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A case of illusory own-body perceptions after transcranial magnetic stimulation of the cerebellum

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Abstract
Illusory own-body perceptions are 'body in space' misinterpretations of the brain and belong to the class of out-of-body experiences wherein the angular gyrus seems importantly implicated. In the present study additional cerebellum involvement in illusory own-body perceptions was investigated in a healthy young female right-handed volunteer. Transcranial magnetic stimulation (TMS) was applied over the cerebellum. Placebo cerebellum TMS and occipital TMS served as control conditions. Illusory own-body perceptions accompanied by electric brain activity over the somatosensory cortex were only observed after cerebellum TMS. The data provide the first evidence that the cerebellum might be involved in a neuronal network underlying illusory own-body perceptions.

Key words: *Cerebellum, illusory own-body perceptions, transcranial magnetic stimulation*

Introduction

Out-of-body experiences (OBEs) have been considered as supernatural phenomena wherein the mind detaches itself from the body. Illusory own-body perceptions are 'body in space' misinterpretations of the brain belonging to the class of OBEs wherein the angular gyrus seems to be implicated (1–3). Here, we report illusory own-body perceptions and increased EEG activity in the vicinity of the angular gyrus in a healthy young woman after transcranial magnetic stimulation (TMS) over the cerebellum. Illusory own-body perceptions are often peculiar and short-lasting sensations that include reports on body levitation, feeling of lightness and experiences of falling. In recent years evidence has been accumulating that the occurrence of illusory own-body perceptions has a neurophysiological rather than supernatural origin (1,2). Interestingly, illusory own-body perceptions were observed in an epileptic patient after electric stimulation of the angular gyrus (2). The angular gyrus is located near the vestibular cortex, a brain structure concerned with the representation of body orientation. Illusory own-body perceptions are argued to result from a temporal dissociation in the processing of somatosensory and vestibular information. This assumption has found support from recent functional neuroanatomical studies. Interestingly, a brain structure located in the posterior parts of the head, contains somatotopical organized nuclei of the body and is directly involved in the processing of vestibular information is the cerebellum (4,5). Correlational evidence for a cerebellum-illusory perception relationship was recently provided by a functional neuroimaging study that showed cerebellar activity during the illusion of touching one's own hand (6). A technique that may be able to address this issue more directly is repetitive TMS (rTMS), a method that can transiently interfere and disrupt neuronal processing through Faraday's principle of electromagnetic induction. Thus, if illusory own-body perceptions depend on distortions in brain regions related to the processing of somatosensory input, vestibular and temporal information, then the cerebellum might be involved.

Method

Participant

A healthy young right-handed female volunteer, 21 years of age, participated. The subject had no history of neurological or psychiatric conditions, was non-smoking, used oral contraceptives, and had more than 12 years of education. Standard safety-screening procedure did not yield contra-indications for TMS (7). She was instructed to refrain from using

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psychotropic substances, including alcohol, chocolate, tea and coffee, two hours before each session. Informed consent was obtained and the participant was blind to the aim of the study. The study was approved by the medical ethical committee of the Utrecht University and in accordance with the declaration of Helsinki.

Transcranial magnetic stimulation (TMS)

Repetitive TMS (rTMS) was performed using a biphasic magnetic brain stimulator (maximum output 2300 A peak/1750 VAC peak) and iron core coil with a current magnetic induction field of approximately 2 Tesla (Neotonus Inc., Atlanta). Placebo rTMS was performed using an identical coil, but with a metal plate built in directly under the iron-core (Neotonus Inc., Atlanta). Although the coil mimics the sound and sensation of real rTMS, the brain is shielded from actual stimulation, Mean individual motor threshold (MT) of the left hemisphere was 49% and stimulation intensity was set at 45% maximum machine output corresponding to 90%MT.

Structural MRI scan and stimulation targets

T_1-weighted three-dimensional fast field echo (3D-FFE) scans with 160 contiguous coronal slices (TE=4.6 msec, TR=30 msec, flip angle=30°, $1 \times 1 \times 1.2$ mm^3 voxels) were acquired on a Philips NT 1.5T scanner. The stimulation target site of the cerebellum (Cb) was referenced to the inion (8–10) and determined one centimeter below the inion. Control sites included the occiput, located three centimeters above the inion (Oc), and placebo rTMS over the Cb region as illustrated in Figure 1.

Electroencephalogram (EEG)

EEG was recorded from 32 scalp locations according to the International 10–20 EEG System using Ag–AgCl-tipped electrodes (sampling rate: 256 Hz). Electro-oculogram (EOG) was recorded from a bipolar montage from the sub- and supra-orbital regions of the right eye and the outer canthi of the eyes. Raw EEG recordings were made with the ActiveTwo system (BioSemi, Amsterdam, The Netherlands) relative to the common mode sense (CMS). Raw EEG signals were referenced to the vertex (Cz) electrode, chunked into 4-s epochs and corrected for horizontal and vertical eye movements using the Gratton & Coles method (BrainVision, Munich). EEG epochs containing residual muscle movements and other artifacts resulting in amplitudes greater than +/− 50 μV were rejected prior to further analysis. The designation of an artifact in one of the leads resulted in removal of that epoch for all channels in order to ensure that the remaining data were identical for all sites in time. Chunks of averaged artifact-free EEG were filtered by applying a band-pass of 1–30 Hz (24 dB/octave) and a fast Fourier transform method (Hamming window length: 10%) was applied to obtain estimates of spectral power (μV^2) in the alpha (8–13 Hz) frequency band.

