GT (TherapyCare Resources Inc., Indianapolis, IN) was used for the soft tissue mobilization intervention and the VT100 (VibraTrim LLC, Gig Harbor, WA) was used for the vibration intervention. The following sections will discuss the protocols, procedures, and data analyses that were used in this study.

Figure 3. Biodex isokinetic dynamometer 4.0.

GRASTON TECHNIQUE PROTOCOL

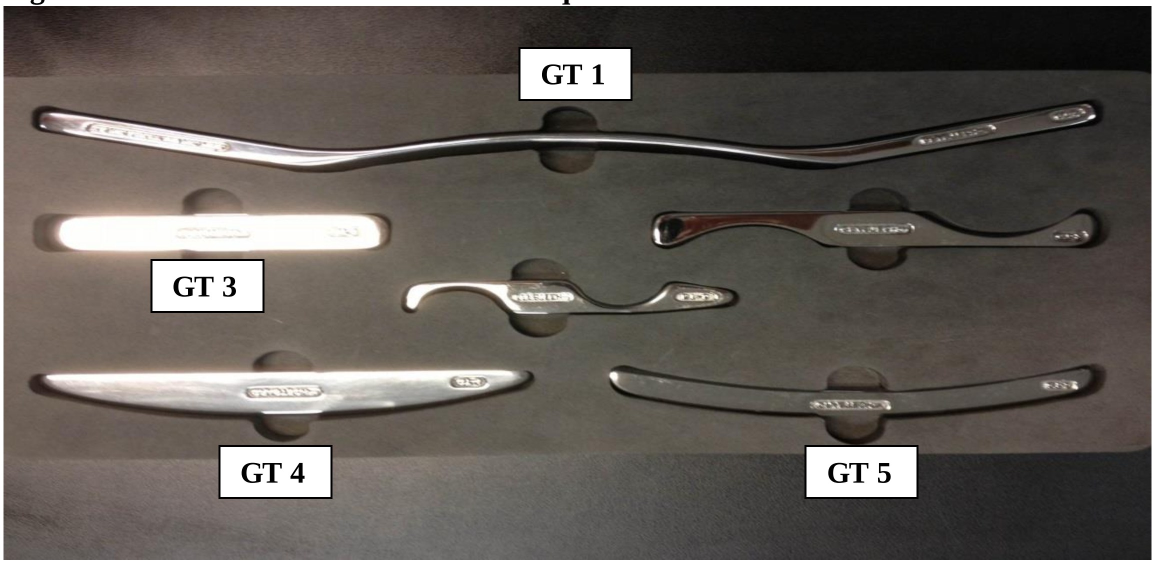
The GT intervention used in this study was modeled after Table 4. The typical protocol for the GT is a warm-up, the application of the GT instruments, stretching, eccentric exercise and cryotherapy. However, the protocol for this study was modified due to the GT being applied as a pre-competition treatment. A 5 minute warm-up consisting of cycling on a stationary bike with no resistance was used in accordance with the studies. Sixty (60) seconds of initial scanning strokes were used superficially with intent of feeling for areas of adhesions. In the studies, 30-60 second bouts were predominately used.

	Warm-up	Graston Method	Stretching	Eccentric Exercises	Edema Control
Burke et al.[8] 2007	12 minutes riding a bike or treadmill.	Forearm-wrist-hand areas.	Applied but not specified.	Closed kinetic chain	Applied but not specified.
Hammer.[32] 2008	3-5 minutes moist heat.	30 seconds-1 minute for localized lesion.	3 sets of 30 seconds static stretching.	High repetitions, low-load. 2 sets of 15 reps.	If necessary.
Howitt et al.[34] 2009	Electrical stimulation and Ultrasound.	GT and ART. Posterior to the medial malleolus.	N/A	N/A	Ice applied for 10 minutes.
Black.[13] 2010	5-7 minutes moist heat pack.	Brief bouts of 30-60 seconds from the ankle retinaculum to the AIIS.	PROM in a supine or seated position. 5 second hold for each repetition.	Concentric and eccentric short arc quads.	20 minute ice pack.
Looney et al.[4] 2011	N/A	1-2 minutes in the areas of concern.	2 sets of 30 seconds static stretching.	N/A	Ice applied for 15-20 minutes.
Miners and Bougie.[36] 2011	5 minutes heat + cycling warm-up.	GT and ART.	3 sets of 30 seconds static stretching.	Slow eccentric calf lowering. 3 sets of 10.	Ice applied for 10 minutes.

Table 4. Protocols of the GT interventions.

