Acute Effects of Neuromuscular-Training with Handheld-Vibration on Elbow Joint Position Sense

Donald A. Faust, Brady L. Tripp, Michelle A. Cleary, Patrick Jacobs P*
Florida International University, Miami, FL
*Florida Atlantic University, Boca Raton, FL

Context: Clinicians use exercises in rehabilitation to enhance sensorimotor-function, however evidence supporting their use is scarce. **Objective:** To evaluate acute effects of handheld-vibration on joint position sense (JPS). **Design:** A repeated-measure, randomized, counter-balanced 3-condition design. **Setting:** Sports Medicine and Science Research Laboratory. **Patients or Other Participants:** 31 healthy college-aged volunteers (16-males, 15-females; age=23±3y, mass=76±14kg, height=173±8cm). **Interventions:** We measured elbow JPS and monitored training using the Flock-of-Birds system (Ascension Technology, Burlington, VT) and MotionMonitor software (Innsport, Chicago, IL), accurate to 0.5°. For each condition (15,5,0Hz vibration), subjects completed three 15-s bouts holding a 2.55kg Mini-VibraFlex dumbbell (Orthometric, New York, NY), and used software-generated audio/visual biofeedback to locate the target. Participants performed separate pre- and post-test JPS measures for each condition. For JPS testing, subjects held a non-vibrating dumbbell, identified the target (90°flexion) using biofeedback, and relaxed 3-5s. We removed feedback and subjects recreated the target and pressed a trigger. We used SPSS 14.0 (SPSS Inc., Chicago, IL) to perform separate ANOVAs ($p \leq 0.05$) for each protocol and calculated effect sizes using standard-mean differences. **Main Outcome Measures:** Dependent variables were absolute and variable error between target and reproduced angles, pre-post vibration training. **Results:** 0Hz ($F_{1,61}=1.310, p=0.3$) and 5Hz ($F_{1,61}=2.625, p=0.1$) vibration did not affect accuracy. 15Hz vibration enhanced accuracy (6.5±0.6 to 5.0±0.5°) ($F_{1,61}=8.681, p=0.005$, ES=0.3). 0Hz did not affect variability ($F_{1,61}=0.007, p=0.9$). 5Hz vibration decreased variability (3.0±1.8 to 2.3±1.3°) ($F_{1,61}=7.250, p=0.009$), as did 15Hz (2.8±1.8 to 1.8±1.2°) ($F_{1,61}=24.027$, $p<0.001$). **Conclusions:** Our results support using handheld-vibration to improve sensorimotor-function. Future research should include injured subjects, functional multi-joint/multi-planar measures, and long-term effects of similar training. **Key words:** sensorimotor-function, active repositioning, audio/visual biofeedback

The elbow endures large magnitudes of force during the overhead throw.[1,2] To avoid injury, the senorimotor system (SMS) must control and disperse stress by coordinating joint motion and position.[3-7] When loads are too great, the stabilizing structures of the joint are at risk for injury.[1,2] Structural damage compromises stability, hampers SMS function, and may lead to further structural damage and fatigue.[8-15] Clinicians use this paradigm to identify perspective interventions including endurance training, surgical procedures, and rehabilitation. Clinical trials have observed postponement of fatigue through a combination of resistance and endurance training.[16] Surgical interventions followed by rehabilitation incorporating neuromuscular-training rectify structural damage and restore SMS function.[17] During post-surgical or conservative rehabilitation programs, clinicians employ exercises using manual rhythmic stabilization or oscillatory devices with the goal of enhancing neuromuscular control (NMC).[18] These exercises include short bursts of resistance that require an almost subconscious SMS reaction to restore or maintain joint position and stability. Evidence validating the efficacy of these rehabilitation exercises is scarce however, because standardizing the applied resistance is challenging. Our goal was to standardize a neuromuscular-training exercise and observe the acute effects on active JPS at the elbow. We used a vibrating dumbbell to standardize the applied resistance during elbow neuromuscular-training. Traditionally, research examining vibration has reported the occupational hazards of exposure to high loads/frequencies produced by industrial machinery on SMS function.[19-22] Strength and conditioning research has observed positive acute effects of vibration using high frequencies of whole body vibration (WBV), for periods ranging from 1 to 10 minutes.[23-28] These short bouts of WBV immediately enhance average velocity, force, and power,[23] through neuromuscular mechanisms similar to the changes observed over the first ten weeks of power-training.[29] Researchers[23-28] attribute these transient augmentations following vibration to neuromuscular mechanisms including a heightened awareness and joint control strategy with quicker rate of force development. While the precise mechanisms remain largely unknown,[22-28] researchers postulate they stem from enhanced neuromuscular efficiency.[24] Although such vibration exercises affect the components providing NMC, no research has investigated the acute effects of vibration-enhanced neuromuscular-training on SMS function. Therefore, our purpose was to examine the acute effects of neuromuscular-training using handheld-vibration (HV) on SMS function as measured through active elbow JPS.

