

The effect of muscle vibration on human position sense during movements controlled by lengthening muscle contraction

J.T. Inglis*, J.S. Frank, and B. Inglis

Department of Kinesiology, University of Waterloo, Waterloo, Ontario N2L 3G1, Canada

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Summary. Muscle vibration studies suggest that during voluntary movement limb position is coded by muscle spindle information derived from the lengthening, antagonist muscle. However, these investigations have been limited to movements controlled by shortening contractions. This study further examined this property of kinesthesia during movements controlled by lengthening contraction. Subjects performed a horizontal flexion of the right forearm to a mechanical stop randomly positioned at 30, 50 and 70° from the starting position. The movement was performed against a flexor load (1 kg) requiring contraction of the triceps muscle. Vision was occluded and movements were performed under three conditions: no vibration, vibration of the right biceps and vibration of the right triceps. The perceived position of the right forearm was assessed by instructing subjects to simultaneously match the right limb position with the left limb. Vibration of the shortening biceps muscle had no effect on limb matching accuracy. However, triceps vibration resulted in significant overestimation of the vibrated limb position (10–13°). The variability in movement distance was uninfluenced by muscle vibration. During movements controlled by lengthening contraction, there is a concurrent gamma dynamic fusimotor input that would enhance primary afferent discharge. Despite this additional regulating input to the muscle spindle, it appears that muscle spindle information from the lengthening muscle is important for the accurate perception of limb movement and/or position.

Key words: Muscle vibration – Kinesthesia – Lengthening contraction – Human

Introduction

A series of experiments Goodwin et al. (1972) demonstrated clearly a role for the muscle spindle in the conscious awareness of limb position and movement. With the

development of chronic muscle spindle recording techniques in freely-moving animals (Loeb et al. 1977; Prochazka et al. 1976, 1977) and microneurographic studies performed on human subjects (Burke et al. 1978; Vallbo 1970; Roll and Vedel 1982), muscle spindle behavior under a variety of isometric and isotonic conditions has been observed directly. A number of investigators have reported that during the active shortening of a muscle, muscle spindles within that muscle demonstrate a decrease in discharge rate (Burke et al. 1978); however, if the velocity of muscle shortening is above 0.2 resting lengths/s. (Prochazka 1981), then most spindle afferents fall silent (Prochazka et al. 1979). Therefore, during movements of moderate to fast velocity, muscle spindle information from the shortening agonist muscle seems to be limited.

Capaday and Cooke (1981, 1983) studied the effects of muscle vibration on the attainment of a learned target position during rapid voluntary arm movements. Muscle vibration is known to be a powerful stimulus for muscle spindles, especially the primary endings, in humans (Burke et al. 1976a,b; Roll et al. 1989). The results demonstrated that vibration of the antagonist muscle caused a systematic undershooting of the target, while vibration of the agonist muscle did not disrupt accurate attainment of the target. The authors suggested that “the CNS monitors the muscle afferent activity of the lengthening (antagonist) muscle rather than the muscle which acts as the prime mover” (Capaday and Cooke 1981, p. 230). Inglis and Frank (1990) found similar results for both obstructed movements and self-terminated movements to a target performed at a slower rate of movement (50 deg/s). A question that arises from the above studies is what happens when the muscle responsible for the control of a movement is a lengthening muscle, i.e. the lengthening muscle is contracted throughout the movement? We present here data concerning the effect that vibration of a lengthening contracting muscle has on human kinesthesia.

Method

A total of 8 subjects volunteered for the experiment (mean age 24). A limb matching task was chosen to eliminate any possible vibration-induced reflex effects on limb movement performance (Capaday and Cooke 1981, 1983). The subject was seated comfortably in an upright

* Present address: Dept. of Anatomy, Queen's University, Kingston, Ontario, Canada

Offprint requests to: J.S. Frank (address see above)

position with the arms raised to the side and flexed at the elbows. The forearms were strapped into position on lever arms that were positioned at right angles to the body, allowing for elbow flexion (adduction) in the horizontal plane (Fig. 1a). Subjects were blindfolded throughout the entire experiment. Linear potentiometers recorded displacement of each lever arm. A 1 kg weight was suspended via a cable from a 6 inch flywheel attached to the axle of the right lever arm; this caused a constant torque in the flexion direction throughout the entire range of movement (Fig. 1a, inset). Electromyographic recordings from both the biceps and triceps illustrated that the torque was great enough to cause the movement to be strictly controlled by contraction of the lengthening triceps muscle (Fig. 1b).

