The Specificity of Mu Rhythm Activity

Crossmodal Classification of Mu Rhythm Activity during Action Observation and Execution Suggests Specificity to Somatosensory Features of Actions

Coll et al., 2017

Orhan Soyuhos

Introduction

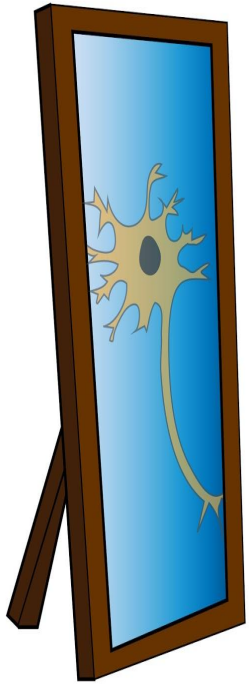
- Mirror neurons (MNs), fire both during the observation and execution of actions. *(di Pellegrino et al., 1992)*

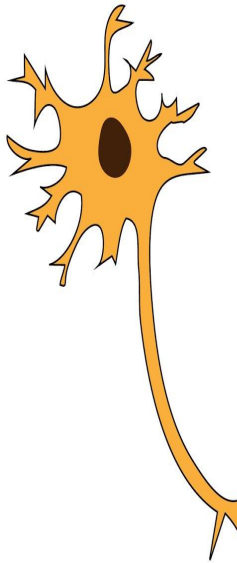
- The alpha mu rhythm (8–13 Hz) is an oscillation measured over sensorimotor areas that is attenuated both during the observation and execution of actions. *(Fox et al., 2016)*

- On the basis of this similar response during action observation and execution, the mu rhythm has been considered to index MN activity. *(Pineda, 2005; Fox et al., 2016)*

Two important problems

- For the mu rhythm to be considered a valid index of MN, it should show crossmodal action specificity.
    - The response associated with one action should be similar whether it is observed or executed **(crossmodality)**.
    - Also, it should be distinguishable for different actions **(specificity)**.
- However, most studies do not provide a convincing demonstration of the **specificity** of mu rhythm response.





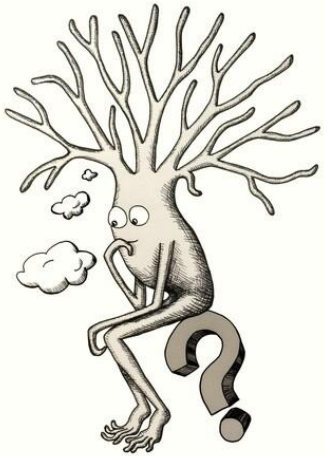
Two important problems

- Empirical evidence suggests that the mu rhythm might index sensory processing rather than motor activity. *(Cheyne et al., 2003; Ritter et al., 2009; Coll et al., 2015)*

- Hence, the mu rhythm may index the observation and receipt of tactile stimulation rather than the observation and execution of actions.

Research questions

- Is the mu rhythm a valid measure of mirror neuron activity?
- Does the mu rhythm demonstrate crossmodal and specific responses to the observation and receipt of tactile stimulation?



Materials and Methods

Experimental Design

- They wanted to show the crossmodal specificity of the mu rhythm to two different actions (Action type factor) **while manipulating the amount of tactile stimulation** involved in these actions in two different ways.

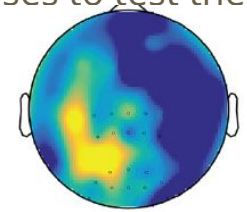
- 2 manipulations:
  - the presence or absence of an external tactile stimulation (Vibration factor)
  - whether the actions were directed toward an object or simply mimed (Transitivity factor)

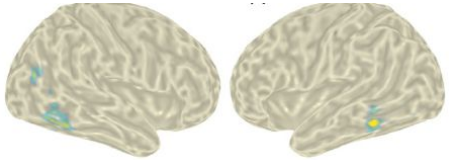
- **The idea:**
  - If the mu rhythm is specific to the action observed and executed, then the crossmodal classifier should be able to discriminate the two actions.
  - If the mu rhythm is sensitive to differences in tactile stimulation, then the classifier should be able to discriminate between the presence and absence of the vibration and between transitive and intransitive actions.

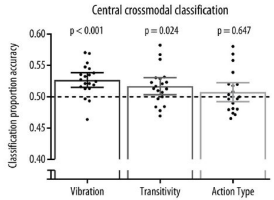
Prediction and approaches

- They expect that crossmodal classification accuracy in **central channels** would increase with the strength of the difference in tactile stimulation in each condition:
  - Vibration > Transitivity > Action type pattern

- 3 main approaches:
  - searchlight analyses at the **channel level** to investigate the scalp distribution of the effects
  - searchlight analyses at the **source level** to visualize the neural sources contributing to the observed scalp effects
  - **region of interest (ROI)** analyses to test the claim that the central mu rhythm shows crossmodal specificity



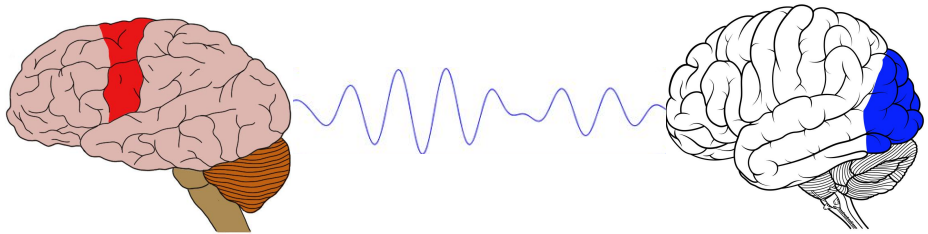




- Also, they wanted to ensure that any crossmodal effect observed in this central cluster is specific to the central alpha mu rhythm and **not confounded with the occipital alpha rhythm**.

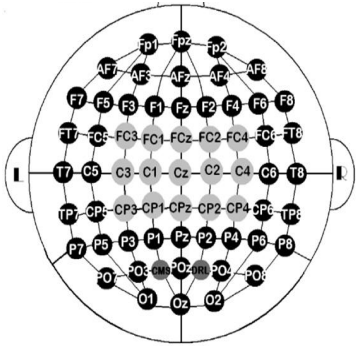
- For this reason, they decided to perform analyses at both central and occipital scalp locations.

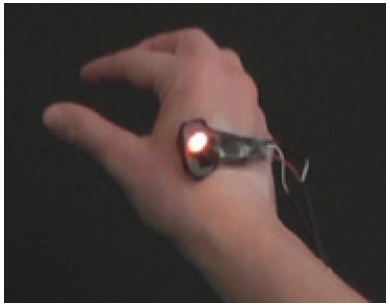
- They predicted that crossmodal classification would be observed **only at the central location**.



- **Participants:**
  - 20 healthy right-handed adults (12 females)
  - Aged on average 24.60 years (SD 6.75, range 19–49 years)

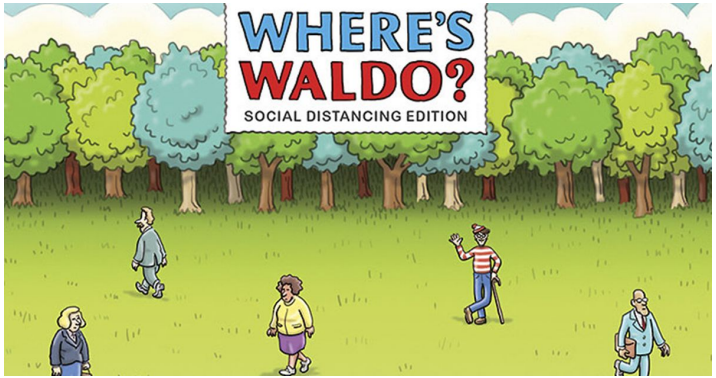
- **EEG recordings:**
  - 61 channel (extended 10–20 montage)
  - Three additional EOG electrodes
  - The sampling rate was 500 Hz
  - Reference at FCz and ground at AFz





- **Vibration stimulator:**
  - Fixed on the back of the participant's right hand using medical tape
  - Vibrating at 10,000 rotations per minute
  - When the stimulator was turned on, it produced a continuous vibrating sensation on the back of the hand.
  - A yellow LED light was placed on the top of the motors and was lit when the stimulator was turned on.

- **Visual stimuli:**
  - consisted of 3000 ms video clips depicting a hand wearing the vibration stimulator executing one of the 6 types of actions:
    - Action type (Precision grip, Whole-hand grip)
    - Vibration (Vibration on, Vibration off)
    - Transitivity (Transitive, Intransitive)
  - filmed from a first-person point of view
  - The models executed the actions twice for a total of 32 different stimuli (8 types x 2 models x 2 executions).