Methods

Research Design

We used a repeated-measure, randomized, and counterbalanced 3-condition (crossover) design. The independent variables were frequency of HV at three levels (0 [control], 5, and 15Hz) and time at two levels (pre- and post-test). The dependant variables were absolute (accuracy) and variable (variability) error scores measured through active elbow JPS. Subjects performed pre and post-tests 3 separate times, thereby serving as members of each group (control, 5 and 15Hz)

Participants

We randomly sampled of 31 healthy college-aged individuals (16 males, 15 females; 29 right-handed, 2 left-handed; age= 23±3 y, mass= 76±14 kg, height= 173±8 cm). We screened participants using a health history questionnaire and excluded subjects based on prior history of upper-extremity injury (within the last year), major upper-extremity surgery, or central nervous system disorder. We asked participants, 24hr before their appointment, to abstain from strenuous upper-extremity activity to help eliminate any possible fatigue or carry-over soreness. Prior to data collection, all participants read and signed an informed consent form approved by the Institutional Review Board.

Instruments

We collected and analyzed degrees of bilateral elbow flexion using four wired sensors from the Flock-of-Birds electromagnetic tracking system (Ascension Technology, Burlington, VT), and MotionMonitor software (Innsport, Chicago, IL). This system is considered reliable[14] and accurate (0.5° at 0.91m).[30] During the intervention, participants held a 2.55kg Mini-VibraFlex dumbbell (Orthometric, New York, NY).

Procedures

Digitizing. We digitized participants according to the International Society of Biomechanics' standardized protocol.[31] We attached sensors bilaterally to participants' distal posterior forearm and over the deltoid tuberosity of the ulna with elastic straps and a mild spray adhesive. We palpated, marked and digitized bony landmarks on each arm including medial and lateral humeral epicondyles, radial and ulnar styloid processes.

Order of Testing. Participants performed a pre-test measure of JPS, underwent a randomized intervention and repeated the JPS measure. We tested each arm individually and randomly assigned the order of arm testing (dominant or non-dominant). Each participant was tested as a member of one intervention group, rested for 45-minutes (to limit any physical or mental fatigue or learning effect), and returned to serve as a member of the remaining intervention groups.

JPS Measure. For each elbow JPS test, participants stood, resting their test elbow on a padded, adjustable armrest. We adjusted the height of the pipe by adding or removing 1.9cm wooden planks to attain 60±5° of shoulder flexion. Because adding resistance[32] with auditory and visual biofeedback[33, 34] during JPS testing enhances NMC, during NM-training, our participants held a 2.55kg non-metal dumbbell and used both visual and auditory real-time feedback provided by the biofeedback software. The software generated a tone when the test-elbow deviated more than 1 degree from the desired target angle. The participants faced a monitor on which the software presented visual feedback including oscilloscopes illustrating position of the test-elbow in relation to the target angle. An investigator trained participants to produce the desired target angle of 90 ° elbow flexion using the software generated real-time visual and auditory biofeedback. The visual biofeedback included line graphs indicating the participant's elbow flexion angle in relation to the target angle. The computer generated a tone when elbow flexion angle deviated from the target by more than one degree. To begin each JPS test, subject found the target angle, maintained the position for 3-5s, then relaxed their arm, resting the dumbbell on the table. Before attempting angle-reproduction trials, participants blindfold themselves and we removed auditory biofeedback. To indicate when they believed they had reproduced the target angle, participants pressed a trigger in their contra-lateral hand. After pressing the trigger, participants returned their arm to the resting position and began the next angle-reproduction trail within three seconds. Participants performed three angle-reproduction trails for each JPS test.

HV Training Protocol. Participants underwent separate JPS testing before and after each of the three interventions (0, 5, 15Hz). Two of the three experimental interventions included vibration of the 2.55kg dumbbell at 5 or 15Hz with an amplitude of 2mm. The remaining intervention used no vibration (0Hz, control). To maintain the position of 60±5° of shoulder flexion during training, we raised or lowered the height of the padded bar (based of the participant's height) and instructed participants to refrain from resting their elbow on the padded bar during the training. We did this to maintain a consistent shoulder angle and eliminate distribution of force to the table and any discomfort it may have caused. We began the vibration and reintroduced to the target elbow position to participants actively, using the software generated real-time visual and auditory biofeedback. Participants held this position for 15s using the biofeedback, before lowering their arm and resting for 60s. Participants repeated the vibration bout two more times, with a minute of rest between each bout.