After the initial diagnostic strokes with GT 1 and GT 5, 5 minutes of deeper and more specific instrument application was used. A fan stroke was used with GT 4 and a brush/strum stroke was used with GT 3 on each subject in this group. The name of the GT instruments can be seen in Figure 4. The GT was administered by a trained and certified athletic trainer using GT protocols. Lastly, strength and fatigue measurements were taken immediately on the biodex following the intervention.

Figure 4. The name of each Graston Technique instrument used.



WHOLE BODY VIBRATION PROTOCOL

The WBV intervention is modeled after the studies in Table 5. First, a 5 minute warm-up consisting of cycling on a stationary bike with no resistance was used. The vibration portion consisted of 3 sets of 30 seconds. Due to the lack of standardization between the WBV protocols throughout the research, sets and duration were chosen by what has been used more consistently. Sixty (60) seconds of rest in between each set was the most common rest interval between each study. Predominately, amplitudes between 2-6 and 10 mm have been used in the studies. In this study, the amplitude of 10 mm was used. The frequency of 30 Hz was chosen as it has been widely used throughout the studies. Ritzmann et al. found that electromyography (EMG) activity had greater change at 30 Hz compared to frequencies that were lower.[20] Also, the study resulted in greater muscle activity in subjects with greater knee flexion.

Table 5. One day WBV intervention protocols.

	Machine	*F*	mm	Exposure	Rest	Position
Cardinale and Lim.[50] 2003	NEMES LC (Ergotest, Greece)	20 Hz 40 Hz	4 mm	5 sets of 60 seconds.	60 seconds.	Semi-squatting position.
Cardinale and Lim.[49] 2003	Nemes Bosco-system (OMP, Rieti, Italy)	30 Hz; 40 Hz; 50 Hz	10 mm	4 sets of 60 seconds.	60 seconds.	100 degree squat.
Cochrane and Stannard.[42] 2005	Galileo Sport Machine (Novotec Pforzheim Germany)	26 Hz	6 mm	90 seconds.	No rest.	Variety.
Van Den Tillaar.[45] 2006	NEMES Bosco-system (OMP, Rieti, Italy)	28 Hz	10 mm	30 seconds.	No rest.	90 degree squat.
Hazell et al.[36] 2007	WAVE™, Canada	Either 25-45 Hz	Either 2-4 mm	30 seconds.	No rest.	Static semi-squat 120 degrees.
McBride et al.[22] 2010	Power Plate International, Irvine, CA, USA	30 Hz	3.5 mm	3 sets 30 bilateral: 3 sets of 30 unilateral each leg.	60 second rest period between each squat.	Static squat 100 degree knee angle.
Aminian-Far et al.[43] 2011	Pro 5; Power Plat North America, Inc., Irvine, CA	35 Hz	5 mm	60 seconds.	Before eccentric exercise.	Static squat 100 degree knee angle.
Dabbs et al.[40] 2011	MedVibe NitroFit Deluxe vibration platform (Scottsdale, AZ, USA)	30 Hz	6.5 mm	4 sets of 30 seconds.	30 seconds.	Quarter squat every 5 seconds.

*Torvinen et al.[19] 2002	WAVE™, Canada	Increased in 1 min. intervals: 15-30 Hz.	10 mm	4 minutes.	No rest.	Variety.
*Cormie et al.[18] 2006	Power Plate International, Irvine, CA, USA	30 Hz	2.5 mm	30 seconds.	No rest.	100 degree squat.
*Jordan et al.[17] 2010	Pro 5; Power Plat North America, Inc., Irvine, CA	30 Hz	4 mm	3 sets of 60 seconds.	60 seconds.	130 degree squat.

***Negative effects on strength.**

In this current study, a 60° static squat was used in this study and the subjects were required to grasp the handles but not to pull or lean on them (Figure 5). The knee flexion angle was monitored throughout the intervention through the use of a goniometer. The subjects wore similar cotton socks to avoid any limitations that could occur with different footwear. Lastly, strength and fatigue measurements were taken immediately on the biodex following the intervention.

Figure 5. A subject in a 60° squat.

CONTROL PROTOCOL

The control group completed a 5 minute warm-up consisting of cycling on a bike with no resistance. The control group then rested for 5 minutes similar to the time it took to complete the GT intervention. After relaxing for 5 minutes strength and fatigue measurements were taken immediately.