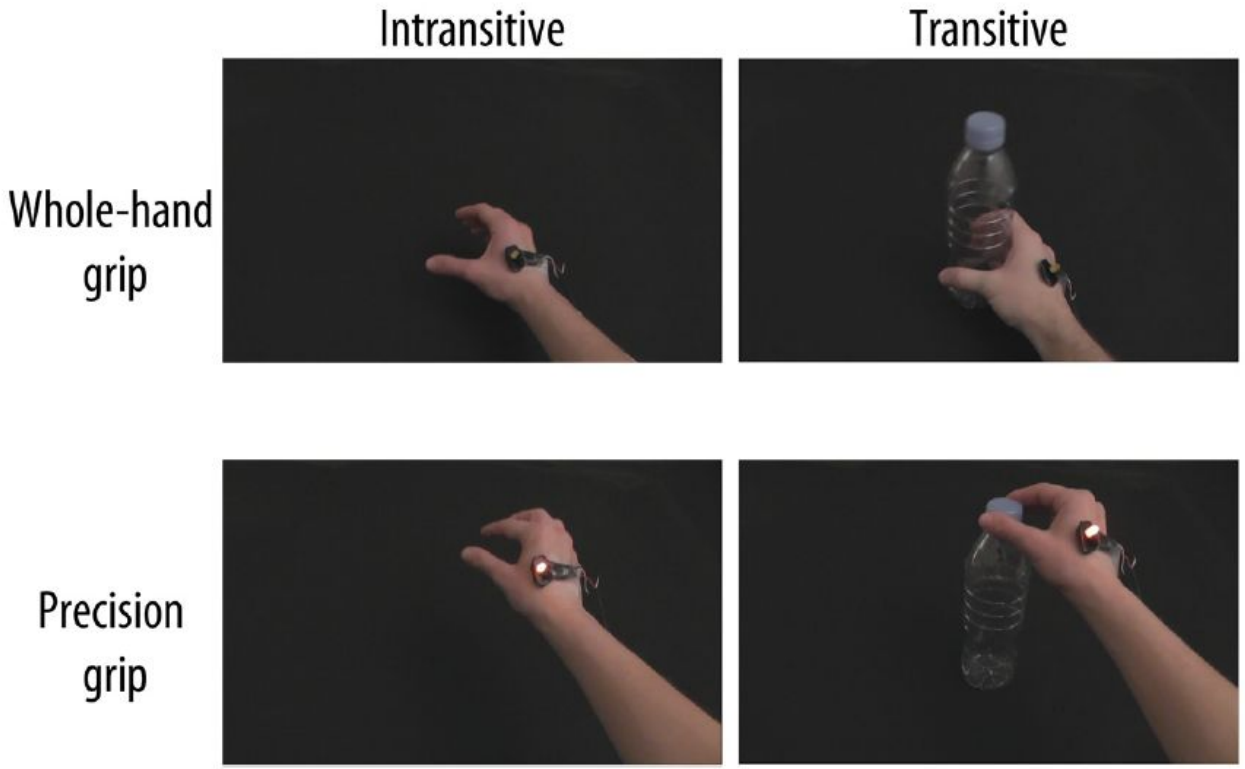


Figure 1. Frames from the visual stimuli illustrating the different types of action observed or executed by the participants. Participants either performed a Transitive (right column) or an Intransitive (left column) Whole-hand grip (top row) or Precision grip (bottom row). These actions were observed and performed with the Vibration device on (bottom row) or the Vibration device off (top row).

Experimental Procedure

- During the experimental task, participants were asked to **either observe the video clips or to execute one of the six action types** using the same plastic bottle as in the video clips.

- They were explicitly instructed that the hand in the video clips received the same vibrating stimulation when the LED light was turned on.

- A practice session was performed.

- Trials with incorrect action execution or with movement during observation were noted and removed from the analyses.

Execution blocks

- Participants first saw the instructions indicating which action type should be executed:
  - (e.g., "**Execute**, Fine **OR** Full grip, With **OR** Without the object, With **OR** Without vibration)

- They were told to begin executing the action as soon as they saw the **green circle**.

- During **vibration on trials**, the vibration stimulator was turned on during the presentation of the green circle.
  - During Vibration off trials, a second stimulator was turned on to produce a similar sound.

Observation blocks

- Participants received the instruction “Please remain still and watch the video clips”.
- The stimulator was never turned on during the Observation blocks.
- Eight of the 28 Observation blocks were **catch blocks**:
  - During which, one of the 10 video clips was presented with a red dot in the center.
  - Later, participants were asked to indicate whether they saw a red dot.
  - They are used to ensure continuous attention to the stimuli and were not included in the EEG analyses

EEG Analyses

- **Univariate analyses:**
  - To compare the mu rhythm suppression in the current experiment to the previous studies.

- **Multivariate pattern classification:**
  - A linear support vector machine classifier was used to perform a fivefold cross-validated classification on all trials.
  - Subsets of trials were created for classifier input by dividing the data into five independent chunks for each modality (for a total of 10 chunks)
  - A leave-one-chunk-out cross-validation was performed in which four chunks were used to train the classifier, which was then tested on an independent chunk.

Multivariate pattern classification

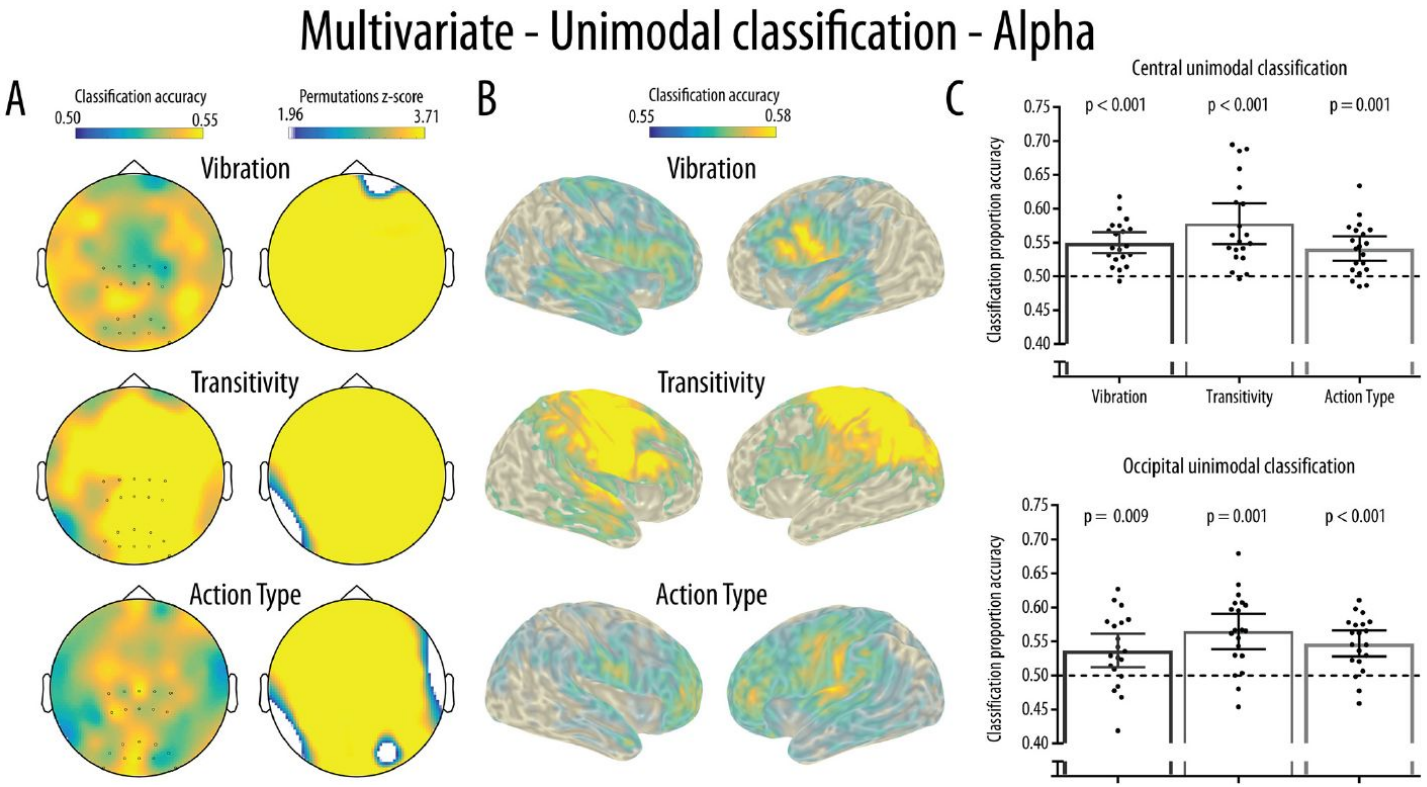
- **Unimodal classification analysis:**
  - To ensure that the mu rhythm response for each condition was distinguishable **within modality**.
  - The classifier was trained and tested on trials of the same modality (Execution or Observation).

