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Research Report

Changes in corticomotor excitability of forearm muscles in relation to static shoulder positions

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ABSTRACT

We examined whether the recruitment properties of the corticospinal pathway to forearm muscles are influenced by variations of the shoulder joint angle. Flexor carpi radialis (FCR) and extensor carpi radialis (ECR) muscles motor evoked potentials (MEPs) in response to transcranial magnetic stimulation were examined during different static positions of shoulder joint in the horizontal plane: from 30° abduction to 30° adduction. We found that at 30° shoulder adduction, maximum slope and plateau phase of the ECR and FCR input–output relationship (i.e., relation between MEP size and stimulus intensity) were significantly higher and lower than at 30° abduction of the shoulder joint, respectively. Intracortical inhibition (ICI) and intracortical facilitation (ICF) of the FCR were assessed using a paired-magnetic pulse paradigm. A significant decrease in ICF was observed after changing shoulder position from 30° abduction to 30° adduction. On the contrary, no variation in the amount of ICI occurred in relation to the same changes in shoulder position. FCR H-reflex to electrical stimulation of median nerve at elbow did not differ significantly between the two shoulder positions. We conclude that shoulder position influences the recruitment efficiency (gain) of the corticospinal volleys to motoneurons of forearm muscles. It is proposed that activity of peripheral receptors signaling static shoulder position influences corticomotor excitability of forearm muscles mainly at cortical level, although C3–C4 propriospinal system could be also involved. It is proposed that the above changes in corticomotoneuronal excitability to forearm muscles as function of shoulder joint position are part of a global proximal–distal synergy operating throughout reaching movements.

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1. Introduction

The evolution of recent anatomical and physiological studies suggests the motor cortex may contribute to the mechanisms required to specify the arm muscle recruitment patterns as a function of its geometry or postures. A large

body of evidence suggests that motor cortex controls the different limb segments as a whole rather than individually (Scott, 2000). This reduces the number of degrees of freedom and thereby reduces the complexity of the control problem. In rhesus macaques, a motor cortical region containing neurons that specify functional synergies of distal and

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proximal muscle has been identified (Park et al., 2001; Devanne et al., 2002). In addition, electrical microstimulation of monkey's motor cortex evokes complex, highly coordinated movements across multiple joint, that appear to match common gesture in the monkey's natural repertoire (Graziano et al., 2002). This suggests that each neuron in motor cortex is connected in a complex way to the periphery and might contribute to arm movements that require the coordinated contraction of some muscles and relaxation of others. Therefore, movement control in motor cortex might be organized in terms of behaviorally useful actions aimed toward a goal posture. Finally, intracortical connections (Capaday et al., 1998) as well as intraspinal branching of corticospinal axons are regarded as the neural substrates of muscle synergies involved in coordinated multi-joint movements (Capaday et al., 1998; Devanne et al., 2002; McKiernan et al., 1998; Tantisira et al., 1996).

Coordinated activity between shoulder and hand is exemplified by a large number of everyday activity (Jeannerod et al., 1995). For example, reaching movement to spatial targets or manual prehension of an object require the motor patterns at the shoulder to be coordinated carefully with those at the elbow and wrist joints to smoothly move the hand through space. Proximal joints participate in the transportation of the hand in vicinity of the object, while distal joint, at the fingers level, shape the hand appropriately for the object and its planned use. The coordination of the fingers, wrist, and arm indicates that a global control strategy may be utilized (Scott, 2000).

We have recently found that passive shoulder joint rotation from 30° abduction to 30° adduction in the horizontal plane, increased the corticomotor outflow to abductor digiti minimi (Ginanneschi et al., 2005). In contrast, shoulder joint rotation failed to influence the corticospinal innervation to the first dorsal interosseus (Dominici et al., 2005). We hypothesized that it may reflect a proximal–distal synergy operating during reaching to grasp movements. In fact, facilitation of the corticomotoneuronal pathway to intrinsic abductor digiti muscles, such as the abductor digiti minimi, is coherent with the pre-shaping phase of the hand (i.e., opening of the fingers) in anticipation of the grasp (Mason et al., 2002). However, since our fingers do not move in isolation of the hand, nor does the hand move in isolation of the arm, it is plausible that different static shoulder joint positions also influence muscles acting at wrist joint level. This aspect is specifically addressed in the present study (Fig. 1).