DATA COLLECTION & ANALYSIS

Subjects were randomly assigned to one of the following three groups: GT, WBV, and control group after drawing a number from a box. Prior to the pre-test measurements, subjects were familiarized with the protocols and dynamometer. During the pre-test measurement, the subjects sat on the Biodex isokinetic dynamometer 4.0 and were strapped down at the right ankle 2-3 cm above the lateral malleolus. This allowed the subject to extend the arm of the dynamometer. The thigh and upper body were strapped down as well but to limit counter-movements by other parts of the body. The hip was locked in at 90^o of flexion while the knee started in the position of 90^o of flexion. Once seated and secured, the subjects performed the Thorstennson protocol, which consisted of fifty repetitions of knee extension that lasted approximately one minute. Following the pre-test measurements, the subjects were given a week to rest to eliminate any soreness or effects of the protocol. A week later the subjects returned and were instructed on the GT, WBV or control protocol; based on their assigned group. Instructions were given to every subject throughout each protocol as well. Post-measurements were taken immediately after intervention following the same protocol as the pre-test. Peak isokinetic torque, total work, and work fatigue measurements were collected. Peak isokinetic torque represents strength as it is the highest muscular force output at any moment during a repetition. Total work represents fatigue as it is the amount of work accomplished during the protocol. Work fatigue also represents fatigue as it is the ratio of difference between the first 1/3 of work and the last 1/3 of work in the test bout. Following data collection, independent sample t-tests and a one-way ANOVA were performed to measure the difference between pre-test and post-test of the isokinetic peak torque, total work, and work fatigue values of the three groups as well as difference between the three groups.

CHAPTER IV

RESULTS

SUBJECTS

Five subjects were excluded from data for failing to return the second week of testing resulting in fifty-five subjects completing the experiment (17 males, 38 females). The subjects' characteristics ranged from (mean ± SD): age, 19.6 ± 1.3 years; and body mass, 68.1 ± 15.8 kg. Subjects were randomly selected into each group. The GT had 19 subjects (8 males, 11 females), the WBV group had 18 subjects (5 males and 13 females), and the control group had 18 subjects (4 males and 14 females). The body mass and age of each subject is summarized in Table 6.

Table 6. Characteristics of subjects in each group (Mean ± SD).

Intervention	Subjects (gender)	Body Mass (kg)	Age (yr)
All	55 (17 M; 38 F)	68.1 ± 15.8	19.6 ± 1.3
GT	19 (8 M; 11 F)	69.7 ± 16.6	19.5 ± 1.0
WBV	18 (5 M; 13 F)	71.3 ± 16.9	19.8 ± 1.5
Control	18 (4 M; 14 F)	63.3 ± 13.2	19.6 ± 1.3

MEASUREMENTS

The baseline and post-treatment values for peak isokinetic torque, total work, and work fatigue are summarized in Table 7. Peak isokinetic torque decreased following each intervention (Table 8). Peak isokinetic torque decreased by -10.8 ± 14.4Nm (mean ± SD) in the GT intervention. In the WBV intervention and control intervention, peak isokinetic torque decreased by -6.4 ± 9.7Nm and -7.1 ± 12.3Nm, respectively. A comparison of these changes was not significantly different between any of these interventions.

Table 7. Mean (SD) baseline and post-treatment for peak isokinetic torque, total work, and work fatigue.

Treatment	Pre-test peak isokinetic torque (Nm)	Post-test peak isokinetic torque (Nm)	Pre-test total work (Nm)	Post-test total work (Nm)	Pre-test work fatigue (%)	Post-test work fatigue (%)
GT	120.8 (± 35)	109.9 (± 37.2)	3314.9 (± 1222.1)	3407.5 (± 1273)	54.2 (± 21.2)	44.9 (± 22.9)
WBV	116.3 (± 38.8)	109.9 (± 36)	3564.4 (± 1169.9)	3392.1 (± 1140.3)	62.3 (± 14.4)	52.1 (± 16)
Control	110.3 (± 38.9)	103.1 (± 36)	3134.6 (± 1144.4)	3044.8 (± 1136.1)	60.1 (± 7.9)	49.8 (± 21.8)

Total work decreased following the WBV intervention as did the control intervention but did not decease for the GT intervention. The mean change (± SD) of total work was -172.3 ± 256.2 Nm following the WBV intervention and -89.8 ± 265.7 Nm following the control intervention. Total work increased by 92.6 ± 427.6 Nm following the GT intervention. A comparison of these changes was not significantly different between the WBV intervention and control intervention (P=0.131) and the GT intervention and control intervention (P=0.350). There was significant difference in total work between the GT intervention and WBV intervention (P=0.030).