- **Crossmodal classification analysis:**
  - The classifier was trained on four chunks from one modality and tested on a chunk of trials of the opposite modality.

- Later, the accuracies obtained were **averaged across modalities** to obtain one classification accuracy for each participant, condition, and location for both unimodal and crossmodal classifications.

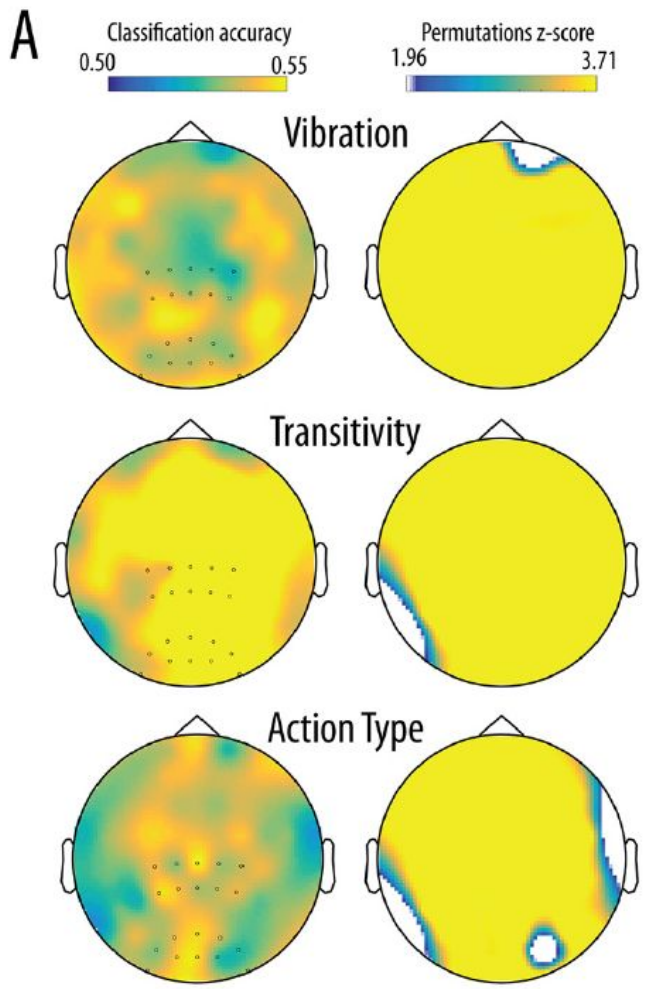
Results

MVPA - Unimodal classification

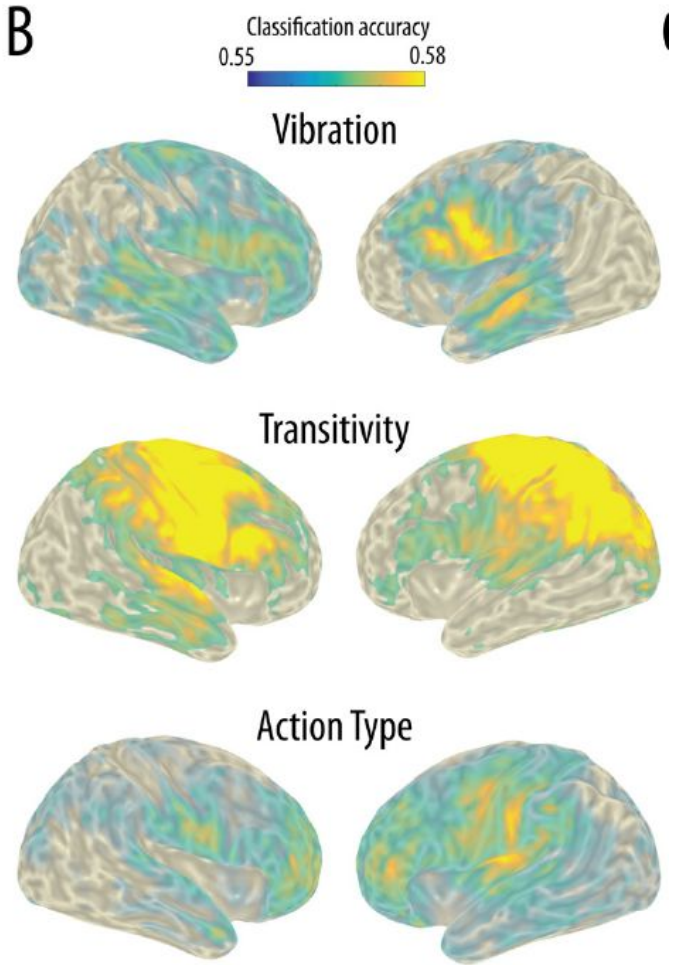


Results for the multivariate unimodal classification for the alpha bands. A, Searchlight analyses at the channel level. B, Searchlight analyses at the source level. C, The ROI analyses

- The spatial searchlight analysis performed at **the channel level** revealed widespread above-chance unimodal classification accuracy across all channels for the three experimental conditions.



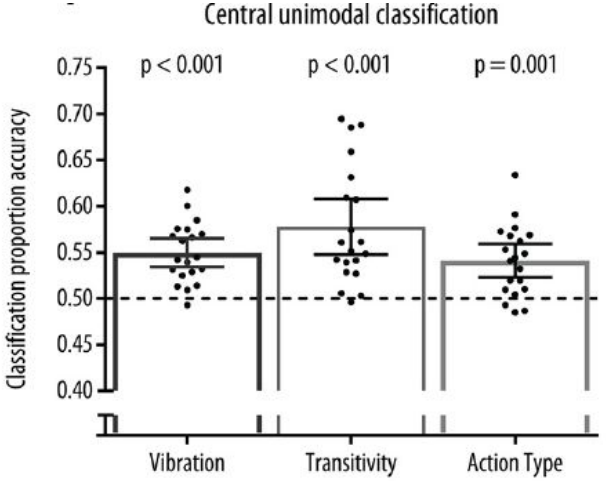
- Classification at **the source level** for the alpha band suggested that widespread sources mainly located in the frontal and parietal areas were responsible for the unimodal classification in all three conditions

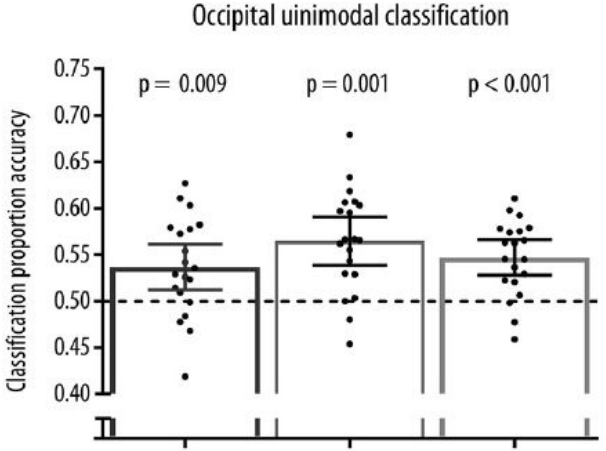


- In the **ROI analyses**, significantly above-chance classification accuracy was seen for all conditions at both the central and occipital electrode clusters

