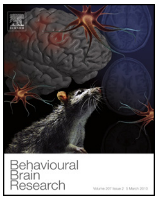
Behavioural Brain Research xxx (2013) xxx–xxx

Contents lists available at ScienceDirect

Behavioural Brain Research

journal homepage: www.elsevier.com/locate/bbr



Short Communication

# Does comprehension of symbolic gestures and corresponding-in-meaning words make use of motor simulation?

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## HIGHLIGHTS

- We searched for the processes used to understand the meaning of emblems and words.
- TMS was applied to motor cortex during observation/listening of gestures and words.
- As controls meaningless gestures, pseudo-words and a still actor were presented.
- Motor cortex was activated by presentation of meaningless signals only.
- Understanding emblems and corresponding words probably use semantic circuits.

## ARTICLE INFO

*Article history:*
Received 10 October 2013
Received in revised form
13 November 2013
Accepted 15 November 2013
Available online xxx

*Keywords:*
Meaningful intransitive gesture
Meaningless gesture
Communicative word
Pseudo-word
Transcranial magnetic stimulation (TMS)
Motor evoked potentials (MEPs)
Primary motor cortex (M1)
Embodied theory of language
comprehension

## ABSTRACT

The present study aimed at determining whether or not the comprehension of symbolic gestures, and corresponding-in-meaning words, makes use of cortical circuits involved in movement execution control. Participants were presented with videos of an actress producing meaningful or meaningless gestures, pronouncing corresponding-in-meaning words or pseudo-words; they were required to judge whether the signal was meaningful or meaningless. Single pulse TMS was applied to forearm primary motor cortex area 150–200 ms after the point when the stimulus meaning could be understood. MEPs were significantly greater when processing meaningless signals as compared to a baseline condition presenting a still-and-silent actress. In contrast, this was not the case for meaningful signals whose motor activation did not differ from that for the baseline stimulus. MEPs were significantly greater for meaningless than meaningful signals and no significant difference was found between gesture and speech. On the basis of these results, we hypothesized that the observation-of/listening-to meaningless signals recruits motor areas. In contrast, this did not occur when the signals were meaningful. Overall, the data suggest that the processes related to comprehension of symbolic gestures and communicative words do not involve primary motor area and probably use brain areas involved in semantics.

Single-pulse TMS studies have demonstrated that the observation of hand/arm object-directed (i.e. transitive) actions induces an increase in MEPs recorded from hand muscles involved in the observed action [1,2]. Accordingly, brain imaging studies have shown that during the observation of transitive hand/arm actions, there is signal activation in the ventral premotor cortex and in the adjacent posterior pars opercularis of the inferior frontal gyrus (IFG) [3]. Ventral premotor cortex and posterior pars opercularis of IFG are also activated by execution of object-directed hand/arm actions [4]. Thus, this circuit may be involved in understanding the meaning (aim) of the action by matching observation with action execution by means of motor simulation (mirror circuit) [3].

The present experiment firstly aimed to determine whether simulation is used even for understanding intransitive gestures. Intransitive gestures are communicative signals and can be emblematic, that is symbols or signs expressed by intentional bodily movements or request gestures which convey request to initiate, maintain, or terminate various types of interaction. Villarreal and colleagues [5] assessed cortical activity during recognition of communicative gestures containing symbolic connotations (e.g.,

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0166-4328/$ – see front matter © 2013 Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.bbr.2013.11.025

victory, salute), transitive gestures (i.e., pantomimes of actions involving tool use) and meaningless control movements. A stronger activation for symbolic compared to transitive gestures was found in the pars opercularis and pars orbitalis of the left IFG (Inferior Frontal Gyrus) and in Dorsolateral Prefrontal Cortex (DPC), bilaterally. The authors argued that the greater engagement of left IFG as compared to other areas such as premotor areas reflected the symbolic/linguistic nature of intransitive gestures.

Up to now, TMS studies have not investigated the role of motor cortex in understanding intransitive gestures, i.e. whether M1 is necessary to retrieve the gesture meaning or, conversely, whether gesture observation without motor simulation is sufficient to access semantics.

The embodied theory of language assumes that language comprehension makes use of the neural system ordinarily recruited for action control [6]. Focusing on spoken language material related to concrete actions, recent neurophysiological studies have shown that premotor regions are involved in language processing [7]. Also, in keeping with the involvement of the motor system in processing action-related material, the results reported by Buccino et al. [8] in a single pulse TMS study, have shown that motor evoked potentials (MEPs) recorded from hand muscles are modulated during listening to hand-related action sentences. Regarding abstract words, the issue is much more debated [9]. Scorolli et al. [10] found M1 activation when TMS applied in an abstract verb condition was delayed (650 ms post-stimulus). In contrast, Innocenti et al. [11] found M1 activation 300 ms post stimulus in response to hand-action verbs and no activation 300 and 500 ms post-stimulus in response to abstract verbs. Consequently, it is possible to suppose that cognitive and neural organization of concrete and abstract concepts may be partially distinct.

