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Original

Effects of Neck Position and Movement on the Tonic Vibration Reflex in the Arms

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Abstract : The present study investigated the tonic vibration reflex (TVR) in humans elicited by vibratory stimulation applied to the muscle of the triceps brachii and examined the effects of rotation of the neck on misperception of movement of the elbow. Fifteen healthy subjects actively flexed their elbows from 0° to 90° for 3 s with their eyes closed. During the time that the elbow was flexed, vibratory stimulation (100 Hz) was applied to the tendon of the right triceps brachii. In the first experiment, only the right elbow was flexed (one-arm experiment), whereas in the second experiment both elbows were flexed simultaneously (two-arm experiment). In the two-arm experiment with vibratory stimulation, the mean (± SD) angle of the elbow was 63.2 ± 11.2° with neck rotation at 0°, which decreased significantly to 53.0 ± 15.5° ($P < 0.05$) when the neck was rotated back to 0° from the position of maximal right rotation. This suggests that there is an asymmetric tonic neck reflex as a result of neck movement, with the pathways involved in the crossed extension reflex enhanced by the simultaneous movement of both elbows. The TVR is an effective tool with which the convergence of various reflexes on α-motor neurons innervating the muscles of the extremity can be examined.

Key words : Tonic vibration reflex (TVR), neuromuscular facilitation, kinesthesia, neck, elbow

Introduction

Continuous vibratory stimulation applied to the bellies of skeletal muscles or tendons induces tonic contraction in these muscles. This phenomenon is known as the tonic vibration reflex (TVR). The artificial production of tonic muscle contraction is seldom used clinically and is not yet used in conventional therapy.

During TVR, vibratory stimulation increases Ia afferent activity in muscle spindles. Even though the TVR constitutes a polysynaptic pathway, it is affected by supraspinal centers[1, 2]. When the tonic muscle contraction induced by TVR occurs simultaneously with isometric muscle contraction, a large contractile force is elicited. Attempts have been made to increase the clinical effectiveness of this technique. One study noted that the technique

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increased leg strength and improved postural control in elderly women[3]. Another study also described using this technique to improve postural stability during rehabilitation following reconstruction of the anterior cruciate ligament of the knee[4]. Yet another study described the use of vibratory stimulation in addition to conventional physical therapy to improve gait performance in patients with foot drop secondary to the chronic phase after stroke[5]. In these circumstances, there is a clinical significance to further clarifying the action of factors influencing the TVR and determining ways to use the TVR more effectively.

Kinesthesia is the sensation produced when the positions of the limbs change due to muscle contraction and information from muscle spindles and joint receptors is processed by the central nervous system. Vibratory stimulation of muscles excites proprioceptors and elicits a TVR ; when a joint is moved during stimulation, movement is misperceived[6].

Neck movement affects the sensing of the position of joints and muscle output in the arms. This is presumed to be caused by proprioceptive information from the neck muscles, sensations from eye movement, and sensations from vestibular information[7-13], but the exact effects of neck movement are yet to be clearly defined.

As yet, no studies have examined ways in which the TVR may be modulated by investigating the extent of the effects of the position and direction of movement of the neck when a TVR is elicited and misperception of movement of the arms occurs. In the present study, we used the extent of misperception of elbow flexion as an index of the modulatory action of the position and direction of neck movement on TVR following vibratory stimulation of the triceps brachii muscle in humans.

Methods

Study subjects

The subjects of the present study were 15 healthy adults (two women, 13 men ; mean [± SD] age 26.3 ± 8.4 years). All subjects were right handed. The present study was approved by the Institutional Review Board for Clinical Research of Suzuka University of Medical Science. In accordance with the Declaration of Helsinki, the details and risks of the study, in addition to ethical considerations and such voluntary participation, were explained to all subjects verbally and in writing. All subjects provided written informed consent prior to participating in the study.

