Clap Your Hands!

Inter-Brain Synchronization During Monastic Debate

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Abstract

Monastic debate is an interactive learning strategy that is assumed to sharpen reasoning and improve learning (Liberman, 2015; Perdue, 2008). During the debate, handclaps are made that punctuate propositions, signal the defender to respond immediately and to set the rhythm of the debate. Since these handclaps seem to play such an important role, we examined the function of a handclap on a cognitive level using EEG hyperscanning. It was expected that after a handclap, theta power would be increased and alpha power decreased due to increased attention. However, after correction for multiple comparisons, no significant differences in power were found between the time interval prior to the clap and the time interval after the clap for alpha and theta frequencies. Likewise, after correction for multiple comparisons, no support was found for the hypothesis that a clap would manifest in an ERP-like signal and that in the 0.5-second time interval after a handclap inter-brain synchronization would be increased in the alpha and theta band compared to the 0.5-second time interval prior to the clap. The uncorrected results show that inter-brain synchronization is increased after a clap for theta frequencies in the right temporal area and in the left central and parietal area. Although one should be cautious when interpreting these uncorrected results, they could suggest that a handclap indeed might play a communicational role. Future research is needed to assess whether a clap indeed plays a communicational role and a more controlled experimental design could reveal the exact cognitive processes underlying this increased inter-brain synchronization.

Introduction

Social learning theory suggests that social interaction makes learning more effective than non-social learning since a great deal of learning arises by observing and imitating others (Bandura, 1971). Indeed, interactive courses seem to contribute to the learning of students by enhancing comprehension, critical thinking skills and problem-solving skills compared to lecture-centered courses (Hurst, Wallace & Nixon, 2013). Okita, Bailenson & Schwartz (2007) showed that even the mere belief of engaging in social interaction can improve learning. Subjects that were made to believe that they interacted with a human controlled avatar showed improved learning compared to subjects that were made to believe they interacted with a computer controlled agent. Taken together, social interaction seems to have a positive effect on learning. However, little is known about the inter-individual cognitive processes involved in social interaction during learning.

In this study, the effects of a very interactive learning strategy on inter-individual cognitive processes are explored. This learning strategy is monastic debate as practiced in Tibetan monastic universities. Monastic debate plays a prominent role in Tibetan monastic universities and it is practiced for up to five hours on a daily basis. Similar to the effects of social interaction on learning in the previously mentioned study by Hurst at al. (2013), monastic debate is presumed to sharpen reasoning, improve learning and enhance critical thinking skills (Liberman, 2015; Perdue, 2008).

The debates have a very structured format. The debates most frequently take place in pairs where one person is the challenger and the other is the defender. The goal of the challenger is to try to make the defender contradict himself whereas the defender is supposed to maintain a consistent position. The defender is sitting on the ground while the challenger is standing. The challenger presents a thesis to the defender and tries to find inconsistencies in the reasoning of the defender. He does so by asking questions or formulating formal propositions that are punctuated by a handclap. The defender is then to respond immediately, no pauses are allowed during the debate. He can either 1) accept the proposition, 2) call for the reason or 3) declare that the thesis has not been proven.

An important aspect of the debate is the rhythm that participants develop during the debate in their speech and body movements (Liberman, 2015). This dialogue between challenger and defender is like a metronome. The series of propositions is set to the challenger's handclaps. The rhythm is thought to make the participants more attentive, improve the clarity of the propositions and helping the debaters to think as one. If these handclaps play such a crucial role in the debate, what function do they have? In this study, we will attempt to learn more about the function of a handclap on a cognitive level.

In order to study the cognitive processes during the debate, EEG will be a useful measure because of its high temporal resolution. Brain oscillations will be analyzed because they are less strictly time-locked compared to ERPs. That makes brain oscillations suitable to study real-world situations in which no clear temporal event markers are present. In this study, we will, therefore, attempt to learn more about the function of a handclap on a cognitive level by examining the effect of a handclap on neural oscillations.

