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Effects of vibration training on elbow joint position sensing

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Abstract

Some proprioceptive rehabilitation programs utilize tendon vibration to improve and restore sensory and motor function. Few studies have examined adaptation and learning effects that may occur with repeated exposures to tendon vibration. It is well established that vibration stimulates muscle spindles, resulting in a kinesthetic illusion of muscle stretch and lengthening. This kinesthetic illusion results in misperception of the corresponding joint angle position. The present study assessed learning effects on elbow joint position sense that occurred after training with unilateral vibration of the biceps brachii. Young, healthy adults (n = 20) were randomized into one of two training groups, a control group undergoing joint position training without vibration and a treatment group undergoing training with vibration. Each group completed five training sessions in which they practiced an elbow joint matching task between their left and right arms. Elbow joint position accuracy was evaluated by absolute angle error, the difference between the right arm target angle and the perceived "matched" angle of the left arm. Absolute error was compared between the two training groups pre-and post-training, in both non-vibration and vibration conditions. Following training, both groups reduced absolute error in the condition in which they trained. Non-vibration error was not significantly affected in the vibration treatment group, suggesting vibration training is not detrimental to performance when tendon vibration is no longer present. Overall, the vibration treatment group was able to effectively integrate altered muscle spindle afferent information to improve elbow joint proprioceptive accuracy. This information can be used to inform the development of tendon vibration-based rehabilitation protocols for selected patient populations experiencing sensory and motor control problems.

Introduction

Impairment of proprioception is associated with conditions and diseases such as Parkinson's disease, stroke, peripheral neuropathy, and diabetes and a number of nerve-based injuries such as carpal tunnel syndrome. It is well known that when applied to tendons vibration stimulates afferent Ia-muscle spindles, resulting in a kinesthetic illusion that can produce joint position errors [1–4]. Utilization of tendon vibration in rehabilitation programs has shown promise because the vibration illusion is independent of motor ability [5–9]. Several studies have reported improved performance resulting from vibration-based therapy [7-10]. The ability to effectively perform in multiple sensory conditions has been labeled as "duel adaptation" [11]. This type of adaptation can be induced by repeatedly adapting and readapting to different sensory environments, in this case with and without sensory input induced by vibration. Because of its potential for use in sensory and motor rehabilitation, it is necessary to understand effects of long-term use of tendon vibration, such as adaptation and learning, and any possible detrimental effects resulting from vibration-based therapy.

The purpose of the present study was to determine if it is possible to learn a joint matching task while training with vibration. It was hypothesized that healthy participants training with vibration would improve their elbow joint position accuracy despite being exposed to disruption via tendon vibration. This would be confirmed by a reduction in elbow joint position error during vibration exposure, suggesting the previously disruptive afferent input can be integrated in such a way that learning can occur. The ability to learn to accurately position the limbs in the presence of disruptive proprioception in a healthy population would support the concept of duel adaptation and may provide insights that can be incorporated into sensorimotor rehabilitation training programs for clinical populations.

Methods and materials

Subjects

Twenty healthy adults (12 females and 8 males, mean age ± SD: 22.4 ± 2.9 years) voluntarily participated in this study. Exclusion criteria included history of upper limb injury within the past year of the study, upper limb surgery or neurological disorders such as Parkinson's disease, peripheral neuropathies, or stroke. All participants read and signed the informed consent form, which was approved by the Committee for the Protection of Human Subjects (CPHS) at the University of Houston.

Equipment

Vibration was applied unilaterally, on the left biceps brachii tendon at a frequency of 80 Hz (VB 115, Techno-concept, Cereste, France). A stimulation frequency of 80 Hz is within the range of vibration known to preferentially stimulate muscle spindles [12–14]. While seated, participants placed their forearms into two vertical kinethesiometer devices (Lafayette Instrument Company, Lafayette, Indiana), which measure angles to the nearest degree, placed shoulder width apart on a tabletop.

