

# Finger Movements Induced by Transcranial Magnetic Stimulation Change With Hand Posture, But Not With Coil Position

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**Abstract:** We attempted to map the representations of movements in 2 normal subjects by delivering five transcranial magnetic stimuli (TMS) with a focal coil to each of a grid of positions over the primary motor area (M1). Isometric forces were recorded from the contralateral index finger. Maps were made with the hand in a semiflexed “neutral” position, and with the thumb and index finger opposed in a “pincer” grip. The electromyogram (EMG) was monitored to ensure relaxation. The wrist was immobilized. In the neutral position, TMS at almost all positions produced abduction. Flexion was produced in the pincer position. Thus, while sensitive to changes in posture, TMS mapping may not be sensitive to the topographical organization of the M1 by movements as detected with direct cortical stimulation. *Hum. Brain Mapping* 6:390–393, 1998. © 1998 Wiley-Liss, Inc.

**Key words:** motor cortex; brain mapping; spinal cord; corticospinal tracts; human

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## INTRODUCTION

Mapping with transcranial magnetic stimulation (TMS) has been used to distinguish the cortical motor representations of resting muscles in the upper extremities [Wassermann et al., 1992], and refinements of the basic technique have permitted others to distinguish the representations of intrinsic muscles of the same hand [Wilson et al., 1993]. In our previous study [Wassermann et al., 1992], we moved the stimulating coil over the scalp while recording motor-evoked potentials (MEPs) from muscles in the contralateral

arm and hand. MEPs in these muscles were evoked from largely overlapping scalp regions. However, numerical analysis of the data revealed a tendency for the centers of gravity of the maps and loci of peak response to lie in the predicted somatotopic order along the posteromedial to anterolateral axis of the primary motor area (M1).

The fine structure of the output map of the primary motor area (M1) of humans [Woolsey et al., 1979] and animals [Asanuma, 1989] is organized in terms of movements rather than body parts or muscles. Therefore, it was of interest to see whether TMS mapping was sensitive to this type of organization as well. Specifically, we wondered whether the diffuse areas from which MEPs of various sizes could be evoked in individual muscles might be divided into zones where stimulation produced different movements of

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the limb by activating the muscles in different combinations. In order to answer this question, we recorded the isometric forces generated by the muscles controlling a single digit in response to TMS at different scalp positions.

It has also been shown that the muscle response to TMS depends on the functional state of the limb [Flament et al., 1993]. This raises the issue of whether the shape of TMS motor maps changes when the posture of the target limb is changed. This issue was addressed by repeating the mapping process under two different postural conditions.

### SUBJECTS AND METHODS

Subjects were 2 right-handed healthy men, aged 23 and 40, who gave informed consent for the study, which was approved by the local ethical committee of the University of Valencia, Spain. During the mapping experiments, in order to isolate the recorded force to the index finger, the subjects' right wrists and digits 3–5 were immobilized comfortably in a neutral position with a padded, plaster, bivalve cast. The cast was fixed firmly to a table, with the index finger passing through the ring of a load cell which measured isometric forces in the horizontal and vertical directions. The output of the load cell was recorded by a computer. The evoked "movement" was the vector sum of the peak force in each direction occurring in the first 100 msec following each TMS pulse.

TMS was delivered through an 8-shaped coil powered by a Dantec MagPro® stimulator. This apparatus delivers a relatively focal stimulus and is substantially similar to that used in previous TMS motor mapping studies [Wassermann et al., 1992; Wilson et al., 1993]. Prior to casting, we found the optimal position for producing MEPs in the first dorsal interosseous muscle (FDI, which abducts and extends the index finger) in each subject, and marked it on the scalp. For mapping, the intensity of the stimulation was set at a level that produced a consistent visible twitch in the index finger. Five stimuli at this intensity were delivered to each of 25 grid positions 1 cm apart, centered around the optimal position for producing MEPs in the FDI. The orientation of the coil was held constant, with the axis of the junction of the coil in the sagittal plane. This resulted in an angle of approximately 45° to the central sulcus. The force traces were averaged across the five trials of stimulation at each scalp position.

Mapping was done under two conditions: "neutral," where the hand was relaxed with the fingers partially flexed, and "pincer," where the thumb and index finger were placed in opposition, but without muscle

activation. Surface EMG was monitored from the flexors and extensors of the finger in the forearm in order to ensure relaxation during the experiment. The stimulation intensity was the same for each mapping condition in each subject.