There are two opposing views about the relationship between gesture and speech. The first posits that gesture and speech are two different communication systems [12]. The other view [13,14] posits that gesture and speech form a single system of communication, since they are linked to the same mental processes even if they differ in expression modalities. In line with the views of McNeill [13] and Kendon [14], we have hypothesized that manual gestures and speech share in-part the same control circuit [15,16]. This idea has been confirmed by behavioral [17] and r(repetitive) TMS data [18] in which the relations between emblems and the corresponding-in-meaning words were analyzed. Behavioral data [17] showed that when individuals performed symbolic gestures and simultaneously pronounced a corresponding-in-meaning word, the gesture kinematics and voice spectra of the word changed as compared to the sole gesture performance or word pronunciation. This effect was not observed after rTMS of Broca's area [18].

On the basis of the literature reported above, we reasoned that, if simulation processes are at the basis of understanding the meaning of visually presented transitive actions and acoustically presented action words, a motor representation of hand/arm movement may be activated in order to understand both the meaning of meaningful intransitive gestures and their corresponding-in-meaning words. Alternatively, if comprehension of these signals mainly relies on symbolic/linguistic processes, no motor simulation should be observed. Finally, if gestures and corresponding-in-meaning words are reciprocally related [15,16], the type of activation seen should not differ from each.

We addressed these issues in the present study. We applied single pulse TMS to forearm motor cortex when participants were presented with meaningful intransitive gestures, meaningless gestures, corresponding-in-meaning words, or pseudo-words. We expected either no activation or the same activation of arm M1 when presenting meaningful intransitive gestures and words. The same was expected even for meaningless gestures and pseudo-words. By comparison of these conditions with a baseline condition (still/silent actor) we verified the possible existence of a different M1 activation between meaningful and meaningless signals. Moreover, we conducted a control experiment to compare the times of recognition of meaningful stimuli with those of meaningless stimuli.

Ten right-handed [19] Italian native, naïve volunteers (7 females and 3 males, age 21–28 years.), participated in the TMS experiment. All participants signed consent forms and were screened to rule out any history of neurological, psychiatric, or medical problems, and to check for possible contraindications to TMS [20]. The Ethics Committee of the Medical Faculty at the University of Parma approved the study, which was carried out according to the declaration of Helsinki.

Excitability of the forearm area of left M1 was evoked using single pulse TMS of the extensor carpi radialis (ECR) muscle area, and measured by evaluating the area of the resultant MEPs. Participants sat relaxed in a comfortable chair, while EMG activity of their right ECR muscle was recorded. Surface electrodes (Ag–AgCl, disposable, 7 mm × 4 mm) were attached, one on the belly of the ECR muscle (active electrode), and one on the elbow (reference electrode).

Muscle activity was amplified (1000×) and filtered (highpass 0.1 Hz, AC couple, 50 Hz notch, CED 1902, CED Ltd.). The signal was digitized at a sampling rate of 5 kHz (CED1401 interface, CED Ltd.). Visualization and later processing was done using Spike2 software (CED Ltd.). TMS was delivered using one module of a Bistim system (Magstim Co. Ltd.) and using a 70 mm figure-of-eight standard coil (Magstim Co. Ltd.). The coil was held tangential to the head. Once the site for stimulation of the ECR muscle was found, the participants' threshold was measured as the level of stimulation required to evoke at least 50 μv MEP on 5 out of 10 stimulations. Stimulation during the task was set to be 120% of the threshold level.

The experiment took place in a soundproofed room where participants were seated on a comfortable armchair, with their elbow flexed at 90° and their hands prone in a relaxed position. Participants wore earphones (to listen to auditory stimuli, see below). By means of a PC monitor (19 inch) placed at a distance of 110 cm from the observer, five types of audio-visual video-clips (sampling rate: 25 frames per second, duration: 2 s) were presented to the participants (Fig. 1). In the videos, an actress executed a meaningful gesture ("ciao", "no", "okay" or "stop": meaningful gesture condition), pronounced the corresponding-in-meaning words (/ciao/,/no/,/okay/or/stop/: word condition), executed meaningless gestures consisting of moving her arm up and down, from right and left, from right to left transversally, and from left to right (meaningless gesture condition), or pronounced pseudo-words (/ciar/,/nu/,/okoa/or/stor/: pseudo-word condition). Finally, in a baseline condition the actress was still and silent.