Measurement of the angle of elbow flexion

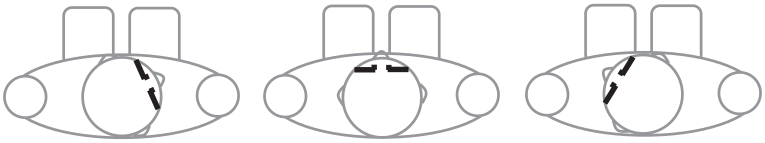
Subjects were seated on a chair with an electronic goniometer (MLTS700 ; ADInstruments, Sydney, NSW, Australia) attached to the outside of both elbows so that the angle of right and left elbow flexion could be measured continuously. Subjects wore a blindfold and had their eyes closed during the experiment. Subjects were instructed not to move their shoulder when flexing their elbows. Subjects were also required to keep their forearm supinated at 90° and actively moved their elbow from a natural downward position to flexion of 90°. Once subjects had flexed their elbow, they were required to maintain the position for 3 s in accordance with a digital metronome (Digital Metronome DM01; Seiko Sports Life, Tokyo, Japan) that sounded every second. The degree of flexion of one elbow (right) or both elbows was measured, with the angle of elbow flexion averaged over three trials. Subjects practiced adjusting the angle of elbow flexion to 90°. Kinesthesia at the elbow and the actual angle of flexion, as measured by the goniometer, were matched just prior to the experiments performed in one or both arms. Based on this perception, subjects were then asked to close their eyes and flex their elbow to 90°. The experimenter then relayed the actual angle, as measured by the goniometer, to the subject. Subjects practiced flexing their elbow to 90° with their eyes closed until they were able to achieve flexion to 90° with a deviation of $\leq 5^\circ$ three times in a row.

Conditions for vibratory stimulation

Vibratory stimulation was applied using a vibrator (ZERO Pro Masseur; Cosmo Ultrasonic Waves Laboratory, Fukui, Japan) used in physical therapy. The hand-held vibrator had a circular 1.5-cm diameter rubber tip. The stimulation frequency was 100 Hz, and the vibrator was moved back and forth with respect to the direction of vibration; the amplitude of the vibration was approximately 2 mm. The stimulation site was 2 cm above the right olecranon and the triceps brachii tendon. The site was marked on the skin, and the experimenter manually placed the tip of the vibrator on the stimulation site 1 s before flexion of the elbow. While the subject's elbow was flexed, vibratory stimulation was applied at a position perpendicular to the long axis of the triceps tendon and adjusted so that there were no changes in pressure as a result of contact with the vibrator.

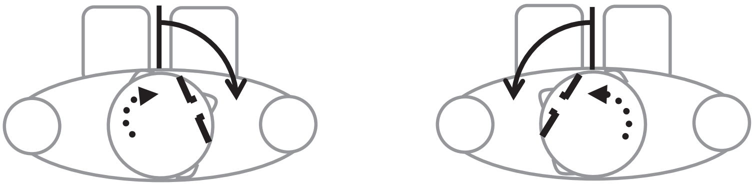
Neck position and movement

As a control to enable the effects of neck position and movement on kinesthesia to be examined, subjects were asked to remain face forward during flexion of the elbow (rotation 0°) for 6 s (3 s to flex the elbow and then 3 s in that position). In addition to the control position, subjects were asked to perform various patterns of neck movements and neck positioning. Pattern 1 consisted of subjects maintaining a neck position of maximum rotation to the left and right for 6 s ($\mathrm{Max}_{\mathrm{left}}$ and $\mathrm{Max}_{\mathrm{right}}$, respectively; Fig. 1). In Pattern 2, subjects actively moved their necks from 0° to $\mathrm{Max}_{\mathrm{right}}$ for 3 s and maintained this position for a further 3 s (rotation to the right); similarly, subjects were asked to rotate their necks from 0° to $\mathrm{Max}_{\mathrm{left}}$ (rotation to the left). In Pattern 3, subjects were asked to rotate their necks from $\mathrm{Max}_{\mathrm{right}}$ (or $\mathrm{Max}_{\mathrm{left}}$) to 0° in 3 s and to maintain this position for a further 3 s (return from $\mathrm{Max}_{\mathrm{right}}$ or $\mathrm{Max}_{\mathrm{left}}$; Fig. 2). The range of neck rotation was measured beforehand and subjects practiced the movements until they could rotate their necks the maximum range of motion in 3 s at a fixed angular velocity.

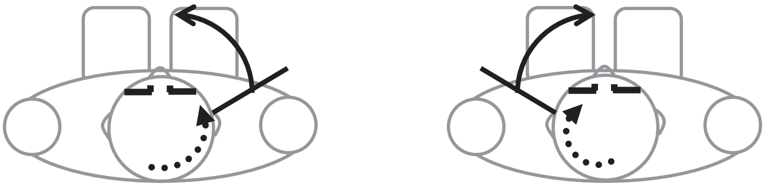


$\mathrm{Max}_{\mathrm{right}}$ Rotation of 0° $\mathrm{Max}_{\mathrm{left}}$

Fig. 1. Conditions of neck position



Rotation to $\mathrm{Max}_{\mathrm{right}}$ Rotation to $\mathrm{Max}_{\mathrm{left}}$



Return from $\mathrm{Max}_{\mathrm{right}}$ Return from $\mathrm{Max}_{\mathrm{left}}$

Fig. 2. Conditions of neck rotation

Experimental procedures

Experiments were divided into three phases based on the pattern of neck movement, with each phase separated by an interval of 24 h or longer. In Experiment 1, subjects moved one or both elbows to the positions for Pattern 1, with or without vibratory stimulation. In Experiments 2 and 3, subjects were asked to make the movements specified for Patterns 2 and 3, respectively, but otherwise the experimental conditions were the same as for Experiment 1.