In order to explore what communicational function the handclap might serve on a cognitive level, speech processing theories are studied. The auditory cortex responds strongly to speech (Giraud, Poeppel, 2012). Speech is known to reset ongoing oscillations and the neural response is very similar to the spectro-temporal structure of the speech envelope. A phase-reset is a modulation of the phase of ongoing oscillations either by external or internal input (Lakatos et al., 2009). During speech, the phase-resets preferentially take place in the theta and high and low gamma frequencies. Theta phase tracking of the speech envelope seems critical for parsing continuous speech since when phase tracking fails, speech intelligibility is compromised.

The sound signal of a handclap does not look similar to the sound signal of speech. However, other sounds than speech are also able to cause a phase-reset in ongoing oscillations. Oscillations have been shown to be phase locked to sounds in experiments that study the effect of synchronization of oscillations on perception (Fiebelkorn et al., 2011; Romei, Gross & Thut, 2012; Diederich, Schomburg & Van Vugt, 2014). Attention plays a large role in whether the stimuli can cause a phase-reset because only attended auditory stimuli seem to cause a reset (Kayser, 2009; Lakatos et al., 2009). Although attention seems to direct the phase-reset, it is likely that it is not so much attention to the stimulus that drives the reset but salience of the stimulus. Van der Burg, Olivers, Bronkhorst, Talsma & Theeuwes (2008) illustrated this by showing that combining visual stimuli with an unattended sound makes the combined visual stimulus pop out from a crowded visual environment. These synchronized stimuli form a salient event that can draw attention automatically. Taken together, stimuli that are salient enough to capture attention can cause a phase-reset in ongoing oscillations.

Based on the just discussed research, it is very likely that the sound of a handclap during the debate is a salient stimulus for a monk. The handclap signals the end of a proposition after which an answer needs to be provided immediately and it sets the rhythm that the monks should maintain during the debate. Furthermore, the handclap is a very notable and even intimidating action. It has a long wind up and sometimes ends right in front of the defenders face. This makes it very likely that the handclap captures attention. It is, therefore, possible that the handclaps help the debaters to focus. Brain oscillations that are known to be related to attention are alpha and theta frequencies. Alpha-band activity desynchronizes when attention increases (Klimesch, 2012). Therefore, if the claps make the debaters more attentive, it is expected that alpha-band power will be lower after a handclap than prior to a handclap. Theta rhythms are known to appear during tasks that require focused attention (Ishii et al., 2014). Therefore, increased power in theta activity is predicted after a handclap compared to prior to a handclap. If the claps evoke sufficiently punctate activity, they might even result in an event-related potential at the time point when the clap occurred.

Described above are possible effects of a handclap on intra-individual cognitive processes. Another effect to consider is the effect of a handclap on inter-individual cognitive processes. As mentioned before, debate is a form of social interaction and the best way to study social interaction in a detailed fashion is hyperscanning. The term hyperscanning was introduced by Montague et al (2002) who defined hyperscanning as the simultaneous scanning of two participants using fMRI. Hyperscanning is not exclusively for fMRI, but also possible for EEG. EEG hyperscanning makes it possible to measure brain activity that is not related to behavioral markers. That way, one can study brain to brain interaction that might take place in the absence of detectable behavior.

Hyperscanning is used to measure inter-brain synchronization, a phenomenon that can be observed when measuring neuronal activity in a social context. Inter-brain synchronization is the synchronization of neural oscillations across subjects. Neural synchrony is assumed to reflect underlying neural computations belonging to psychological processes (Dikker et al., 2017). Therefore, the occurrence of inter-brain synchronization might give an indication that similar psychological processes are going on across different subjects in synchrony.