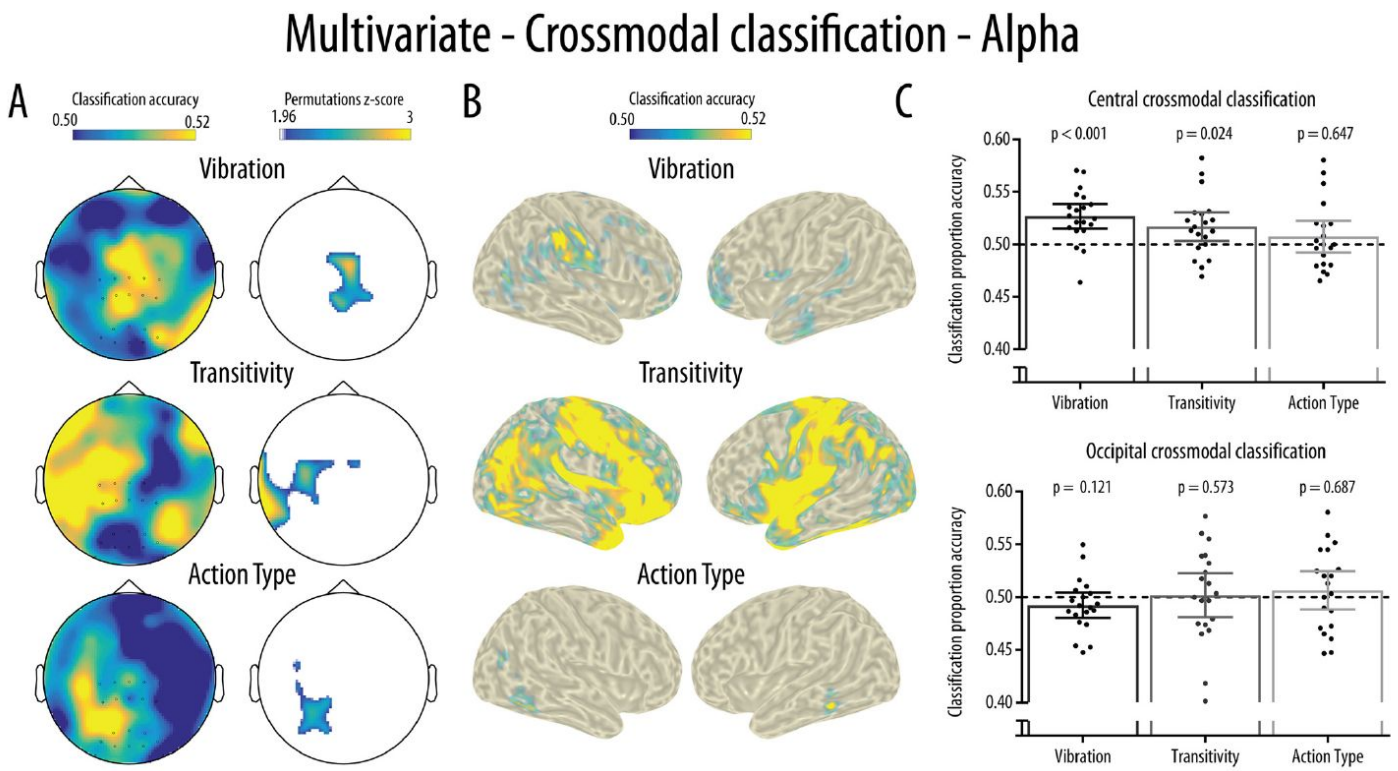
- A significant effect of Condition at the central cluster:
  - due to a significantly higher unimodal classification accuracy in the Transitivity compared with the Action type manipulation.

- There was no significant effect of Condition at the occipital cluster.



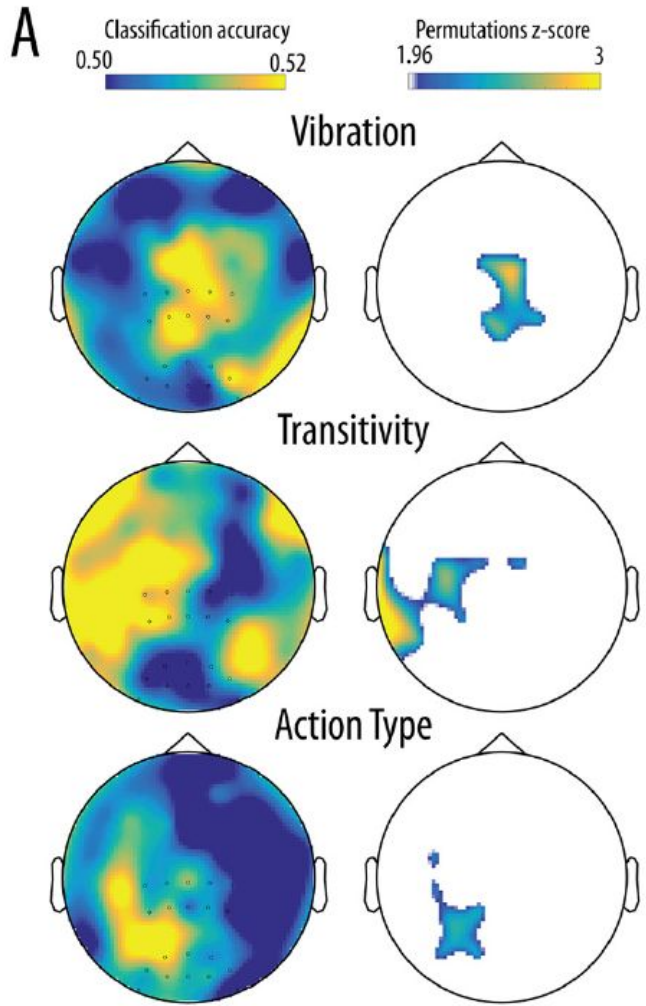


MVPA - Crossmodal classification



Results for the multivariate crossmodal classification for the alpha bands. A, Searchlight analyses at the channel level. B, Searchlight analyses at the source level. C, The ROI analyses

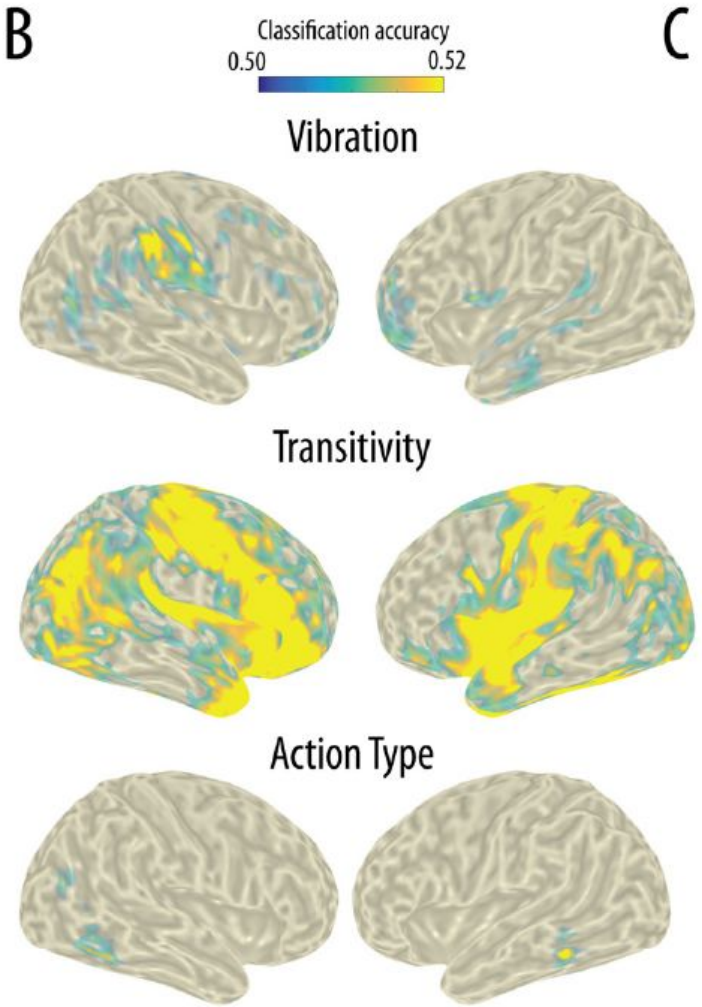
- The spatial searchlight analysis performed at the **channel level** revealed clusters of channels showing above chance crossmodal classification accuracy for the three experimental conditions.
    - For the **Vibration condition**, this cluster covered mainly central channels.
    - For the **Transitivity condition**, the significant cluster covered left central and temporal channels.
    - A cluster of left parieto-occipital channels showed above-chance classification in the **Action type condition**.



