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# Neural Correlates of Motor Imagery during Action Observation in Affordance-based Actions: Preliminary Results

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*Abstract*— **Object affordance, a characterization of the different functionalities of an object, refers to an object's numerous possibilities of interaction. It has a significant part to play in priming motoric actions which depends on the actor's spontaneous neurological behaviour. Action Observation (AO) and Motor Imagery (MI) also lead to the stimulation of motor system. In fact, AO and MI result in activation of overlapping brain areas as the actual motor task. AO combined with MI (referred to as AO+MI) initiates higher cortical activity in comparison with either MI or AO alone. In this paper, we investigate the influence of affordance driven motor priming during AO, MI and AO + MI. Source current density as an EEG parameter is estimated by Low Resolution Electromagnetic Tomography (LORETA). Our results demonstrate that affordance driven motor priming during AO+MI indicates stronger electrophysiological and behavioural changes. This is evident from the N2 ERP component. Further, the current source density (in brain regions associated with motor planning) during affordance driven AO+MI is found to be maximum.**

## INTRODUCTION

Affordance is what a user can do with an object based on users' capabilities [1]. The term 'affordance' has a significant role in establishing the relationship between a user and an object. In 'Theory of affordances' [2], J.J. Gibson mentioned the term 'affordance' for the first time. Gibson used the concept of affordance to describe how a living being is related to its environment. Object affordance gets its importance from its significance in motor priming which depends upon the typical neurological behaviour of a participant when an action related task is performed. In this paper, observing another individual performing some affordance-driven action is referred to as Action Observation (AO). Motor Imagery (MI), on the contrary, is the mental execution of a movement [3]. An individual visualizes himself/herself performing a specific task or action, almost realizing the kinaesthetic experience of the movement. The process of MI gets activated during various cognitive operations like putting an information into memory, thinking of a goal, spatial orientation, navigational planning etc. There are a number of evidences that support the efficiency of AO and MI as individual techniques in neurorehabilitation [4], [5]. Research has suggested that the process of learning any task and services associated with rehabilitation could successfully implement MI and AO to enhance the motor activities [4], [6], [7], [5], [8], [9]. Research is also focused on applications that combine AO+MI. The combination seems to establish the most influential approach. Neurophysiological evidences from an emerging body of research shows that cortico-motor activity become significantly higher in brain areas associated with motor activities during combined AO+MI, rather than independent AO or MI [10]. Taube et al. [11], in their study found significant dissimilarities in the pattern of neural activities stimulated by MI, AO and AO+MI and claimed that the neural activity for AO+MI, when compared to that for AO is greater in the supplementary motor area (SMA), basal ganglia and cerebellum. Similarly, neural activity for AO+MI when compared to that for MI is greater in bilateral cerebellum and praecuneus. Subsequently, Eaves et al. [12] proposed a hypothesis where they used both observed and mental simulation that could be represented concurrently in the brain of an observer. Meers et al. [13] provided some insights into why AO + MI may lead to better brain activity. While the MI component is about motor simulation, the accompanying AO primarily acts as an 'external visual scaffolding'. Possibly it is the visual guiding in AO + MI that leads to clearer mental simulation than MI alone.

The concept of object affordance encouraged versatile research in various fields of psychology, robotics and neuroscience [14]. Object affordance has a significant part to play in priming motoric actions: affecting our preparation to handle objects. Parsons et al. [15] used event-related potential (ERP)s to investigate the relative time that reflects the response of affordances. Proverbio et. al [16] and Rowe et. al [17] emphasized on the use of N2 ERP component that was able to significantly reflect the presence of object affordance. Hence, in our study, to investigate the affordance driven AO+MI, N2 ERP component is our signal of interest.

Studies have shown correlation between N2 ERP and functional properties of an object. However, it remains unclear how affordance-based actions influence cortical activity. This motivates our neurophysiological investigation of the functional interaction of object affordance with AO and MI. In this paper, we explore the neural correlates of combined AO+MI in affordance based actions, compared

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with both pure AO and pure MI; with a primary focus on the related brain activity using electroencephalography (EEG). Our study focuses on evaluating whether combined AO + MI during object affordance driven action would facilitate stronger motor priming than either AO or MI alone. The paper studies and analyses different ERP responses along with LORETA analysis during object affordance-based actions using EEG signals.

