Does focusing on hand-grasping intentions modulate electroencephalogram μ and α suppressions?

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Understanding the intentions of others presumably involves a human analog of the mirror neuron system. A putative marker of such mirror activity is the suppression of electroencephalographic oscillations in the 8–12 Hz range, which, when recorded over somatosensory areas, is associated with motor activity and labeled μ rhythms. We investigated whether μ-suppression can be modulated by attention to another person's intention as expressed by her hand movement toward an object and whether this suppression is distinguished from the suppression of α waves that oscillate in the same frequency range and are modulated by attention and cognitive load. Both μ and α suppressions were modulated by task difficulty, and not distinctively by intention, reflecting the recruitment of resources needed for task performance. *NeuroReport* 21:1050–1054 © 2010 Wolters Kluwer Health | Lippincott Williams & Wilkins.

Introduction

The discovery of the mirror neuron system (MNS), which is active in the monkey during the observation and the execution of an action [1–3], established the biological plausibility of a link between perception and action, which has been frequently predicated by cognitive psychologists [4]. To this end, researchers proposed that an analog MNS also exists in humans (hMNS), in whom it may have evolved into a more complex network, expanding its role to form the basis for imitation [5], language development [6], and even higher-level social skills such as understanding others' emotions and providing the basis for empathy [7].

The contribution of a mirror-like system to efficient social interaction has received additional support from functional magnetic resonance imaging (fMRI) studies, showing that brain activity in regions corresponding to the putative hMNS are involved in understanding the intentions of observed actions [8,9]. For instance, viewing hand-grasping actions embedded in contexts that implied the intention of the action, yielded higher blood–oxygen-level-dependent signal than viewing the same hand actions without a context or viewing the context without the hand movement [8]. Furthermore, the synergy between the type of grasp observed and the type of context in which the action occurred was indicated by greater activity when the type of grasp suggested the same intention as the context than when the action and the context were incongruent [9]. These studies played an important role in linking the hMNS to the understanding of intentions, suggesting that the motor system infers a forthcoming new goal in an automatic way, through simulation of the other's motor acts. One aim of this study was to corroborate this link and extend the fMRI findings.

Putative evidence for an hMNS has also been found using electrophysiological measures such as the modulation of motor-evoked potentials elicited by transcranial magnetic stimulation [10], intracranial single-unit recordings [11], magnetoencephalography [12], and electroencephalography (EEG). The last line of research focused particularly on the modulation of EEG oscillations within the range of 8–12 Hz. Given their presumed sources in the somatomotor cortex, these oscillations had been labeled as Rolandic or 'μ' rhythms [13].

The suppression of μ rhythms is considered to reflect event-related desynchronization of the EEG induced by an enhancement of neural activity in somato-motor and prefrontal cortex leading to asynchronous neural firing [13]. This manifestation is analogous to the desynchronization of EEG-α oscillations by visual input, increased attention and/or mental load [14]. It should be noted, however, that although in the same frequency range, the modulation of μ rhythms differs from that of the α rhythms in several ways. First, in contrast to α rhythms, μ rhythms are not modulated primarily by visual stimulation or attention, but rather are desynchronized and their power attenuated during motor activity [15] and, crucially, also during the observation of actions executed by other humans, but not by nonbiological motion [16–19]. Second, the modulation of μ is usually seen in more anterior areas (largely recorded over the sensorymotor cortex) compared with the more posterior (parieto-occipital) distribution, in which α suppression is characteristically measured [13].

We recently found that μ and α rhythms are suppressed while participants inferred the intention of a dot-light-displayed human figure by its motion (indicated by whether the figure walked toward the observer or away from her), and that this suppression was greater than the suppression occurring when participants were asked to infer the sex or the emotion of the same figure [20]. However, although both fMRI and EEG studies used the term 'intention', the former implied an intention toward an object, whereas the latter implied a more socially relevant interaction. Therefore, additional investigation is required to explore whether these phenomena are, indeed, neurological representations of the same mechanism.

In this study, we investigated whether μ and α suppressions can be manipulated by focusing attention on the intention of another human as suggested by the action of her hand toward an object. Shifting participants' attention from the object, to the fingers touching the object, or to the intention of the moving hand, we asked whether EEG suppression in the 8–12 Hz range is modulated by attempting to understand the intention of the action toward an object more than by other tasks. Further, a second goal of this study was to distinguish between the modulation of μ and α rhythms by these cognitive activities.

Methods
Participants
A total of 24 participants (12 male) took part in the study. All were right-handed undergraduates from the Hebrew University ranging in age from 19 to 27 years (mean = 22.87 years, standard deviation = 2.5). They participated in the experiment for course credit or payment and signed an informed consent. All participants reported normal or corrected-to-normal visual acuity and had no history of psychiatric or neurological disorders.

