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Differences in Mu rhythm when seeing grasping/motor actions in a real context versus on screens

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Mu rhythm (~8–12 Hz) in the somatosensory cortex has traditionally been linked with doing and seeing motor activities. Here, we aimed to learn how the medium (physical or screened) in which motor actions are seen could impact on that specific brain rhythm. To do so, we presented to 40 participants the very same narrative content both in a one-shot movie with no cuts and in a real theatrical performance. We recorded subjects' brain activities with electroencephalographic (EEG) procedures, and analyzed Mu rhythm present in left (C3) and right (C4) somatosensory areas in relation to the 24 motor activities included in each visual stimulus (screen vs. reality) (24 motor and grasping actions x 40 participants x 2 conditions = 1920 trials). We found lower Mu spectral power in the somatosensory area after the onset of the motor actions in real performance than on-screened content, more pronounced in the left hemisphere. In our results, the sensorimotor Mu-ERD (event-related desynchronization) was stronger during the real-world observation compared to screen observation. This could be relevant in research areas where the somatosensory cortex is important, such as online learning, virtual reality, or brain-computer interfaces.

Keywords Visual perception, Motor actions, Reality vs. screen, Neurocinematics

We perceive various others' body actions in narrative contents throughout the day. Observation (or even imagination) of those motor behaviors has an impact on our brain activities[1–3]. One of the most studied actions has been grasping[4–7]. It has been reported that human electroencephalographic Mu rhythm (~8–12 Hz), in somatosensory areas, changes while observing others doing motor activities such as grasping, holding, gripping, and tearing[1,8–10]. Observing facial expression has also been connected with Mu desynchronization (event-related desynchronization or ERD, referred to the decrease in the oscillation amplitude), suggesting a role of this rhythm in expression recognition[11,12]. Moreover, previous experience in developing specific tasks seems to be more influential on this Mu rhythm than observation of the task itself[13,14]. Besides, other brain rhythms have been studied in relation to grasping and action movements, such as occipital and central Alpha (~8–12 Hz)[15]or Beta (~13–35 Hz) rhythms[16,17]. Several studies have revealed neural correlates of grasping and other hand movements when doing them[18], when imaging them[19,20], or when looking at someone doing them[21]. Some of these studies have approached the desynchronization, ERD, in the Mu band in somatosensory cortex[22]. There are also studies that compare the modulation of brain activities while producing or observing social actions[23]. In the available literature, some of these stimuli are presented via screens, others are presented in real performance, and some are imagined by participants. The latter are especially related to brain-computer-interface (BCI) protocols[24]since action observation can be very useful to activate sensorimotor circuits through the mirror neuron system as a form of BCI feedback[25]. Also, it has been proven that motor imagery can be enhanced via synchronous action observation[26]. There are also studies comparing visual-alone or audio-alone vs. audio-visual experiences[27]. In accordance, the study of this brain rhythm when looking at a grasping movement has been of interest in the last years in both, real and screened contexts. On the other hand, despite being able to clearly distinguish between reality and screened content, we know little about cognitive and brain activity differences between the two conditions. In this regard, we have previously found that viewers' attention differs when watching narrative contents in films or looking at them in real performance, computed through the number of evoked eyeblinks[28], a well-known attentional marker. Screened narratives decrease viewers' eyeblink rate, suggesting an increase of

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attention compared with looking at the same narrative content in a real performance, which increases viewers' spontaneous eyeblink rate. Meanwhile, there has been a great development of various screened technologies used for creating audiovisual immersive and realistic environments: the so-called virtual-, augmented-, and mixed-realities, as well as metaverses, among others. These technologies involve a multimodal context of interactions where real actions are mixed with screened contents[29]. Finally, and despite several studies working to learn more about how the brain processes those virtual environments and to use most of them for BCI purposes[30–32], to our knowledge no study has compared brain electrical activities underlying the perception when seeing real performances versus on screens. Here, we joined both interests, the well-known impact that the act of grasping has on observers and the differences in visual perception between reality and screens. In accordance, this work was aimed to learn how the Mu rhythm of viewers differs when seeing motor actions made with the hands in a screened movie vs. through a real performance.

Results

We investigated whether the type of format in which motor actions were perceived (reality vs. screen) affected brain behavior.