Data analysis

Data are presented as the mean ± SD and were analyzed by one-way analysis of variance, with Dunnett's test for multiple comparisons when a main effect was noted. All analyses were performed using Statistica 6J (Statsoft, Tokyo, Japan).

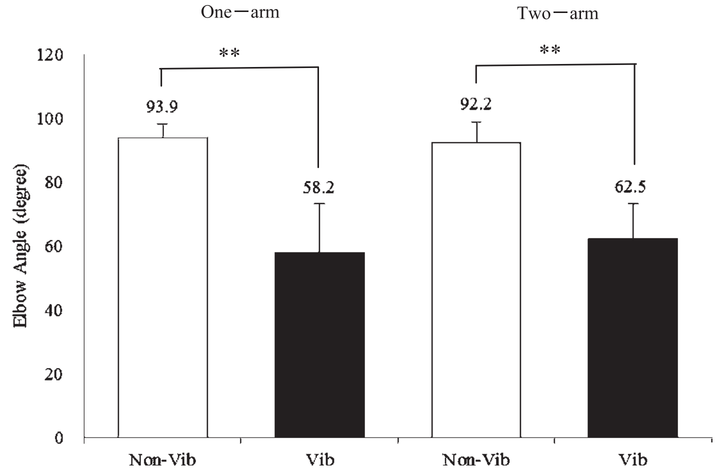


Fig. 3. Effect of vibration on the flexion angle of one-arm experiment and two-arm experiment.
Values are mean ± SD. **: Significantly different from non vibration (p < 0.01).

Results

Effects of vibratory stimulation on kinesthesia at the elbow

Figure 3 shows the average angle of the elbow with a neck rotation of 0° in all experiments. With a neck rotation of 0° in all experiments, the angle of the elbow was 93.9 ± 4.4° when one arm was moved in the absence of vibratory stimulation. When vibratory stimulation was applied, the angle decreased significantly to 58.2 ± 14.9° ($P < 0.001$). When both elbows were flexed, the angle of flexion of the elbow in the absence of vibratory stimulation was 92.2 ± 6.8°. Again, a significant decrease was observed in the angle of flexion when vibratory stimulation was applied (62.5 ± 10.8°; $P < 0.001$).

Effects of neck position and movement on kinesthesia at the elbow

Figures 4 and 5 show the average angle of flexion of the elbow for each experiment in the absence of vibratory stimulation. In the absence of vibratory stimulation, there were no significant differences in the angle of flexion of the elbow when neck rotation was 0° compared with $\mathrm{Max}_{\mathrm{right}}$ or $\mathrm{Max}_{\mathrm{left}}$, regardless of whether the joint of one or both arms was moved (control vs Pattern 1), between rotation 0° and movement to $\mathrm{Max}_{\mathrm{right}}$ or $\mathrm{Max}_{\mathrm{left}}$ (Pattern 2), or between rotation 0° and return from $\mathrm{Max}_{\mathrm{right}}$ or $\mathrm{Max}_{\mathrm{left}}$ (Pattern 3).

Effects of vibratory stimulation, as well as neck position and movement, on kinesthesia at the elbow

Figures 6 and 7 show the average angle of the elbow in each experiment in the presence of vibratory stimulation. When vibratory stimulation was applied and one elbow was flexed, there were no significant differences in the angle of flexion of the elbow when neck rotation

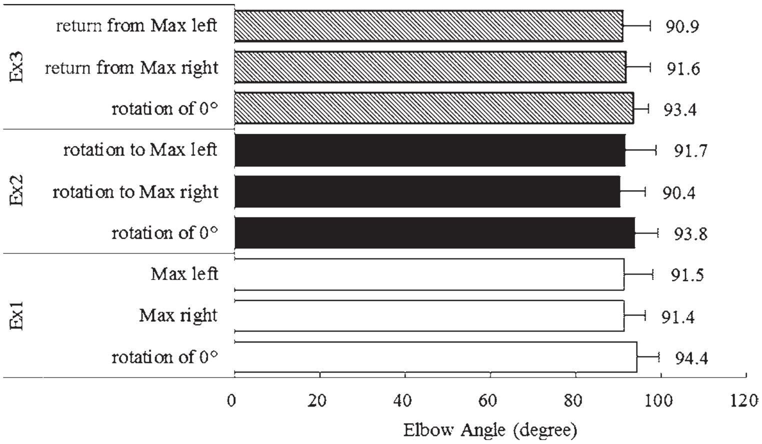


Fig. 4. Elbow flexion angle without Vibration in one-arm experiment. Values are mean ± SD.