Video-clips were aligned in order that the TMS single pulse was delivered 200 ms after the critical point after which a meaning (if present) was accessible for videos showing movements (e.g. the hand waving beginning for gesture "ciao"), and 150 ms [21] after the isolation point (i.e. the point after which it was possible to discriminate if the string of letters, was meaningful or meaningless) for videos presenting spoken words and pseudo-words. This difference in time of stimulation was due to briefer acoustical perception of strings of letters [22]. Once the critical point time was determined for each signal, all videos were temporally shifted order to align stimulation and all times to critical point.

The participants were required to carefully observe or to observe-and-listen-to the video-clips. Three blocks of 20 trials were presented. Every communicative or meaningless stimulus was quasi-randomly presented once per block, whereas baseline videos were quasi-randomly presented four times. In four random trials per block (twelve in total) a question on the meaning of the last presented video-clip appeared at the end of the trial and participants were required to verbally respond 'yes' or 'no', to indicate

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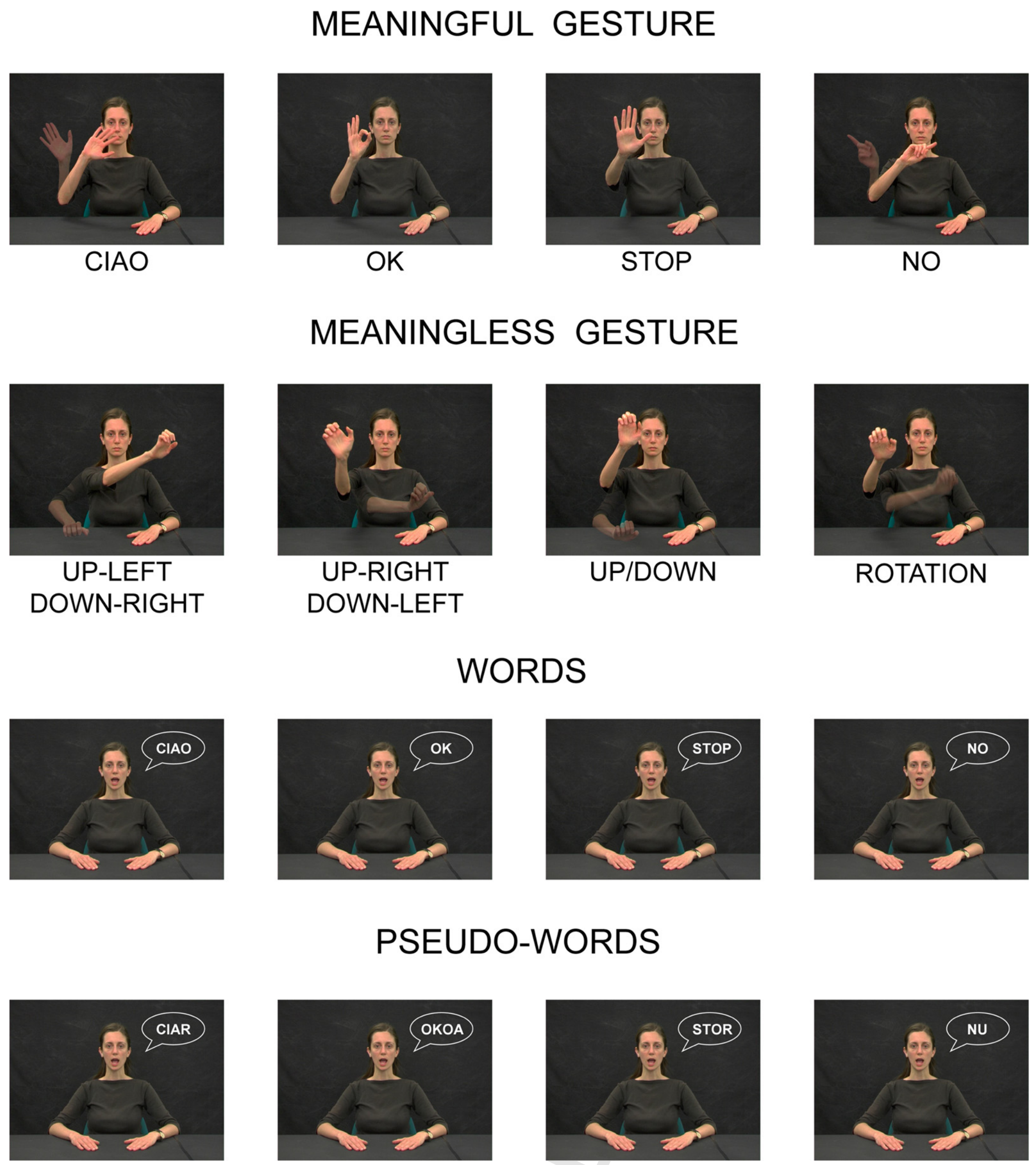