First, we compared the impact that the onset of the grasp may have had on the Mu band (8–12 Hz) at C3 and C4 electrodes, in both conditions (reality and screen), taking before (from − 500 to 0 ms) and after (from 0 to 1000 ms) the onset as parameters. In the reality condition, we found a significant decrease of spectral power in both C3 ($Z = 2.312$, $p = 0.02$, Wilcoxon signed-rank test) and C4 ($Z = 3.643$, $p = < 0.001$, Wilcoxon signed-rank test) electrodes. In the screen condition, we found a significant decrease of power in C3 ($Z = 2.151$, $p = 0.031$, Wilcoxon signed-rank test), but not in C4 ($Z = 1.196$, $p = 0.237$, Wilcoxon signed-rank test) electrodes (Fig. 1).

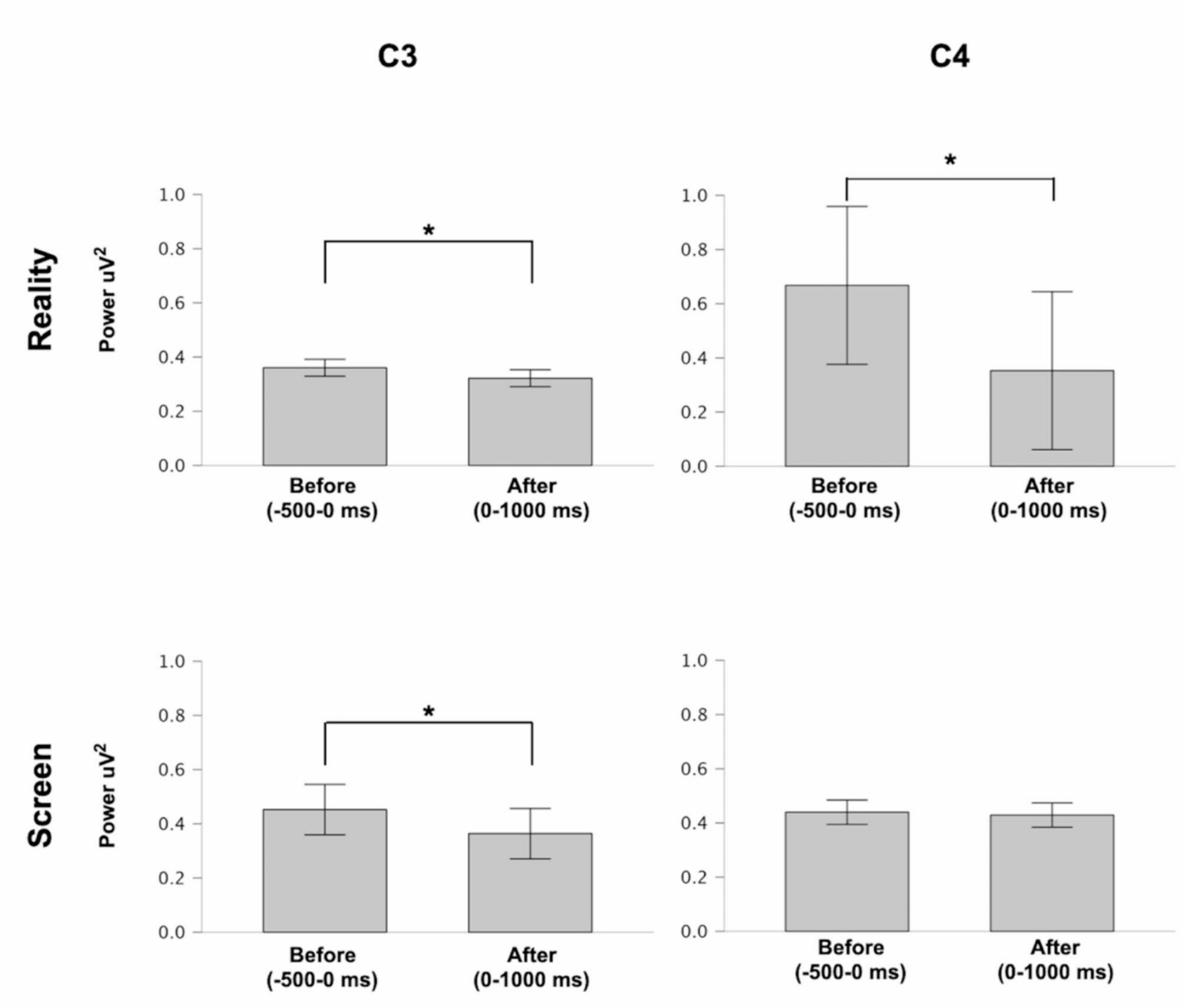

Fig. 1. Mean power spectra (μV^2) in the alpha band (8–12 Hz) and confidence interval (95%) in C3 (left hemisphere) and C4 (right hemisphere) electrodes, where there are classical Mu rhythm sites, before and after the onset of a grasping activity, in both studied conditions: reality and screen. (Paired t-test). *, $p < 0.005$.

