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Acute improvement of hand sensibility after selective ipsilateral cutaneous forearm anaesthesia

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Abstract

The cortical representation of body parts is constantly modulated in response to the afferent input, and acute deafferentation of a body part results in bilateral cortical reorganization. To study the effects on hand function of right forearm anaesthesia, we investigated ten human subjects (group 1) for perception of touch, tactile discrimination and grip strength in the right (ipsilateral) and left (contralateral) hand before, during and 24 h after forearm skin anaesthesia with a local anaesthetic cream (EMLA®). Ten age-matched controls (group 2) were investigated in the same way but received placebo. In group 1 a significant improvement was seen in tactile discrimination in the ipsilateral hand compared to base line ($P = 0.009$) and compared to group 2 ($P = 0.006$). The improvement in tactile discrimination remained for at least 24 h after anaesthesia. Perception of touch, was improved during anaesthesia compared to baseline values in group 1 ($P = 0.046$) and remained for at least 24 h. Grip strength did not change. These findings suggest that transient selective deafferentation of an extremity results in enhanced sensory functions of the functionally preserved parts of the same extremity, presumably as a result of expansion of adjacent cortical territories. Such rapid functional changes suggest unmasking of pre-existing synaptic connections as the mechanism underlying the acute modulation of sensory functions in the hand. Our findings open new perspectives for sensory re-education and rehabilitation following injury to the peripheral and central nervous system.

Introduction

The cortical representation of body parts is constantly modulated in response to the extent and character of afferent input (Kaas, 1991; Donoghue *et al*., 1996; Lundborg, 2000; Chen *et al*., 2002; Wall *et al*., 2002). Increased tactile experience leads to cortical expansion of the corresponding cortical representation (Jenkins *et al*., 1990; Merzenich & Jenkins, 1993; Godde *et al*., 1996; Coq & Xerri, 1999; Dinse *et al*., 2003) while sensory deprivation and deafferentation results in decreased cortical representation and expansion of adjacent cortical territories (Liepert *et al*., 1995; Sadato *et al*., 1995; Coq & Xerri, 1999; Chen *et al*., 2002). Examples of such deafferentations are local anaesthetic blocks (Metzler & Marks, 1979; Calford & Tweedale, 1991; Brasil-Neto *et al*., 1992; Rossini *et al*., 1994; Tinazzi *et al*., 1997), nerve injury (Kaas *et al*., 1983; Wall *et al*., 1986; Merzenich & Jenkins, 1993; Silva *et al*., 1996; Lundborg, 2003) and amputation (Kelahan *et al*., 1981; Merzenich *et al*., 1984; Merzenich & Jenkins, 1993; Weiss *et al*., 2000).

Deafferentation of the upper extremity may lead to cortical reorganization in the contralateral, as well as the ipsilateral hemisphere, and may be linked to changes in hand function. Tourniquet-induced anaesthesia of the forearm results in cortical expansion, improved tactile discrimination and improved grip strength of the contralateral hand (Werhahn *et al*., 2002a,b; Björkman *et al*., 2004).

Transient selective deafferentation of an arm can result in improved function of functionally intact parts also of the same, ipsilateral arm. Muellbacher *et al*. (2002) blocked selectively the upper brachial plexus roots, innervating muscles of the shoulder and elbow, in stroke patients. The anaesthetic block resulted in improved grip strength in the hand receiving its motor innervations from the lower brachial plexus roots. The improvement was associated with an increase in transcranial magnetic stimulation-evoked motor output to the practice hand muscles. It is not known whether a corresponding effect on sensory functions can be achieved by an analogous selective sensory block.

The aim of the present study was to investigate if a selective cutaneous anaesthesia of the forearm would result in improved sensory function of the ipsilateral hand in analogy with the findings of Muellbacher *et al*. (2002) regarding motor function. Improved sensory function of the hand, as a result of transient anaesthesia of the forearm, would have important potential implications in the rehabilitation of patients suffering from injuries in the peripheral and central nervous system.