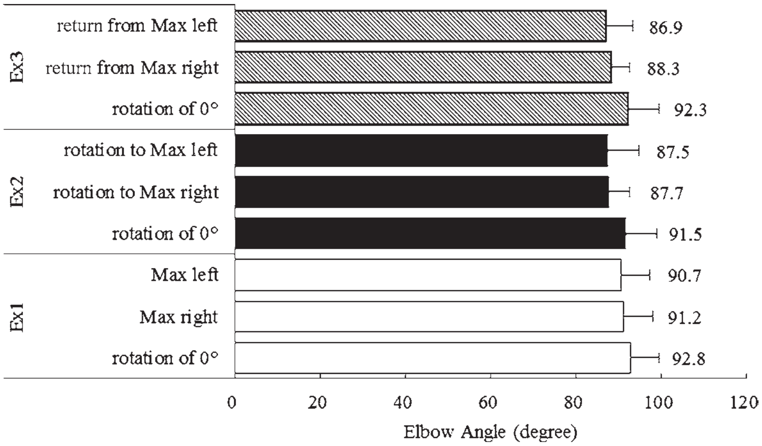


Fig. 5. Elbow flexion angle without Vibration in two-arm experiment. Values are mean ± SD.

was 0° compared with $\mathrm{Max_{right}}$ or $\mathrm{Max_{left}}$ (control vs Pattern 1), between rotation 0° and movement to $\mathrm{Max_{right}}$ or $\mathrm{Max_{left}}$ (Pattern 2), or between rotation 0° and return from $\mathrm{Max_{right}}$ or $\mathrm{Max_{left}}$ (Pattern 3).

At a neck rotation of 0°, when both elbows were flexed in the presence of vibratory stimulation the angle of elbow flexion was 63.2 ± 11.2°. A significant decrease in the angle of flexion was observed upon return from $\mathrm{Max_{right}}$ (to 53.0 ± 15.5°; $P < 0.05$). However, there were no significant differences in the angle of elbow flexion between rotation 0° and $\mathrm{Max_{right}}$ or $\mathrm{Max_{left}}$, or upon return from $\mathrm{Max_{left}}$.

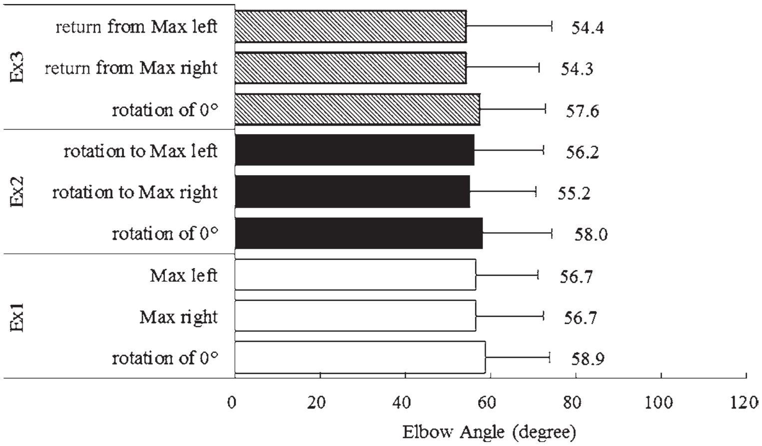


Fig. 6. Elbow flexion angle with Vibration in one-arm experiment.
Values are mean ± SD.

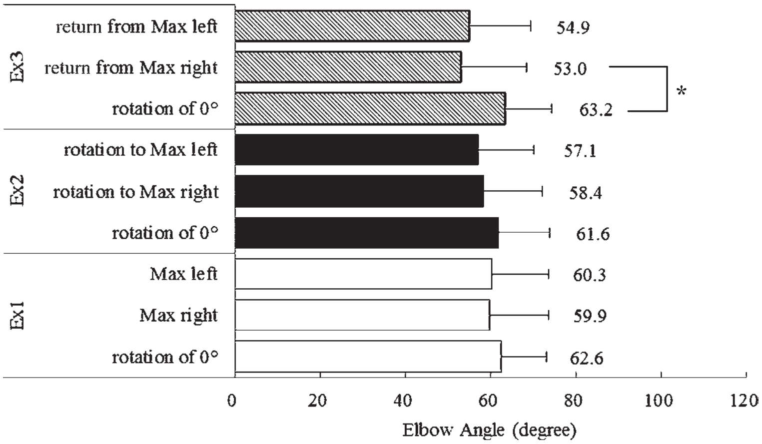


Fig. 7. Elbow flexion angle with Vibration in two-arm experiment.
Values are mean ± SD. * : Significantly different from rotation of 0° ($p < 0.05$).

