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Location-specific and task-dependent modulation of cutaneous reflexes in intrinsic human hand muscles

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Abstract

Objective: The current study was designed to determine location-specificity in long latency cutaneous reflexes in intrinsic human hand muscles while performing a simple abduction and a manual task.

Methods: Subjects comprised of 13 neurologically intact healthy volunteers. Cutaneous reflexes following non-noxious electrical stimulation to the digits of the hand (digit 1, D1; digit 2, D2; and digit 5, D5) were elicited while the subjects performed isolated isometric contraction of the abductor pollicis brevis (APB), first dorsal interosseous (FDI) and abductor digiti minimi muscles (ADM). The cutaneous reflexes were also elicited while the subjects performed a pincer grip with D1 and D2 while slightly lifting the hand from the supporting surface by abduction of D5 (manual task).

Results: While performing isolated tonic voluntary contraction of the APB, FDI and ADM, the magnitude of E2 (peak latency ~60–90 ms) was larger when stimulation was delivered to the homotopic digit (e.g. APB response following D1 stimulation) than to the heterotopic nearby (e.g. APB response following D2 stimulation) or heterotopic distant digit (e.g. APB response following D5 stimulation). I2 (~90–120 ms) and E3 (~120–180 ms) were significantly larger following D5 stimulation than D1 or D2 stimulation in all muscles tested. The size of each component in the ADM following D1 and D2 stimulation did not increase even when the contraction level of the ADM increased. However, while performing the manual task, the E2 response in the ADM following both D1 and D2 stimulation was significantly increased as compared to that recorded during isolated D5 abduction.

Conclusions: Long latency cutaneous reflexes following non-noxious electrical stimulation are organized in a highly location-specific as well as task-dependent manner.

Significance: Our findings provide further insight into the nature and functional significance of long latency cutaneous reflexes in human intrinsic hand muscles.

Keywords: Cutaneous reflex; Intrinsic hand muscles; Location-specificity; Task-dependent modulation

1. Introduction

Electromyographic (EMG) activity within the intrinsic hand muscles of humans is characterized by distinct facilitatory and inhibitory responses with different latencies when exposed to non-noxious electrical, natural and air-puff stimulation of the digits (Caccia et al., 1973; Deuschl et al., 1995; Jenner and Stephens, 1982; McNulty and Macefield, 2001; McNulty et al., 1999). The initial increase in EMG activity (E1) is thought to be mediated by an oligosynaptic spinal pathway, followed by an inhibitory (I1) and then a second excitatory response (E2). The E2 response is known to require the integrity of the dorsal columns, sensorimotor cortex and corticospinal tract (Chen and Ashby, 1993; Jenner and Stephens, 1982; Macefield and Johansson, 1994; Ohki et al., 1994). In addition, E2 has been shown to be strongly modulated during voluntary finger movement in a task-dependent manner (Evans et al., 1989; Turner et al., 2002). Distinct inhibitory and excitatory EMG responses

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with longer latency than E2 are demonstrated to be present following mechanical and electrical stimulation of digital nerves and are thought to be of importance in reactive control of grip force (Caccia et at al., 1973; Macefield and Johansson, 2003; McNulty et al., 1999). These results suggest that both short and long latency cutaneous reflexes play an important role in regulating individual or synergistic control of human intrinsic hand muscles depending on the task or biomechanical constraints (Edin et al., 1992; Johansson and Westling, 1984; 1987; Macefield and Johansson, 2003). However, the general characteristics of the long latency cutaneous reflexes remain to be elucidated. It would be of great value to fully understand and appreciate the complete organization of these cutaneous reflexes in the human hand.