**Fig. 1.** Video-clips presented to the participants. Significant frames useful for understanding the meaning of the gestures are superimposed in each panel. In vignettes the words or pseudo-words pronounced by the actress are shown. In the baseline stimulus condition a video-clip presented the still and silent actress.

whether the presented stimulus was a meaningful or meaningless signal, respectively. All of the participants correctly responded to all questions.

For each individual, MEP data analysis started with identification of the time window within which the MEP occurred; then the area under the curve of the MEP was calculated. Median values of MEP areas were computed per condition for each individual. Then, means of the medians of all the subjects were calculated per condition.

Four paired *T*-tests were performed in order to test whether arm MEPs were differently modulated by the presentation of the signals (meaningful gesture, meaningless gesture, word and pseudo-words) with respect to the baseline stimulus (still/silent actress). In other words, the MEPs for the baseline stimulus were compared separately with MEPs in the other conditions. The significance level was fixed at $p = 0.05$.

The results showed that the forearm area activation during presentation of meaningless gestures and pseudo-words was greater from the activity recorded during presentation of baseline stimulus ($t(9) = -3.54$, $p = 0.006$; $t(9) = -2.24$, $p = 0.05$; baseline stimulus (mean and SD) = 0.0075 ± 0.0098 mV$^*$s; meaningless gesture = 0.0085 ± 0.0103 mV$^*$s; pseudo-word = 0.0080 ± 0.0095 mV$^*$s; Fig. 2). No differences were found between MEP values for presentation of the baseline stimulus versus meaningful gestures and words ($t(9) = -1.38$, $p = 0.20$, $t(9) = -1.49$, $p = 0.17$; meaningful gesture = 0.0081 ± 0.0109 mV$^*$s; word = 0.0079 ± 0.0095 mV$^*$s; Fig. 2).

To test the effects of meaning as compared with no-meaning, data for each participant were normalized, transforming median MEPs of both meaningful and meaningless gestures and sounds into percentages with respect to MEPs for presentation of the baseline stimulus. A repeated measures ANOVA was performed on MEP normalized values, using the within factors communication (gesture vs. word) and meaning (meaningful vs. meaningless). In all analyses, post hoc comparisons were performed using the Newman–Keuls procedure. The significance level was fixed at $p = 0.05$.

ANOVA showed that MEPs were greater during processing all meaningless as compared to all meaningful signals. In other words, factor meaning was significant ($F(1,9) = 7.35$, $p = 0.02$; meaningful = 11.73; meaningless = 18.72; Fig. 2). Factor communication

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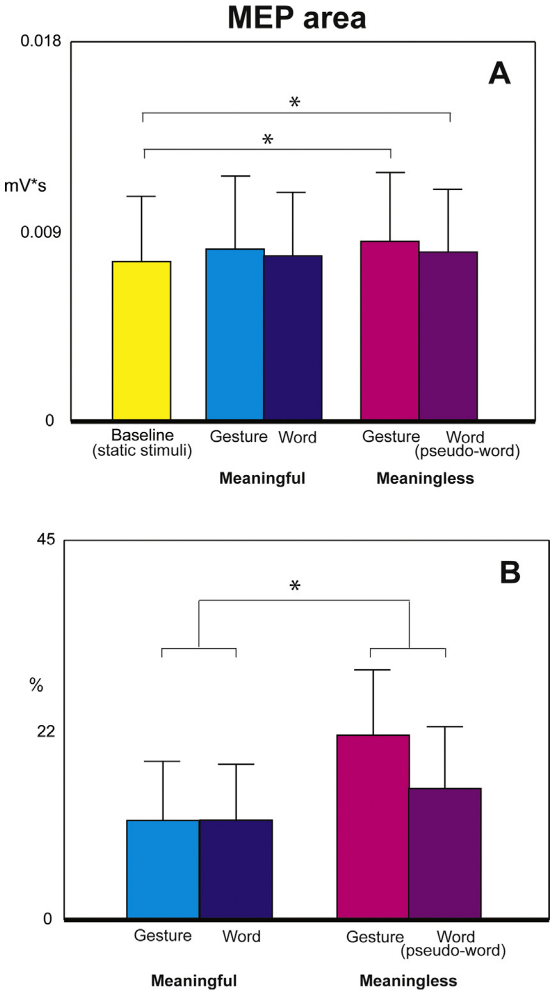

**Fig. 2.** MEP areas recorded in the various experimental conditions. (A) Raw (not normalized) values are presented when observing meaningful and meaningless gestures, observing/listening-to words and pseudo-words and observing baseline stimulus. Asterisk indicates significance in the *T*-tests in which the baseline condition was compared to the other conditions. (B) Variation in MEPs (percentage) in the various experimental conditions of stimulus presentation with respect to baseline condition. Asterisk indicates significance in the ANOVAs. Vertical bars are SE.

showed neither main effect nor significant interaction with meaning.