Statistical Analysis. We performed statistical analyses using SPSS 14.0 statistical package for Windows (SPSS Inc., Chicago, IL) with a significance level set *a priori* at $P \leq 0.05$. For each dependent variable, accuracy (absolute error, absolute distance from the target) and variability (variable error, variability of angles reproduced), and each intervention (vibration at 0, 5, and 15Hz), we used a separate analyses of variance to compare pre-test to post-test values. We calculated effect sizes for each exercise condition using the standard mean difference equation.[35]

Results

Our purpose was to evaluate the acute effects of neuromuscular-training using three frequencies of HV on the accuracy and variability of elbow JPS. Table 1 presents the effects of each vibration protocol on active elbow JPS. The 0Hz and 5Hz vibration protocols did not have a significant effect on accuracy (*P*>0.05), while the 15Hz vibration protocol significantly enhanced accuracy (decreased absolute error) (*P*≤0.05). The 0Hz vibration protocol did not significantly effect variability (*P*>0.05), while 5 and 15Hz vibration significantly enhanced variability (decreased variable error) (*P*≤0.05).

Discussion

We observed an acute enhancement of active elbow JPS (accuracy and variability) after neuromuscular-training using dumbbell vibration at 15Hz. This is the first report indicating vibration may enhance acute JPS when used in neuromuscular-training. We also observed less variability after neuromuscular-training using 5Hz vibration (Table 1). Because we used low frequency vibration for short durations, there is no data affording comparisons to ours. Our general observation that vibration can enhance NMC however, is in contrast to previous reports.[14,36-38]

Our use of low frequencies of vibration for short durations of exposure may have enabled the acute enhancements in SMS function we observed. Research indicates that exposure to high loads of vibration for an extended period is detrimental to SMS function.[36] Large magnitudes (amplitude, frequency, and exposure duration) are believed to disrupt the ability of the peripheral afferents to function.[37] It is also well established that muscular fatigue also decreases NMC.[14,38] We did not observe the negative effects muscular fatigue would have produced, because of the low frequencies and short periods of vibration exposure compared with other reports.[14, 36-38]

While the majority of vibration research focuses on its detrimental effects, not all reports investigating vibration have observed negative results.[22,32,33] We actually observed an acute enhancement of JPS immediately after HV exposure, which is supported by literature. When observing JPS immediately before and after vibration exposure, instead of during vibration exposure, NMC was not impaired.[22] Researchers attribute this observation to the SMS receiving more afferent stimulation during vibration exposure, creating a clearer image of limb position in relation to the remembered framework of the central nervous system.[22] Researchers also observed that when testing JPS in the midranges of motion, NMC was not impaired by vibration exposure.[22] We tried to enhance JPS by incorporating added resistance during the JPS testing and vibration exposure. One JPS report suggests that adding resistance enhances SMS function.[32] We also used auditory and visual biofeedback during the neuromuscular-training to enhance NMC. Researchers observed greater movement velocity while maintaining accuracy with the aid of visual biofeedback during MNC testing.[33] In comparison, we observed acute enhancement of JPS measuring immediately after vibration exposure in the mid range of elbow flexion with audio and visual biofeedback. All proposed mechanisms for the enhancement of JPS, we observed.

Our results support the use of HV in exercise programs designed to improve sensorimotor function. While we used HV to standardize NMC tasks used clinically, further research should investigate if these same enhancements may be elicited using more common clinical techniques. We acknowledge that this study, like all research has limitations. We used a standard 2.55kg dumbbell and did not normalize the magnitude of resistance to participant body mass or maximal force output. Because we used a light dumbbell, only measured elbow flexion, and subjects only held positions for 15s, participants did not report feeling fatigue regardless of body mass. We believe that the 5Hz vibration did not significantly enhance accuracy due to a lack of statistical power (Table 1). We only observed the acute effects of HV; the chronic effects of neuromuscular-training programs warrant further investigation. Our results only apply to healthy college-aged individuals. Further research should investigate the effects of HV in injured populations and those of different age groups. Future research into the use of HV should include other vibration frequencies and exposure durations, measure other joints, and functional multi-joint/multi-planar measures.