Then, we compared spectral power differences between the two conditions (reality vs. screen) in the Mu band before (-500 – 0 ms) the onset of the motor actions in C3 ($Z = 1.882$, $p = 0.061$, Wilcoxon signed-rank test) and C4 ($Z = 0.605$, $p = 0.550$, Wilcoxon signed-rank test) electrodes, with no significant differences as a result. However, the differences we found after the onset of the motor activities (0 – 1000 ms) were significant in C3 ($Z = 2.245$, $p = 0.025$, Wilcoxon signed-rank test), and almost significant in C4 ($Z = 1.949$, $p = 0.052$, Wilcoxon signed-rank test), with lower power activity in reality in both hemispheres.

We computed event-related spectral perturbations (ERSPs) in real performance and screened conditions and compared them with a paired t-test looking for significances ($p < 0.05$). We used common baseline across factors. We found significant differences in 9–14 Hz at around 400–1500 ms after the motor actor started in C3 and C4 electrodes (Fig. 2). When looking at differences in the power spectral density (PSD) function (Log Power $10^*\log_{10}(\mu V^2)$) in C3 and C4, we found statistically significant differences in both electrodes at around 8–12 Hz. In all cases, when significant differences were found the activity when looking at real performances was lower than when watching screened contents (Fig. 3).

Regarding event-related desynchronization (ERD), in the C3 electrode this was [% (±SEM)] -10.9 (±3.818) for in-reality and −11.491 (±4.306) for on-screen; while for the C4 electrode it was −18.198 (±4.295) for in-reality and −4.909 (±5.286) for on-screen. We did not find significant differences in ERD in C3 ($t_{(39)} = 0.129$, $p = 0.898$, paired t-test), but we found significant differences in C4 ($t_{(39)} = -2.039$, $p = 0.048$, paired t-test) (Fig. 4).

Discussion

Seeing others doing motor actions modulates our brain processes. In part, films and performing arts are based on the impact artists and creators have on spectators. In recent years, neuroscientists have studied how looking at someone carrying out a motor action (such as grasping an object) modifies brain activity[33]. In fact, these brain activities have been linked with the mirror neuron system in various studies[1,15,21,34–37]. So far, these studies have been performed in laboratories around the world without further attention to the format of the stimuli, e.g., videos or real performing. As yet, those results have not been compared. Here we proposed to analyze differences