The subject was required to perform a smooth horizontal flexion movement of the right arm to a mechanical stop randomly placed at 30, 50 or 70° from a starting position (48° from coronal) and simultaneously match the end position of the right arm with the left arm. Subjects were given a series of learning trials (10–20) to learn a rate of movement equal to 40–60° per second (no vibration). The moveable stop was positioned at 60° from the starting position during the learning trials. Feedback about movement rate was given to the subject at the end of each trial.

The experiment consisted of three conditions of muscle vibration applied to the right arm: 1) biceps brachii muscle vibration, 2) triceps brachii muscle vibration and 3) no vibration (control). The vibrator was calibrated with an accelerometer to provide a frequency of 83 Hz and an amplitude of approximately 2 mm. Subjects performed two blocks of trials; the vibrator was positioned over the biceps muscle during one trial block and the triceps muscle for the other trial block. Within a block of 30 trials, vibration was presented on half the trials and each of the three movement distances of 30, 50 and 70° were presented an equal number of times. Vibration condition (on/off) and movement distance were introduced in a pseudo-random order. This prevented subjects from accommodating to a particular condition of vibration or movement distance.

At the beginning of each trial, the arms were moved to the starting position. Each trial began with a warning of "ready", followed by a command "move". The vibrator was turned on 500 ms. prior to the "move" command and was turned off 500 ms. after the target was reached by the right arm. The left arm was then move back to the starting position by the experimenter before any post-vibrational position error could be detected by the subject. The right arm remained against the target stop until the next trial began. This was done to avoid fatigue of the triceps muscle. Signals from the