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Procedure

All training sessions were conducted at the University of Houston. Participants completed five one-hour training sessions over a three-week period, at approximately the same time each day. Each training session consisted of three phases, 10 pre-test trials, 50 training trials, and 10 post-test trials. An overview of the training session protocol can be found in Figure 1.

While blindfolded, participants performed an elbow angle-matching task while wearing a vibrator on the biceps insertion tendon of the left arm. For each trial, the participant's right arm was passively moved to 55° by the experimenter. Participants were then asked to match their left arm to the angle of the right arm. The experimenter recorded the angle of the left arm following visual inspection once participants ceased movement of their arm and signified verbally that they believed to have matched the angle. During training, after each trial participants received verbal feedback informing the direction and magnitude of the left elbow angle error in relation to the target angle of 55°. Participants were randomly assigned to one of two groups: a control group (6 females and 4 males, 21.9 ± 1.0 years) and a treatment group (6 females and 4 males, 22.9 ± 0.82 years). Those in the control group performed all training trials without vibration, thus the vibrator on the biceps tendon was not activated ("off"). Those in the treatment group performed all training trials with the vibrator activated at the start of each trial ("on"). Pre- and post-tests were the same for both groups. Pre- and post-tests were conducted under two conditions, five trials with vibration "off" and five trials with vibration "on". The non-vibration pre-test was always conducted before the vibration pre-test. For the post-tests, the order was randomized to limit any potential bias towards the post-test condition similar to the participant's training condition.

Data

Absolute error was calculated using the differences between the right arm target angle (55°) and the matched angle of the left arm for each trial. Absolute error is the magnitude of the difference between the target angle and matched angle regardless of the direction of the error, and is used to represent the accuracy of elbow joint position.

Statistical Analysis

Statistical analyses were performed using SPSS (IBM Corp. Released 2016. IBM SPSS Statistics for Mac, Version 24. Armonk, NY: IBM Corp.) A mixed model repeated measures ANOVA (RM-ANOVA) was performed to determine differences between training *Groups* (control and treatment), under two vibration *Conditions* (non-vibration ("off") and vibration ("on")) at two points in *Time* (pre-test and post-test). Paired t-tests were conducted to compare absolute error in each testing condition before and after training, for both training groups. Statistical significance was set a priori at $p < 0.05$.

Results

A significant main effect of *Condition* was found (F (1,16) = 6.255, $p < 0.05$), such that the non-vibration *Condition* ("off") (*AE* = 4.201 ±0.306) was associated with significantly less mean absolute angle error compared to the vibration *Condition* ("on") (*AE* = 6.378 ± 0.786). No significant *Group* main effect was found (F (1,16) = 0.392, $p = 0.540$) indicating both groups experienced the kinesthetic illusion when experiencing vibration. A significant main effect of *Time* was found (F (1,16) = 8.752, $p < 0.01$). When collapsed over group and condition, the pre-test had a mean absolute angle error of 6.288 ± 0.551 with the post-test absolute error being 4.29 ± 0.506 (Figure 2).

There was a significant interaction between *Condition* and *Group* (F (1,16) = 11.356, $p < 0.005$). When collapsed over *Time,* the Control group had larger mean absolute angle error when experiencing vibration (*AE* = 8.100 ± 1.048) than in the no vibration condition (*AE* = 2.990 ± 0.408). A paired t-test revealed that there was a significant increase in AE in both the pre- and post-test when the Control group received vibration (Vibration Pre-test *AE* = 9.620 ± 5.170; Vibration Post-test *AE* = 6.580 ± 4.373) compared to when they received no vibration (No Vibration Pre-test *AE* = 4.120 ± 2.561; No Vibration Post-test *AE* = 1.860 ± 0.499; Pre-test: t (9) = 2.823, $p < 0.05$; Post-test: t (9) = 3.628, $p < 0.01$), see filled circles in Figure 2A and B. In contrast, when collapsed over *Time*, the Treatment group displayed no change in AE when exposed to vibration (*AE* = 4.656 ± 1.171) compared to no vibration (*AE* = 5.413 ± 0.456). The results of the paired t-test indicated that the pre-test vibration AE was significantly greater than during no vibration pre-testing (Vibration Pre-test *AE* = 7.410 ± 3.697; No Vibration Pre-test *AE* = 4.850 ± 2.127; t (9) = 2.210, $p < 0.05$). However, during post-testing, the opposite effect was found with decreased AE being observed with vibration relative to no vibration (Vibration Post-test *AE* = 2.563 ± 1.398; No Vibration Post-test *AE* = 6.163 ± 3.299; t (7) = 2.928, $p < 0.05$), see open squares in Figure 2A and B.