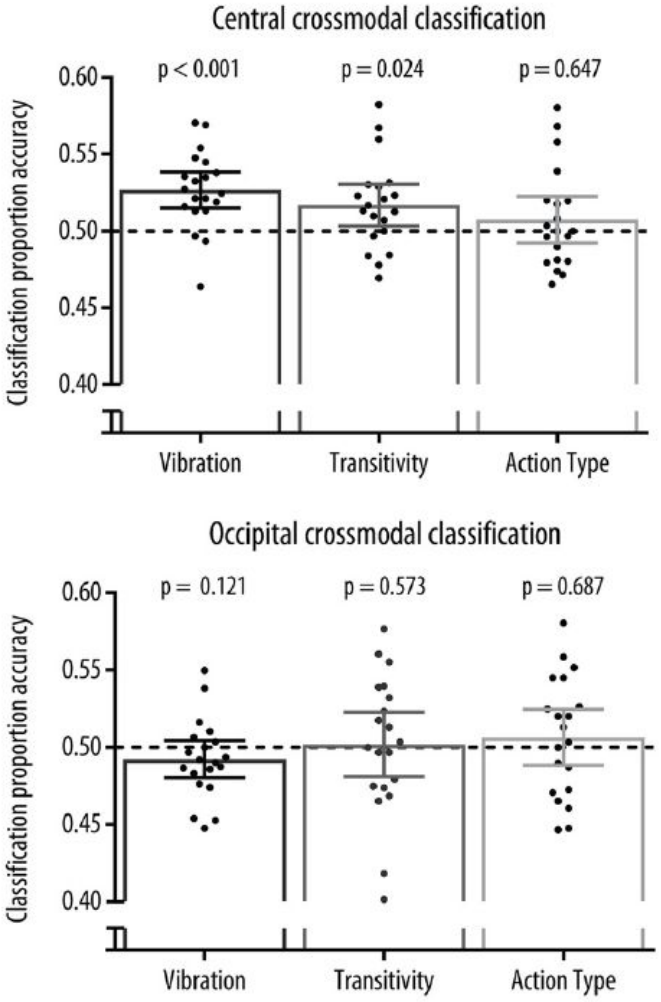
- The classification was not significantly above chance at the **source level**.

- Regardless of significance, source level analyses suggested that:

    - for the **Vibration condition**, a right parietal cluster partly covering the somatosensory cortex contributed most to the crossmodal classification.
    - In the **Transitivity condition**, sources generating the crossmodal classification were widely distributed mainly over frontoparietal areas.
    - Finally, for the **Action type condition**, small clusters located over temporal and occipital areas showed above-chance crossmodal classification.

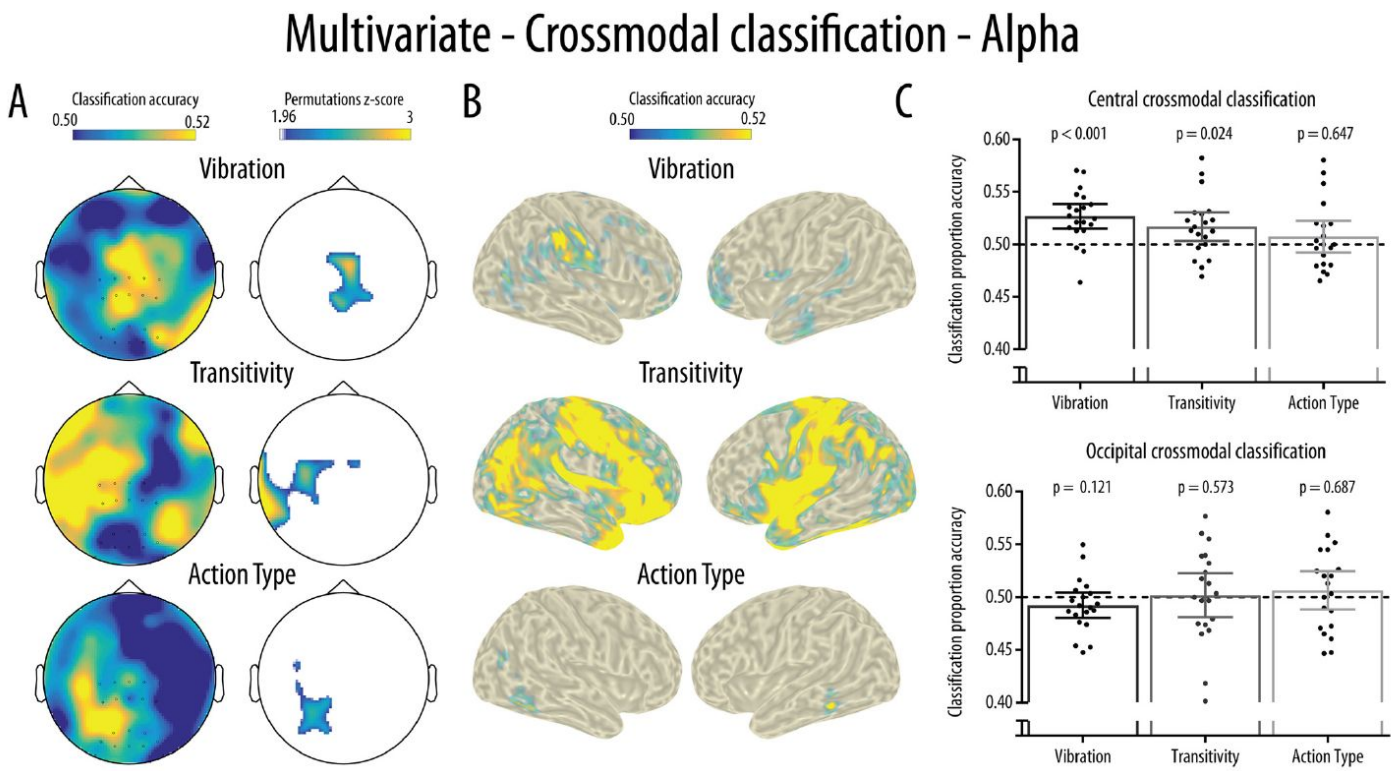


- The **ROI analyses** revealed that significantly above-chance crossmodal classification accuracy was reached only in the Vibration and Transitivity conditions and only at the central cluster.



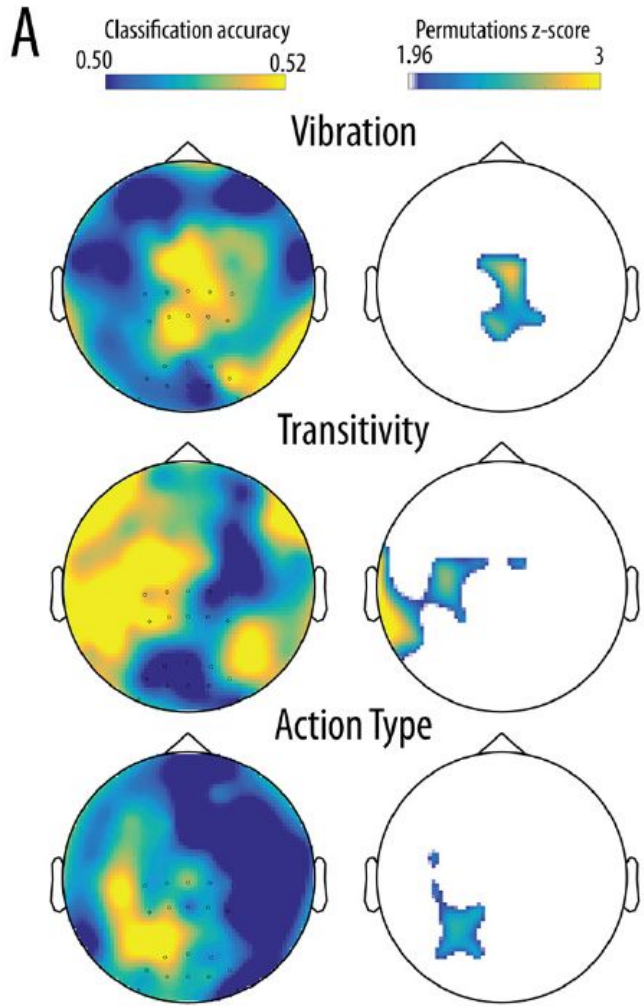
Discussion

MVPA - Crossmodal classification

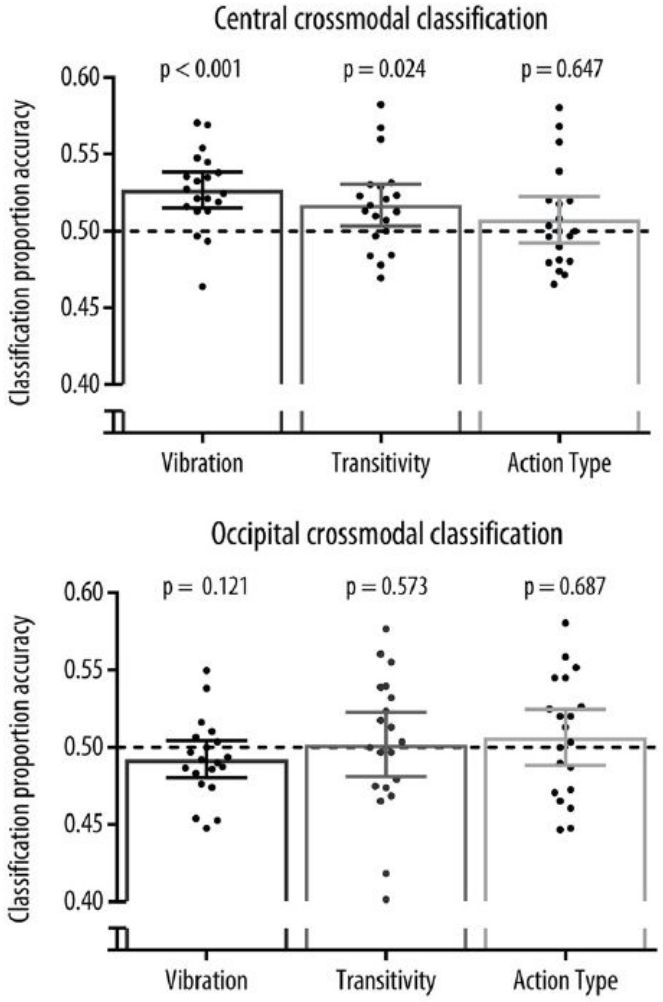


Results for the multivariate crossmodal classification for the alpha bands. A, Searchlight analyses at the channel level. B, Searchlight analyses at the source level. C, The ROI analyses

