

Differential cortical activation during observation and observation-and-imagination

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Abstract The activity of the brain during observation or imagination of movements might facilitate the relearning of motor functions after stroke. The present study examines whether there is an additional effect of imagination over observation-only. Eight healthy subjects observed and observed-and-imagined a movement of a hand; 64-channel EEG was used to measure brain activity. The synchronization of the theta (4–8 Hz), alpha (8–13 Hz) and beta (13–25 Hz) frequency bands was calculated and plotted in topoplots. The temporal changes of the sensorimotor area (C3, C4) and the centro-parietal cortex (Pz) were analyzed in the two experimental conditions. During observation-and-imagination, a significant larger desynchronization ($p = 0.004$) in the sensorimotor area was found compared to observation-only in all electrodes and frequency bands. In addition, temporal differences were found between observation and observation-and-imagination in the alpha frequency bands. During observation-and-imagination, modulations of EEG rhythms were stronger than during observation-only in the theta, alpha and beta frequency bands and during almost the whole activity fragment. These findings suggest an additive effect of imagination to observation in the rehabilitation after stroke.

Keywords Mirror neuron · Imagination · Observation · EEG · Event-related synchronization

Introduction

Neurophysiological experiments in animals and humans have shown that similar brain areas are activated during execution and observation of a movement. These experiments point to “a functional equivalence” or “shared motor representations” between the cortical processes underlying movement observation and execution (Babiloni et al. 2001) and are thought to represent the “observation–execution matching system.” These “mirror-like” properties of the brain are found during both observation and imagination of movements (Jeannerod 2001; Calmels et al. 2006). However, these concepts concern different tasks. Movement observation is defined as the perception of the actions of others. Motor imagery can be defined as “the covert cognitive process of imagining a movement of your own body(-part) without actually moving that body(-part)” (De Vries and Mulder 2007).

The activity of the brain during observation-and-imagination is thought to be important for the development of language (Rizzolatti and Craighero 2004), the understanding of mimics and empathy during social interaction (Schulte-Rüther et al. 2007) and in the relearning of motor function. This latter function is probably relevant in neurological patients, where movement observation or imagination is found to improve the relearning of motor skills (Dijkerman et al. 2004; Ertelt et al. 2007; Page et al. 2007).

Several studies in healthy subjects explored differences between imagination and observation. In an fMRI study, the differences between imagination and observation were studied in healthy subjects by analyzing the blood

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oxygenation level–dependent (BOLD) activations (Filimon et al. 2007). During both observation and imagination of a reach movement of the right arm, activations of the intraparietal sulcus, the superior parietal cortex, the precuneus and the dorsal premotor cortex were found compared to a baseline condition. These activations during both tasks were stronger in the left hemisphere. During imagination, the inferior parietal lobule, the posterior end of the sylvian fissure, the supplementary motor cortex and the inferior frontal gyrus were activated, as well. Grafton et al. (1996) examined the differences between observation and imagination using PET scans. They also found an activation of the dorsal premotor cortex during both tasks. In addition, they found the inferior frontal cortex, the inferior parietal cortex and the supplementary motor area to be active during both tasks. During observation, the rostral superior temporal sulcus was activated while during imagination the middle frontal cortex was active. In accordance with the study of Filimon et al. (2007), most activation was measured in the left hemisphere. Grafton et al. (1996) found that movement observation and movement imagination almost coincide, except for the fact that the extent and intensity of activation were stronger during imagined grasping (Grafton et al. 1996). Methodological differences between these studies, like different movements to be imagined, or different imaging techniques to be used, might explain why Grafton found more areas to be activated.

When the corticospinal excitability is compared between observation, imagination and imitation, imitation was found to induce a larger increase in the corticospinal excitability compared to imagery or “passive observation” (Léonard and Tremblay 2007). Roosink and Zijdwind (2010) found an increased corticospinal excitability during active observation (observation with intention to imitate) compared to passive observation (without prior instructions). In patients suffering from a motor conversion disorder, a difference between the corticospinal excitability during movement observation and movement imagination has been reported too. The corticospinal motor excitability was increased during movement observation, similar to healthy subjects, while the excitability was decreased during imagination of own body movements (Liepert et al. 2011).

Several EEG studies examined the effects of observation or imagination on changes in the power of predefined frequency bands. In the EEG, the μ -rhythm (between 8 and 15 Hz) is generated by the sensorimotor cortex and is most prominent during rest, while it is suppressed during active movements. Similar to the fMRI and PET studies, during observation-and-imagination of finger movements, the activity in the premotor and primary sensorimotor cortex was found to modulate (Pfurtscheller and Lopes da Silva 1999; Cochin et al. 1999; Babiloni et al. 2002). During observation of finger movements, a significant decrease

was found in spectral power in the low-alpha frequency band (7.5–10 Hz), compared to rest. During imagination of a wrist extension, the rhythms in the alpha frequency band attenuated over the sensorimotor cortex. This event-related desynchronization (ERD) appears similar to the ERD found during the execution of the movement. However, the ERD amplitude was larger during the execution (Bai et al. 2008).