Hongo et al. (1990) reported that non-noxious pressure to the toe pads in the cat effectively evoked distinct reflexes within a location-specific manner, acting differentially on the intrinsic plantar muscles of individual digits. In humans, Deuschl et al. (1995) reported that the E2 response (cLLR II in their report) elicited by natural air-puff stimulation in the muscles acting on the stimulated finger was always larger than that in the muscles acting on other fingers. To date, such topographic patterns of cutaneous reflexes with a longer latency than E2 in human intrinsic hand muscles have not been systematically investigated (see also Hongo et al., 1990). In addition, although E2 are strongly modulated while performing functional task (Evans et al., 1989; Turner et al., 2002), little is known about the long latency reflexes. Elucidating topographic patterns and task-dependent modulation of the long latency cutaneous reflex should provide an informative standard when investigating cortical contribution in patients with sensorimotor disorders of the hand.

Therefore, the present study investigated the organization of individual reflex patterns (E2, I2 and E3) among human intrinsic hand muscles following stimulation of each digit while performing isometric contraction and manual tasks. A preliminary account of these experiments has been presented elsewhere (Nakajima et al., 2003).

2. Materials and methods

2.1. Subjects

Subjects were comprised of thirteen, right-handed, neurologically intact healthy male ($n=12$) and female ($n=1$) volunteers between 20 and 44 years of age. All participants gave informed consent prior to participation in the experiments. The protocol was approved by the local ethical committee, and was in accordance with the guidelines set out in the Declaration of Helsinki, 1964.

2.2. Protocol

EMG recordings were made from the first dorsal interosseous (FDI), abductor pollicis brevis (APB) and abductor digiti minimi (ADM) muscles. All experiments were conducted with subjects in a seated position with the right arm in a semi-flexed position. The forearm and hand were pronated and rested on a horizontally placed manipulandum made of wood, and the elbow and wrist joints were immobilized by a strap. Both, the medial margin of the right thumb (D1), index finger (D2) and the lateral margin of the little finger (D5) were independently supported and immobilized by L-shaped aluminum bars to ensure isometric contraction of the hand muscles. The angle between D1 and D2 was held at approximately 50°.

The subjects first performed maximum voluntary contraction of APB, FDI and ADM for ~3 s to determine maximal EMG activity (EMGmax). After 3 min rest, the subjects were asked to perform a sustained voluntary abduction of D1, D2 or D5 under visual feedback from the analog voltmeter (AX-313TR, Sanwa, Japan) which displays the amplitude of the rectified and smoothed EMG signal (low pass filtered at 100 Hz) from the target muscle. Target force ranged between ~1 to 60% of EMGmax. In each task, D1, D2 and D5 were independently stimulated. The digit to be stimulated was selected a priori in a randomized manner. A 2–3 min resting period was provided between sessions to avoid possible effects of muscle fatigue.

While performing a pincer grip with D1 and D2, the cutaneous reflexes were also elicited in 11 subjects. The subjects were asked to pinch a pencil (length ~15 cm, Ø ~7 mm) while slightly lifting the hand (~1 cm) from the supporting surface by abduction of D5. The elbow was kept in a semi-flexed position. Under these postural conditions, the subjects were asked to exert a force of ~10% EMGmax for the APB, FDI and ADM.

2.3. EMG recording

Surface EMG signals were obtained with surface Ag/AgCl disk electrodes (Ø 1.5 cm) oriented 2 cm longitudinally over the FDI, APB and ADM after reducing skin impedance (below 10 KΩ) by light abrasion and alcohol cleaning. The EMG signals were amplified, filtered (×1000, bandpass filtered at 16 Hz–1 kHz), and stored on a hard disk with a sampling rate of 3 kHz.

In eight subjects, the activity of a single motor unit (MU) was recorded from the FDI with a concentric bipolar needle electrode (NM-030T, Nihon Kohden, Japan). MU potentials were amplified (×10000), bandpass filtered (16 Hz–10 kHz) and stored on a hard disk with a sampling rate at 10 kHz.

2.4. Electrical stimulation

For recording of cutaneous reflexes, a pair of stimulating ring electrodes was arranged such that the cathode was placed around the proximal phalanx and the anode was placed around the middle phalanx of D1, D2 and D5. Square wave stimuli with a pulse width of 1 ms were delivered 100