A new sample of ten right-handed [19] Italian native, naïve volunteers (5 females and 5 males, age 24–32 years.), participated in the control experiment. The same stimuli as in TMS experiment were presented and participants were required to decide if the signal was meaningless or meaningful by pressing keyboard key "1" or "2", respectively. Half participants were required to respond by pressing keyboard key "1" or "2" with their right index and middle finger, respectively; for the remaining participants the association of stimuli (meaningful vs. meaningless) to the responding fingers was reversed. We recorded reaction times (RTs). RTs were calculated with respect to stimulus recognition point (see above). A repeated measures ANOVA was performed on medians of RTs. The within subjects factors were communication (gesture vs. word) and meaning (meaningful vs. meaningless). In all analyses, post hoc comparisons were performed using the Newman–Keuls procedure. The significance level was fixed at $p = 0.05$.

The interaction between gesture and meaning was significant ($F(1,9) = 31.5$ $p = 0.0003$, meaningful gesture (mean and SD) 913 ± 79 ms, meaningless gesture 814 ± 111 ms, word 857 ± 59 ms, pseudo word 873 ± 36 ms). All post hoc comparisons were significant ($p < = 0.01$) except between word and pseudo-words ($p = 0.3$). The finding that the difference between words and pseudo-words was not significant probably depends on phonological similarity among stimuli. They differred from each other by 1 or 2 letters, and had similar "*recognition points*" (cohort theory, [23], Fig. 1). This could result in non significant differences in time to make a lexical decision. The finding that meaningless gestures were easier to recognize compared to meaningful gestures probably depended on the fact that the hand posture did not vary among the different gestures, whereas type of movement and direction of the forearm did (Fig. 1).

Single pulse TMS applied to M1 forearm area led ECR muscle activity to significantly increase when meaningless gestures and pseudo-words were presented, as compared to baseline stimulus (still/silent actress). In contrast, the increase was not significant when the signals were meaningful. Normalized data showed that MEPs were greater when presenting meaningless signals as compared to meaningful signals. All these effects were the same in both visual (visible actress producing meaningful and meaningless gestures) and acoustic/visual (visible actress pronouncing words and pseudo-words) modalities. We might explain these results by suggesting that the greater complexity and/or novelty of meaningless stimuli resulted in a longer activation of forearm M1 and, consequently, increase in RTs. However, increase in RTs was found for meaningful rather than meaningless gestures (and no difference was found between words and pseudowords). So, the hypothesis of novelty/complexity can be discarded Instead, This suggests that other (semantic) circuits might be activated by observation-of/listening-to symbolic gesture and word and this was responsible for RT variation. The non significant difference in MEPs between meaningful stimuli and baseline stimulus (silent/still actress) supports this possibility. This result also disproves interference during observation of these gestures [8]. In fact, decrease in MEPs as compared to baseline condition was not found. The increase in MEPs for meaningless stimuli may be due to continue activation of motor circuits because meaning was not quickly retrieved.

In conclusion, the data of the present study may be in favor of the idea that symbolic gestures and communicative words are comprehended without activation of primary motor area. In accordance with previous work [5,24] a fronto-parietal circuit related to language or better to linking meaning to symbols in a modality-independent way may be used for comprehension of symbolic gesture and corresponding word. In contrast, motor circuits including primary motor area are likely activated to comprehend action words used in actual and even metaphoric context [8,25].

A limitation of this study is the use of only one stimulation delay after stimulus presentation since we are unable to rule out that earlier or later stimulation might activate M1 even in response to meaningful signals. However, the delay we used (150–200 ms) is in agreement with the beginning of motor area activation found by the magneto-encephalography study carried out by Pulvermüller et al. [21] during which action verbs were presented. Nevertheless, future studies will test whether or not M1 is modulated by TMS applied at different delays after presentation of symbolic gestures and communicative words.

## Acknowledgments

The work was supported by grant from MIUR (Ministero dell'Istruzione, dell'Università e della Ricerca) to M.G. P.M.G. was supported by European Community Grant [ICT-216125-ROSSI].

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