In addition to the attenuation of the alpha frequency band during the execution of a voluntary movement, β -desynchronization (15–25 Hz) over the Rolandic region can be observed. In a study of Babiloni et al. (2002), ten healthy subjects had to execute an aimless movement of the middle finger, whereafter they had to look at another person executing the same finger movement. This study found a decreased power in the beta frequency band during movement execution and movement observation, while the power of this frequency band increased during the post-movement period. Another study examined the behavior of the beta frequency during imagination of wrist extension. A desynchronization of the beta frequency (20–24 Hz) was found on the contralateral left hemisphere over the sensorimotor cortex and the supplementary motor area (Bai et al. 2008). Desynchronization becomes bilaterally symmetrical just before the execution of the movement, indicating a role of these regions in the planning of the movement. Although no planning is involved in movement observation, desynchronization of the beta frequency during the observation of a movement has been reported.

The effects of the addition of imagining or observation of a movement to the rehabilitation therapy of motor function after stroke have been examined in several studies. Ertelt et al. (2007) studied the effects of action observation on rehabilitation of motor deficits after stroke. They found “pieces of evidence that action observation has a positive additional impact on recovery of motor function after stroke by reactivation of motor areas, which contain the action observation/action execution matching system” of the brain. Page et al. (2007) also found support for the efficacy of incorporating mental practice of specific arm movements for rehabilitation of motor function in patients with chronic stroke, when compared to a placebo condition. Schuster et al. (2012) also demonstrated an additional effect of “motor imagery” on the recovery of motor function after stroke when measuring the motor function. These results suggest an active role of observation and imagination for the rehabilitation after stroke. Therefore, theory as well as intervention studies confirms the possibility of recovery of motor function by imagination or observational training.

Since observation-and-imagination concern different tasks, the question remains which of both tasks is best to be used in the rehabilitation after stroke. Therefore, the present study examines whether there is an additional effect of imagination over observation-only. In order to better

understand these potential additional effects, we study if temporal and spatial differences are present using high-density electroencephalography (EEG).

Methods

Subjects

Eight healthy, right-handed subjects (3 male, mean age 27.1 years) participated in the study.

Experimental protocol

Subjects watched a movie consisting of 64 fragments showing intermittently an aimless hand movement and a baseline condition. The total time of the movie (14 min) was divided into 2 blocks of 7 min with a break between the blocks, to decrease the influence of drowsiness. The whole movie was shown twice: once the subject was asked to observe the movement and once the subject was asked to imagine the movement. The order of observation (obs) and observation-and-imagination (obs-and-ima) was randomized between subjects.

During obs-and-ima, subjects were asked to imagine the movement of the hand while watching the movement on the video. This combination of observation-and-imagination made it possible to directly compare the observation task to the imagination task, since the timing and the cue to imagine or observe was the same.

The baseline fragments consisted of a bouncing dot and followed each action part. The duration of the baseline was randomized between 4 and 12 s. The movement shown during the activity fragments consisted of a right hand performing a pincer grip, that is, a movement of the top of the thumb toward the top of the index finger, and this activity fragment was not preceded by a cue. The movement was shown against a black background and was performed with a frequency of approximately 1 Hz. It was shown in first person perspective. This movement fragment had a fixed duration of 5 s. For one block, subjects were asked to imagine the execution of the movement while the movement was shown in the video. During the other block, subjects were asked to only observe the movement shown. During the baseline condition, the subjects were instructed to observe the dot.

EEG recording

EEG was recorded against a virtual common reference, using a 64-channel Refa amplifier (TMS International, the Netherlands) using the modified international 10/20 system for electrode placement. The impedance of all

EEG electrodes was below 5 kOhm to reduce polarization effects. Sampling frequency was 512 Hz. EOG of the right eye was measured to monitor eye movements. To monitor potential actual movements, EMG was recorded over the left and right musculus abductor pollicis brevis (APB) and the right musculus flexor carpi radialis (FCR). To assure that the EEG synchronizes with the movie, a trigger signal was generated at the start of the movie.

Data analysis

Data analysis was performed offline. All routines were implemented in MATLAB (The Mathworks, Inc.). The EEG was band-pass filtered between 0.01 and 100 Hz. Movement artifacts were removed whenever the EMG in any of the muscles exceeded 50 μ V. To reject the whole movement artifact, 0.05 s surrounding the peak of the artifact and 10 samples at both sides were rejected from the analysis. Artifact rejection was controlled by visual inspection.

