

Paradoxical effect of digital anaesthesia on force and corticospinal excitability

Julie Duque,^{1,CA} Yves Vandermeeren,¹ Thierry M. Lejeune,^{2,3} Jean-Louis Thonnard,²
Allan M. Smith⁴ and Etienne Olivier¹

¹Laboratoire de Neurophysiologie; ²Unité de Réadaptation et Médecine Physique; ³Cliniques Universitaires Saint-Luc, Université Catholique de Louvain, Bruxelles, Belgium; ⁴Département de Physiologie, Centre de Recherche en Sciences Neurologiques, Université de Montréal, Montréal, Canada

^{CA}Corresponding Author: julie.duque@nefy.ucl.ac.be

Received 10 November 2004; accepted 29 December 2004

The role played by sensory information in maintaining motor cortical representations is still incompletely understood. We investigated the effect of digital anaesthesia of the index finger and thumb on the amplitude of motor evoked potentials to transcranial magnetic stimulation (TMS) recorded from the first dorsal interosseus, F-wave response probability and maximal key pinch force.

Whereas digital anaesthesia led to a 29% decrease in maximal force, both motor evoked potential amplitudes and F-wave probability remained unchanged. This dramatic decrease in maximal voluntary contraction following digital anaesthesia may result from a lack of proper sensory feedback during the task. *NeuroReport* 16:259–262 © 2005 Lippincott Williams & Wilkins.

Key words: Deafferentation; Maximal voluntary contraction; Motor maps; Plasticity; Transcranial magnetic stimulation

INTRODUCTION

In the past decade, there have been considerable advances in understanding the neuronal bases of sensory and motor representations in the cortex [1]. It is now widely accepted that in the primary motor cortex, muscle representations are not invariant but are susceptible to rapid adaptation following a central [2] or a peripheral lesion [3] or after an amputation [4]. In particular, within minutes following anaesthesia, it has been shown that the cortical representation of muscles immediately proximal to the paralysed body part increases [5]. However, in most studies, both afferent and efferent signals were interrupted indistinguishably by lesion or anaesthesia and therefore their specific contribution to the reorganization of the motor cortex remains unclear.

In monkeys, the hand area in the primary motor cortex receives abundant projections from the corresponding region of the somatosensory cortex [1] and these projections may play a critical role in controlling motor excitability [6]. In humans, several studies have tried to investigate the specific impact of sensory information on muscle representations in the motor cortex. To do so, they examined the effects of a radial and median nerve block at the wrist level on both the excitability and extent of muscle representations in the primary motor cortex [7,8]. The main finding was a decrease in size of the cortical representation of muscles spared by anaesthesia, but enveloped in the deafferented region, whereas the representation of muscles outside this region remained unaltered [7]. However, because in these studies the anaesthesia involved a large cutaneous territory and affected motor nerves, these results could have been biased by the thenar muscle paralysis or the pain resulting from the anaesthesia.

The purpose of the present study was to investigate the specific influence of sensory information from a restricted area encompassing the index finger and thumb on intrinsic hand muscle representations. We studied the effect of local 'ring' anaesthesia of the thumb and index finger on both the maximal key pinch force and the amplitude of motor evoked potentials (MEPs) recorded from the first dorsal interosseus in response to transcranial magnetic stimulation (TMS) of the primary motor cortex. We hypothesized that removing sensory inputs from the first two digits would yield a decrease in the corticospinal excitability of the first dorsal interosseus, a muscle controlling the index finger abduction and flexion. We expected this decrease to be correlated with a reduction in the maximal voluntary pinch force.

METHODS

The present study was performed in 12 right-handed healthy adults (age: 27 ± 1.1 years). The experimental procedure was approved by the Ethics Committee of the Université Catholique de Louvain and all participants gave their written informed consent.

Anaesthesia procedure: The conduction of the digital nerves of the index finger and thumb of the right hand was blocked at the level of the proximal phalanx of each digit by injection of ~1 ml bupivacain (0.5%) in order to achieve ring-block anaesthesia. By using this protocol, we ensured that only sensory inputs, including cutaneous and some joint information, were interrupted. This anaesthesia protocol, in contrast to previous studies, spared all intrinsic

hand muscles, maintaining intact muscle spindle afferents. The depth and extent of the anaesthesia was assessed by means of the Semmes-Weinstein monofilaments (Lafayette Instrument Company, Loughborough, UK) following a procedure described by Bell-Krotoski and Tomancik [9]. Anaesthesia was considered as adequate when the 20th Semmes-Weinstein monofilament could not be detected anymore. None of the participants reported pain during digital anaesthesia.