## I. Materials and Methods

*Participants*

For our experiment, 12 healthy subjects, aged between 25-35 years, with normal or corrected-to-normal vision volunteered. Participants were naive to the study's purpose. Written informed consent was obtained prior to their participation.The present study was sanctioned by the Institute Human Ethics Committee at IIT Guwahati. Further the participants were given to fill out a short demographic questionnaire (which included name, gender, age, occupation and other relevant information).

*Stimuli*

EEG recording was organised inside a soundproof room. Each participant was allowed to sit conveniently in a chair with their hands idling naturally on their lap. Two self-test reports viz. Visual Analogue Scale-Fatigue (VAS-F) [18] and Chalder Fatigue Scale (CFS) [19] were given to all the participants to scale the fatigueness before and after the task. The to-be-observed video stimuli were presented on an LCD display placed at an observing distance of 80 cm (approx.) from the subject using E-Prime, a behavioural experiment software. In the video, an actor was displayed at the centre of the computer screen and he was performing the generally accepted activity of daily living (ADL) associated with two objects, a hammer and a coffee mug as shown in Fig. 1. These objects were placed in the middle of the table, and the actor was enacting the affordances associated with the objects, which were hammering a nail into a small wooden board to demonstrate *hammerability* and drinking coffee from a coffee mug to demonstrate *drinkability*.

Fig. 1. Screenshots of objects (hammer and coffee mug) captured from the video stimuli. Note that the videos illustrate what each object affords i.e., the hammer is used for *hammering* a nail and the coffee mug is used for *drinking* coffee.

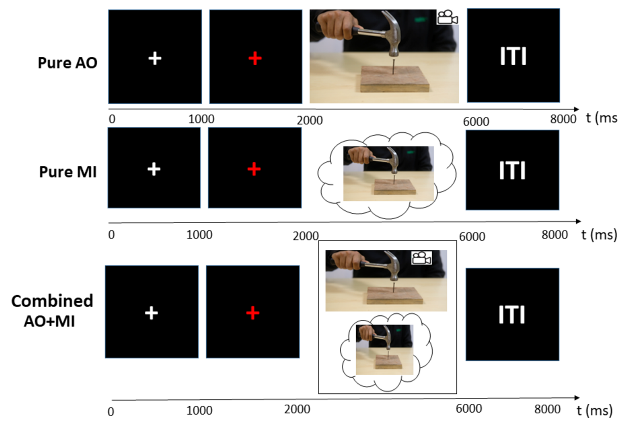


Fig. 2. A visual representation of the three experimental conditions: Pure AO, Pure MI and Combined AO+MI. For Pure AO and Combined AO+MI, the video stimuli was delivered for 4000 ms (from 2000 to 6000 ms after start) with either *hammering* or *drinking* shuffled and counterbalanced among the various trials of the experiment. For Pure MI, there was no video stimuli.

### A. Design and Procedure

The whole experiment consists of two stages, a familiarisation session followed by the main experiment. A familiarisation session was conducted on Day 1. The main experimental sessions were carried out on the successive day. On the first session, each participant was trained to practice MI similar to the actual experiment. However, in the practice session, objects used in the demo videos were unlike those used in the main experimental session.

The experimental conditions are shown in Fig. 2 and highlighted below:

- *Pure AO*: Participants were advised to observe the video passively without performing any MI. To centre the focus of the subject onto a black screen, a white cross appeared for 1000 ms which was followed by a red cross for another 1000 ms as an indication for being ready. A video showing affordances was then displayed for another 4000 ms during which participant had to observe the video only.
- *Pure MI*: In pure MI condition, they were asked to imagine affordance-based action without involving any motor execution. Here, participants were asked only to imagine the object affordance of either of the two objects which was involved in Pure AO.
- *Combined AO+MI*: Participants observed video of an affordance-based action whilst imagining simultaneously the same. A video showing affordances was then displayed for another 4000 ms during which participant had to observe and imagine the same action (as shown in the video) simultaneously. The combined AO + MI, in our case, is referred to as *congruent* as AO and MI is of the same action with the same object. An interval of 2000 ms was given after each condition.