Event-related synchronization (ERS) and event-related desynchronization (ERD) were defined as an increased or decreased (respectively) instant power during obs or obs-and-ima compared to the latest 3 s of the baseline. To avoid possible effects of the phase-locked component on the ERS, the first second after switch of the fragment was disregarded in the analysis (Kalcher and Pfurtscheller 1995; Solis-Escalante et al. 2012). To calculate the power changes, first the EEG was filtered into 3 frequency bands (theta: 4–8 Hz, alpha: 8–13 Hz, beta: 13–25 Hz) with a 256th order zero-phase shift FIR filter. Each fragment was considered an epoch, and the power of each frequency band was subsequently calculated per epoch.

The average power (P) was calculated as

$$P = \frac{1}{N} \sum_{i=1}^{i=n} x_{f(i,j)}^2 \quad (1)$$

where $x_{f(i,j)}$ is the j th sample of the i th trial of the band-pass filtered data.

Subsequently, the ERS was calculated using

$$\text{ERS} = \frac{P_{\text{rest}} - P_{\text{activity}}}{P_{\text{rest}} + P_{\text{activity}}} \quad (2)$$

Since baseline and activity movies interchanged, first the ERS (or relative power difference) of each baseline activity combination was calculated, whereafter the mean of these ERS values was calculated for each subject, electrode and condition (left and right pincer) separately.

Spatial differences

The grand average of all subjects was plotted using topoplots. Negative values reflect desynchronization in a

particular frequency band during the activity movie compared to baseline.

The differences between obs and obs-and-ima were statistically tested using a repeated measures ANOVA, where the ERS was analyzed using task (obs or obs-and-ima) as within-subject variable, and electrode (C3, C4), and band (theta, alpha and beta) as between-subject variables.

In addition, the ERDS from 4 to 25 Hz was plotted. The difference of the ERDS between obs and obs-and-ima at the peak values was tested using a repeated measures ANOVA, where task (obs or obs-and-ima) was the within-subject factor, and frequency and electrode the between-subject factors. Post hoc analyses were done using a paired *t* test. Significance level was chosen to be $\alpha = 0.05$, which was adjusted by using the Bonferroni correction for multiple testing. As the Bonferroni correction may be too conservative, the actual *p*-values are reported to examine the trends toward significance, as well (Burgess and Gruzelier 1999).

Temporal differences

To analyze the temporal changes in EEG power, time–frequency plots were created using a short-time Fourier analysis. The width of the window used was 1 s with an overlap of 15/16 (0.9375). The median signal amplitude measured during the last 3 s of each rest fragment was used as baseline and subtracted from the data measured during obs or obs-and-ima of the hand. To visualize the temporal power changes, the time–frequency plots of C3, C4 and Pz are shown.

When a frequency band shows major changes, the behavior of the ERS over time was separately plotted for a more detailed examination. Temporal differences were statistically tested using a repeated measures ANOVA, where differences between the tasks on time intervals of 1 s were tested. Post hoc analyses were done using a paired *t* test.

Results

Figure 1 shows the relation between ERS during obs and the ERS during obs-and-ima on C3 for each subject. The figure shows a scattered distribution of the ERS, indicating large differences between subjects and within subjects.

Spatial differences

Despite the large variability between and within subjects, using a repeated measures ANOVA, a main effect for task (obs or obs-and-ima) was found ($F = 9.108$, $p = 0.004$). The desynchronization during obs-and-ima (-0.08556 ± 0.138) was significantly higher compared to obs (-0.0184 ± 0.0942).

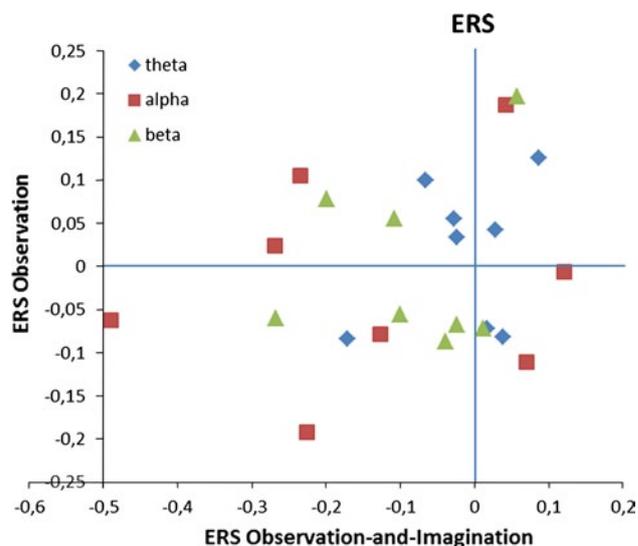


Fig. 1 Scatterplot showing the ERS on C3 during obs and obs-and-ima of all subjects for the three frequency bands considered theta, alpha and beta. A scattered distribution of the ERS indicates large differences between subjects and within subjects

There were no significant main effects for electrode or frequency band, and no significant interaction effects were found.