Maximal voluntary contraction and electromyographic recording: The maximal contraction was measured before and during anaesthesia with a pinch gauge that participants had to squeeze between the tip of the thumb and the side of the index finger (key pinch force) [10]. During anaesthesia, it was placed correctly in the participant's hand to ensure a proper finger positioning on the gauge. The mean maximal force was computed over three trials. Study participants were always provided with a visual feedback of the force they produced.

Electromyographic (EMG) recordings were made from surface electrodes (Neuroline, Medicotest, Oelstykke, Denmark) placed over the right and left first dorsal interosseus muscles. EMG signals were amplified (gain: 500–2k), high-pass filtered at 30 Hz (Neurolog, Digitimer, UK) and digitized on-line at 5 kHz using a personal computer with a 1401 interface (Cambridge Electronic Design, Cambridge, UK). We chose to investigate possible changes in corticospinal excitability of the first dorsal interosseus because it has been suggested that a given muscle representation receives sensory inputs specifically from the body parts it moves [11].

Transcranial magnetic stimulation: Focal TMS was applied sequentially over the hand area of the left and right primary motor cortex in all 12 participants. Stimulations were delivered using a Magstim 200 magnetic stimulator (Magstim Company, Dyfed, UK) through a 70-mm-diameter figure-of-eight coil (maximal output: 2.2 T). The magnetic coil was placed tangentially to the scalp, with the handle pointing backward and laterally at a 45° angle away from the midline, approximately perpendicular to the central sulcus. The coil position was adjusted to optimize the peak-to-peak MEP amplitude recorded from the first dorsal interosseus (hot spot) and was carefully marked on the scalp. Then, the resting motor threshold was determined by progressively decreasing the TMS intensity until it produced MEPs ≥ 50 μ V peak-to-peak in at least five out of 10 trials. The intensity of the stimulation was set at 20% above the resting motor threshold and MEPs were acquired at rest or with a moderate voluntary contraction equal to 20% of the maximal voluntary contraction. The amplitude of 20 consecutive MEPs (0.2 Hz) elicited in each condition, before and during anaesthesia, was averaged and expressed in percent, relative to the maximal *M* response measured before and during anaesthesia (see below). This was performed in order to ensure that possible changes in MEP amplitude after anaesthesia could not be explained by changes in electrode or skin impedance after finger anaesthesia. The MEP latency was also measured. Data gathered from the left, unanaesthetized, first dorsal interosseus were used as control values.

Motoneuron excitability: In order to assess possible changes in motoneuronal excitability consequent to digital anaesthesia, F waves were recorded from the first dorsal interosseus, before and during anaesthesia. At least 20 supramaximal stimulations of the ulnar nerve were applied at the wrist to elicit maximal *M* responses and F waves before and during anaesthesia. The maximum *M* response was used to express MEP amplitude and also to rule out a direct diffusion of the anaesthetic into the muscle. F-wave persistence, that is, the response probability, was used as an index of motoneuron excitability. Although this measurement concerns only a small portion of the motoneurons, this technique is the only one available to assess routinely motoneuronal excitability [12,13].

Data analysis: Data are expressed as mean $\pm$ SE. The effect of anaesthesia was tested on the maximal voluntary contraction, the resting motor threshold, MEP amplitudes and latencies, F-wave persistence and the maximal *M* response using repeated-measures ANOVAs with factors HAND (left–right) and ANAESTHESIA (pre–post). Post-hoc pairwise comparisons were implemented using Tukey tests adjusted for multiple comparisons.

RESULTS

Effect of anaesthesia on maximal voluntary contraction:

ANOVA showed a significant effect of ANAESTHESIA ($F=13.35$, $p=0.004$) and a significant HAND $\times$ ANAESTHESIA interaction ($F=19.90$, $p<0.001$) on the maximal voluntary contraction. Digital anaesthesia of the thumb and index finger led to a significant decrease ($29 \pm 4.9\%$) in the maximal key pinch force of the right hand only ($p<0.001$, Table 1 and Fig. 1a); it became different from the maximum force in the left hand ($p<0.001$) that remained unaffected by anaesthesia ($p=0.89$).