Materials and methods

Twenty healthy subjects (six men and 14 women, mean age 36 years, range 25–52) participated in the study. None of the subjects had any subjective nerve symptoms from their hands. The subjects were matched in pairs based on age, due to the well-known age effect on specific sensory modalities such as tactile discrimination (Dellon, 1981), and randomized to receive a mixture of local anaesthesia containing 2.5% lidocaine and 2.5% prilocaine in an oil and water emulsion (EMLA®, AstraZeneca, Södertälje, Sweden) (group 1) or placebo (on an oil and water emulsion) (group 2). The study design was single blinded, and all study subjects believed that they received the active substance.

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EMLA® or placebo was applied to the volar side of the right forearm in an area from the wrist and 15 cm proximally under occlusive bandage for one hour and the study subjects were instructed not to touch the area to which EMLA® or placebo had been applied, thus making it impossible for the study subjects to recognize the presence or absence of anaesthesia. Group 1 (four men and six women, mean age 35.5 years, range 25–49) received 20 g EMLA® and group 2 (two men and eight women, mean age 36.3 years, range 25–52) received 20 g placebo. The two agents were identical in colour, consistency and packaging. All study subjects were investigated in exactly the same way.

The local ethics committee approved the study design and written informed consent was obtained from all subjects.

Assessment of sensory and motor functions

All sensory measurements were performed on the right and left index finger. Assessments were performed in a quiet environment according to standardized forms (ASHT, 1992) and sensory assessments were performed with the tested hand behind a screen. The limits of tactile discrimination were measured in a two-alternative-force-choice simultaneous two-point discrimination (2 PD) task (Dinse *et al*., 2003). Twelve pairs of blunted needles (diameter 300 microns) were mounted on two discs allowing switching easily between distances. 0.7, 1.0, 1.3, 1.6, 1.9, 2.2, 2.5, 2.8, 3.1, 3.4, 3.7, 4.0 mm separations were used. Zero distance was tested with a single needle (Dinse *et al*., 2003). Semmes–Weinstein monofilaments (SWM) (ASHT, 1992) were used for assessment of perception of touch. Grip strength was measured with a Jamar dynamometer (ASHT, 1992). 2 PD testing was applied in a descending order of magnitude from 4 mm down to 0.7 mm to assess the level at which responses were correct according to recommendations of the American Society of Hand Therapists (ASTH) (seven out of ten correct at just blanching of the skin) (ASHT, 1992). SWM were applied in a descending order of magnitude to assess the level at which the sensation disappeared (ASHT, 1992). Mean grip strength out of three trials with a Jamar dynamometer was recorded (ASHT, 1992).

Baseline results (2 PD, SWM, and Jamar) were established on three separate occasions within one week prior to the experiment to eliminate biased results due to learning effects. The last measurement was performed immediately before the experiment.

Anaesthesia of the forearm occurred approximately one hour after the EMLA® was applied and at this point tactile discrimination (2 PD), touch perception (SWM) and grip strength was evaluated again. Thereafter the EMLA® cream or placebo was carefully washed off. All subjects were also measured 24 h after anaesthesia.

Statistics

Statistical calculations were performed using Wilcoxon signed rank correlation. After calculating the differences between median or mean baseline results and assessment results during and 24 h after anaesthesia, a group comparison was performed using the Mann–Whitney *U*-test.