Our study was unique in that it was the first to observe an acute enhancement of active elbow JPS following neuromuscular–training. We used vibration-enhanced resistance with audio and visual biofeedback to enhance the affect of neuromuscular-training on JPS. We believe we were able to enhance JPS by increasing the amount of afferent information provided to the central nervous system. The added afferent information may have enabled the central nervous system to develop a clearer image of extremity positioning and thus enhance NMC.[23] This is important clinically, because decreased NMC can lead to further injury. One reason this is the first study to observe this is because of the difficulty in standardizing neuromuscular-training exercises. Short bouts of HV in conjunction with other neuromuscular-training shows promise in enhancing SMS function.

Reference List

1. McCall BR, Cain EL, Jr. Diagnosis, treatment, and rehabilitation of the thrower's elbow. *Curr Sports Med Rep.* 2005;4(5):249-54.
2. Werner SL, Murray TA, Hawkins RJ, Gill TJ. Relationship between throwing mechanics and elbow valgus in professional baseball pitchers. *J Shoulder Elbow Surg.* 2002;11(2):151-5.
3. Lephart SM, Pincivero DM, Giraldo JL, Fu FH. The role of proprioception in the management and rehabilitation of athletic injuries. *Am J Sports Med.* 1997;25(1):130-7.
4. Myers JB, Lephart SM. The Role of the Sensorimotor System in the Athletic Shoulder. *J Athl Train.* 2000;35(3):351-63.
5. Myers JB, Lephart SM. Sensorimotor deficits contributing to glenohumeral instability. *Clin Orthop Relat Res.* 2002;(400):98-104.
6. Riemann BL, Lephart SM. The Sensorimotor System, Part II: The Role of Proprioception in Motor Control and Functional Joint Stability. *J Athl Train.* 2002;37(1):80-4.
7. Riemann BL, Lephart SM. The Sensorimotor System, Part I: The Physiologic Basis of Functional Joint Stability. *J Athl Train.* 2002;37(1):71-9.
8. Carpenter JE, Blasier RB, Pellizzon GG. The effects of muscle fatigue on shoulder joint position sense. *Am J Sports Med.* 1998;26(2):262-5.
9. Huysmans MA, Hoozemans MJ, van der Beek AJ, de Looze MP, van Dieen JH. Fatigue effects on tracking performance and muscle activity. *J Electromyogr Kinesiol.* 2007;17(1): January 5.
10. Myers JB, Guskiewicz KM, Schneider RA, Prentice WE. Proprioception and Neuromuscular Control of the Shoulder After Muscle Fatigue. *J Athl Train.* 1999;34(4):362-7.
11. Pedersen J, Ljubisavljevic M, Bergenheim M, Johansson H. Alterations in information transmission in ensembles of primary muscle spindle afferents after muscle fatigue in heteronymous muscle. *Neuroscience.* 1998;84(3):953-9.
12. Pedersen J, Lonn J, Hellstrom F, Djupsjobacka M, Johansson H. Localized muscle fatigue decreases the acuity of the movement sense in the human shoulder. *Med Sci Sports Exerc.* 1999;31(7):1047-52.