The synchronization during obs and obs-and-ima of the movement is depicted in topoplots (Fig. 2).

Theta (4–8 Hz)

During obs, the global power increased (ERS), while during obs-and-ima, a desynchronization was found in most of the cortical areas (ERD), except occipitally and at the left frontal–central area.

Alpha (8–13 Hz)

During both obs-and-ima and obs, a desynchronization was found on C3 and C4 although more pronounced during obs-and-ima. At the (centro-)parietal electrodes, CPz and Pz, a large synchronization was found during both tasks.

Beta (13–25 Hz)

During obs-and-ima, an ERD was found at C3 and C4. In accordance with the alpha frequency band, the power of the beta frequency band, measured at electrodes CPz and Pz, increased during both movement obs and obs-and-ima, compared to the baseline condition.

For both obs-and-ima and obs-only, the alpha and beta frequency bands show almost the same pattern of synchronization and desynchronization. During obs-and-ima,

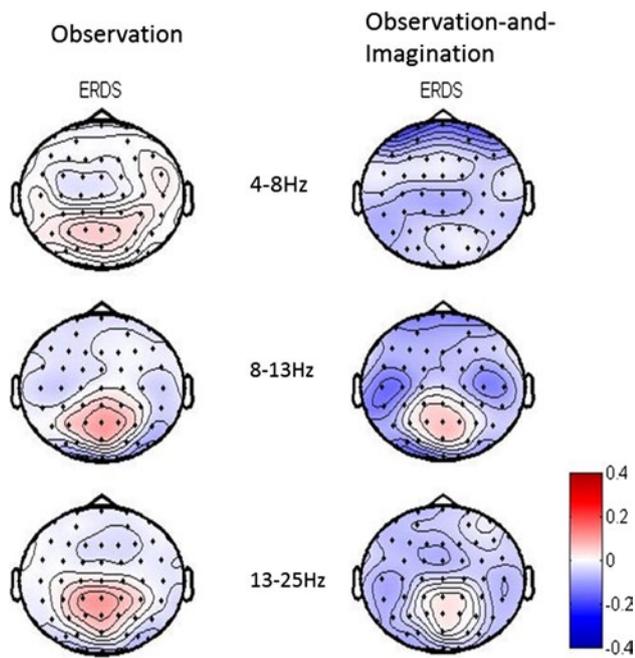


Fig. 2 Topoplots of the grand average of the (de)synchronization during the tasks. The *red* color codes a positive (ERS) synchronization, the power of the frequency band increases during the task compared to baseline. The *blue* color codes a negative ERS (desynchronization), the power of the frequency band decreases during the task compared to baseline. During obs-and-ima, a larger desynchronization can be found in all frequency bands compared to obs

however, the modulation was significantly larger for C3 and C4 compared to obs.

To examine the ERS during the latest 4 s of the activity movie in more detail, Fig. 3 shows the ERS evaluated in