Inter-brain synchronization is mostly observed during successful communication and in contexts where participants cooperate. For example, during the prisoner's dilemma increased synchronization in the alpha band can be found during cooperation compared to defecting (Babiloni et al., 2007). Other examples are during successful therapeutic intervention and shared attention in a classroom (Koole & Tschacher, 2016; Dikker et al., 2017). Inter-brain synchronization also takes place during communication in general. During speech for example. During speech perception, there is a coupling between the rhythms of the neural activity of the listener and the rhythms of the speech signal (Pérez, Carreiras &

Duñabeitia, 2017). This phenomenon is called brain entrainment. But during speech production, neural activity of the speaker also correlates to the amplitude envelope of the own produces sounds. So there is also brain entrainment taking place during speech production. During verbal communication, brain oscillatory activity becomes synchronized between listener and speaker due to shared sensory stimuli.

Inter-brain synchronization during speech does not only occur because of perceiving the same sensory stimuli. Part of the synchronization seems to be due to the social interaction itself. Pérez, Carreiras & Duñabeitia showed that after correcting for brain to speech synchronization, part of the brain to brain entrainment remained. It was demonstrated that brain synchronization in delta and theta bands is mediated by the physical properties of speech. Delta fluctuations seem to correspond to structures like sentences and phrases. Theta fluctuations seem to correspond to the occurrence rate of syllables. Alpha and beta fluctuations, on the other hand, seemed to be influenced by the social interaction itself and not just by the shared sensory stimuli. Taken together, finding increased inter-brain synchronization after a clap would suggest that a clap fulfills a communicational function.

In summary, the function of a handclap during monastic debate will be explored by studying the brain oscillations of monastics during a debate in a hyperscanning EEG study. Given the presumed salience of a handclap, it is expected that a handclap will cause a phase-reset in ongoing oscillations. In addition, since a handclap is likely to improve attention, higher power in the theta frequencies is predicted after a handclap compared to prior to a handclap. For this same reason, a decrease in power of alpha frequencies is expected after a handclap compared to prior to the handclap. Because of the interactive nature of the debate and the communicational role a handclap seems to perform, it is expected that inter-brain synchronization increases after a handclap compared to prior to a handclap.

Method

Participants

The group of participants for the current study consisted of 30 monastics. All of them are students at the Sera Jey Monastery, Bylakuppe, India and were recruited via the disciplinarian of the Monastery. The disciplinarian is the one who ensures that students attend classes and follow the monastic curriculum. He told the students that the debate topic was on *Bodhicitta* and requested that all the students who volunteer for the study would seriously engage with study tasks.

Monastic training persists for 16 years and after entry into the monastery, debate is practiced on average for 5 hours per day for at least 250 days per year (i.e., ~1250 hours per year). The students that participated in the study were recruited from two different cohorts, Beginners, and Experienced monastics. Students having between 0 and 4 years of monastic training are considered Beginners. Students having between 13 and 16 years of training are considered Experienced monastics. Some monastics continue their formal training to obtain advanced degrees. In that case, the training can pursue for an additional 6 to10 years. Therefore, the number of training years for experienced monastics can range from 13 to 25 years of training. In order to get the two groups as equal as possible, an attempt was done to select students that received top marks in their debate classes and had completed their classroom instruction on Bodhicitta.

Procedure

Instructions given to debaters: Debater pairs were asked to participate in a 10-minute "Counting Debate" followed by a 15-minute "Logic Debate". During a counting debate, the foundation of the debate topic is established and the level of quality of the memorization of the text is tested. The counting debate is followed by a "Logic Debate" in which the challenger asks the defender to recite definitions and respond to questions. Since a counting debate followed by a logic debate is the traditional order in the monastery, this order was chosen for the experiment as well. The Counting Debate is regarded as being easier than the Logic Debate, and it serves as a preparation for the Logic Debate. The topic selected for the Counting Debate was "The Definition of Bodhicitta," because both cohorts, Beginner, and Experienced monastics, are familiar with the topic. In order to equalize the monastics familiarity with the topic, monastics reviewed their textbook on Bodhicitta for 15 minutes directly before the counting debate. Participants were explained that participation in the study was entirely voluntary and that they could quit at any time without any repercussions.