Effect of anaesthesia on motor evoked potential amplitude and latency and on motoneuron excitability: Before anaesthesia, the resting motor threshold was, on average, $41 \pm 1.7\%$ and $41 \pm 1.9\%$ of the maximal stimulator output for the right and left first dorsal interosseus, respectively (Table 1). It was not affected by the anaesthesia. In addition, in contrast to our predictions, anaesthesia did not affect the

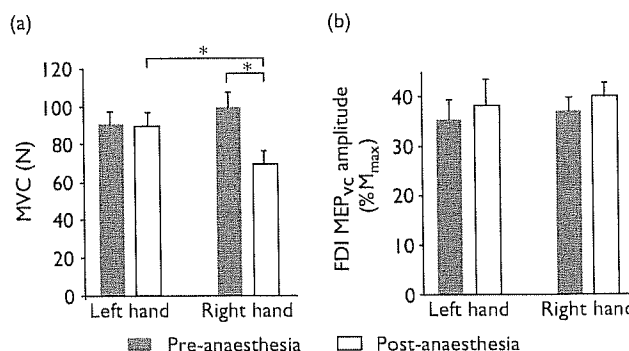


Fig. 1. (a) Histograms represent the mean and SE of the maximal voluntary contraction (MVC) for both hands. N=Newton; *= $p<0.001$. (b) Histograms represent the mean and SE of the motor-evoked potentials acquired while the participants were maintaining a moderate voluntary contraction (MEP_{vc}) and expressed in percent of the maximum *M* response (*M*_{max}) for the left and right first dorsal interosseus.

Table 1. Effect of anaesthesia on the maximal voluntary contraction (MVC), TMS and electrical parameters.

Parameters	Left hand		Right hand	
	Preanaesthesia Mean (SE)	Postanaesthesia Mean (SE)	Preanaesthesia Mean (SE)	Postanaesthesia Mean (SE)
MVC (N)	91.0 (7.5)	90.2 (7.2)	100.1 (8.1)	69.9* (6.9)
rMT (%)	41.4 (1.9)	41.2 (1.8)	40.8 (1.7)	41.7 (2.2)
MEP _r (mV)	1.5 (0.4)	1.9 (0.5)	2.1 (0.4)	2.3 (0.4)
MEP _{vc} (mV)	9.6 (1.9)	11.0 (2.7)	8.7 (1.2)	9.0 (1.1)
MEP _r /M amplitude (%)	8.5 (1.3)	8.3 (1.4)	9.2 (1.8)	10.8 (2.1)
MEP _{vc} /M amplitude (%)	35.0 (3.9)	38.4 (5.1)	38.3 (2.6)	41.0 (2.8)
Latency MEP _r (ms)	22.0 (0.4)	22.2 (0.4)	22.1 (0.3)	22.0 (0.3)
Latency MEP _{vc} (ms)	20.7 (0.4)	20.9 (0.4)	20.3 (0.3)	20.5 (0.3)
F-wave persistence (%)	79.7 (3.9)	70.3 (5.1)	70.8 (4.0)	65.3 (5.1)
M _{max} (mV)	28.1 (3.1)	30.0 (3.4)	22.8 (1.7)	21.9 (1.4)

TMS, transcranial magnetic stimulation; rMT, resting motor threshold; MEP_r/M, motor-evoked potential acquired at rest and expressed in % of the maximal M response (M_{max}); MEP_{vc}/M, motor evoked potentials acquired with a moderate background contraction and expressed in % of M_{max}; SE, standard error; **p* < 0.05 after Tukey tests comparing postanaesthesia values with the preanaesthesia ones. The two values in bold are significantly different.

amplitude and latency of MEPs acquired at rest or with a small background contraction; similar results were found for the left MEPs. The results were identical when MEP amplitudes were expressed relative to the maximum M response not altered by anaesthesia (Table 1 and Fig. 1b). Finally, F-wave persistence was unaffected by anaesthesia (see Table 1).

DISCUSSION

The purpose of this experiment was to investigate possible changes in the corticospinal excitability of the first dorsal interosseus following a reversible suppression of sensory afferents originating from the index finger and thumb. In addition, we wanted to seek a correlation between corticospinal excitability and the maximal key pinch force. In contrast to our predictions, the dramatic decrease in the maximal key pinch force was not accompanied by a lower corticospinal excitability of the first dorsal interosseus.

Motor cortex excitability: Our results may seem, at first sight, to be in contradiction with previous studies. Indeed, following anaesthetic blocks of the median and radial nerves at the wrist, Rossi *et al.* [7] found a decrease in both the excitability and extent of the cortical representation of intrinsic hand muscles encompassed in the anaesthetized region. However, these studies differed in a major aspect from ours because, in the present study, the anaesthetic injected in the proximal phalanges of the index finger and thumb (digital radial and median nerves) blocked only cutaneous and joint sensory information and spared proprioceptive information mediated by muscle afferents [14]. Therefore, it is likely that changes in corticospinal excitability or in map extent in the primary motor cortex reported in previous studies resulted from multiple confounding factors, making indistinguishable the respective contribution of muscle, joint and cutaneous sensory information and that of motor activity disruption.