- Results from the crossmodal classification of mu rhythm response at the **channel level** were predicted by the tactile stimulation account
  - support the idea that the central mu rhythm shows **crossmodal specificity** primarily for the somatosensory features of observed and executed action.
  - Although exploratory searchlight analyses indicated significant crossmodal classification for all conditions, **central channels** contributed mostly to the classification of conditions showing strong variation in tactile features.
  - Crossmodal classification of action type was achieved for alpha-band activity that is not central, and not likely to be reflective of mirror neuron system activity.

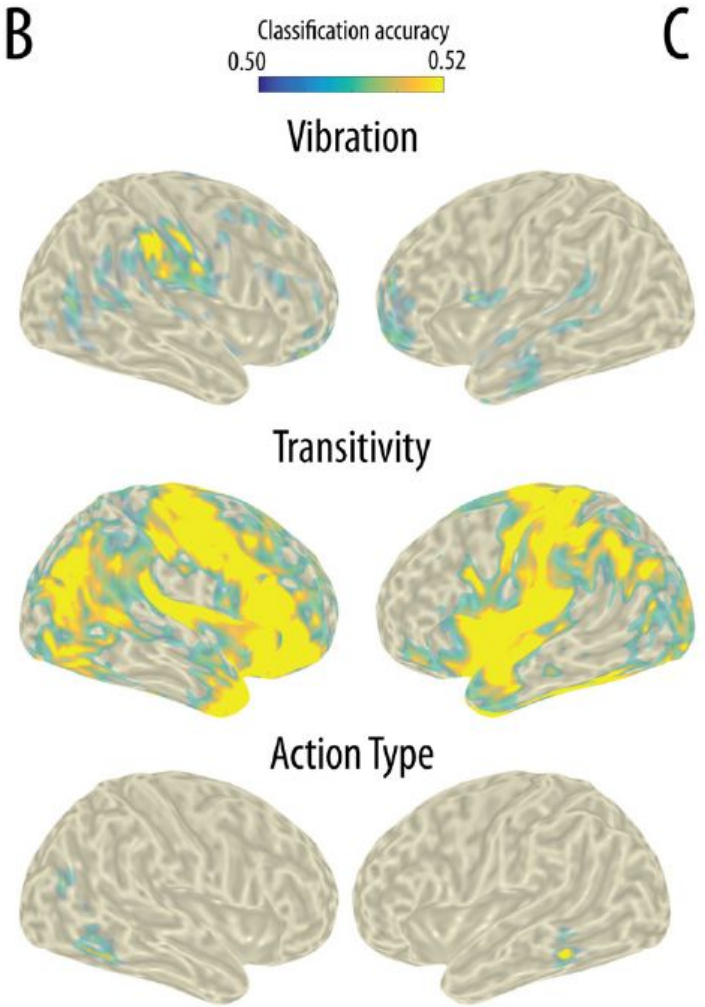


- **The ROI analyses** performed at a cluster of central channels revealed above-chance crossmodal classification only for the tactile stimulation and transitivity conditions, and significantly higher classification accuracy for the presence of tactile stimulation relative to the type of action.
    - The same analysis performed at the control occipital channels did not indicate any significant classification.

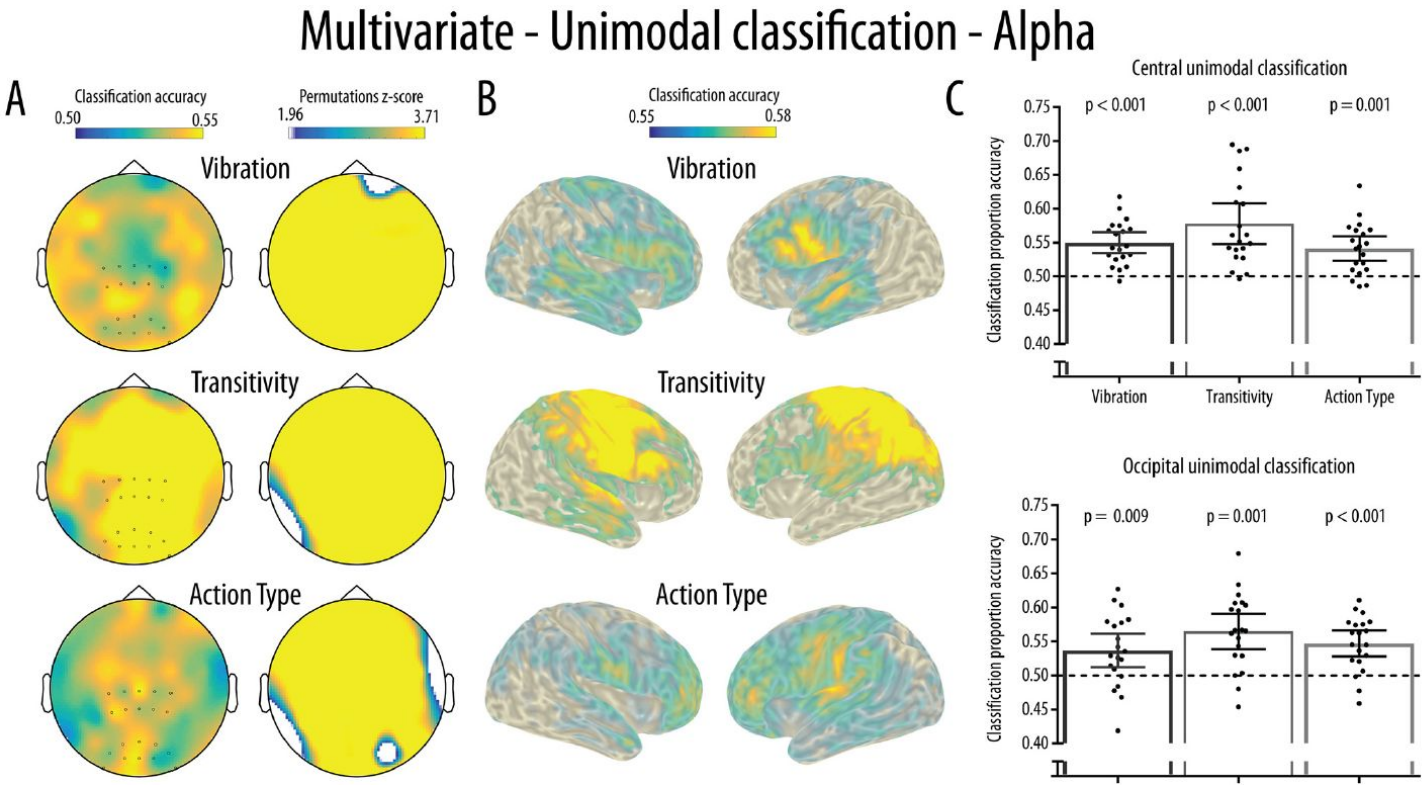


- However, the **source analyses** performed in the current experiment did not reveal any significantly above-chance crossmodal classification.
    - This should be interpreted with **caution** given that the lack of individual anatomical information make these statistical analyses highly conservative.

- **Nevertheless,** the visualization of crossmodal classification accuracy at the source level suggests that crossmodal classification of the mu rhythm response to tactile stimulation and transitivity was driven by frontoparietal sources, including somatosensory areas.



