# Local Field Potential Modulations in the Motor Cortex Arising from Different Tactile Cues and Arm Visual Feedback in a Mixed Reality Environment


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## Introduction

- **Multisensory integration** enables the brain to process inputs from multiple senses, enhancing behavior and performance by creating a unified perception of the environment while developing over time through cross-modal experiences[1].
- The mechanisms by which the brain merges sensory inputs and prioritizes relevant information remain unclear, particularly in terms of how it filters and selects optimal responses in complex environments.
- **Mixed reality platforms (MRP)** allow researchers to study the effects of manipulating visual and tactile information on multisensory integration by altering sensory feedback.
- In a previous study[2], an MRP modified visual feedback by shifting the arm's position visually, while tactile cues were modulated by providing or omitting spatial touch information to observe their impact on reaching movements performed by non-human primates (NHPs).
- Neural activity was recorded using floating microelectrode arrays (FMA) and refined through **spike sorting algorithms**, though results varied across sorting methods, underscoring the need for multiple analyses to accurately interpret neural patterns.

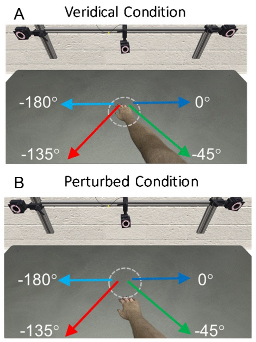


**Fig. 1**: Example of perturbation visual experiment with directions where once the NHP acquired the start position, they would either see (A) veridical representation of the arm or (B) perturbed representation of arm shifted 6cm toward the body

## Aim

- **Local field potentials (LFPs)**, which correlate with behavioral and cognitive processes and represent the incoming signals into a cortical region, may reveal unique activity related to movement, tactile cues and visual feedback[3].
- The aim of this research is to analyze LFPs and quantify how they respond to tactile arm position cues and visual feedback prior to reach movement onset in a mixed reality environment.

## Methods

***Prior Experimental Setup***

- Tactile feedback manipulated in blocks by placing or removing a spatial cue at start position.
- Visual feedback manipulated by rendering the arm in its veridical position or in a shifted position (6-9 cm toward the body)
- Each trial started with no visual feedback of the arm, followed by an invisible hold (no arm view) and a visible hold phase showing either veridical or perturbed arm positioning.
- Neural activity recorded with four 32-channel microelectrode arrays implanted in the frontal cortex (two in premotor, two in motor) of each monkey, with 160 trials conducted per tactile condition.

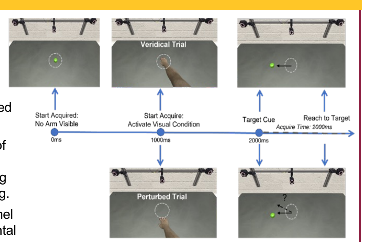


**Fig. 2**: Timeline of timing of the task where the trial starts with no visual feedback of the arm which follows the activation of the visual condition in either the veridical or perturbed condition for the holding phase. The target cue then appears showing it in either one of the four target directions where reach to target tasks occurs.

***Data Analysis***

- LFP analysis was performed in **MATLAB** (MathWorks, Inc.). Channels 1 to 32 (M1 cortex) from Monkey Q during one day of trials (20 to each target) were analyzed for both tasks.
- **Principal component analysis** (PCA) was performed using singular value decomposition (SVD) to reduce dimensionality and clustering analysis was applied. Data was aligned to movement onset and activity occurring 0.5 sec before to 1 sec after movement was analyzed.
- **Power spectrum** of the LFPs was calculated using data aligned to acquire of the start position.

## Results

### Raw LFP Data

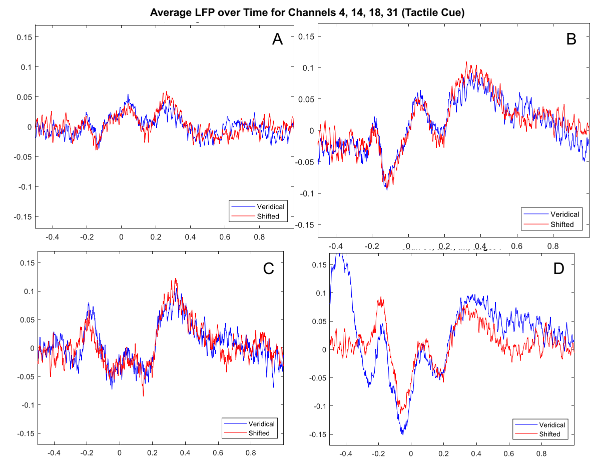


**Fig. 3**: Average LFP amplitude over time for Channels 4 (A), 14 (B), 18 (C), and 31 (D) under the tactile cue condition for reaches to target one. Activity for both Task 1 (veridical) and Task 2 (perturbed) are shown.