Discussion

When subjects were asked to adjust their elbow angle to 90° with their eyes closed while vibratory stimulation was applied to the triceps tendon, the joint angle was 58.2 ± 14.9°. Furthermore, when they were asked to adjust both elbows to 90° while vibratory stimulation was applied to one arm, the angle of elbow flexion of the arm subjected to vibratory stimulation was 62.5 ± 10.8°. These changes in joint angle are the result of the muscle spindles responding to the vibratory stimulation of the triceps brachii. Increased Ia afferent activity leads to changes in the perception of the elbow joint angle. McCloskey 14) reported that TVR decreased the subjective sensation of weight when vibratory stimulation was applied to the tendons of agonist muscles, whereas the sensation of weight increased when vibratory stimulation was applied to antagonist muscles. The subjective sensation may be misperceived following the induction of afferents by vibratory stimulation.

To confirm the effects of neck position and movement on kinesthesia at the elbow, the joint angle was compared with and without neck rotation, and with and without vibratory stimulation. Knox and Hodges8) reported that the angle of elbow flexion increased when the neck was rotated passively away from the elbow being tested. This was due not only to decreased accuracy as the direction of the gaze shifted away from the elbow being tested, but also to increased afferent activity from the proprioceptors, which confused central proprioceptive perception. Knox *et al*10) performed further studies on a patient with limited neck motion who had suffered whiplash >3 months previously and reported that passive rotation of the neck both away from and towards the elbow being tested increased the position error. However, this experiment was performed with the patient in a supine position. In the present study, there were no differences observed in the positioning of the elbow regardless of whether the neck was rotated towards or away from the arm being tested.

However, the effect of neck movement on the perception of joint angle may have been weak in the present study because subjects rotated their neck voluntarily. Curry and Clelland7) have demonstrated that passive neck rotation has a greater effect on reproduction of elbow flexion than voluntary rotation.

Knox *et al*11) have also investigated the effects of vibratory stimulation applied to the sternocleidomastoid and splenius capitis muscles on the reproduction of positioning of the elbow when the neck is rotated. They found that rotating the neck away from the elbow being tested increased the error in the reproduction of elbow positioning. In the present study, there were no differences in the angle of flexion when subjects rotated their necks from either $\mathrm{Max}_{\mathrm{right}}$ or $\mathrm{Max}_{\mathrm{left}}$ when their ipsilateral arm was being stimulated. Similar results were obtained when the contralateral arm, without vibratory stimulation, was voluntarily adjusted to 90°, with the exception of a return to rotation 0° from $\mathrm{Max}_{\mathrm{right}}$, when a significant difference in angles was recorded. This may be due to the effect of a tonic neck reflex. Strong tonic contraction may occur in the right triceps muscle subjected to vibratory stimulation, whereas tonic inhibition may occur in the left triceps muscle. Consequently, there may be an increase in the misperception of movement of the elbow. In a study of the effects of asymmetric tonic neck reflex and TVR on wrist extension, Curry and Clelland7) found that the spatiotemporal summation and convergence of inputs in three forms (i.e. voluntary neck movement, vibratory stimulation, and the asymmetric tonic neck reflex) to the extensor motor neuron pool for the forearm may facilitate input to the motor pool more than any input individually. The results of the present experiments indicate that the pathways involved in the asymmetric tonic neck reflex are activated by active movement from the position of maximum rotation of the neck. The pathways involved in the crossed extensor reflex were also activated by left elbow flexion and facilitated the activity of α-motor neurons innervating the right triceps brachii.

With regard to the clinical uses of TVR, Ribot-Ciscar *et al*16) have reported on the use of vibration to produce TVR in patients with chronic cervical spinal cord injury who had partial voluntary control of their triceps brachii. Vibratory stimulation increased the maximum force of voluntary elbow extension in these patients, who also reported less discomfort with this procedure than with electrical stimulation. TVR has also been reported to improve the gait pattern of leg muscles in children with cerebral palsy17). Thus, muscle vibration may be useful in the physical therapy of patients by facilitating passive or active movements of the extremities18–21).

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