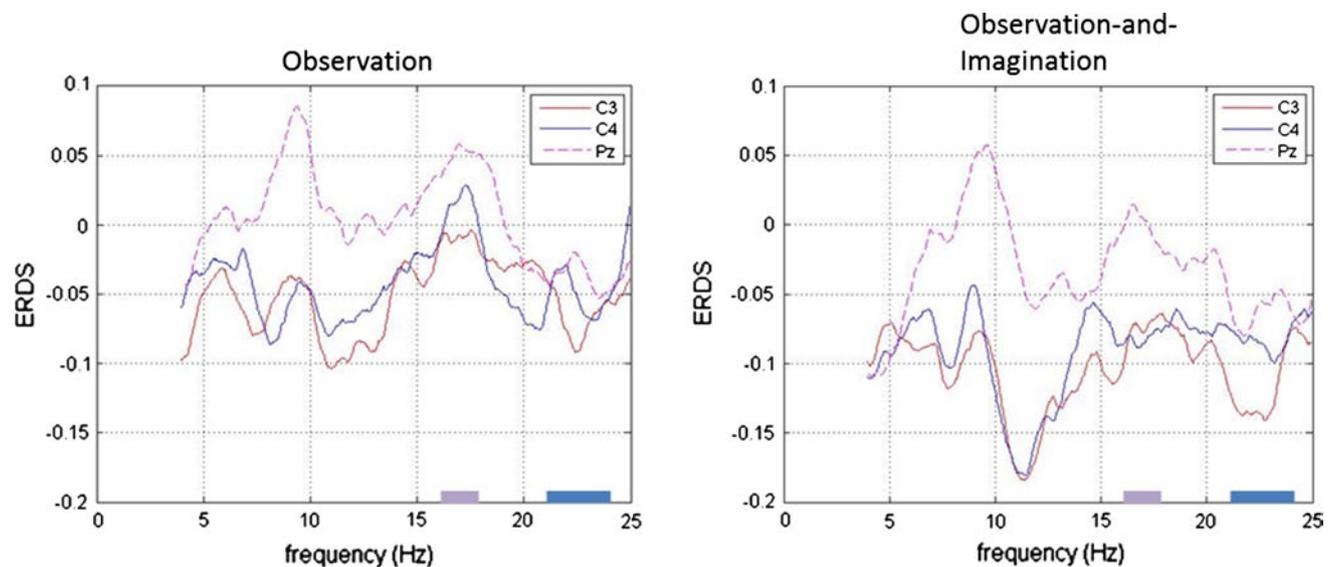


Fig. 3 The modulation of the ERDS during obs and obs-and-ima in the latest 4 s of the activity movie. The *thick lines* on the *x-axis* indicate the frequency intervals where the trends toward significant differences between obs and obs-and-ima are found. *Purple* Pz, *blue* C4 (color figure online)

the different frequency bands over C3 and C4 of this time epoch.

During obs-and-ima, a sharp decrease was found in the frequency band between 10 and 13 Hz at both C3 and C4, with a (negative) peak at 11 Hz. At the left (contralateral) hemisphere, also a large negative peak was found at 22 Hz.

During obs, at the contralateral side (C3), a small negative peak can also be seen at 11 Hz, although less pronounced compared to obs-and-ima. In the higher frequencies, also two small negative peaks can be found at 20 Hz (C4) and 22 Hz (C3). In addition, an increased power was found mainly at C4 at 17 Hz.

At Pz, 2 positive peaks can be found during both obs and obs-and-ima at 9 and 17 Hz.

To examine the differences between obs and obs-and-ima, differences were tested at the low-alpha ($\alpha_1 = 8\text{--}10$ Hz), high-alpha ($\alpha_2 = 10.5\text{--}11.5$ Hz), low-beta ($\beta_1 = 16\text{--}18$ Hz) and beta ($\beta_2 = 21\text{--}23$ Hz) frequency bands, using a repeated measures ANOVA. Task (obs and obs-and-ima) was the within-subject factor, and frequency bands (α_1 , α_2 , β_1 and β_2) and electrodes (C3, C4 and Pz) were between-subjects factors. A significant difference between the tasks ($F = 63.77$, $p = 0.000$), and an interaction effect for task and electrode ($F = 3.113$, $p = 0.047$) were found.

Post hoc tests were done using paired *t* tests, and $p < 0.004$ was considered to be significant. No significant differences between obs and obs-and-ima were found. However, trends toward significance were found at C4 between 21 and 23 Hz, where obs (-0.0454 ± 0.0758) is higher compared to obs-and-ima (-0.08745 ± 0.0631) ($p = 0.025$). At Pz, a significant difference was found at

16–18 Hz, where obs (0.0490 ± 0.137) was higher compared to obs-and-ima (0.00389 ± 0.0779) ($p = 0.012$).

Temporal differences

As shown in the topoplots, a strong synchronization was found at CPz and Pz. Besides the time–frequency analysis (TFA) at C3 and C4, also the temporal behavior at Pz is described (Fig. 4).