13. Sterner RL, Pincivero DM, Lephart SM. The effects of muscular fatigue on shoulder proprioception. *Clin J Sport Med.* 1998;8(2):96-101.
14. Tripp BL, Boswell L, Gansneder BM, Shultz SJ. Functional Fatigue Decreases 3-Dimensional Multijoint Position Reproduction Acuity in the Overhead-Throwing Athlete. *J Athl Train.* 2004;39(4):316-20.
15. Walsh LD, Hesse CW, Morgan DL, Proske U. Human forearm position sense after fatigue of elbow flexor muscles. *J Physiol.* 2004;558(Pt 2):705-15.
16. Verney J, Kadi F, Saafi MA, Piehl-Aulin K, Denis C. Combined lower body endurance and upper body resistance training improves performance and health parameters in healthy active elderly. *Eur J Appl Physiol.* 2006;97(3):288-97.
17. Lephart SM, Myers JB, Bradley JP, Fu FH. Shoulder proprioception and function following thermal capsulorraphy. *Arthroscopy.* 2002;18(7):770-8.
18. Wilk KE, Reinold MM, Andrews JR. Rehabilitation of the thrower's elbow. *Clin Sports Med.* 2004;23(4):765-801, xii.
19. Cardinale M, Pope MH. The effects of whole body vibration on humans: dangerous or advantageous? *Acta Physiol Hung.* 2003;90(3):195-206.
20. Di LC, Ranchelli A, Lucidi P et al. Effects of whole-body vibration exercise on the endocrine system of healthy men. *J Endocrinol Invest.* 2004;27(4):323-7.
21. Jordan MJ, Norris SR, Smith DJ, Herzog W. Vibration training: an overview of the area, training consequences, and future considerations. *J Strength Cond Res.* 2005;19(2):459-66.
22. Radovanovic S, Day SJ, Johansson H. The impact of whole-hand vibration exposure on the sense of angular position about the wrist joint. *Int Arch Occup Environ Health.* 2006;79(2):153-60.
23. Bosco C, Colli R, Introini E et al. Adaptive responses of human skeletal muscle to vibration exposure. *Clin Physiol.* 1999;19(2):183-7.
24. Cormie P, Deane RS, Triplett NT, McBride JM. Acute effects of whole-body vibration on muscle activity, strength, and power. *J Strength Cond Res.* 2006;20(2):257-61.
25. Delecluse C, Roelants M, Verschueren S. Strength increase after whole-body vibration compared with resistance training. *Med Sci Sports Exerc.* 2003;35(6):1033-41.
26. Ronnestad BR. Comparing the performance-enhancing effects of squats on a vibration platform with conventional squats in recreationally resistance-trained men. *J Strength Cond Res.* 2004;18(4):839-45.
27. Torvinen S, Kannus P, Sievanen H et al. Effect of four-month vertical whole body vibration on performance and balance. *Med Sci Sports Exerc.* 2002;34(9):1523-8.
28. Torvinen S, Kannus P, Sievanen H et al. Effect of 8-month vertical whole body vibration on bone, muscle performance, and body balance: a randomized controlled study. *J Bone Miner Res.* 2003;18(5):876-84.
29. Kyrolainen H, Avela J, McBride JM et al. Effects of power training on muscle structure and neuromuscular performance. *Scand J Med Sci Sports.* 2005;15(1):58-64.
30. Tripp BL, Uhl TL, Mattacola CG, Srinivasan C, Shapiro R. A comparison of individual joint contributions to multijoint position reproduction acuity in overhead-throwing athletes. *Clin Biomech (Bristol , Avon).* 2006;21(5):466-473.
31. Wu G, van der Helm FC, Veeger HE et al. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion--Part II: shoulder, elbow, wrist and hand. *J Biomech.* 2005;38(5):981-92.

32. Brindle TJ, Uhl TL, Nitz AJ, Shapiro R. The influence of external loads on movement precision during active shoulder internal rotation movements as measured by 3 indices of accuracy. *J Athl Train* 2006 January;41(1):60-6.
33. Brindle TJ, Nitz AJ, Uhl TL, Kifer E, Shapiro R. Kinematic and EMG characteristics of simple shoulder movements with proprioception and visual feedback. *J Electromyogr Kinesiol* 2006 June;16(3):236-49.
34. Mroczek N, Halpern D, McHugh R. Electromyographic feedback and physical therapy for neuromuscular retraining in hemiplegia. *Arch Phys Med Rehabil* 1978 June;59(6):258-67.
35. Cohen J. *Statistical power analysis for the behavioral sciences, revised edition*. New York: Academic Press; 1997.
36. Gauthier GM, Roll JP, Martin B, Harlay F. Effects of whole-body vibrations on sensory motor system performance in man. *Aviat Space Environ Med* 1981 August;52(8):473-9.
37. Rogers DK, Bendrups AP, Lewis MM. Disturbed proprioception following a period of muscle vibration in humans. *Neurosci Lett* 1985 June 12;57(2):147-52.
38. Allen TJ, Proske U. Effect of muscle fatigue on the sense of limb position and movement. *Exp Brain Res* 2006 March;170(1):30-8.

Tables and Figures

Table 1. Analysis of the acute effects of neuromuscular-training with hand-held vibration on accuracy and variability of active elbow joint position sense

Vibration Frequency	Pre-test	Post-test	F	*p*	Power	Effect Size*
0Hz-a	7.0±4.9	6.3±4.3	1.310	0.257	0.203	n/a
0Hz-v	3.0±2.1	2.9±1.8	0.007	0.933	0.051	n/a
5Hz-a	5.4±3.5	4.7±2.8	2.625	0.110	0.358	n/a
5Hz-v	3.0±1.8	2.3±1.3	7.250	0.009	n/a	0.42
15Hz-a	6.5±4.9	5.0±3.5	8.681	0.005	n/a	0.33
15Hz-v	2.8±1.8	1.8±1.2	24.027	<0.001	n/a	0.62

Legend: a=absolute error; v=variable error; *Effect size calculated by using the standard mean difference equation