Work fatigue decreased compared to baseline values following each intervention. Work fatigue decreased by -9.3 ± 18.8% (mean ± SD) in the GT intervention. In the WBV intervention and control intervention, work fatigue decreased by -10.2 ± 23.3% and -10.3 ± 24.6%, respectively. A comparison of these changes was not significantly different between any of these interventions.

Table 8. Mean (SD) values for changes in peak isokinetic torque, total work and work fatigue following GT, WBV and control intervention.

Treatment	Change in peak isokinetic torque (Nm)	Change in total work (Nm)	Change in work fatigue (%)
GT	-10.8 (± 14.4)	92.6 (± 427.6)*	-9.3 (± 18.8)
WBV	-6.4 (± 9.7)	-172.3 (± 256.2)	-10.2 (± 23.3)
Control	-7.1 (± 12.3)	-89.8 (± 265.7)	-10.3 (± 24.6)

***Statistical significance as compared with WBV (P<0.05).**

CHAPTER V

DISCUSSION

PEAK ISOKINETIC TORQUE

One of the primary purposes of this study was to examine the acute effects of the GT and WBV on peak isokinetic torque of the knee extensors. The findings from this investigation indicate that the acute application of the GT or WBV is not sufficient enough to induce immediate strength gains. This is indicated by the decrease in peak isokinetic torque immediately post intervention. Peak isokinetic torque of the knee extensors did not significantly improve with either intervention when compared to the control intervention. The findings on the GT do not support the strength gains reported by Burke et al.[8] and Black.[13]

However, the use of the GT in these cases was for rehabilitation purposes. Burke et al. used a 6-week treatment protocol consisting of ten treatments of GT for patients over the age of fifty with carpal tunnel syndrome. Grip strength increased from 20.2 ± 8.79kg to 25.7 ± 10.56kg immediately post intervention. Nonetheless, when considering the healthy wrists in the Burke et al. study, the GT did not provide any gains on grip strength.[8] This is similar to the results of the current study as there was no gain in strength; in fact, the GT had a decrease effect on strength. Although not significant, the decrease in strength was more than the control intervention which consisted of subjects resting for five minutes before their post-test. Rationale for this could be due to the theory that the GT introduces controlled micro-trauma to the area of application and breaks down existing extracellular matrix adhesions.[4,11,12] Black noted an improvement in strength based on improvement in activities of daily living. This was a case study involving a patient recovering from a patellar tendon repair 10-weeks prior. Five treatments of the GT was used throughout a month in combination with joint mobilization and strengthening activities.[13] The strengthening exercises included in the treatment of Black's study are thought to remodel the collagen matrix making the connective tissue stronger.[34] Since the current study investigated the acute effects of the GT without the use of eccentric exercise, it is possible that the GT broke up the adhesions or restrictions a subject may have had in their quadriceps, but the connective tissues was not strong enough to allow the muscles to generate high levels of tension.[2] The subjects being treated once with the GT did not have time for the connective tissue to go through the healing process and the exclusion of eccentric exercises to remodel the connective tissue[35] could have led to the decrease in peak isokinetic torque as seen in this study. In addition, this study inclusion criterion consisted of a healthy population while Burke et al. and Black observed strength gains in subjects with muscular pathologies.

Peak isokinetic torque decreased after the WBV intervention similar to Cormie et al.[18] In the Cormie et al. study, peak force slightly decreased from baseline during isometric squats following WBV; however, jump height increased following the intervention. This could indicate that vibration can impact certain performance over others such as power over strength. The results of Torvinen et al.[19] and Cochrane and Stannard[42] supports the idea that WBV can improve power through performance measurements as vertical jump height and arm countermovement vertical jump increased, respectively. It is theorized that WBV reduces recruitment threshold in fast twitch muscle fibers[21] and increases motor unit synchronization through the tonic vibration reflex,[39,43,52] which can ultimately lead to an increase in muscle activity.[20,43,52] The possible reasoning why strength was not affected by WBV in the current study could be linked to the theory that motor unit synchronization does not translate into an increase in muscle strength but instead be the cause of an increase in muscle activity.[52] Semmler suggested the neuromuscular performance affected by the increase in muscle synchronization is rate of force development.[56] Also, reducing the recruitment threshold in fast twitch muscle fibers will have a greater effect on power by increasing contractile speed[21] rather than strength.