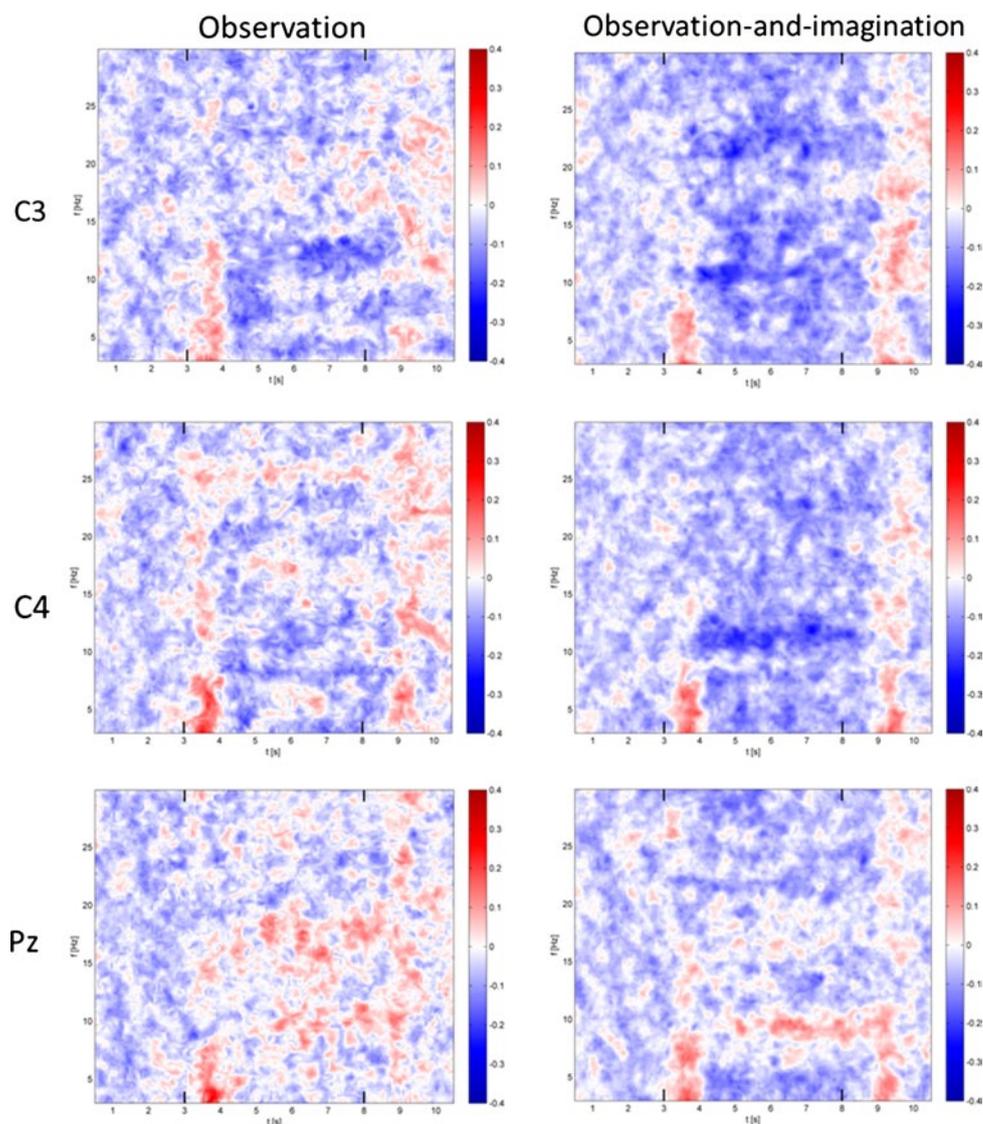
During both obs and obs-and-ima, the power increased after the task switched from baseline to activity and also vice versa. This synchronization is mainly found in the lower frequency bands.

After this short synchronization, overall, a broader frequency spectrum was found to desynchronize during obs-and-ima compared to obs. In more detail, when subjects were asked to observe-and-imagine the movement, a

decreased power was found between 10 and 14 Hz (higher alpha frequency band) and between 20 and 23 Hz (higher beta frequency band), although this latest power decrease seemed to be stronger at C3 compared to C4. During obs, the desynchronization of the frequency bands between 10 and 14 Hz can also be seen at C3, although less pronounced compared to obs-and-ima. At C4, during observation, mainly the lower alpha frequency band, between 8 and 10 Hz desynchronized, compared to a desynchronization of the higher alpha frequency band at C3.

Centro-parietally, at Pz, a synchronization was found in the lower frequency bands after the switch of the fragments, like it was found at C3 and C4. However, in contrast to C3 and C4, between 8 and 10 Hz, the synchronization remained during the whole activity fragment. During obs, this power increase can be found also in the higher frequency bands between 10 and 20 Hz while

Fig. 4 Time frequency power plots during obs and obs-and-ima of C3, C4 and Pz. During both obs and obs-and-ima, a synchronization was found after the switch of the fragment (at 3 s switch to activity, at 8 s switch to baseline). At C3 and C4, the desynchronization during obs-and-ima seems to be larger compared to obs