Stimuli, task, and design
The stimuli used were 2-s long video clips presenting a right hand of a male or a female reaching toward an object and grasping it. In some clips the action conformed to the normal use of the object whereas in others the hand reached the same object but the action ended with the hand resting on it with the palm up. As different objects were used, the grasping involved between two and five fingers in different trials. As a μ activity baseline, videos of the same objects were presented with a tennis ball rolling toward them either from the left or from the right. The video clips were presented on a cathode ray tube monitor, 70 cm away from the participant's eyes with the hand and arm displays subtending on average a visual angle of $3 \times 8°$.

The same video clips were presented in three experimental blocks. In the first block ('Object') the participants focused on the object rather than the action, and were asked to silently count in how many clips a predesignated box appeared and to report this number at the end of the block. In the second block ('Fingers') the task was to silently count the clips in which less than five fingers touched the object and report this number. Hence, although in this block the participants were oriented toward the action, the intention of the action was task irrelevant. Finally, in the third block ('Intention') the participants focused on the intention expressed in the action. This was achieved by instructing the participants to silently count the clips in which the action toward the object did not depict the typically expected intention of the target (e.g. the palm facing upwards instead of picking up the phone). These three blocks were always administered in this sequence, to minimize carry-over of an intention-processing strategy from the Intention to the other blocks. In the baseline block, the participants were asked to count clips in which the tennis ball rolled from left to right. This block was either first or last, alternating across participants. Each block consisted of 80 different clips keeping one of the levels of the relevant dimension constant (e.g. five fingers touching the object) and 8–12 clips presenting the other level (e.g. less than five fingers touching the object).

After the EEG experiment, the relative difficulty of the three experimental tasks was tested in a behavioral experiment. This test consisted of three blocks corresponding to the three relevant dimensions (Fingers, Object, and Intention). In each block there were 100 clips, 50 of which presented one level of the task (e.g. five fingers touching the object) and the remaining 50 presented the other level (e.g. less than five fingers touching the object). The participants were instructed to press as fast and as accurately as possible alternative buttons according to the level presented in each trial. The video clips were presented on the same cathode ray tube monitor, from the same distance as in the EEG experiment.

Data acquisition and analysis
Electroencephalographic recording
The EEG analog signals were recorded continuously (from direct current with a low-pass filter set at 100 Hz) by 64 Ag–AgCl pin-type active electrodes mounted on an elastic cap according to the extended 10–20 system, and from two additional electrodes placed at the mastoids. All electrodes were referenced during recording to a common-mode signal electrode between POz and PO3 and were subsequently re-referenced digitally. Eye movements, and blinks, were monitored using bipolar horizontal and vertical electrooculographic derivations through two pairs of electrodes, one pair attached to the external canthi, and the other to the infraorbital and supraorbital regions of the right eye. Both EEG and electrooculogram were digitally amplified and sampled at 256 Hz using a Biosemi Active II system (*www.biosemi.com*).

Data processing

Data were analyzed using Brain Vision Analyzer software (Brain Products, Gilching, Germany) and Matlab routines (MathWorks, Massachusetts, USA). Raw EEG was initially 0.5 Hz high-pass-filtered (24 dB) and re-referenced to the digital average of the two mastoids. Eye movements were corrected using an independent component analysis procedure [21]. Remaining artifacts exceeding ± 100 μV in amplitude were rejected. For each such segment, the integrated power in the 8–12 Hz range was computed using a fast Fourier transform performed at 0.5 Hz intervals (using a Hanning window).

A suppression index was calculated as the ratio of the power during each experimental condition relative to the power during the baseline condition, and used as a dependent variable. Further, as ratio data are inherently not normally distributed as a result of lower bounding, a log transform was also used before analyzing these data by analysis of variance (ANOVA). Hence, a log ratio of less than zero indicates suppression in the EEG amplitude, whereas a value of zero indicates no change and values greater than zero indicate enhancement. Suppression was computed and analyzed at four sites: occipital sites O1 and O2, in which classical α modulation is expected; and central sites C3 and C4, which are classical μ-rhythm sites.

## Results

Electroencephalogram: 8–12 Hz suppression

Although identical video clips were presented in all three conditions, EEG suppression in the 8–12 Hz range was observed only if attention was directed to the hand movement rather than to the stationary object (Fig. 1a). At both central and occipital sites the suppression seemed to be higher in the Fingers task than in the Intention task. Bonferroni-corrected t-tests showed that the suppression index in the object condition was not significantly different from zero, whereas the suppression in both the Fingers and Intention conditions was significant at all sites.