One possible explanation for the absence of detectable change in corticospinal excitability in the present study is that the anaesthesia we used was too restricted to influence the corticospinal excitability as estimated with MEP amplitude. This is consistent with a recent study that failed to show a modulation in the amplitude of MEPs recorded from the abductor digiti minimi after a 2 h cutaneous

stimulation of fingers 4 and 5 [15]. It is important to stress that these results, together with those reported in the present study, cannot be compared with numerous, although conflicting, reports that investigated the effect of a single, short-lasting, digital nerve stimulation on the amplitude of MEPs recorded from intrinsic hand muscles [16,17].

Alternatively, it could be hypothesized that, in the present study, proprioceptive information left intact by the anaesthesia compensated, in terms of corticospinal excitability, for the loss of cutaneous and joint information. Indeed, a selective reduction of cutaneous and joint inputs from a restricted skin area following a radial nerve block at the wrist level has been shown to result in larger 'proprioceptive' evoked potentials recorded from the somatosensory cortex and elicited by stimulating muscle afferents from the first dorsal interosseus, which was enveloped in the anaesthetized area [18]. Note that this short-term plasticity across sensory modalities vanishes when the anaesthesia leads to the paralysis of several muscles [19], supporting the apparent inconsistency of our results with respect to previous studies where both efferent and afferent signals were interrupted by anaesthesia [7,8]. Finally, the lack of change in F-wave persistence after anaesthesia suggests that our results were not biased by a modulation of the motoneuron excitability at a segmental level that could mask a change in corticospinal excitability [12].

Maximal voluntary contraction: The absence of changes in corticospinal excitability is made even more puzzling by the finding that the maximal key pinch force decreased by about 30% during digital anaesthesia; this decrease in maximal contraction was observed even though participants received a constant visual feedback of their performance. Cutaneous afferents have been repeatedly shown to play a critical role in motor control and, in particular, in the control of the grip force, that is, the force required to grasp and manipulate objects between the index finger and thumb [20,21]. An adequate sensory feedback therefore appears essential for providing continuous information regarding the actual state of the system and to update the anticipatory commands [20,22]. The present results show that sensory afferents are essential not only while controlling very precise forces such as grip force but also when generating a maximal contraction.

Digital anaesthesia is known to induce distortions of the perceived body part size [23] and of the heaviness of weights supported by the deafferented body part [24]. In our study, all participants reported the subjective sensation of having a larger thumb and index finger than before anaesthesia, and of squeezing the pinch gauge extremely strongly, although they were provided with visual feedback of their force. Perceptual illusions of weight are thought to occur because the digital anaesthesia distorts the normal balance between agonist-antagonist muscle action during movement [25], possibly as a result of the loss of reflexes that facilitate or inhibit motoneuron pools [24]. Our findings suggest that perceptual distortions during digital anaesthesia occur without any long-lasting corticospinal excitability changes and emphasize the close functional relationship between cutaneous and joint afferent information and motor control [25].

CONCLUSION

Digital anaesthesia of the index finger and thumb led to a dramatic decrease in the maximal key pinch force that was found to be unrelated to changes in corticospinal excitability of the first dorsal interosseus. This force decrease most likely resulted from a lack of proper sensory feedback during the task.