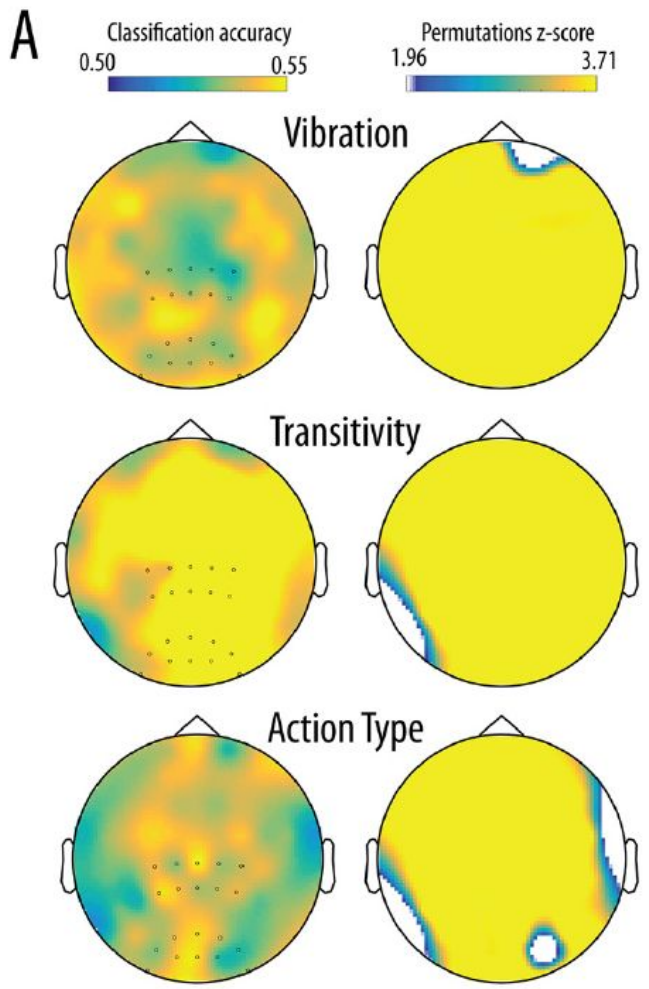
MVPA - Unimodal classification



Results for the multivariate unimodal classification for the alpha bands. A, Searchlight analyses at the channel level. B, Searchlight analyses at the source level. C, The ROI analyses

- The **unimodal classification** results suggest that the unimodal mu rhythm response shows little specificity.

- Indeed, classifiers trained and tested on trials of the same modality showed widespread above-chance classification at both channel and source levels



Univariate analyses

- Traditional **univariate analyses** applied to the same data were insensitive to differences between conditions.

- This suggests that the analytical approach used in previous research is **inadequate** to detect the specificity of crossmodal mu rhythm responses and is **insensitive** to subtle differences between conditions.
    - This was to be expected considering that, by averaging over all features of the data, this approach does not take into account differences in multivariate patterns that can differ between conditions and participants.

Conclusion

- The **first study to investigate** the crossmodal specificity of mu rhythm responses using multivariate classification.

- They show that crossmodal EEG mu rhythm responses primarily index the somatosensory features of actions, suggesting that **the mu rhythm is not a valid measure of mirror neuron activity.**

- Results may lead to **the revision of the conclusions of many previous studies**, and to the transition toward a theory of mu rhythm function that is more consistent with current models of sensory processing.

Thank you for listening!

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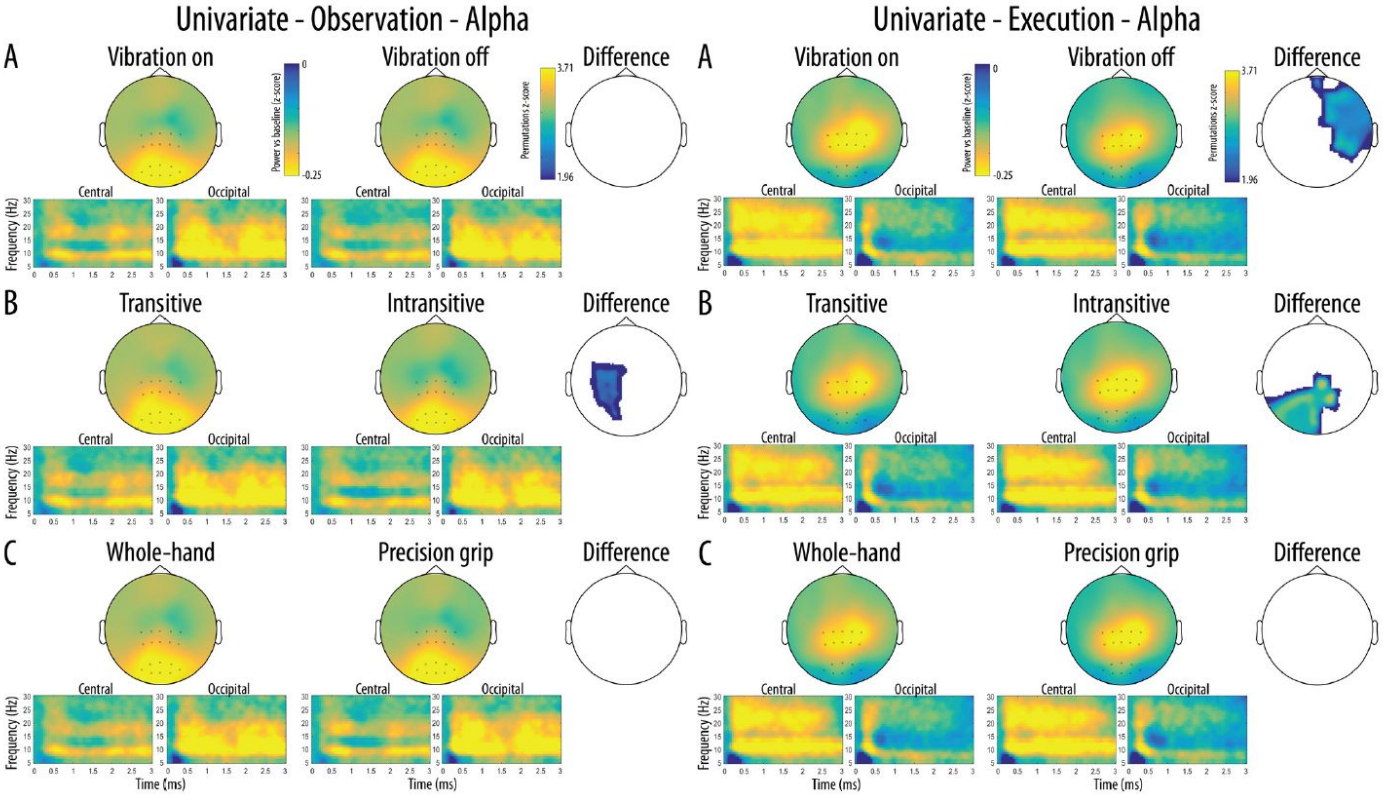
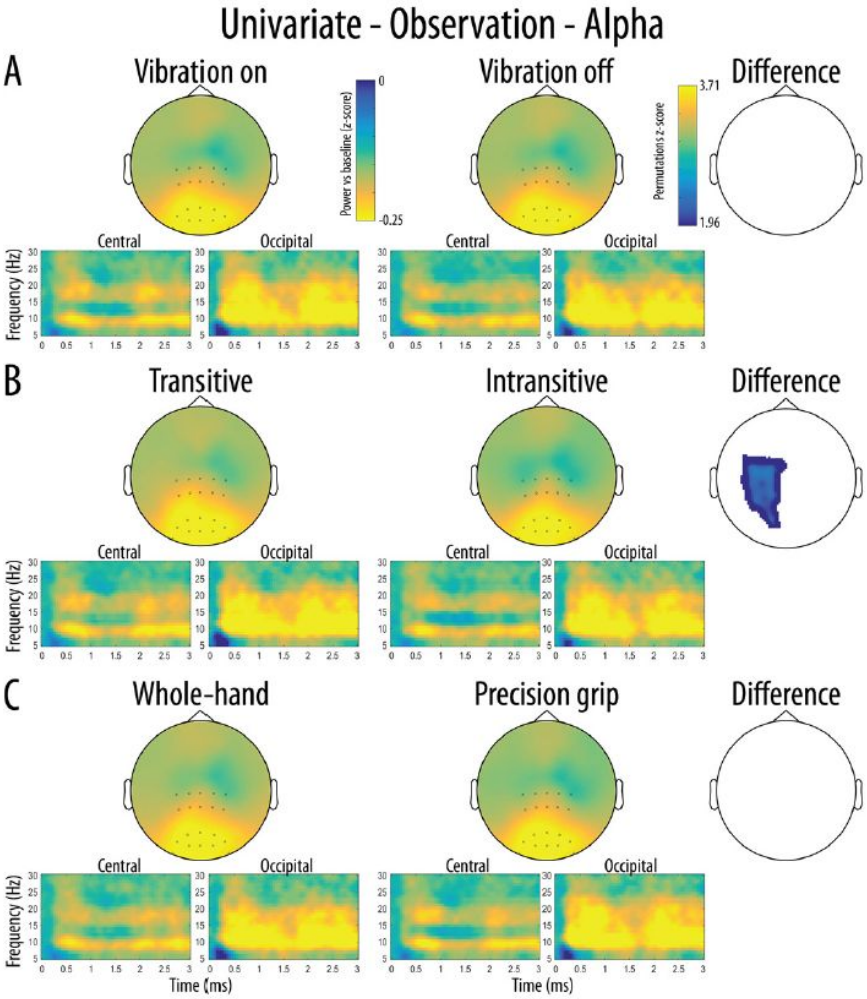
Additional Slides