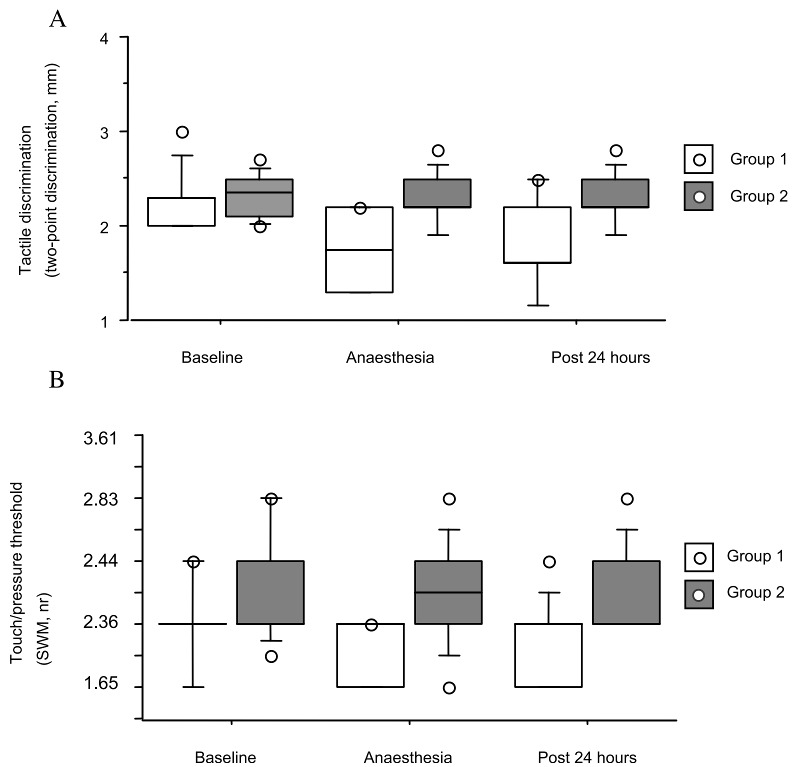

FIG. 1. Box plots illustrating the results before (baseline), during and 24 h after EMLA® induced skin anaesthesia of the volar aspect of the right forearm. Each box encloses 50% of the data with the median value displayed as a line. The top and bottom of the box mark the upper and lower quartile. The lines extending from the top and bottom of each box mark the 90th and the 10th percentile. Any value outside this range (outlier) is displayed as an individual point. (A) Tactile discrimination in the right index finger, measured with two-point discrimination, improved significantly in group 1 ($P = 0.009$) and compared to group 2 ($P = 0.006$) during anaesthesia. The improvement remained 24 h after anaesthesia. (B) Perception of touch in the right index finger, measured with Semmes–Weinstein monofilament (SWM), improved in group 1 ($P = 0.046$) during anaesthesia and remained for at least 24 h after anaesthesia.

Results

In group 1 right forearm anaesthesia resulted in significantly improved tactile discrimination in the right, ipsilateral hand, measured as 2 PD, compared to mean baseline values in group 1 ($P = 0.009$) and group 2 ($P = 0.006$). The improvement remained for at least 24 h (Fig. 1A). No change in tactile discrimination was noted in the left, contralateral hand during the experiment.

In group 1 perception of touch, measured with SWM was improved in the right hand during anaesthesia compared to median baseline values in group 1 ($P = 0.046$) and the improvement remained for at least 24 h (Fig. 1B).

However, no significant group difference was noted in perception of touch between group 1 and 2. No change in perception of touch was noted in the left, contralateral hand, in either group during the experiment.

No change in grip strength was seen in group 1.

In group 2 no significant changes in tactile discrimination, perception of touch or grip strength were noted in the right or left hand during the experiment.

Discussion

Local skin anaesthesia of the forearm resulted in a rapid significant improvement in tactile discrimination in the ipsilateral hand. The improvement remained for at least 24 h. An improvement was seen also in perception of touch and the improvement remained for at least 24 h after the anaesthesia. In contrast to previous experiments with tourniquet-induced forearm anaesthesia (Björkman *et al*., 2004), the type of anaesthesia used in the present experiments, involving sensory cutaneous components only, did not induce any changes in motor function of the hand. Moreover, the observed changes in hand sensibility involved only the ipsilateral hand with no changes in the left, contralateral hand.