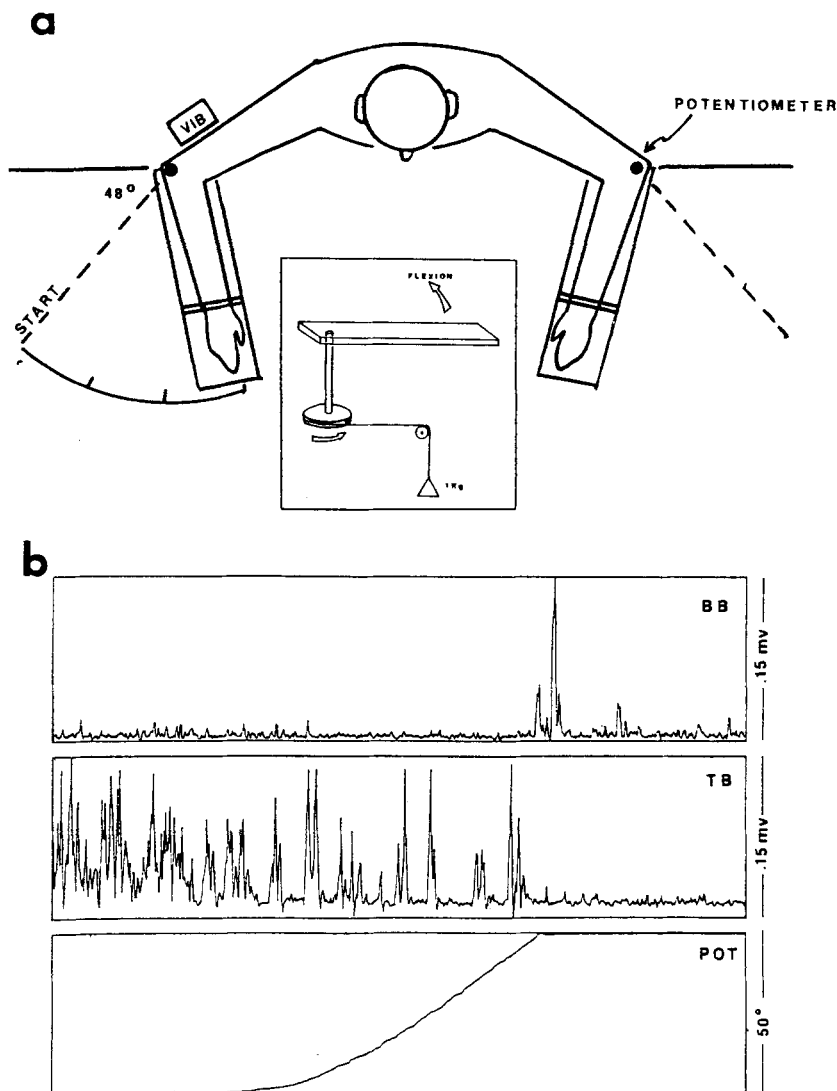


Fig. 1. a Aerial view of the apparatus used to support the subject's arms and record elbow flexion movements during the experiment. A 1 kg weight suspended from a flywheel attachment on the right lever arm caused a constant flexor torque (insert). b Sample electromyographic record (2.5 s) from right arm biceps brachii (top trace) and triceps brachii (middle trace) for movement with a flexor load. Potentiometer output (bottom trace) shows duration (0.8 s) and amplitude of movement (50°)

potentiometers were recorded online with an IBM computer for later offline analysis of movement time and movement amplitude for each limb.

Results

Results are presented in Fig. 2 for the distance moved by the matching limb for each of the three conditions of vibration: no vibration, biceps vibration, and triceps vibration. For each subject, a mean distance (degrees) and standard deviation value was computed for each vibration condition at each movement distance. A two-way ANOVA (condition \times target) was performed on these mean and standard deviation values to examine the effects of vibration conditions and movement distance on matching accuracy. There was a significant effect of vibration condi-

tion on the distance moved by the matching limb [$F(2, 14) = 18.23$, $P < 0.00001$]. Post hoc analysis [Turkey, $P < 0.01$] revealed that vibration of the triceps muscle gave rise to a significant overestimation of limb position by the matching limb when compared to control trial performance (10–13 degree overestimation). Vibration of the biceps brachii muscle tendon did not significantly affect subjects' perception of limb position. Also, muscle vibration did not significantly affect the intra-individual variability in matching limb performance [$F(2, 14) = 0.82$, $P < 0.46$]. Therefore, the spindle information from the triceps was apparently altered in a very characteristic and directional way. Even if the vibration had some effect on the shortening muscle spindles, the altered spindle information from the biceps does not seem to be important for the control of this type of movement.

Discussion

The results presented here demonstrate that when mechanical vibration is applied to a lengthening contracting muscle that is responsible for the control of a movement, there is a distortion of the kinaesthesia for the limb involved. Muscle vibration has been found to activate muscle spindles in humans whether the vibrated muscle is actively contracting or passive (Burke et al. 1976a,b). In this experiment, vibration of the triceps muscle leads to an increase in the discharge level of the triceps muscle spindles; this increase is interpreted by the CNS as the muscle being at a greater length. This perceived longer triceps muscle length is interpreted as the right limb being more flexed.

Aside from the consistent effects of vibration, flexion movements controlled by lengthening contraction of the triceps muscle differ from our previous investigation of movements controlled by shortening contraction of the biceps muscle (Inglis and Frank, 1990) in two ways. First, subjects did not demonstrate a consistent overestimation of the target position. During flexion movements to an obstruction controlled by contraction of the shortening biceps muscle, we consistently observed a 10-degree overestimation of the target position in the absence of vibration. This finding also has been reported by Hollingworth (1909). The second difference is that intra-individual variability in matching performance (standard deviation) was greater for flexion movements controlled by contraction of the lengthening triceps muscle (6–7°) than previously reported for flexion movements controlled by contraction of the shortening biceps muscle (3–4°). This greater variability may be related to the novelty of controlling forearm movement by contraction of a lengthening muscle.