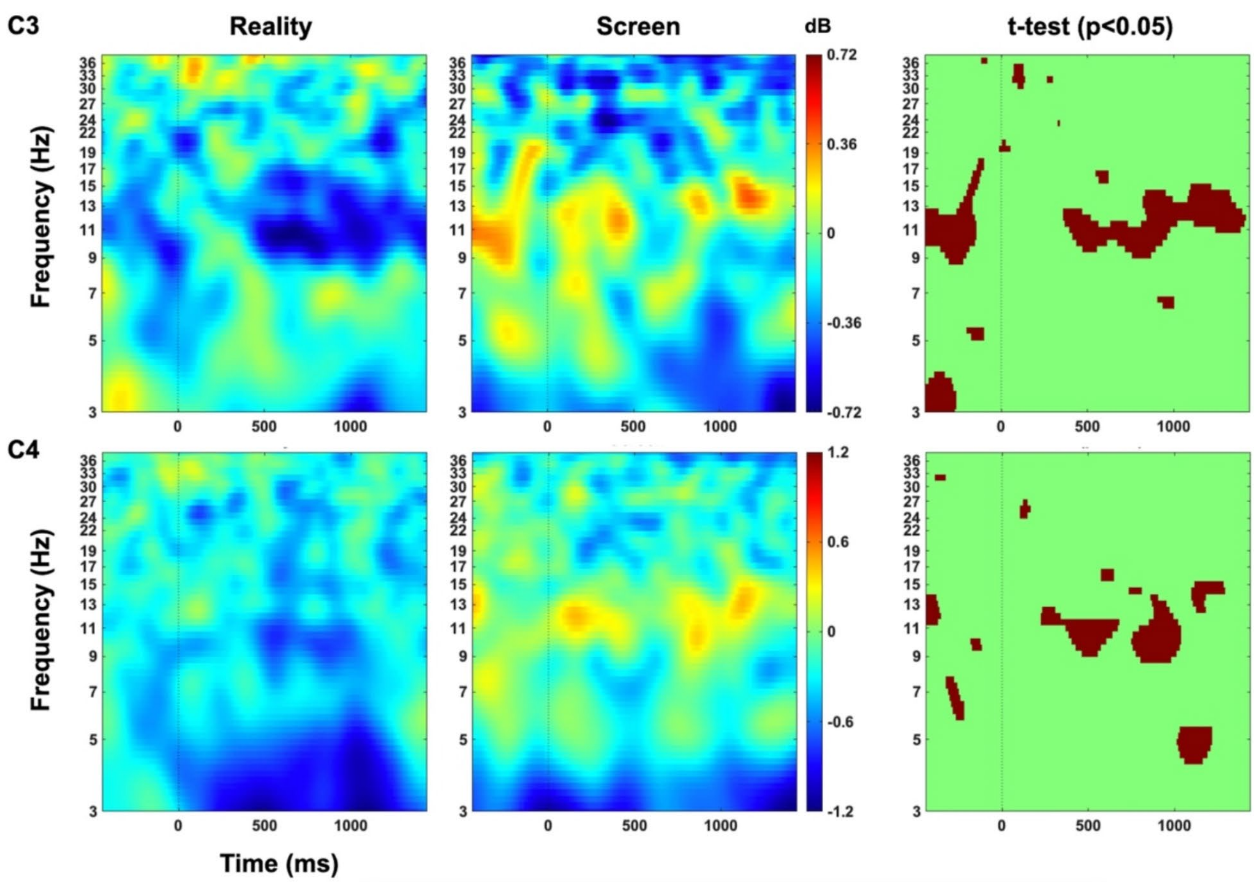

Fig. 2. Event-related spectral perturbations (ERSPs) in C3 (upper) and C4 (lower) electrodes when looking at motor activities in real performance (left) and in a screened movie (middle). The right images show a paired t-test comparison between the two conditions. The comparison was done per frequency (y-axis) and time (x-axis) with 200 time points (a time point per 10 ms). The comparison image (right side) shows the result of the paired t-test comparison showing in green non-significant differences and in brown significant differences, taking significance as p-value < 0.05.

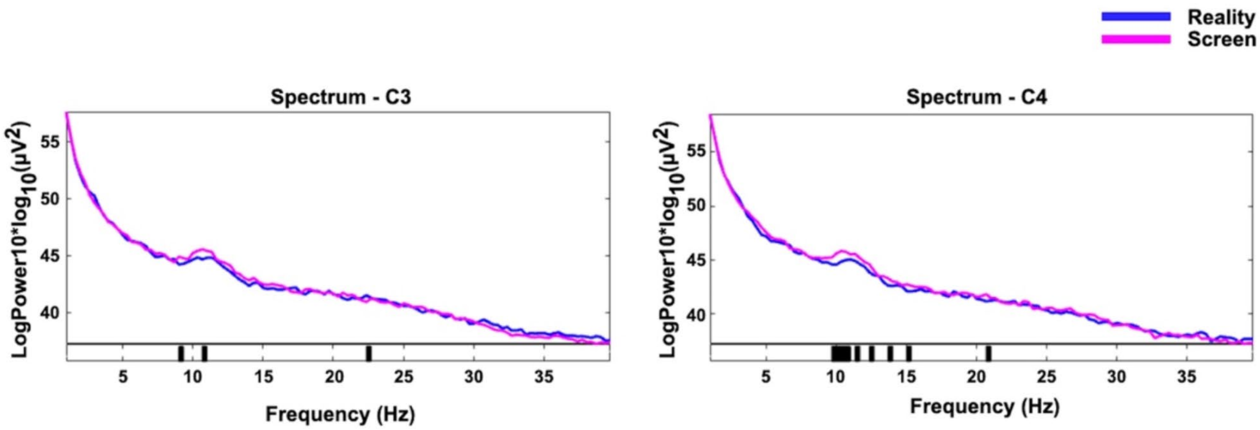

Fig. 3. Power spectrum density (PSD) in C3 (left) and C4 (right) electrodes when looking at motor actions in a real performance (blue lines) and a screened video (pink lines). Black vertical lines on the x-axis indicate significant differences between the two conditions (paired t-test, $p < 0.05$). Note that we found significant differences in the 8–12 Hz band.