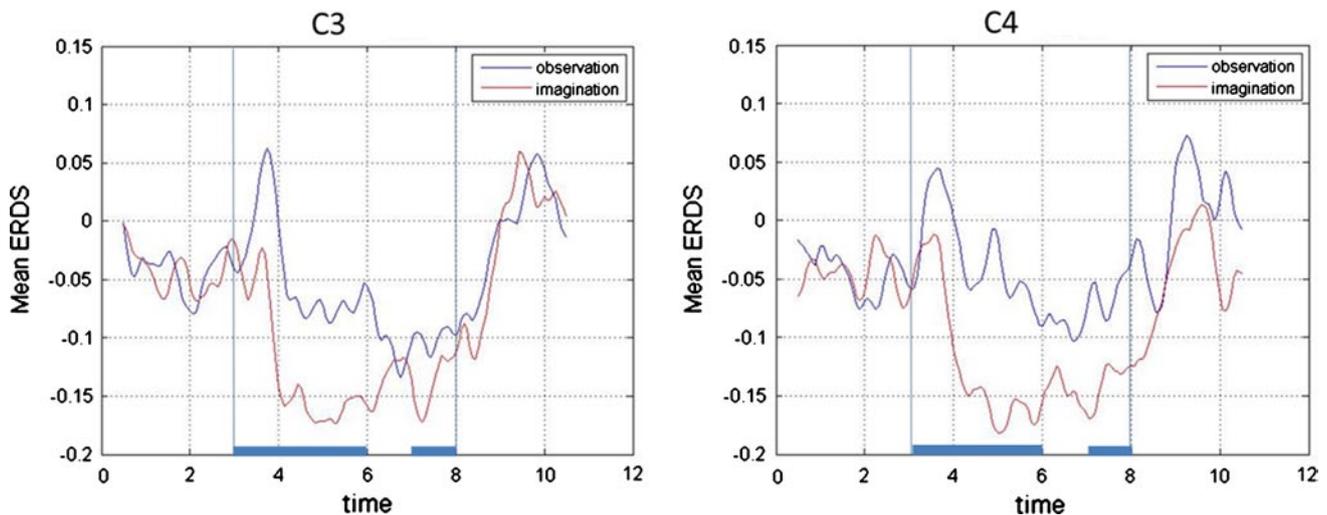


Fig. 5 Time course of the ERS in the 11–14 Hz frequency range. The first 3 s shows the baseline. At $t = 3$ s, the fragments switch to the activity movie. At 8 s, the *baseline* fragments were shown again.

The *blue colored lines* on the x-axis indicate the time intervals where the trends toward significant differences between obs and obs-and-ima were found (color figure online)

during obs-and-ima this increased power was not markedly present.

The largest modification was found between 11 and 14 Hz; therefore, the temporal modifications of this frequency interval were analyzed in more detail (Fig. 5).

To statistically test the differences between obs and obs-and-ima, the plot was separated into 9 time intervals of 1 s ($t_1 = 1\text{--}2$ s, $t_2 = 2\text{--}3$ s ... $t_9 = 9\text{--}10$ s). A repeated measures ANOVA was subsequently performed for each interval, where time interval and task (observation-and-imagination) were within-subject variables.

Main effects were found for task ($F = 5.777$, $p = 0.033$) and time interval ($F = 13.383$, $p = 0.000$). In accordance with the topoplots, obs-and-ima was significantly lower (-0.113 ± 0.123) than obs (-0.0463 ± 0.0067). Differences between the time intervals were found between t_3 and t_5 ($p = 0.035027$), t_3 and t_6 ($p = 0.045$) and t_3 and t_7 ($p = 0.009$), t_7 and t_1 ($p = 0.033$), t_7 and t_8 ($p = 0.008$), t_7 and t_9 ($p = 0.014$), t_9 and t_5 ($p = 0.029$), t_9 and t_6 ($p = 0.029$). An interaction effect of task and time was also significant ($F = 3.255$, $p = 0.004$). No interaction effects for electrodes were found.

Post hoc tests were done using a paired t test, where the significance level was Bonferroni corrected: $p = 0.0055$. No significant differences between observation and imagination were found. Trends toward significance were found: t_3 : $p = 0.022$ (obs: 0.0062 ± 0.050 , obs-and-ima: -0.054 ± 0.084), t_4 : $p = 0.011$ (obs: -0.049 ± 0.068 , obs-and-ima: -0.17 ± 0.15), t_5 : $p = 0.014$ (obs: -0.066 ± 0.087 , obs-and-ima: -0.18 ± 0.15), and t_7 : $p = 0.042$ (obs: -0.081 ± 0.070 , obs-and-ima: -0.17 ± 0.12) (Fig. 5).

Discussion

During observation-and-imagination, a significant larger desynchronization was found compared to observation-only. This was found in all frequency bands and electrodes and during almost the whole activity fragment. These results suggest a functional difference in brain states between the two tasks.

Although the alpha frequency band is often considered as one, it can be divided into 2 or even 3 bands: the lower, intermediate and higher alpha frequency band. In a study of Klimesch et al. (1998), the lower and intermediate alpha bands (8–10 Hz) are considered to reflect phasic alertness and expectancy, while the upper alpha frequency band reflects the performance of the tasks. Although the difference was not statistically tested, data suggest that the higher alpha band is desynchronized during imagination where the lower alpha band is desynchronized during observation. When the classification of the alpha frequency band of Klimesch is considered, imagination should relate more closely to performance compared to observation, which only requires alertness. Intuitively, this is not surprising, since imagination is more closely related to performance compared to observation. In addition, during imagination, the arousal is possibly increased. What is surprising is that the difference is only found in the ipsilateral hemisphere, while at the contralateral side (C3), most desynchronization was found in the higher alpha and higher beta frequency bands during both imagination and observation.