There was also a significant *Condition x Time* interaction (F (1,16) = 6.117, $p < 0.05$). Collapsed over both treatment groups, when tested with vibration, mean absolute angle error was significantly reduced post-test (*AE* = 4.571 ± 0.808), compared to pre-test (*AE* = 8.185 ± 1.029). When tested without vibration, mean absolute angle error did not significantly change post-test (*AE* = 4.011 ± 0.525) compared to pre-test (*AE* = 4.391 ± 0.564). However, paired t-tests revealed that when tested with vibration the Treatment group displayed a significant decrease in AE during the post-test compared to the pre-test (Pre-test *AE* = 6.589 ± 2.791; Post-test *AE* = 2.611 ± 1.315; t (8) = 3.447, $p < 0.01$). The decline in absolute error when tested with vibration shows that those in the Treatment group learned while training with tendon vibration. Conversely, the Control group displayed no change during post-testing with vibration relative to pre-testing with vibration (Pre-test *AE* = 9.620 ± 5.170; Post-test *AE* = 6.580 ± 4.373; t (9) = 2.158, $p = 0.059$), see right side of Figure 2A and B. Additionally, paired t-tests

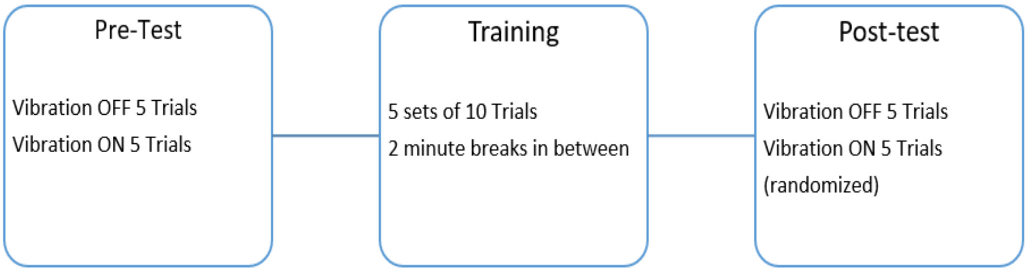

Figure 1. Order of Testing Procedures.

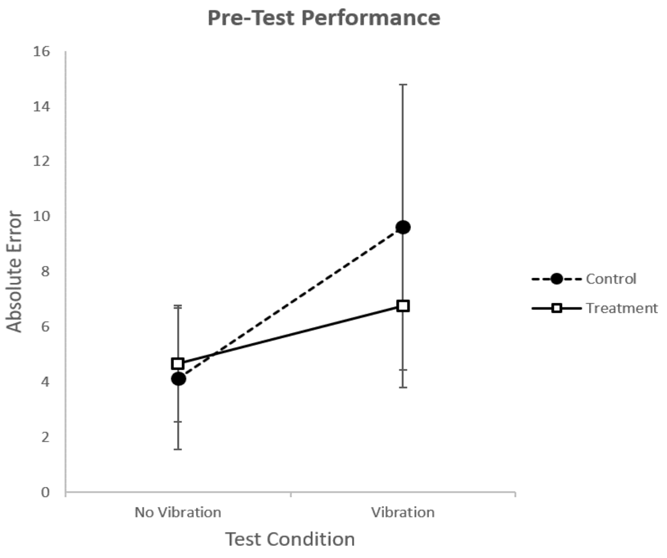

Figure 2A. Training Group (Control/Treatment) by Time (Pre-Test/Post-Test) Interaction Effect. Pre-Test mean absolute error of the left arm for both No Vibration and Vibration test conditions for both the Control (solid circles) and Treatment (open squares) groups. Error bars represent standard deviation.