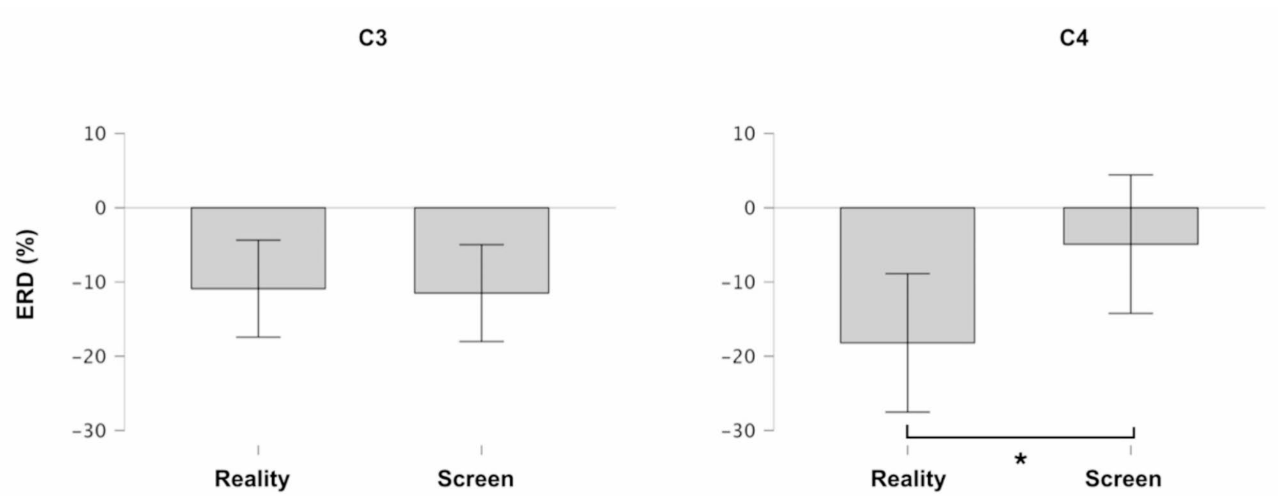

Fig. 4. Event-related desynchronization (ERD) in the Mu band [% (± SEM)] in left and right somatosensory area (C3 and C4 electrodes, respectively)[1] when looking at motor actions after the onset of the grasp (0 − 1000 ms), taking the period − 500 − 0 ms as a reference. (Paired t-test). *, $p < 0.05$.

in brain activity when seeing someone doing motor activities such as grasping objects with their hands in a real performance versus in a screened video. As expected, we found that seeing grasping actions decreases the Mu band in left and right hemispheres of the somatosensory cortex during both reality and screen conditions, with a significant decrease in all comparisons, except for the right hemisphere (C4) electrode in the screen condition. Interestingly, when comparing that brain activity at those frequencies (8–12 Hz) before the presentation of the motor action, we did not find significant differences between real and screen condition, suggesting that without grasping/motor actions, the somatosensory cortex is not affected in this rhythm by the type of format/medium (real performance or screen) in which the content is presented. However, we found differences in C3 and C4 electrodes after the onset of the grasping/motor action (more pronounced in left hemisphere), always with a lower activity in real performance, suggesting that during the perception of grasping/motor actions, Mu rhythm is affected by the medium in which those actions are presented. In terms of ERD, reality in the right hemisphere showed the greatest impact. All these results indicate that reality decreases the Mu band in a more impactful way than screens do. These results may have an effect in several areas, such as online learning, virtual reality, and BCI.

Online learning has increased drastically in the last few years, especially after the Covid-19 pandemic. In fact, online communication is an extremely common practice in society today. Previously, the use of screens for communication in children has been negatively associated with language learning[38]or comprehension[39], among other cognitive functions. However, since the Mu rhythm has already been found in infancy[40–43], based on our results, online learning should be rethought, because of the apparently lower impact on the Mu rhythm of screens compared with real communication.