For the higher beta frequency band, a previous study (Bai et al. 2008) found that the desynchronization becomes bilaterally symmetrical just before the execution of a

movement, suggesting a role in the planning of the movement. The present study found a larger desynchronization of the beta frequency band during obs-and-ima, although no cue was used to introduce the activity fragment. In accordance with the study of Bai, this might be explained by the planning of the movement, since imagination requires more planning compared to observation. In the study of Sabate et al. (2012), the preparation for a passive observation of a movement was compared with the preparation of the execution of a movement. They found a higher response during motor planning compared to passive observation, making them to suggest that “the task associated with stimuli is a relevant variable for visually induced mu-rhythm suppression.” The present study found a higher desynchronization during obs-and-ima compared to obs, and this might underline the suggestion of Sabate et al. (2012), since the tasks can be segregated by the amount of desynchronization. Considering these explanations by Bai et al. (2008) and Sabate et al. (2012), it can be expected that the power of the beta frequency band increases after the planning phase, while in the present study, the desynchronization remains during the whole activity fragment. The relation between beta frequency desynchronization and high focus and concentration (Pfurtscheller et al. 1997) might better explain the differences found in the present study between obs and obs-and-ima, since imagination requires more concentration compared to observation. The spatial results, depicted in the topoplots, agree with this suggestion, and also other studies suggest a difference in effort between the two tasks (Grafton et al. 1996, Filimon et al. 2007).

Immediately after the switch from baseline to action, and also vice versa, a short synchronization was found in all frequency bands. The short increase in power after a preparation cue of the mu-alpha band was previously published by Kalcher and Pfurtscheller (1995), who found a phase-locked increased response of mu-alpha (8–12 Hz) activity which started ≈ 50 ms after stimulus onset and persisted for 150–200 ms. Although the presence of alpha activity might indicate a resting (or idling) state of the brain, the lower alpha bands are also suggested to be present during expectancy and alertness. The present study did not use a preparation cue; however, the switch of the fragment tells the subject to come into (mental) action, which might cause the increase in the alpha frequency band. Additionally, the short increase in the beta frequency band might be caused by the suppression of the actual movement of the hand (Zhang et al. 2008). The beta band synchronized after obs and obs-and-ima stopped and the baseline fragment appeared. This might be compared to the “post-movement beta synchronization.” This post-movement beta synchronization is previously found after the execution of a movement and has been interpreted as a correlate of “idling” motor cortex neurons (Pfurtscheller et al. 1996).

The theta rhythm is associated with drowsiness and sleepiness. Instead of an increase shortly after the switch of the fragment, an increase in this rhythm could be expected at the end of a fragment. However, a modulation of the parietal (Perfetti et al. 2011) and frontal (Tombini et al. 2009) theta activity during a movement task has been linked to cognitive or attentional resources and seem to link spatial (attentional) selection of a target, in order to capture it with a movement (Rawle et al. 2012). This might explain the synchronization of the power of the theta frequency band at the start of the fragments. However, since this synchronization occurs during both obs and obs-and-ima, this result is not caused by the addition of imagination to observation-only.

Synchronization at centro-parietal areas

The centro-parietal synchronization neither discriminates between obs and obs-and-ima, and the synchronization appears to be caused by the observation. Molenberghs et al. (2010) found a significant activity of the left superior parietal lobule and also in the left supramarginal gyrus, left dorsal premotor area and bilateral superior temporal sulcus, using fMRI. These signs indicate a function of the parietal lobule in imitation and observation. Although this seems to be in contrast with our results, the relationship between the event-related synchronization measured by EEG and the blood flow or BOLD signal is still under debate (Rosa et al. 2010).

Studies examining the cortical activity of pistol shooters and golf players also found a parietal alpha ERS (Del Percio et al. 2009, 2011; Babiloni et al. 2011). It has been suggested that parietal alpha ERS reflects a focus on visuospatial attention. A diffuse parietal alpha ERS is found in combination with focused alpha ERD in the small region of the cortex related to the spatial area where the attention is focused. In the present study, the subjects were asked to observe or imagine the presented movements on the screen. It is likely that subjects pay extra attention during the movement fragment compared to the bouncing ball, resulting in the diffuse parietal alpha ERS.

In sum, ERD of the sensorimotor cortex is significantly higher during observation-and-imagination compared to observation-only. The increased desynchronization during observation-and-imagination is found in all frequency bands and remains during the whole activity period. Assuming that a larger ERD is correlated with a larger participation of neurons that are (presumably) also activated by actual movement, these findings suggest an additive effect of imagination instead of observation-only in the rehabilitation after stroke.

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