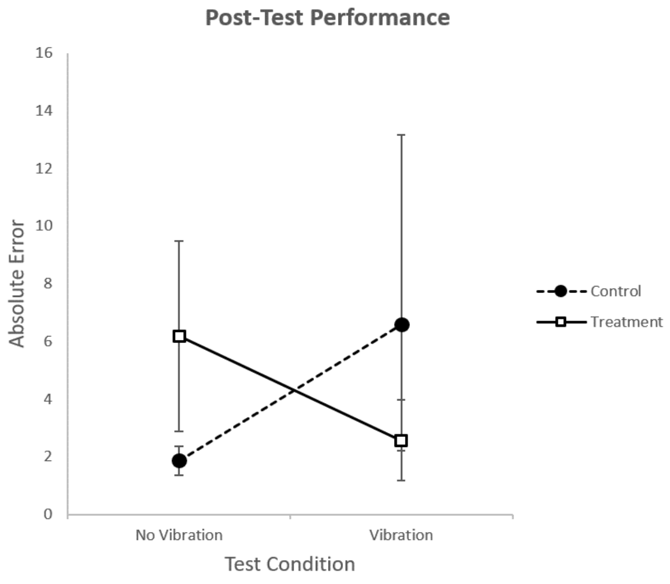

Figure 2B. Training Group (Control/Treatment) by Time (Pre-Test/Post-Test) Interaction Effect. Post-Test mean absolute error of the left arm for both No Vibration and Vibration test conditions for both the Control (solid circles) and Treatment (open squares) groups. Error bars represent standard deviation.

revealed that the Treatment group performed equally as well when tested without vibration pre- and post-training (Pre-test $AE = 4.663 \pm 2.116$; Post-test $AE = 6.163 \pm 3.299$; t (7) = 0.885, $p = 0.406$). On the other hand, when tested without vibration the Control group displayed a significant decrease in AE during the post -test compared to the pre-test (Pre-test $AE = 4.120 \pm 2.562$; Post-test $AE = 1.860 \pm 0.499$; t (9) = 2.563, $p < 0.05$), see left side of Figure 2A and B. Finally, the *Group x Time* interaction was not significant (F (1,16) = 0.936, $p = 0.348$).

Discussion

With the increased use of technology in sensorimotor rehabilitation programs, it is necessary to understand the effects of long-term use of tendon vibration on motor adaptation and learning. The purpose of the present study was to examine the changes in elbow joint proprioceptive accuracy from training with unilateral bicep tendon vibration.

The combination of the significant *Condition x Group* and *Condition x Time* interaction effects support our main hypothesis that individuals can improve their performance as a result of training with tendon vibration when they are tested using vibration after training. After training, elbow joint position accuracy was improved in the vibration treatment group when compared to the control group during the posttest with vibration. The vibration treatment group was more inaccurate than the control group during the posttest without vibration. However, there were no differences in this group between pre- and post-training when tested without vibration. The control group displayed no difference between pre- and post, when testing with vibration. However, when tested without vibration they showed significant improvement relative to their pretest performance. Additionally, the control group's performance was significantly superior to that of the vibration treatment group when tested without vibration after training. Overall, both groups improved their performance in the condition in which they trained. Because the non-vibration error was not significantly affected in the vibration treatment group, this suggests that vibration training is not detrimental to proprioceptive position sense when performed without vibration.