### B. EEG Measurement and Analysis

EEG data was collected from 16 channels namely Fp1, Fp2, F3, F4, C3, C4, Cz, P3, P4, O1, O2, F7, F8, T7, T8 and EOG. Sampling rate of the recorded data was 500 Hz. For recording and pre-processing of EEG, BrainVision recorder and BrainVision Analyser (Brain Products, 2008) software were used respectively. Impedance of electrodes was retained below 10 kΩ during the whole experiment.

For the analysis of ERP, EEG data were down-sampled to 256 Hz and band pass filtered in a pass frequency range of 0.1 Hz to 40 Hz; and notch filtered at 50 Hz. A zero phase shift butterworth filter was also applied to the EEG data. Re-referencing was done offline with average of all channels excluding EOG. After filtering, segmentation of data were performed into epochs of duration 5200 ms; 200 ms earlier to the stimulus onset and 5000 ms posterior to the stimulus presentation. Artifact rejection and ocular correction was done in the analyser itself and a window in the range of -200 ms to 0 ms was considered for baseline correction prior to the onset of the stimulus. N1 wave mirrors visual oriented information. Similarly, anterior N2 component reflects the existence of affordances[20]. We have computed N1 and N2 ERP waveforms for Pure AO, pure MI as well as AO+MI condition.

## II. Results

### A. ERP Analysis

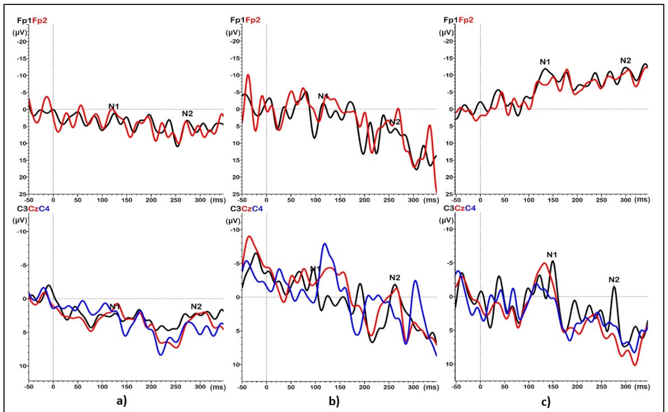


Fig. 3. ERP waveforms showing N1 and N2 peaks for a) AO, b) MI, c) AO+MI condition. The vertical axes show voltages in microvolts while the horizontal axes show time in milliseconds.

For affordance reasoning, analysis of ERPs focused mainly on the peak amplitude of N1 and N2 components. N1, the first negative going component, is associated with the visual discrimination that is elicited in response to visual onsets, offsets, and changes. N2 is the second negative-going ERP component posterior to stimulus onset and has been related to motor related activities. It is elicited when a person observes and recognizes some objects and its enactment of different functionalities.

In the study, grand average is calculated for all the participants. However, as Fp1, Fp2, F3, Fz, F4, C3, Cz and C4 electrodes are placed close to the area responsible for motor related activities, peak ERPs for N1 and N2 components were computed for the above mentioned electrodes only. From figure 3, we observe a distinct N1 component in the interval 100-150 ms and N2 component in the interval 250-300 ms after stimulus onset. From the self-report responses, it was observed that the participants were able to successfully focus on the task while watching the video and during combine AO+MI, they were able to imagine concurrently. Hence, the amplitude of N1 is visibly largest, negative going and insinuates a benefit of correctly allocating attentional resources in the frontal sites (Fp1 and Fp2). Also, there is an enhanced N2 in all the three conditions, which reflects the presence of object affordance. N2 component is comparatively stronger in the central electrode sites (C3, Cz, C4) as it is the prime region for performing motor related activities.