2. Results

The relationship between TMS stimulus intensity (input) and the size of the evoked motor potential (output) defines the recruitment property of the corticospinal pathway in humans. This input–output relationship has a sigmoidal shape with a threshold, reflecting the size of the subliminal fringe of the most excitable corticospinal neurons; a slope, indicating the recruitment efficiency (gain) of the corticospinal pathway; and a plateau value, reflecting the magnitude of the excitatory component that determines the number of spinal motoneur-

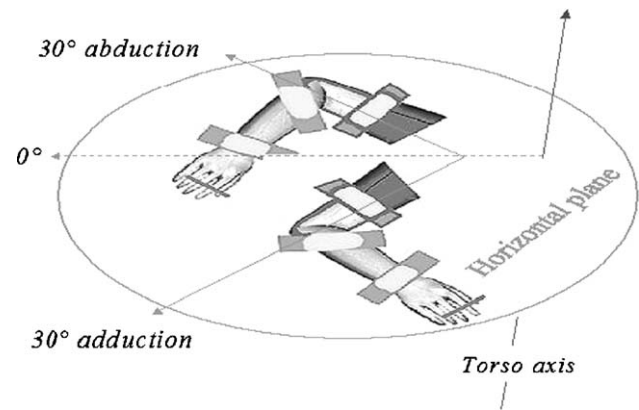


Fig. 1 – Schematic representation of the arm position. Upper limb was placed and secured on a rigid support with the elbow and wrist joint fixed at 90° and 0°, respectively. The arm, placed on horizontal plane (i.e., perpendicular to the torso axis), could be freely rotated forward (30° adduction) and backward (30° abduction).

ones which are ultimately recruited (Capaday, 1997; Carroll et al., 2001; Devanne et al., 1997; Rothwell et al., 1991).

Fig. 2 compares the group average curves of FCR and ECR expressing the relationship between MEP size and TMS stimulus intensity at 30° adduction and 30° abduction shoulder joint angle. In FCR, threshold values corresponded to $49.42\% \pm 12.2$ SE at adducted and to $50\% \pm 13.5$ at abducted shoulder position. Their difference did not reach statistical significance. Average slope (i.e., 1/slope) of the Boltzmann equation fitted to experimental data was 0.135 ± 0.021 SE at 30° abduction and 0.153 ± 0.034 SE at 30° adduction. Their difference reached a significant level ($F = 18.42$, $P = 0.014$) indicating that gain of the FCR input–output curve was decreased in adduction with respect to abduction shoulder position. Similarly, the plateau level of the FCR input–output relationship was significantly higher at 30° abduction than at 30° adduction (84.43 ± 3.13 and 101.80 ± 2.35 , respectively) ($F = 10.97$; $P = 0.004$). Insert of Fig. 2A illustrates the size of the FCR MEP an intensity of $1.3 \times rMT$ in relation to different static shoulder positions: at 30° adduction MEP size was significantly smaller than at 30° abduction (53.81 ± 9.20 SE and 68.63 ± 10.97 SE, respectively) ($F = 26.12$, $P < 0.001$). MEP latencies were significantly delayed at 30° adduction (17.32 ± 0.16 SE ms) with respect to 30° abduction (16.91 ± 0.2 SE ms) ($F = 14.01$, $P = 0.003$). The alterations in MEP amplitude, according with the covarying nature of these two parameters when TMS is utilized (Rossini et al., 1994).

In ECR, MEP threshold value was not significant different in the two shoulder positions: $51.28\% \pm 8.53$ SE at 30° abduction and $51.86\% \pm 9.22$ SE at 30° adduction shoulder position. Average slope of the Boltzmann equation fitted to ECR data was significantly higher at 30° adduction (0.28 ± 0.080 SE) than at 30° abduction (0.30 ± 0.12 SE) ($F = 9.97$, $P = 0.005$). Similarly, plateau phase was significantly higher in adduction than in abduction (112.60 ± 10.05 SE and 86.69 ± 11.60 SE respectively) ($F = 26.76$, $P < 0.001$). Insert of Fig. 2B illustrates the size of the ECR MEP an intensity of $1.3 \times rMT$ in relation to different

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