Although the decrease in strength was minimal for all conditions, the change in strength was less following the WBV intervention. These observations are in accordance with Jordan et al.[17] In the Jordan et al. study, peak isometric torque and voluntary muscle activation of the knee extensors decreased. It was suggested that improvement in strength could possibly be seen through dynamic movements rather than isometric movements. The current study rejects this suggestion as peak isokinetic torque did not have any significant change when compared to baseline measurements and the control intervention. Another explanation could be the WBV parameters chosen was not able to elicit a tonic vibration reflex and sufficient sensory stimulation as there were no electromyography recordings to directly assess any neurogenic enhancements. In addition, there was no significant difference in peak isokinetic torque between the GT group and WBV group.

FATIGUE

The other primary purpose of the current study was to examine the acute effects of the GT and WBV on fatigue. Total work and work fatigue did not have any significant difference in either intervention when compared to the control group. The decrease in work fatigue indicates that fatigue improved; however, both interventions did not improve more than the control group. When reviewing at the ability for the muscle to maintain high torque, the GT was the only intervention to have a positive change in total work, 92.6 ± 427.6Nm (mean ± SD). Despite the increase, the standard deviation indicates too much random error occurred compared to the other interventions. An explanation for an improvement in fatigue for the GT could be the breaking up of the extracellular matrix adhesions. These adhesions can limit function,[11,26,32,34] range of motion[8,32,35] and pain threshold.[4,12,36] The adhesions could potentially cause fatigue in the muscles as they would have to work harder to contract as the tissues are adhering to one another. Once the GT is applied, it is theorized that the connective tissue realigns itself to function more smoothly.[4,11,12]

On the contrary, WBV was not able to maintain high torque throughout the Thorstennson protocol as total work decreased more than the control intervention, although not significantly. Change in work fatigue was similar to the control intervention, as fatigue improved in both interventions. The explanation for the increase in fatigue for the WBV could be that WBV elicited the tonic vibration reflex. The tonic vibration reflex is theorized to increase muscle activity, slow-twitch muscle fibers and motor unit synchronization.[26,27,44] Due to the lower recruitment threshold in slow-twitch muscle fibers, more motor units could have been recruited throughout the protocol. This could possibly lead to the quadriceps having more endurance to perform continuous knee extensions.[29] Lastly, it is believed that the change in peak isokinetic torque and fatigue were not due to environemental or psychological variables as subjects were verbally and encouraged throughout the protocol.

There was a statistically significant difference in total work between the GT group and WBV group; howerver, too much random error was observed in total work to conclude any difference. This could be the result of a few limitations in the study. The subjects' effort could have caused the variability in total work as there were a few outliers in each group. In addition, the subjects positioning on the biodex should have been recorded so it could be replicated during the post-measuremetn visit. Future research should investigate subjects with muscular pathologies rather than a healthy population as in this study. Also, researchers should identify the effects of the GT on strength and fatigue of other muscles than the quadriceps and possibly implement an eccentric exercise to the protocol. In regards to WBV, researchers should alter the vibration parameters when looking at the effects of WBV on strength fatigue and look at muscle activity in regards to strength. Lastly, researchers should record measurements at different intervals post-intervention.

PRACTICAL APPLICATION

The GT and WBV did not significantly decrease peak isokinetic torque, total work or work fatigue when comparing baseline to post-measurements or control group. For contemporary practice, it is safe to apply the GT or use WBV before competition as it does not affect strength or fatigue significantly. For strength and fatigue, it is not better or worse than resting for 5 minutes before practice or competition.

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VITA

Daniel Romero

Candidate for the Degree of

Master of Science

Thesis: EFFECTS OF INSTRUMENT-ASSISTED SOFT TISSUE MOBILIZATION ON ISOKINETIC KNEE EXTENSOR STRENGTH AND FATIGUE

Major Field: Health and Human Performance

Biographical:

Education:

Completed the requirements for the Master of Science in Health and Human Performance option Athletic Training at Oklahoma State University, Stillwater, Oklahoma in May, 2014.

Completed the requirements for the Bachelor of Science in Athletic Training at Sacramento State University, Sacramento, California in 2012.

Experience:

Completed ATEP program at Sacramento State University. Completed rotations at Sacramento State University and American River Junior College covering various D1 and junior college sports such as football, basketball, baseball, soccer, volleyball, track and field, swimming, water polo and tennis. During summers, covered various sport camps and tournaments such as wrestling, basketball, soccer and baseball in California and basketball in Oklahoma. I am a BOC certified and a Licensed Athletic Trainer in the State of Oklahoma. I am certified in the Graston Technique as well as CPR/AED for the Professional Rescuer and the Healthcare Provider and in Emergency Response.

Professional Memberships:

NATA member #41519.