### B. Topographic Analysis

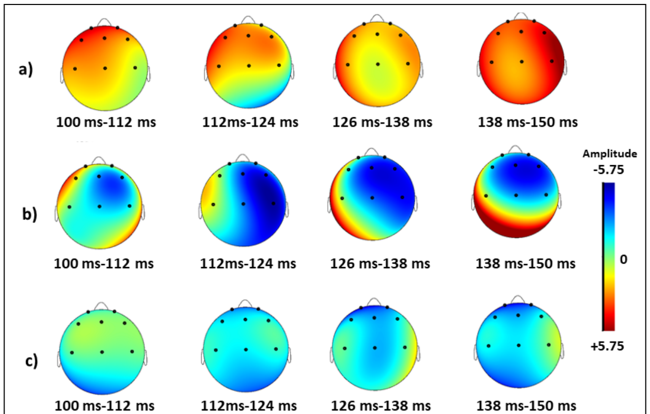


Fig. 4. Topographical plots for a) pure AO, b) pure MI, c) combined AO+MI conditions for N1 component.

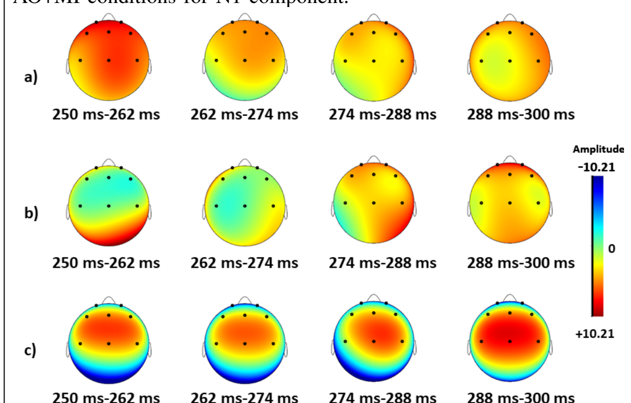


Fig. 5. Topographical plots for a) pure AO, b) pure MI, c) combined AO+MI conditions for N2 component.

Our results investigate the influence of object affordance with particular reference to affordance-driven motor priming during AO, MI and AO+MI. Fig. 4 compares the topographical plots of N1 ERP components for all the three experimental conditions viz. a) pure AO, b) pure MI, and c) combined AO+MI. As N1 component is associated with the visual discrimination and attention, it is clearly distinguishable from our results that frontal and sensorimotor areas are highly activated for pure AO condition when analogized with MI or AO + MI and it is highest in the range of 138-150 ms.

Similarly, Fig. 5 depicts the topographic plots of human brain considering all three above mentioned conditions for

N2 ERP component. This component is associated with object affordance which occurs around 250 to 300 ms after stimulus onset. Our result shows stronger motor priming in combined AO+MI condition, specifically in the range of 288-300 ms, rather than pure AO and pure MI, near the premotor cortex (PMC) along with supplementary motor area (SMA).

### C. Source Analysis

EEG patterns reflect the superposition of many neuronal sources distributed across the brain. Analysis of such sources help in decomposing various EEG signals into its underlying neuronal connectivity. It also helps to localize the sources of EEG activity within the brain [21].

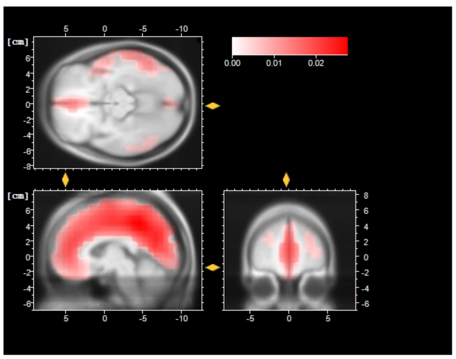


Fig. 6. LORETA reconstruction of N2 component for Pure AO.

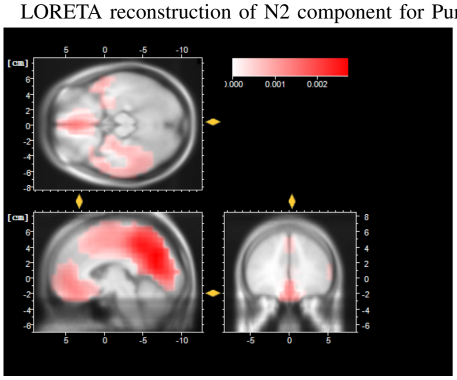


Fig. 7. LORETA reconstruction of N2 component for Pure MI.