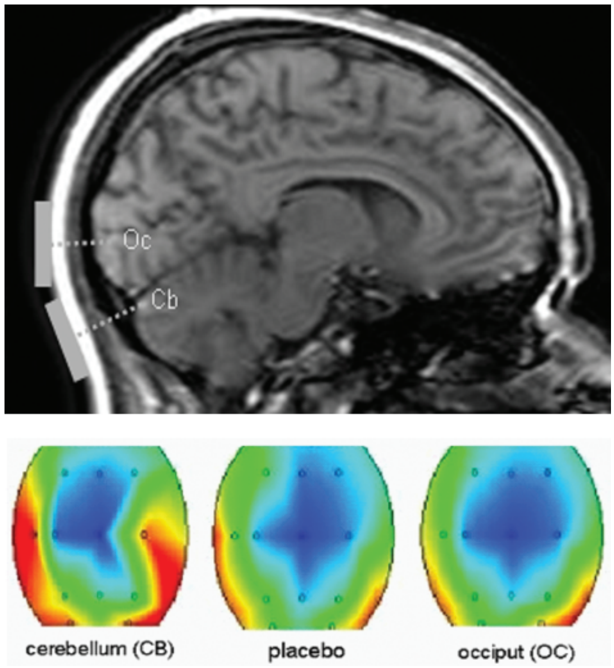

Figure 1. Upper panel: Midsagittal view depicting the target positions areas for slow inhibitory repetitive transcranial magnetic stimulation (TMS). TMS was performed using a biphasic magnetic brain stimulator (maximum output 2300 A peak/1750 VAC peak) and highly focal iron core figure of eight-coil with a current magnetic induction field of approximately 2 Tesla (Neotonus Inc., Atlanta). Placebo TMS was performed over the cerebellum target site using an identical coil, but with a metal plate built in directly under the iron-core (Neotonus Inc., Atlanta). Although the coil mimics the sound and sensation of real TMS, the brain is shielded from actual stimulation. Lower panel: Topographical maps (top view) showing increased parieto-temporal EEG activity in the alpha frequency range (α: 8–13 Hz) during illusory own body perceptions after 1-Hz rTMS over the cerebellum. Cb: cerebellum; Oc: occiput.

Procedure

In a randomly assigned counterbalanced order the subject received 20 min of cerebellum, occipital and placebo 1-Hz rTMS (1200 pulses p/session) on three consecutive days. After rTMS the participant was seated in a dentist chair in a darkened room for 4 min and was instructed to relax. During the 4 min resting state period, the EEG was registered continuously. Stimulation parameters are in accordance with the safety guidelines of the International Federation of Clinical Neurophysiology (www.ifcn.info). To prevent priming effects, the experimenter simply asked the participant after completion of the third session if she had felt or noticed anything during the 4 min relaxation period in either of the three sessions.

Results

Although blind to stimulation condition and aim of the study the participant reported that after cerebellum rTMS there were several occasions during the 4 min relaxation period in which she experienced her body falling/drifting side wards and even out of the chair, while the experimenter in the adjacent room verified that she was sitting motionless. Furthermore, the illusory body perceptions went accompanied by physiological activity in the vicinity of the angular gyrus as indexed by the electroencephalogram. The participant reported no such experiences were absent after occipital and placebo rTMS, and in concordance no significant physiological activity in the vicinity of the angular gyrus was observed (Figure 1).

Discussion

The current results indicate that together with the angular gyrus and vestibular cortex (1–3), the cerebellum is directly implicated in a neural network underlying illusory own-body perceptions. Under regular conditions this network processes information considering body orientation in three-dimensional space, but when the circuit malfunctions illusory own body perceptions can be triggered. Interestingly, clinical research has provided some support for the hypothesis that cerebellar dysfunction may be involved in psychotic symptoms, subjective states wherein the external and internal representations of one-self in the world become disintegrated (11,12).

Alternatively, the cerebellum and in particular the caudal vermis that is comprised of the uvula (IX) and nodulus (X) are known subdivisions to receive afferent otolith input. Several studies have recently provided insights into cerebellar processing of otolith information, showing involvement in inertial motion detection and spatial orientation (13,14). Disturbances of otolith information processing within the vestibulocerebellum may explain the present observations.

It should be mentioned that presently the method for coil positioning was not optimal. However apart from an anatomical scan to verify location of the target region, the occipital rTMS condition was included to dissociate cerebellar from cortical effects. The possibility that in addition to the cerebellum peripheral nerves were stimulated as well cannot be completely ruled out. Furthermore, clinical TMS trials have evidenced that the occurrence of phenomenological effects to TMS depend at least partially on the individual neurophysiological state (15), thus more objective behavioural assessments would be a valuable addition to capture more subtle disturbances in own-body perceptions across subjects (16).

To our knowledge, the current data provide the first electrophysiological and phenomenological evidence for cerebellar involvement in a neuronal network underlying illusory own-body perceptions, and legitimize further research to test the tenability of this observation.

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