Studies in animals (Calford & Tweedale, 1990; Calford & Tweedale, 1991) and humans (Rossini *et al*., 1994) have shown that following injury to the peripheral nervous system, such as nerve injury or amputation, the somatosensory cortex responding to the deafferentated body part becomes responsive to neighbouring body parts (Calford & Tweedale, 1990; Calford & Tweedale, 1991; Rossini *et al*., 1994; Chen *et al*., 2002). Local anaesthetic blocks in humans cause rapid reorganization of cortical maps. This has been shown in studies where somatosensory evoked potentials to electrical stimulation of the median nerve were studied following nerve blockade of the adjacent ulnar nerve in normal humans. Within 10–30 min following blockage, somatosensory evoked potentials to inputs from the median nerve were increased in amplitude in the somatosensory cortex. (Rossini *et al*., 1994; Tinazzi *et al*., 1997).

Our results show that a transient selective deafferentation of an extremity can improve sensory function of nonanaesthetized areas of the same extremity. Transient deafferentation of the volar aspect of the right forearm resulted in improved sensory functions in the ipsilateral hand while the function of the left, contralateral hand was not influenced at all. This is in contrast to previous findings indicating that forearm anaesthesia induced by a tourniquet resulted in sensory improvement in the contralateral hand (Werhahn *et al*., 2002b; Björkman *et al*., 2004). The physiological mechanisms behind these differences are not clear. One explanation may be that the limited anaesthetized area (volar part of the forearm) is too small to induce cortical reorganizational changes in both hemispheres as seen when the whole forearm is anaesthetized by a tourniquet (Werhahn *et al*., 2002b; Björkman *et al*., 2004). Tourniquet induced anaesthesia induces not only tactile loss, but also proprioceptive sensation, as well as motor paresis in the anaesthetized hand, which in combination with the ischemic pain makes the method very difficult to use in the clinical situation. Our method using EMLA® is more attractive in a clinical situation. Cortical areas adjacent to those belonging to the anaesthetized side might also be even faster in occupying the deafferentated area than cortical areas belonging to the nonanaesthetized side.

Dynamics between the hemispheres may result in functional changes in the ipsilateral or contralateral arm depending on the prevailing conditions. Homotopic regions of primary somatosensory cortex are linked such that cortical changes induced in one hemisphere in the form of receptive field expansion brought about by a limited peripheral denervation, are immediately mirrored in the opposite hemisphere (Calford & Tweedale, 1990; Rossini *et al*., 1994; Werhahn *et al*., 2002a,b). Deafferentation of one hand resulting in improved tactile discrimination in the contralateral hand may be due to rapid redistribution of cortical resources to recruit cortical areas to serve sensory and motor functions in the contralateral hand. Such cortical redistribution likely represents a behavioural compensatory gain (Werhahn *et al*., 2002b).

Cortical competition that has been shown to play an important role especially in the visual cortex (Wiesel & Hubel, 1963; Stryker & Harris, 1986) may also play a role here. Short-term synaptic dynamics are driven by loss of sensory input or competition between deprived and spared inputs, and competition between sensory inputs may be necessary for large scale changes (Finnerty & Connors, 2000).

Our findings open interesting perspectives for the future with respect to postoperative rehabilitation following peripheral nerve injury and repair. Injuries of peripheral nerves lead to profound changes in the cerebral cortex (Lundborg, 2003). These changes are thought to be a major factor behind the disappointing results after nerve injury and repair (Lundborg, 2003). Various programs for sensory re-education and relearning have been suggested and are routinely used (Wynn Parry & Salter, 1976; Dellon, 1981), but none of these regimes includes a temporary enhancement of the cortical processing capacity during the training session to optimize the effectiveness of the training. During the re-innervation phase after nerve repair a temporarily induced sensory improvement, for example through the use of forearm anaesthesia, might enhance the effects of intense sensory training during this specific period and repeated sessions of this kind might help to enhance sensory recovery after nerve injury in a long-term perspective.

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Abbreviations

2 PD, two-point discrimination; SWM, Semmes–Weinstein monofilament.

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