At the same time, different immersive video formats have appeared intended to faithfully imitate reality. These formats include virtual reality, also known as VR, augmented reality (or AR), mixed reality, videos in 360º, and — more recently — Mark Zuckerberg has made the concept of metaverse fashionable[44], even though the metaverse, such as virtual environments, had already been implemented by industry and studied by academics in the last few decades[45]. Since the final goal of all these immersive worlds seems to be making the virtual or screened interaction as real as possible, such technologies could benefit from our results here, according to which mediated presentations do not have the same impact in the somatosensory area as real presentations, suggesting that these virtual environments attempting to imitate reality may never achieve provoking the same impact on viewers. Further research with these new environments should be done.

Finally, the context of the BCI quite frequently uses this Mu rhythm in the somatosensory cortex to create triggers that activate the digital systems[46], based somehow on the idea of translating the thinking (the "seeing" and/or "hearing") into the action[47]. Recently, training in the Mu rhythm[48]has been used in BCI communication with intellectually impaired autistic children[49]. By learning differences in this brain rhythm in real and screened conditions, training protocols in BCI could be designed to make the most of it based on the impact of the medium. Moreover, analyzing the impact of that training with screens or in reality could also be useful for people with motor impairment such as Parkinson's patients[50].

Regarding the limitations of our study, we did not find symmetrical ERD in both hemispheres. This could be due to the contralateral characteristics of Mu rhythm as described previously[51]. This points out that we did not ask participants their handedness. Also, we did not pay attention to the hand that the actor used for carrying out his motor/grasping actions. Both parameters would be crucial to analyze the asymmetrical ERD between hemispheres. Further research should be done paying attention to this point.

Some other limitations and considerations must be mentioned in this study. First, we did not analyzed female – male differences. Previous studies have found sex differences during the execution and observation of simple motor actions[52], and the effect of female sex steroids have on executive movement control[53], but since the sample was not equally distributed and we did not ask female participants about their menstrual cycle, we decided not to consider sex as a potential factor in our study. Related to this, another limitation could be the fact that the actor was a male. In future studies in which sex could be a factor, it would be worth it to consider designing stimuli with female and male actors. On the other hand, in this study, we have used a relatively low spatial resolution EEG system compared with previous works using electrocorticography with intracranial recordings comparing action observation and execution[54], visuo-motor execution and perception with speech execution and perception[55], or finally recording extracellular activity from neurons comparing execution and observation of actions[56], providing much higher precise spatial information. Thus, even if, in general terms, our results coincide with those more precise ones, bringing potential use in scientific investigation and/or clinical rehabilitation in humans with a more unexpensive and non-invasive protocol, further studies using more precise techniques should be done.

In conclusion, the fact that the Mu rhythm differs in real environments compared with screened contexts suggests that it may be of interest to be taken into account in designing research and industrial protocols based on reality perception and brain activity.

Materials and methods

Participants. A total of 40 participants [28–56 (43.75 ± 7.837) years old] took part in this study. Nine of them were females. All had normal or corrected-to-normal visual acuity. Subjects did not receive any economic compensation. The studies involving human participants were reviewed and approved by the Ethics Commission for Research with Animals and Humans (CEEAH) of the Universitat Autònoma de Barcelona, Barcelona (Spain). All experiments were performed in accordance with relevant named guidelines and regulations. All the participants provided a written informed consent to participate in this study. A limitation of this study is that we did not ask handedness to participants.

Stimuli and procedure. We created two stimuli with the same narrative but different formats: (1) a one-shot movie with no camera movements; and (2) a real performance. The movie had a duration of 198 s. In the case of the real performance, since it was represented each time for each participant, the intended duration was ≈ 198 s, but in fact it lasted 205.56 ± 12.802 s (M ± SD). The narrative included 24 grasping/motor actions that were used as triggers to analyze participants' brain activities. Selected motor actions included grasping a chair, grasping juggle balls, grasping a zip, grasping a PC, grasping a book, grasping a torch, grasping an apple, and moving the hand across the face (Fig. 5).