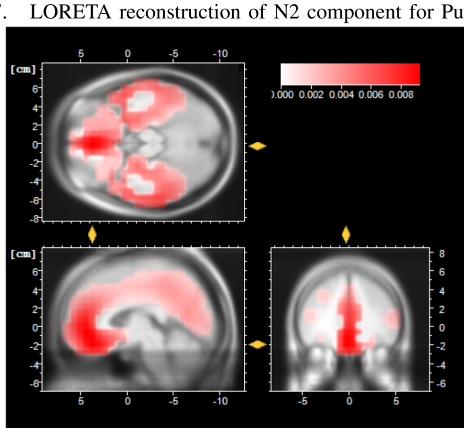


Fig. 8. LORETA reconstruction of N2 component for Combined AO+MI.

Due to the fact that the number of sources are not known, source localization from EEG signals has been marked as an ill-posed problem [22]. There are various methods for investigating localization of brain sources. LORETA (Low Resolution Electromagnetic Tomography) [21] has been considered as one of the broadly utilized source imaging or current density reconstruction methodologies because of its simplicity and cost-effectiveness [23]. In our study, we have mainly used LORETA for localization of N2 ERP component (similar to Invitto et.al [24]). We have used LORETA as a transient transformation in BrainVision analyser for displaying and inspecting the location of activated brain areas. This mode of transformation provides the average current density magnitude within the range associated to a specific voxel. Fig. 6, 7, 8 displays the LORETA transformation of N2 ERP component for pure AO, pure MI and combined AO+MI with a maximum current density magnitude of 0.000665 $\mu A/mm^2$, 0.00147 $\mu A/mm^2$, 0.00508 $\mu A/mm^2$ respectively in the frontal lobe of the brain, specifically in Brodmann area 4.

Thus, from both topographical and LORETA plots, it can be concluded that during affordance reasoning combined AO+MI has a stronger influence on motor priming in the frontal lobe area of the brain.

## III. Discussion

The objective of our study is to observe the motor priming in various conditions such as pure AO, pure MI and combined AO+MI during object affordance driven action. In topographic plots, Fig. 5(a) represents the cortical activity of the brain under pure AO condition at the time range of 250-300 ms. When a healthy participant is asked to observe a motor task via a video, its presumable that the person is already familiar with that object and it's associated functional affordance. As the participant was asked only to observe the video without performing any actual/mental motor execution, it is clearly visible from Fig. 5(a) that pure AO leads to a small change in the electric potential in the motor cortex. Fig. 5(b) delineates the brain activity for pure MI condition. It is fascinating to observe, how asking the participant to imagine the execution of same action which was shown to him or her during pure AO leads to a comparatively higher change in the neural activity around 300 ms. It can be concluded that this occurs mainly because the individual attempts a mental rehearsal of the given action like hammering or drinking. In other words, the individual will first try to create a scene mentally and then perform the stipulated task. These findings motivate us to observe the affordance driven action under the condition of combined AO and MI. From Fig. 5(c), it is clearly visible that during combined AO and MI, motor priming is stronger for N2 component which reflects presence of object affordance in the range of 250-300 ms.

Similarly, LORETA source localization analysis also demonstrates maximum current source density for combined AO+MI in the neighborhood of Brodmann area 4, which is primarily responsible for execution of motor tasks/ movements. It is worthwhile to note that similar motor priming is observed post-stroke, as reported recently by Rowe et al.

[20]. These results highlight that object affordance driven AO + MI holds a promise for neurorehabilitation.

## IV. Conclusion

This study enhanced our understanding of the role of affordance driven action, particularly during AO, MI and AO+MI. Our study investigated and compared two different ERP components: N1 and N2. This was done along with topographical localization as well as LORETA source localization. It is clearly observable from our results that motor priming during combined AO+MI indicates stronger electrophysiological and behavioural changes as evident from peak amplitude of N2 ERP component. The topographic plots as well as LORETA source localization support this observation. Possibly, it is the visual guiding in AO+MI that leads to clearer mental simulation than MI alone. For a comprehensive understanding of affordance driven AO+MI, a study involving a substantial number of participants with more trials and with behavioural analysis needs to be completed. The current study considered congruent AO+MI, i.e., AO and MI are in tandem. It would be interesting to explore conflicting AO+MI, i.e., when AO would be different from MI (for the same object). This is part of ongoing research.

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