REFERENCES

- Porter R, Lemon RN. Inputs from peripheral receptors to motor cortex neurones. In: Porter R, Lemon RN (Eds). *Corticospinal Function and Voluntary Movement. Monographs of the Physiological Society* – 45. Oxford: Clarendon Press; 1993. pp. 247–272.
- Traversa R, Cicinelli P, Bassi A, Rossini PM, Bernardi G. Mapping of motor cortical reorganization after stroke. A brain stimulation study with focal magnetic pulses. *Stroke* 1997; **28**:110–117.
- Brasil-Neto JP, Valls-Sole J, Pascual-Leone A, Cammarota A, Amassian VE, Cracco R *et al.* Rapid modulation of human cortical motor outputs following ischaemic nerve block. *Brain* 1993; **116**(Pt 3):511–525.
- Cohen LG, Bandinelli S, Findley TW, Hallett M. Motor reorganization after upper limb amputation in man. A study with focal magnetic stimulation. *Brain* 1991; **114**(Pt 1B):615–627.
- Ziemann U, Hallett M, Cohen LG. Mechanisms of deafferentation-induced plasticity in human motor cortex. *J Neurosci* 1998; **18**:7000–7007.
- Kaneko T, Caria MA, Asanuma H. Information processing within the motor cortex. I. Responses of morphologically identified motor cortical cells to stimulation of the somatosensory cortex. *J Comp Neurol* 1994; **345**:161–171.
- Rossi S, Pasqualetti P, Tecchio F, Sabato A, Rossini PM. Modulation of corticospinal output to human hand muscles following deprivation of sensory feedback. *Neuroimage* 1998; **8**:163–175.
- Liepert J, Weiss T, Meissner W, Steinrucke K, Weiller C. Exercise-induced changes of motor excitability with and without sensory block. *Brain Res* 2004; **1003**:68–76.
- Bell-Krotoski J, Tomancik E. The repeatability of testing with Semmes-Weinstein monofilaments. *J Hand Surg [Am]* 1987; **12**:155–161.
- Mathiowetz V, Wiemer DM, Federman SM. Grip and pinch strength: norms for 6- to 19-year-olds. *Am J Occup Ther* 1986; **40**:705–711.
- Asanuma H, Stoney SD Jr, Abzug C. Relationship between afferent input and motor outflow in cat motor sensory cortex. *J Neurophysiol* 1968; **31**:670–681.
- Lin JZ, Floeter MK. Do F-wave measurements detect changes in motor neuron excitability? *Muscle Nerve* 2004; **30**:289–294.
- Olivier E, Baker SN, Lemon RN. Comparison of direct and indirect measurements of the central motor conduction time in the monkey. *Clin Neurophysiol* 2002; **113**:469–477.
- Gandevia SC, McCloskey DI, Burke D. Kinaesthetic signals and muscle contraction. *Trends Neurosci* 1992; **15**:62–65.
- Ridding MC, Brouwer B, Miles TS, Pitcher JB, Thompson PD. Changes in muscle responses to stimulation of the motor cortex induced by peripheral nerve stimulation in human subjects. *Exp Brain Res* 2000; **131**:135–143.
- Maertens de Noordhout A, Rothwell JC, Day BL *et al.* Effect of digital nerve stimuli on responses to electrical or magnetic stimulation of the human brain. *J Physiol* 1992; **447**:535–548.
- Delwaide PJ, Olivier E. Conditioning transcranial cortical stimulation (TCCS) by exteroceptive stimulation in parkinsonian patients. *Adv Neurol* 1990; **53**:175–181.
- Tinazzi M, Rosso T, Zanette G, Fiaschi A, Aglioti SM. Rapid modulation of cortical proprioceptive activity induced by transient cutaneous deafferentation: neurophysiological evidence of short-term plasticity across different somatosensory modalities in humans. *Eur J Neurosci* 2003; **18**:3053–3060.
- Murphy BA, Haavik Taylor H, Wilson SA, Knight JA, Mathers KM, Schug S. Changes in median nerve somatosensory transmission and motor output following transient deafferentation of the radial nerve in humans. *Clin Neurophysiol* 2003; **114**:1477–1488.
- Augurelle AS, Smith AM, Lejeune T, Thonnard JL. Importance of cutaneous feedback in maintaining a secure grip during manipulation of hand-held objects. *J Neurophysiol* 2003; **89**:665–671.
- Fisher RJ, Galea MP, Brown P, Lemon RN. Digital nerve anaesthesia decreases EMG-EMG coherence in a human precision grip task. *Exp Brain Res* 2002; **145**:207–214.
- Witney AG, Wing A, Thonnard JL, Smith AM. The cutaneous contribution to adaptive precision grip. *Trends Neurosci* 2004; **27**:637–643.
- Gandevia SC, Phegan CM. Perceptual distortions of the human body image produced by local anaesthesia, pain and cutaneous stimulation. *J Physiol* 1999; **514**(Pt 2):609–616.
- Gandevia SC, McCloskey DI, Potter EK. Alterations in perceived heaviness during digital anaesthesia. *J Physiol* 1980; **306**:365–375.
- Marsden CD, Rothwell JC, Traub MM. Effect of thumb anaesthesia on weight perception, muscle activity and the stretch reflex in man. *J Physiol* 1979; **294**:303–315.

Acknowledgements: J.D. is a research assistant at the Belgian National Funds for Scientific Research (FNRS).