The video stimulus was presented on a 42-inch HD Led display (Panasonic TH-42PZ70EA), and participants were placed at 150 cm from the screen. The theatrical stimulus was presented at ~ 300 cm from each subject. Stimuli were presented with Paradigm Stimulus Presentation (Perception Research System Inc.). To maximize the similitudes between the two conditions (movie and theatre) we created an ad-hoc structure for presenting video stimuli and real performance with the context as similarly as possible. Participants were asked to look at the visual stimuli with no further instructions other than that a questionnaire would be asked subsequently. At the end of the experimental session, we presented a distractor questionnaire without interest for the research.

Data acquisition. Continuous EEG recordings were acquired with the help of a wireless system (Enobio, Neuroelectrics), with 20 electrodes placed according to the International 10–20 system [O1, O2, P7, P3, Pz, P4, P8, T7, C3, Cz, C4, T8, F7, F3, Fz, F4, F8, Fp1, Fp2, and an external electrode used for electrooculogram (EOG) recording]. EEG electrodes were referenced to electronically linked mastoid electrodes [see[57] for details]. Data were sampled at 500 Hz. We recorded facial expressions of participants with an HD video-camera (Panasonic TH-42PZ70EA, Panasonic Corporation, Osaka, Japan) for contrasting participants' behavior during the sessions.

Fig. 5. Some examples of a motor action (grasping) presented as stimuli: a man grasps a chair; a man grasps three balls; a man grasps a computer; and a man grasps an apple.

Data analysis. EEG data were processed using EEGLAB[58] software version 2022.1 running on MATLAB R2022b (The MathWorks Inc., CA, USA) under a macOS Ventura 13.2.1 (Apple Inc., CA, USA). We used a spherical BESA template for channel location. We band-pass filtered the data between 0.5 and 40 Hz. We computed average reference of the data. We removed bad channels when needed, but no C3 or C4 were removed. We decomposed data with an ICA analysis (infomax algorithm) and got rid of artefactual components, including the activity of the extraocular muscles. We made 3 s epochs with 1 s before and 2 s after the onset of the motor activity, marked with triggers, using the previous 1000 ms as baseline. In total, we had 40 participants that attended 24 motor actions in each one of the two conditions (movie and performance), making a total of $40 \times 24 \times 2 = 1920$ potential trials of 3 s each. We rejected bad epochs through visual inspection. We rejected a total amount of 225 trials (11.72%) out of the 1920 potential ones. Those epochs that were rejected had the following distribution: 119 in real condition and 106 in screen condition. Overall, we used 1695 trials (88.28% of the potential ones), distributed as follows: in the real condition we used 841 epochs (87.60%) and in screen condition we used 854 epochs (88.96%).

We analyzed data as follows. First, we computed spectral activities between 8 Hz and 12 Hz (Mu band) registered by C3 (left) and C4 (right) electrodes and compared them using a Wilcoxon signed-rank test before (− 500–0 ms) and after (0–1000 ms) the onset of the grasping/motor actions, in both conditions namely, reality and screened stimuli. Note that for all situations, we took such short periods for before and after conditions because the grasping actions were inserted in a fluid narrative and were not isolated grasping movements. If longer periods of time were taken, other narrative activities could contaminate the data of interest. For a normality test we used the Shapiro Wilk. Then, we computed the ERSP and the PSD along the whole epoch [− 1000–2000 ms] for those electrodes and compared them throughout the conditions of reality and screen. PSD was obtained using Welch's method with Hamming window within EEGLAB software running on MATLAB. We used EEGLAB's spectopo.m function. Since we knew in advance where (at which sensor) and when the effect may be observed[59], we computed paired t-tests with a significance of $p < 0.05$. Both parameters are good to explore not only the frequency of interest, but others.

We obtained percentage values of ERD, based on the formula $ERD\ (\%) = (A - R)/Rx100$, where A is the power within the frequency of interest (we analyzed 8–12 Hz) in the period after the onset of the grasp (we analyzed 0-1000 ms), and R is the preceding baseline or reference period (we used $-500 - 0$ ms), following previous works[60]. We computed paired t-tests with a significance of $p < 0.05$.

Data availability

The datasets generated during and analyzed during the current study are available from the corresponding author on reasonable request.

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Author contributions

CA-S, MÁM-P, AG, and JMD-G did the experimental design and contributed to the article. CA-S and MÁM-P carried out experiments and data analyses. All authors wrote the article and approved the submitted version.

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Declarations

Competing interests

The authors declare no competing interests.

Competing interests

The author(s) declare no competing interests.

Additional information

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