These results suggest that participants in the vibration treatment group were effectively able to integrate altered (vibration induced) muscle spindle information to enhance their joint matching performance. These results can be interpreted to suggest that our vibration treatment group had become duel adapted in that they were able to effectively perform in the altered sensory environment induced by tendon vibration. Conversely our control group displayed no ability to effectively perform in this environment. Additionally, training with altered proprioception did not negatively impact performance without vibration, suggesting these subjects could effectively switch between sensory environments without performance detriments, thereby supporting the dual adaptation argument. With respect to our findings, we speculate that individuals undergoing vibration training could retain their dual adaptation as well. Future studies could further explore retention of altered muscle spindle information integration.

Overall, absolute angle error was reduced significantly with training, regardless of training treatment. This is not unexpected, as practice generally results in improved performance. The lack of a significant *Group x Time* interaction effect also supports that both groups improved with practice. At pre-test, absolute angle error was significantly larger when participants were exposed to vibration. This signifies the presence of the desired kinesthetic illusion induced by 80 Hz vibration in both groups, resulting in greater error and uncertainty in elbow joint position than without vibration prior to the start of training. This is consistent with numerous studies that have reported a kinesthetic illusion of muscle lengthening when vibration is applied to the tendon resulting in proprioceptive errors [1,2,14,15].

Previous studies have found mixed results on the benefits of vibration for joint position sense. A study by Tripp, Faust & Jacobs found 15 Hz vibration applied indirectly via a vibrated handheld device improved elbow joint position performance [16]. However, Chelette & Layne found the same frequency of vibration applied directly to the quadriceps tendon did not significantly improve knee joint position sensitivity [17]. These studies however applied low frequency vibration while our study applied 80 Hz, aiming to induce a kinesthetic illusion. Also, these previous studies only involved single sessions of joint position sense training with vibration. It is possible that multiple exposures to the disruptive proprioception are necessary to learn to integrate the input in a way that can lead to learning and dual adaptation.

Use of tendon vibration in clinical populations has been effective in improving functional performance [7,9,10,18,19]. Our findings show that with practice, a normally disruptive stimulation can be integrated to be beneficial and improve proprioceptive awareness. These results also provide evidence for the ability to create a dual adaptation to altered proprioceptive feedback. Participants were able to retain and switch between multiple adaptation models (no vibration and vibration). A similar adaptation may occur in clinical populations training with tendon vibration for rehabilitation purposes. The ability to integrate altered afferent information is promising for current and future sensorimotor rehabilitation programs and devices involving tendon vibration.

A potential limitation of our study is the risk of habituation. A continuous stimulus can result in habituation, leading to a lesser perception of the illusion over time. This risk however, is minimal in our study because vibration was turned off in between trials, with rest periods between blocks. Also, the vibration stimulus was turned on only for short amounts of time, just long enough for participants to “match” their arm to the perceived angle. Another limitation of our study is the amount of exposure the control group received to vibration. Due to the design of the study, those in the control group experienced vibration at ten instances, pre-test and post-test for each session, resulting in a total of 50 total trials of exposure (compared to 300 total vibration trials for the vibration treatment group). This amount of exposure could have potentially reduced the training effect between the two treatment groups. The control group essentially received a small amount of training with vibration and indeed, by the end of the five sessions, the control group did reduce their error during the vibration condition compared to pre-test values. However, when compared to their post-test non-vibration error they remained impaired.

Conclusion

In conclusion, upon completing a five-session long training program with 80 Hz vibration of the biceps tendon, participants could effectively integrate altered afferent information to improve accuracy of an elbow joint positioning task. Elbow joint position accuracy improved overall with training regardless of training treatment but those training with vibration improved significantly more. Additionally, this learned skill did not negatively impact performance with unaltered information suggesting those who trained with vibration were dually adapted to both sensory environments.

Conflict of interest

The Authors declare that there is no conflict of interest.