### Time Domain Analysis

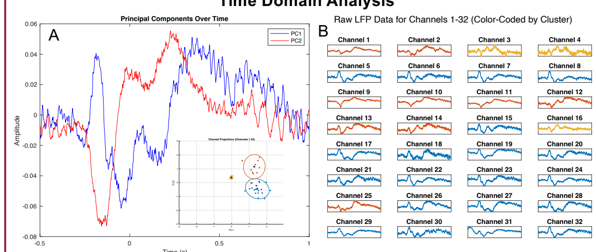


**Fig. 4:** (A) First two principal components of LFP data over time for task one and target one under the tactile cue condition, capturing the primary temporal patterns and variance in neural activity within the M1 cortex across trials. The PCA for task 2 is almost identical to task 1. (B) Average LFP data for channels 1 to 32 (M1 cortex), color-coded by cluster: cluster one in blue, cluster two in red, and cluster three in yellow.

### Frequency Domain Analysis

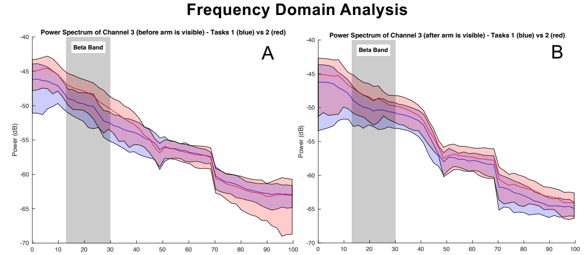


**Fig. 6**: Power spectrum analysis for Channel 3 in task one and two, target one under tactile cue conditions, comparing two intervals: (A) 0.25 to 0.75 seconds before holding arm becomes visible, and (B) 1.25 to 1.75 seconds after the arm is visible. The LFP power generally decreased with frequency in both epochs, but beta band (13-30 Hz) activity remained relatively unchanged.

## Results

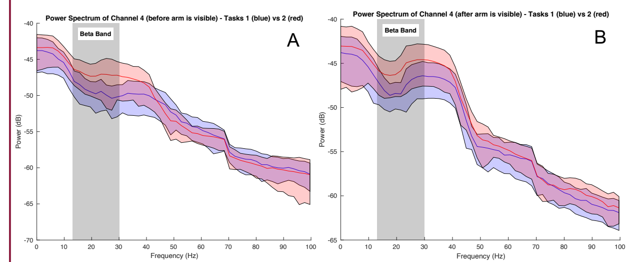


**Fig. 7**: Power spectrum analysis for Channel 4 in task one and two, target one under tactile cue conditions, comparing two intervals: (A) 0.25 to 0.75 seconds before holding arm becomes visible, and (B) 1.25 to 1.75 seconds after the arm is visible. Before the arm was viewed, LFP power looked similar in many way to the example in Figure 6, with the exception a small increase in power in the low gamma band (30-50Hz). After the arm was viewed however, power in both the beta and low gamma bands was markedly increased.

## Discussion

- The clustering analysis shown in Figure 5 reveals groups of channels that share similar activity patterns, which could be associated with specific neural processing functions or anatomical regions within the motor cortex.
- Figure 6 shows that Channel 3 demonstrated little change in beta power before and after the animals viewed their arm, indicating that neurons in this area may not be as sensitive to visual feedback or may be involved in processing other sensory information.
- In contrast, Figure 7 shows that Channel 4 exhibiting a marked increase in beta power after the hand becomes visible, suggesting enhanced neural activity in response to visual feedback of the arm, which could be associated with the motor cortex's role in updating the internal representation of arm position based on visual input.
- Channels that showed clear differences in LFP power in the beta and low gamma bands, like 3 and 4, were better identified by their position on the recording array than by their PCA cluster.
- Tactile cues influenced beta power in the motor cortex, with channel-specific effects such as heightened activity in Channel 4, suggesting that tactile input primes the motor cortex for integrating sensory modalities during movement planning.

## Summary, Conclusions and Future Directions

- LFPs were analyzed in the motor cortex to examine multisensory integration of tactile, proprioceptive, and visual arm position cues. The results suggest the presence of anatomically selective cortical processing of visual arm position cues in motor cortex.
- Future directions will involve examining difference in the power spectrum (beta/low gamma bands) for different amplitudes of visual arm position shifts. It is hypothesized that differences in power would be larger as the arm is shifted distances.
- Another future study could examine if certain M1 channels respond differently when the virtual arm is replaced with an inanimate object such as a ball, which as been used in previous studies

## References


[1] Stein, B. E., Stanford, T. R., & Rowland, B. A. (2014). Development of multisensory integration from the perspective of the individual neuron. *Nature reviews. Neuroscience*, *15*(8), 520–535. https://doi.org/10.1038/nrn3742

[2] Phataphruk, P. K. (2023). *A Mixed Reality Platform for Systematic Investigation of the Neural Mechanisms of Multisensory Integration During Motor Planning* [Published PhD Dissertation]. Arizona State University

[3] Betti, S., Castiello, U., & Begliomini, C. (2021). Reach-to-Grasp: A Multisensory Experience. *Frontiers in Psychology*, *12*, 614471–614471. https://doi.org/10.3389/fpsyg.2021.614471


## Acknowledgements


I would like to thank Kris Phataraphruk for allowing me to use her experimental results, serving as the backbone of this analysis and Dr. Christopher Buneo for his extensive help and guidance throughout the entire process.