### RESULTS

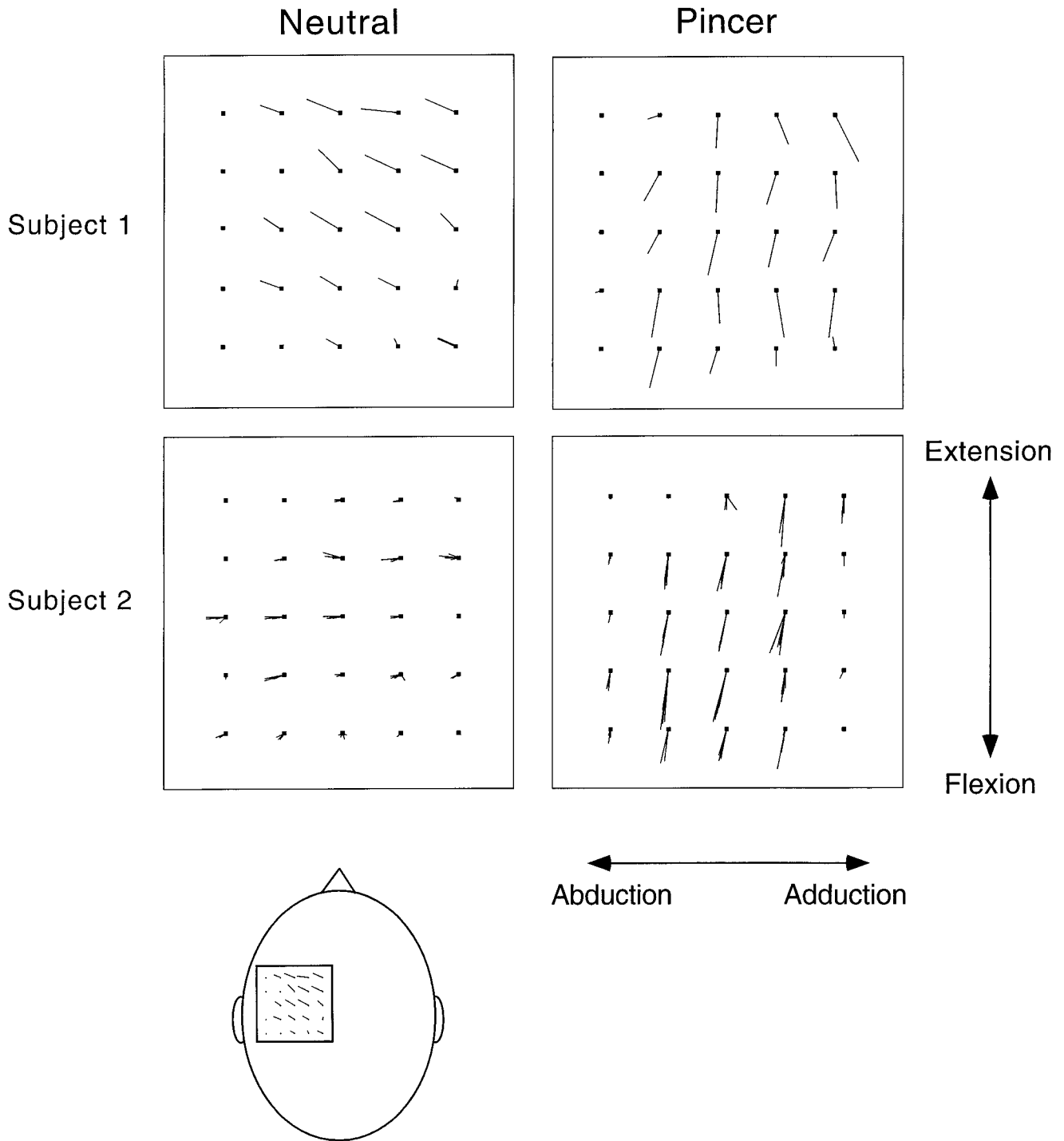
With the hand in the neutral position, TMS at most positions produced abduction of the index finger in both subjects. However, in the pincer position, stimulation at most of the same positions produced flexion (Fig. 1). The direction and amplitude of the evoked movement were remarkably consistent from trial to trial, and there was a tendency for clustering of high-response sites. There was no evidence that the movement vector tended to change in a consistent or predictable way as the coil was moved.