Univariate Analyses

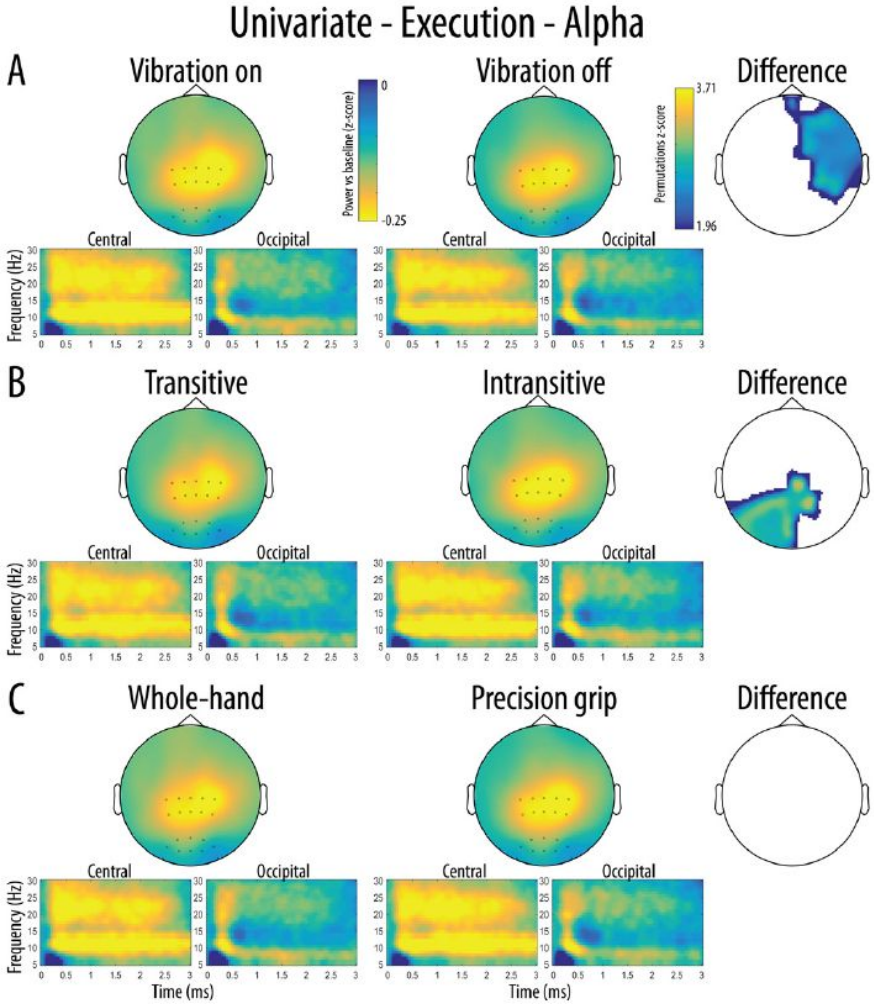


Scalp distribution of the alpha mu rhythm suppression relative to baseline for the two levels of each Condition as a function of Modality (Left, Execution; Right, Observation).

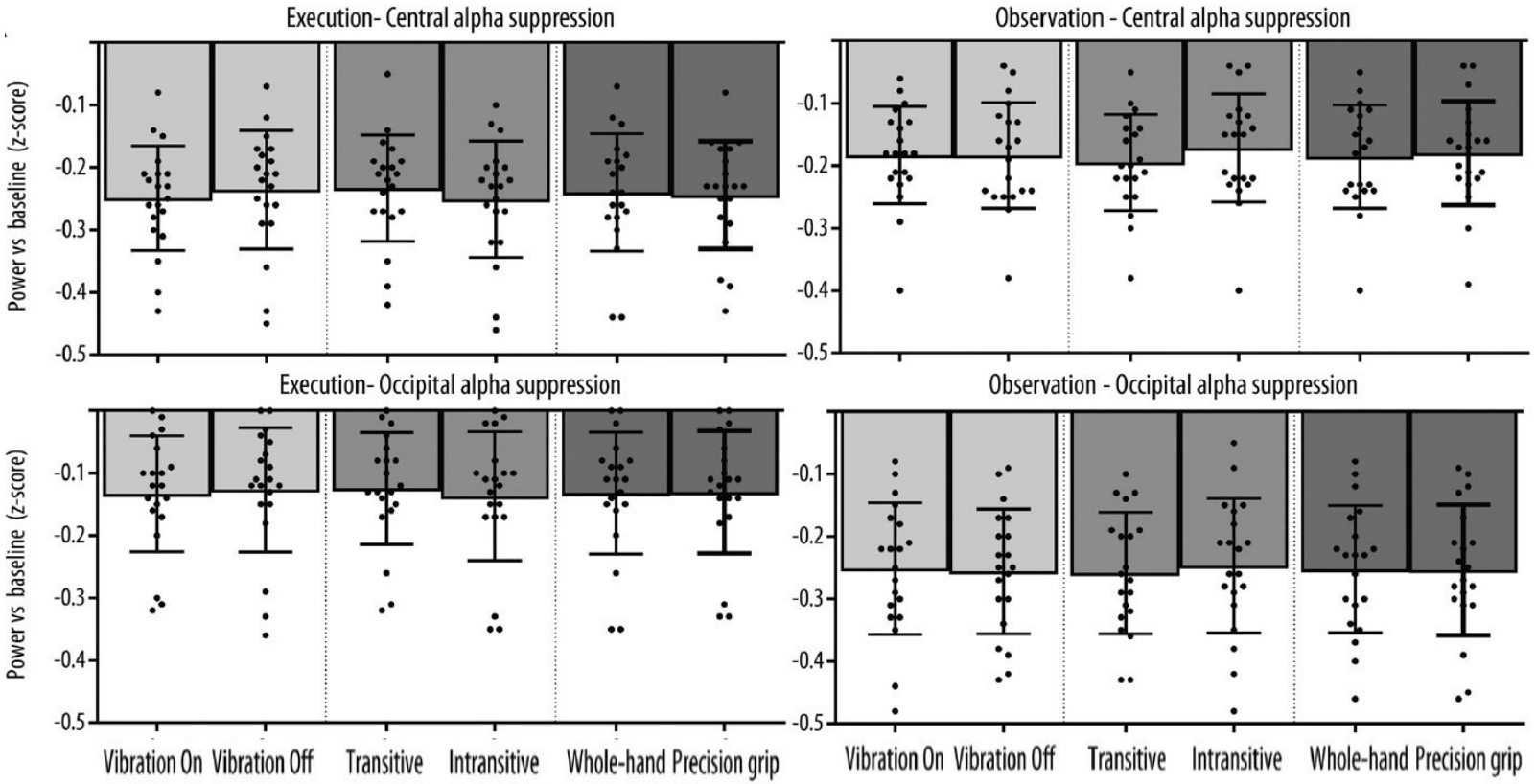
- Scalp distribution of the alpha mu rhythm suppression relative to baseline for **observation modality**:
    - significant main effects of Transitivity at a central left cluster of channels indicating stronger mu suppression.
    - No significant main effects of Vibration and Action type were found during observation.



- Scalp distribution of the alpha mu rhythm suppression relative to baseline for **execution modality**:
    - significantly stronger suppression for Vibration on trials in a large frontal-right cluster of channels
    - significantly stronger suppression for intransitive trials in a cluster of left central and parieto-occipital channels.
    - No significant main effect of Action type was found during execution.



Univariate Analyses



Mean alpha suppression relative to baseline for the two levels of each Condition as a function of Modality and Location.

- **significant Modality x Location interaction:**
  - The overall effect of the experimental conditions was stronger at the central relative to the occipital location in the observation modality
  - But not in the execution modality

- **significant Modality x Type interaction**
  - In the Transitive condition, transitive trials led to a stronger mu suppression relative to intransitive trials during observation
  - But the opposite effect was present during execution

- There was no significant main effects of Modality, Location, or Type and no other interaction reached significance.