The selective effect of agonist/antagonist muscle vibration previously has been reported for movements controlled by shortening muscle contractions (Capaday and Cooke 1981, 1983; Bullen and Brunt 1986; Inglis and Frank 1990). Microneurographic recordings from spindle afferents demonstrate that the discharge pattern from afferents originating in the actively shortening muscle is poorly related to muscle length (Hulliger and Vallbo 1979;

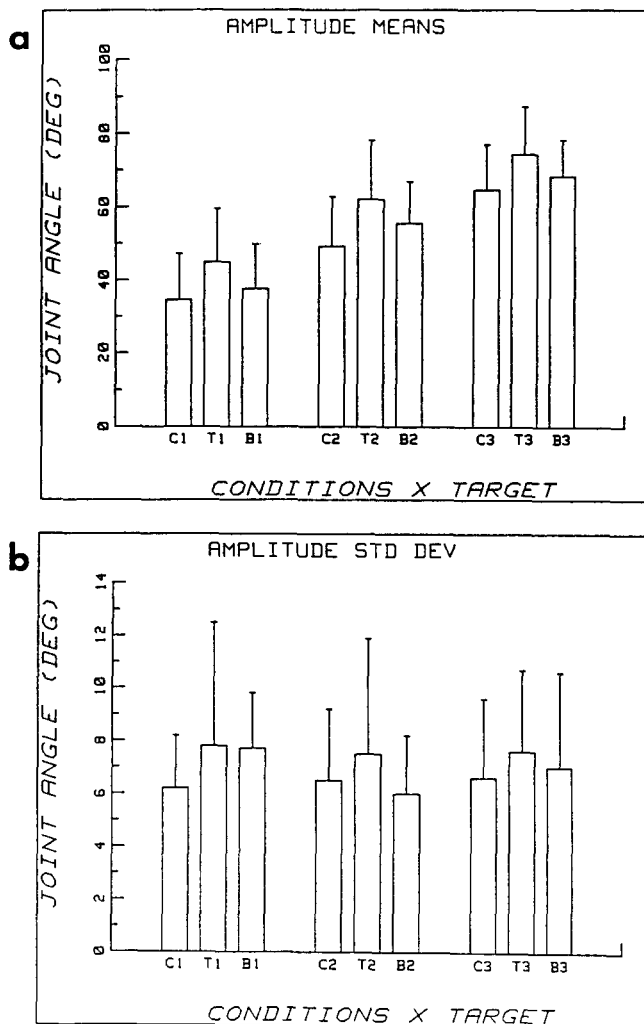


Fig. 2a, b. Mean angular displacement (a) and intrasubject variability (b) of the left arm displacement when attempting to match the terminal position of the right arm. Between subject standard deviations are represented by the line extending above each bar. Notations C, T and B refer to control (no vibration), triceps vibration and biceps vibration, respectively; 1, 2 and 3 refer to target distances of 30, 50 and 70°

Prochazka et al. 1979; Prochazka 1986). This situation appears to persist during movements controlled by contraction of the lengthening muscle. Logigian et al. (1989) found a silencing of afferent discharge from muscle spindles of the quiescent, shortening wrist flexors during wrist flexion movements controlled by the lengthening extensors. The pattern of afferent discharge from muscle spindles of the lengthening muscle is related to muscle length and, hence, could code for joint position and limb movement (Burke et al. 1978; Roll and Vedel 1982; Vedel and Roll 1983; Roll et al. 1989). However, during movements controlled by contraction of the lengthening muscle, there is a concurrent gamma dynamic fusimotor input that would enhance spindle primary afferent discharge (Hulliger and Prochazka 1983; Loeb 1985). Despite this additional regulating input to the muscle spindle, the results presented here suggest that during a limb movement controlled by contraction of the lengthening muscle, muscle spindle information from the lengthening muscle continues to be important for the accurate perception of limb movement and position sense.

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