When only the scalar amplitude of the evoked movement was taken into account, the amplitude-weighted centers of gravity of the maps differed only slightly between the neutral and pincer conditions (<0.25 cm in both subjects).

### DISCUSSION

Despite exploring a limited number of stimulation sites in only 2 subjects, this study suggests strongly that topographic mapping with TMS is not able to subdivide the cortical motor representations of body parts in terms of movements. Rather, it appears either that TMS accesses the same combination of corticospinal outputs regardless of the location of the coil, or that the bias imposed on the motor output system by subthreshold efferent activity related to the posture of the limb or to the resulting set of peripheral inputs swamps any variation in response due to the site of stimulation. The dramatic and uniform difference in the direction of the evoked movement that we observed between the neutral and pincer conditions suggests that posture plays a significant role. This factor may not be as important in studies on anesthetized animal or human subjects in whom the processing of afferent activity may be depressed. It should be mentioned, however, that changing the orientation of the stimulating current with respect to the brain may result in changes in the evoked pattern of muscle activation [Brasil-Neto et al., 1992], and that rotating the coil instead of moving it might produce changes in movement.

In a study of the effect of various static hand "tasks," including simple index-finger abduction and pincer grip [Flament et al., 1993], it was found that the task



**Figure 1.**

Force maps from 2 subjects, with the hand in neutral and pincer positions. Lines show amplitude and direction of force evoked by TMS at each scalp site. Abduction is to the left and adduction is to the right; extension is up and flexion is down. Responses arranged in topographical order. Inset: orientation of mapping grid on scalp.

Normalization of force amplitudes is the same in the neutral and pincer maps for each subject. Averaged data are shown for subject 1. Individual trials are shown for subject 2 in order to indicate the degree of consistency in the response.

had a significant effect on the size of the MEP evoked in the FDI, despite the fact that the degree of activation in the muscle was held constant. These differences were present not only with magnetic, but also with electrical transcranial stimulation, which tends to activate the descending corticospinal axons directly [Rothwell et al., 1991], bypassing the intracortical integrative apparatus. This suggests that the “task specificity” of the response was determined at least partially at the level of the spinal segment where multiple peripheral and central inputs converged to set the bias of spinal circuits upon which the corticospinal commands acted [Brooks, 1986]. Limb position appears to have a profound effect on the direction of force evoked by microstimulation of the spinal cord in frogs [Giszter et al., 1993], with the different movements tending to converge toward a single equilibrium point. Therefore, spinal mechanisms may contribute significantly to determining the direction of TMS-evoked movements.

On the other hand, in contrast to direct electrical stimulation of the cortex with trains of low-intensity pulses, TMS is relatively nonfocal and must access the corticospinal cells via very brief and relatively massive activation of excitatory interneurons [Rothwell et al., 1991]. Therefore, perhaps the stereotypical evoked movement results from mass action within an interneuronal network that tends to produce idiosyncratic patterns of descending activity when activated in this nonphysiological way. In this regard, it is interesting that the direction of an evoked thumb movement can be conditioned by prior training [Classen et al., 1998]. Classen et al. [1998] encountered similarly consistent movement responses to TMS at a single scalp site, but found that the direction of movement could be changed temporarily by repetitive voluntary movement of the digit in the opposite direction. In this case, comparison of magnetically and electrically evoked responses after training suggested that the substrate of the change in movement direction was primarily cortical. Fadiga et al. [1995] found that simply observing actions performed by others could bias the pattern of corticospinal output in response to TMS pulses. This demonstrates that even when peripheral factors are held

constant, the TMS-evoked movement is not “hard-wired,” but results from a behaviorally modifiable set of connections.

It is possible that we failed to detect a low level of voluntary muscle activation that determined the direction of movement. This could explain the flexion bias observed in the pincer position, but it is very unlikely to have been responsible for the uniform adduction seen in the neutral position.

In conclusion, TMS does not appear to be a useful means of mapping the representations of movements within the M1 in single subjects. Nevertheless, TMS is very sensitive to central and peripheral changes that modulate the direction of evoked movements.

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