The suppression index was first analyzed by ANOVA with repeated measures. The factors were Condition (Object, Fingers, Intention), Hemisphere (Left, Right), and Region (Central, Occipital). The Mauchly test of sphericity was not significant for any source of variance.

There were no main effects for Region and Hemisphere [for both, $F_{(1,23)} < 1.0$]. There was a significant main effect for Condition [$F_{(2,46)} = 15.9$, MSE = 0.1, $P < 0.001$], which was qualified by a condition × region interaction [$F_{(2,46)} = 4.7$, MSE = 0.02, $P < 0.015$]. No other interactions were significant, except a trend for a second-order condition × region × hemisphere interaction [$F_{(2,46)} = 2.6$, MSE = 0.002, $P = 0.085$].

The condition × region interaction was investigated by separate condition × hemisphere ANOVAs for each region.

Fig. 1
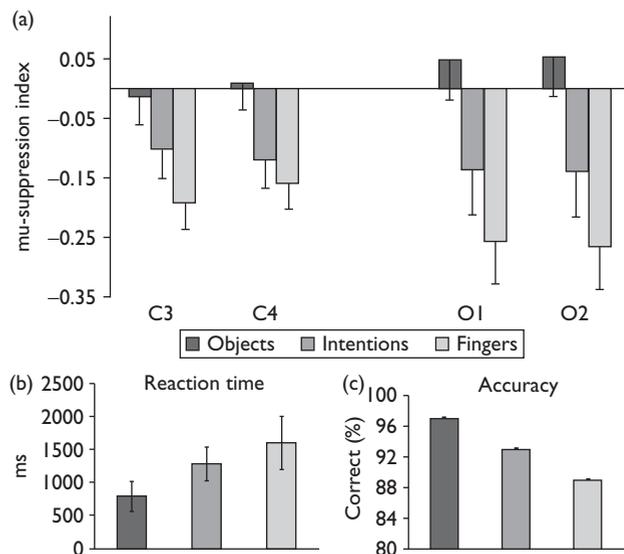
(a) Suppression measured for the different conditions at central electrodes (C3, C4) and occipital electrodes (O1, O2) in the 8–12 Hz range. The y axis indicates the suppression index (log ratio of the power in the experimental conditions over baseline; a value of zero means no suppression, see text). (b) Reaction time in the behavioral task for the three experimental conditions. (c) Accuracy in the behavioral task for the three experimental conditions.

The condition effect was significant both at the central and at the occipital sites [$F_{(2,46)} = 13.1$, MSE = 0.03, $P < 0.001$ and $F_{(2,46)} = 13.7$, MSE = 0.1, $P < 0.001$, respectively]. These effects were explained primarily by the large difference between the Object and the other two conditions. However, a closer look showed a slightly more complex pattern. At the central sites a significant condition × hemisphere interaction [$F_{(2,46)} = 3.6$, MSE = 0.002, $P < 0.5$] followed by t-tests showed that at C3 (left hemisphere) the suppression index was significantly larger during the fingers task (-0.19) than during the intention task [-0.10; $t_{(23)} = 2.396$, $P < 0.025$]. At C4 (right hemisphere), this difference was not significant [-0.16 and -0.12 for the fingers and intention tasks, respectively; $t_{(23)} = 1.123$, $P = 0.273$]. At the occipital sites there was no condition × hemisphere interaction [$F_{(2,46)} < 1.0$]. Post-hoc contrasts showed that at both hemisphere sites the suppression was larger during the fingers task than during the intention task.

Performance

The reaction time and accuracy differences (Fig. 1b and c) among the three conditions were analyzed using repeated measures ANOVAs. There was a significant difference between the reaction times [mean (SEM): Object = 788 ms (46), Intention = 1268 ms (52), Fingers = 1584 ms (82), $P < 0.0001$]. Pairwise comparisons showed that the differences among all the three conditions were significant (all $P < 0.0001$). There was also a significant effect of

accuracy [mean correct (SEM): Object = 97% (6), Intention = 93% (9), Fingers = 89% (9), F = 15.02, MSE = 0.003, $P < 0.0001$]. Pairwise comparisons showed that the differences were significant only between the Fingers and Object tasks ($P < 0.0001$) and between the Fingers and Intention tasks ($P < 0.05$) but not between the Intention and Object tasks ($P = 0.086$).

