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Acute immobilisation facilitates premotor preparatory activity for the non-restrained hand when facing grasp affordances

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ABSTRACT

Use and non-use of body parts during goal-directed action are major forces driving reorganisation of neural processing. We investigated changes in functional brain activity resulting from acute short-term immobilisation of the dominant right hand. Informed by the concept of object affordances, we predicted that the presence or absence of a limb restraint would influence the perception of graspable objects in a laterally specific way.

Twenty-three participants underwent fMRI scanning during a passive object-viewing task before the intervention as well as with and without wearing an orthosis. The right dorsal premotor cortex and the left cerebellum were more strongly activated when the handle of an object was oriented towards the left hand while the right hand was immobilised compared with a situation where the hand was not immobilised. The cluster in the premotor cortex showing an interaction between condition (with restraint, without restraint) and stimulus action side (right vs. left) overlapped with the general task vs. baseline contrast prior to the intervention, confirming its functional significance for the task.

These results show that acute immobilisation of the dominant right hand leads to rapid changes of the perceived affordance of objects. We conclude that changes in action requirements lead to almost instantaneous changes in functional activation patterns, which in turn may trigger structural cortical plasticity.

Introduction

Plasticity and reorganisation are intrinsic properties of the human brain across the entire lifespan. In the sensorimotor domain, this adaptability has been investigated using two main routes: the observation of changes related to increases of sensory input or motor output (Pascual-Leone et al., 2005) as well as the deprivation of similar input and output (Bassolino et al., 2012; Taub et al., 2006). Regarding the latter approach, a standard manipulation is the immobilisation of limbs for a limited period of time, either experimentally induced or as a consequence of fractures, which allows investigating the central effects of non-use. Studies focussing on long-term immobilisation over periods of several weeks observed structural decreases in contralateral primary motor areas (Granert et al., 2011; Langer et al., 2012) and increases in cortical thickness and white matter properties on the ipsilateral side (Langer et al., 2012). Functionally, decreases in corticomotor excitability (Granert et al., 2011) and increases in intracortical inhibition (Clark et al., 2010) were detected by means of transcranial magnetic stimulation (TMS) over the contralateral motor area after long-term immobilisation. Likewise, reductions of blood flow in motor areas of the non-used side have been demonstrated using positron emission tomography (Coert et al., 2009).

Even short-term immobilisation in the range of days or only several hours can affect the central representation of movement. Behaviourally, changes in reaching to grasp (Bassolino et al., 2012), anticipatory postural adjustments of the elbow and the shoulder (Bolzoni et al., 2012), and in interjoint coordination were observed. The resulting changes were smaller in amplitude but similar in quality to those reported in deafferented patients (Moisello et al., 2008). Four days of immobilisation have been shown to decrease corticospinal excitability in the contralateral motor cortex (Avanzino et al., 2011; Facchini et al., 2002; Ngomo et al., 2012) as well as inhibitory influence onto the ipsilateral motor cortex (Avanzino et al., 2011) when probed by TMS. By means of functional magnetic resonance imaging (fMRI), short-term immobilisation effects were shown in the somatosensory cortex in association with discrimination thresholds (Lissek et al., 2009). Another group has shown an increased cortical activation during tactile stimulation of the non-immobilised hand, particularly in the ipsilateral somatosensory cortex, after only 72 h of immobilisation (Weibull et al., 2011).

The effects of long- and short-term immobilisation reported so far are based on non-use periods of at least several hours to months. In contrast, the present study aimed at investigating more rapid effects of immobilisation. Participants' dominant right hand was immobilised by means of an orthosis immediately preceding data acquisition.

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Hence, the focus of this study is on the influence of *knowing* that one cannot move the right hand, rather than extensive experience with the inability to move the hand. While the effects of immobilisation observed in previous studies were strongly tied to action execution or somatosensory stimulation, we aimed at investigating the acute effects of immobilisation in a more abstract cognitive task domain. During the task, objects with handles that were either oriented to the right or left side were shown, and participants were instructed to passively observe them. Based on the concept of affordances, it has been argued that humans perceive objects in terms of the ways in which they can be used in action (Gibson, 1977; Prinz, 1997). Multiple studies have shown evidence for the automatic extraction of affordances when seeing objects and the spontaneous activation of associated action representations (Castiello, 1999; Craighero et al., 1996; Gentilucci, 2002; Grèzes et al., 2003). Based on this notion, we hypothesized that acute immobilisation of the dominant right hand would facilitate preparatory motor activity for the left hand when the handle is oriented to the left side compared to an unrestrained condition.

Methods

Participants

Twenty-three healthy young adults (age: mean = 25.43 years, ranging from 20 to 35, 11 females) participated after having given a written informed consent. The study was conducted according to the Declaration of Helsinki, with approval of the German Psychological Society ethics committee. All participants had normal or corrected-to-normal vision, and no history of neurological, major medical, or psychiatric disorder (as assessed by means of the MINI, Lecrubier et al., 1997) nor did they use psychotropic drugs during the last year. Moreover they did not wear a hand cast or an orthosis during the last five years. All participants were right-handed as assessed by the Edinburgh handedness questionnaire (mean score = 88.9; SD = 6.9, Oldfield, 1971).