References

1. Cordo P, Gurfinkel VS, Bevan L, Kerr GK (1995) Proprioceptive consequences of tendon vibration during movement Proprioceptive Consequences of Tendon Vibration During Movement. *J Neurophysiol* 74: 1675–1688. [Crossref]
2. Goodwin GM, McCloskey DI, Matthews PB (1972) Proprioceptive illusions induced by muscle vibration: contribution by muscle spindles to perception? *Science* 175: 1382–1384. [Crossref]
3. Kito T, Hashimoto T, Yoneda T, Katamoto S, Naito E (2006) Sensory processing during kinesthetic aftereffect following illusory hand movement elicited by tendon vibration. *Brain Res* 1114: 75–84. [Crossref]
4. Seizova-Cajic T, Azzi R (2011) Conflict with vision diminishes proprioceptive adaptation to muscle vibration. *Exp Brain Res* 211: 169–175. [Crossref]
5. Aman JE, Elangovan N, Yeh I-L, Konczak J (2014) The effectiveness of proprioceptive training for improving motor function: a systematic review. *Front Hum Neurosci* 8: 1075. [Crossref]
6. Fusco G, Tidoni E, Barone N, Pilati C, Aglioti SM (2016) Illusion of arm movement evoked by tendon vibration in patients with spinal cord injury. *Restor Neurol Neurosci* 34: 815–826. [Crossref]
7. Pereira MP, Gobbi LTB, Almeida QJ (2016) Freezing of gait in Parkinson’s disease: Evidence of sensory rather than attentional mechanisms through muscle vibration. *Parkinsonism Relat Disord* 29: 78–82. [Crossref]
8. Schofield JS, Dawson MR, Carey JP, Hebert JS (2015) Characterizing the effects of amplitude, frequency and limb position on vibration induced movement illusions: Implications in sensory-motor rehabilitation. *Technol Health Care* 23: 129–141. [Crossref]
9. Rinderknecht MD, Kim Y, Santos-Carreras L, Bleuler H, Gassert R (2013) Combined Tendon Vibration and Virtual Reality for Hand Rehabilitation Based on Illusory Movements. *IEEE World Haptics Conference* 2013: 277–282.
10. Novak P, Novak V (2006) Effect of step-synchronized vibration stimulation of soles on gait in Parkinson’s disease: a pilot study. *J Neuroeng Rehabil* 3: 9.
11. Welch R, Bridgeman B, Anand S, Browman K (1993) Alternating prism exposure causes dual adaptation and generalization to a novel displacement. *Percept Psychophys* 54: 195–204. [Crossref]
12. Ribot-Ciscar E, Rossi-Durand C, Roll JP (1998) Muscle spindle activity following muscle tendon vibration in man. *Neurosci Lett* 258: 147–150. [Crossref]
13. Roll JP, Vedel JP, Ribot E (1989) Alteration of proprioceptive messages induced by tendon vibration in man: a microneurographic study. *Exp Brain Res* 76: 213–222. [Crossref]
14. Roll JP, Vedel JP (1982) Kinaesthetic role of muscle afferents in man, studied by tendon vibration and microneurography. *Exp Brain Res* 47: 177–190. [Crossref]
15. Rogers DK, Bendrups AP, Lewis MM (1985) Disturbed proprioception following a period of muscle vibration in humans. *Neurosci Lett* 57: 147–152. [Crossref]
16. Tripp BL, Faust D, Jacobs P (2009) Elbow joint position sense after neuromuscular training with handheld vibration. *J Athl Train* 44: 617–623. [Crossref]
17. Chelette AM, Layne CS (2014) Effects of low frequency continuous muscle vibration on learning and transfer of a knee joint positioning task. *IEEE Haptics Symposium (HAPTICS)* 2014: 427–430.
18. Marconi B, Filippi GM, Koch G, Giacobbe V, Pecchioli C, et al. (2011) Long-Term Effects on Cortical Excitability and Motor Recovery Induced by Repeated Muscle Vibration in Chronic Stroke Patients. *Neurorehabil Neural Repair* 25: 48–60. [Crossref]
19. Kawahira K, Higashihara K, Matsumoto S, Shimodozono M, Etoh S, et al. (2004) New functional vibratory stimulation device for extremities in patients with stroke. *Int J Rehabil Res* 27: 335–337. [Crossref]