Discussion

We investigated the involvement of hMNS while participants tried to assess the intention of a target's movement toward an object. To achieve this goal we compared the suppression of EEG in the μ–α (8–12 Hz) range induced by identical scenes, while shifting the focus of the observer's attention between the intention of an action toward an object, the movement of the hand itself, and the object. Relative to a baseline condition consisting of nonbiological movement, μ–α suppression was observed only if attention was directed to the moving hand rather than to the stationary grasped object.

A fairly similar pattern was found in both occipital and central regions. Although slightly qualified by a condition × region interaction, in both regions suppression was greater when the participants focused on the exact type of grasping (the Fingers condition) than when they focused on the intention of the action (the Intention condition). As suggested by the second-order interaction this difference was slightly larger in the occipital than in the central region. It is noteworthy, however, that the suppression was similar across regions in the Intention condition but larger in the occipital regions than in the central regions in the Fingers condition.

The absence of suppression in the Object condition despite the hand movement included in the clips suggests a strong involvement of attention in mediating these phenomena. A possible account for this pattern is suggested by the behavioral results, which showed that the participants were most accurate and fastest at discriminating the objects, and more accurate and faster at distinguishing between purposeful intentions and meaningless grasps than at observing the number of fingers touching the object. The reaction time in this case is less interesting, as one can indeed differentiate the object immediately at the clip onset whereas the number of fingers touching the object is the last event in the clip time course. However, the accuracy results suggest that counting fingers was probably more difficult than determining the intended action and that discriminating between the objects was the easiest task. A possible interpretation of the similarly ordered performance accuracy and the amount of EEG suppression is that in this study the suppression of the 8–12 Hz oscillations manifested primarily the recruitment of attention resources needed for task performance rather than a simulation mechanism activated in an attempt to understand

the intention of an action. This interpretation is supported by the posterior distribution of the condition effect on EEG suppression, which suggests a higher contribution of α than of μ sources. This goes along with studies that linked decreases in α power to increasing demands of attention, alertness, episodic memory, and task load in general [14,22,23].

The above interpretation leads us to reconsider the results of our earlier study, which, using biological motion, suggested more suppression when the observer focused on the intention of figures than on their emotion or sex [20]. The term 'intention' was used for conditions in which participants discriminated between human figures moving toward or away from them. It may be the case that μ suppression is more affected by socially relevant stimuli involving self and other, and less so by an intention toward an object. An alternative explanation of the discrepancy between these results and our earlier ones is that μ suppression is similarly affected while focusing on the hand's actions, whereas deciphering the intention of an action is an automatic outcome of this mechanism. Finally, it could also be the case that the stimuli and the task chosen were not optimal, and that cognitive load and attention affected not only occipital electrodes but also more central ones. As this is a strong effect, it might mask more subtle effects over central regions which we cannot see.

These EEG results also differ from the described fMRI study in which elaborating the intention of an action increased the neural activity [8]. It could be that μ suppression measured by EEG does not reflect the same mechanisms as activation in the MNS regions measured by fMRI. However, it is also possible that design differences between this study and the fMRI study account for different outcomes. Although in this study the expected intention of the movement was predetermined and the participants had to determine whether the movement matched the intention or not, in the fMRI study the context determined a higher-reaching intention (drinking or cleaning). If, indeed, the use of different contexts determined the difference between the outcome of this study and the fMRI evidence, it is interesting that the hMNS is sensitive to intentions derived from the scene but not to the immediate intention of the movement.

Finally, another possible account for the absence of μ-suppression sensitivity to intention is that the main effect seen is that of α modulation, which masked smaller μ effects. Comparing tasks that are equally difficult, thus affecting α to the same extent, may shed light on more subtle effects if they exist.

Although technical, it is important to remember that both α and μ suppression are measured in the same frequency range and that the spatial resolution of EEG is low. Therefore, these two phenomena are hard to disentangle

except when μ suppression is elicited by the participant's actual movement (e.g. [24,25]). Future research should try to disentangle these two phenomena not only in conditions in which the participants perform motor acts, but also in the more subtle conditions in which the participants are asked to perceive, count, or judge biological motion, and are affected by attention and cognitive load. Furthermore, these data suggest that μ suppression reports should always include not only experimental effects at the central sites, but also in the occipital regions to help fully understand the phenomenon being studied.

Conclusion

EEG oscillations in the 8–12 Hz range were not modulated specifically by focusing attention on the intention (or goal) of an action toward an object; rather their modulation was a function of task difficulty. This outcome suggests that the suppression seen in this study probably reflected primarily the recruitment of attention resources needed for task performance rather than a simulation mechanism activated in an attempt to understand the intention of an action. To this end, this study highlights the need to report EEG modulations in a multitude of scalp regions in μ-suppression studies.

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