Materials

To immobilise the right hand of the participants we used a commercially available orthosis (Model 28P44, Ottobock, Duderstadt, Germany). The hand was fixed in a way that prevented extension and flexion of the fingers, the thumb and the wrist. A piece of cloth was placed between the skin and the orthosis. To minimize differences in tactile stimulation between conditions, the same piece of cloth was also placed under the hand when the unrestrained measurement without the orthosis was performed.

For the object task, we selected 20 pictures of objects such as a cup, a hair dryer, a teapot, or scissors. Each object was presented in the original and a mirror-reversed version, suggesting either a right-hand or left-hand grasp (handle facing right or left side). This resulted in a total of 40 visual stimuli.

Object task

During the experiment, participants were shown the object pictures. They were instructed to watch the pictures carefully. Each trial started with a presentation of one of the pictures for 3 s. After a jitter interval between 5 and 7 s (varied in steps of 500 ms) the next object was presented (Fig. 1A). The experiment consisted of 3 runs, each containing 40 trials, with an overall duration of approximately 6 min per run.

Before the use of the orthosis was introduced to the participants, the object task was performed in the scanner once to localize the regions involved in task performance (this phase is called localizer phase from now on). Subsequently, participants completed the object task once with and once without the orthosis. The order of these latter two conditions was counterbalanced across participants (Fig. 1B). That is, twelve of the participants performed the tasks in the order: localizer, with orthosis, without orthosis; and eleven in the order: localizer, without orthosis, with orthosis.

Scanning procedure

Images were collected on a 3 T Magnetom Trio MRI scanner system (Siemens Medical Systems, Erlangen, Germany) using a 32-channel radiofrequency head coil. The structural images were obtained using a three-dimensional T1-weighted magnetisation prepared gradient-echo sequence (MPRAGE) based on the ADNI protocol (www.adni-info.org) (repetition time (TR) = 2500 ms; echo time (TE) = 4.77 ms; TI = 1100 ms, acquisition matrix = 256 × 256 × 176, flip angle = 7°; 1 × 1 × 1 mm voxel size). Functional images were collected using a T2*-weighted echo planar imaging (EPI) sequence sensitive to blood oxygen level dependent (BOLD) contrast (TR = 2000 ms, TE = 30 ms, image matrix = 64 × 64, FOV = 216 mm, flip angle = 80°, voxel size 3 × 3 × 3 mm^3, 36 axial slices).

fMRI data pre-processing and main analysis

The fMRI data were analysed using SPM8 software (Wellcome Department of Cognitive Neurology, London, UK). The first four volumes of all EPI series were excluded from the analysis to allow the magnetisation to approach a dynamic equilibrium. Data processing started with slice time correction and realignment of the EPI datasets. A mean image for all EPI volumes was created, to which individual volumes were spatially realigned by means of rigid body transformations. The structural image was co-registered with the mean image of the EPI series. Then the structural image was normalised to the Montreal Neurological Institute (MNI) template, and the normalisation parameters were applied to the EPI images to ensure an anatomically informed normalisation. A commonly applied filter of 8 mm FWHM (full-width at half maximum) was used. Low-frequency drifts in the time domain were removed by modelling the time series for each voxel by a set of discrete cosine functions to which a cut-off of 128 s was applied. The statistical analyses were performed using the general linear model (GLM). We modelled the visually presented objects separately depending on the orientation of the handle (right vs. left). These vectors were convolved with a canonical hemodynamic response function (HRF) and its temporal derivatives to form regressors in a design matrix. The parameters of the ensuing general linear model were estimated in the usual way and used to form contrasts, testing for main effects and interactions. The resulting contrast images were then entered into a series of one sample *t*-tests at the second (between-subject) level. This is the usual summary statistic approach to random effect analyses. For display purposes the resulting SPMs were thresholded at $p < 0.001$ (uncorrected). A significant effect was reported when the volume of the cluster was greater than the Monte Carlo simulation determined minimum cluster size above which the probability of type I error was <0.05 (AlphaSim, Ward, 2000). We were primarily interested in the whole brain interaction effects of condition (with restraint, without restraint) × stimulus action side (right vs. left). The resulting maps were overlaid onto a normalised T1 weighted MNI template (colin27) and the coordinates reported correspond to the MNI coordinate system.

Analysis strategy

We used the images from the first data acquisition during the localizer task in order to determine the task-related brain regions as ROIs. For both tasks, we computed task against baseline contrasts and built ROIs of the resulting significant clusters. Within each significant functionally defined cluster (all significant voxels included) we extracted mean percent signal change over a time window of 4–6 s after a stimulus onset for each subject, region and condition (http://marsbar.sourceforge.net/, Brett et al., 2002). On the resulting percent signal changes we computed a repeated-measures ANOVA in search for