Conducting the Debates: A total of 56 debates was performed, 28 counting debates and 28 logic debates. An anonymous identification number was allocated to the monastics after they provided their age, the year they entered the monastery and the year and level of monastic training they had achieved. Then, monastics were wired with the EEG sensors after which they performed one counting debate, followed by a logic debate. If there was time left, data of another counting debate and logic debate were collected but with reversed roles of the Challenger and Defender. After the debates, the participants were debriefed. The debaters were not paid for their participation but were served lunch or dinner after the experiment.

EEG recording

A 32-channel EEG system (BrainProducts actiCAP) with BrainVision Recorder software was used to record the EEG data simultaneously for the two monks. The data were sampled with a sampling rate of 500 Hz and the data were recorded with a 0.1-1000Hz bandpass filter. The impedances of the individual channels were kept below 25 kΩ. A trigger button was pressed to indicate the start of the debate in the EEG recordings.

High-density video recordings were made during the debates in order to synchronize behavior with the EEG signal. The audio signal of these videos was used to detect the occurrence of a handclap. The timepoints at which these handclaps occurred were saved in a CSV file and used for the time locking between the claps and the EEG signal. Unfortunately, the video recordings were started at the moment the start trigger in the EEG signal was pressed. That makes it likely that there is some delay in when the video recordings started with respect to the start trigger in the EEG signal. The delay might have a range up to a second and is likely to differ for the different debates.

EEG preprocessing

For preprocessing, we first applied a 0.5-45Hz bandpass filter to remove muscle activity that occurs in high gamma bands (Muthukumaraswamy, 2013). Then an independent component analysis (ICA) was done separately for each of the two simultaneously recorded monks. We removed any ICA component that looked suspicious (eye movements, blinks, and muscle artifacts) before transforming back to the original space. After that, the data were re-referenced to the average reference. For the analysis, we segmented the data into 4-second segments from 2 seconds prior and 2 seconds posterior to each handclap. This window was chosen to make sure that even if the estimation of the timepoints at which a clap took place was off by a second, the segments would still enclose the clap. We did not choose a window wider than 2 seconds before and 2 seconds after the clap to prevent overlapping of the segments. For the time-lock analyses, we also selected random 4-second segments.

Data analysis

Data analysis was carried out in Matlab using the Fieldtrip toolbox (Oostenveld, Fries, Maris, & Schoffelen, 2011). In order to examine whether an effect of a handclap is already visible in the raw EEG signal, we visually inspected the pre-processed EEG signal on an individual level of a random selection of debates before segmentation. This visual inspection was performed separately for the defender and challenger. The timepoints at which a handclap occurred were marked by plotting a vertical line for each handclap on top of the EEG data.

After segmentation, a time-lock analysis was done by computing the ERPs for each channel to examine whether event-related potentials were evoked by the clapping. ERPs were computed for the randomly selected 4-second segments as well as for the 4-second segments surrounding the handclap. ERPs were then compared using a paired t-test.

It is also possible that claps do not evoke sufficiently punctate activity to manifest in event-related potentials, but appear as temporary increases in oscillatory power. To examine this, the EEG data were frequency-transformed by means of a convolution with a Hanning taper. This was done for all channels for the theta frequencies (4-9 Hz) and alpha frequencies (9-14 Hz). For each participant, the oscillatory power before and after the handclap was compared using a paired t-test.

Finally, we wanted to know whether hand claps affected the connection between the two monks, e.g., by synchronizing their attention. To examine this hypothesis, inter-brain synchronization was calculated. The average phase angle across time segments of 0.5 seconds was computed. This was done for all electrode analogous pairs (i.e., Fz in one monk compared to Fz in the other), computed over multiple trials. The phase difference between corresponding channels before a handclap will be compared to the phase difference between corresponding channels after a handclap using a t-test.

Results

We started by visually inspecting the EEG signal in a sample of individuals to examine whether an effect of a clap was already visible in the raw EEG signal. If an effect of a clap can be observed in the raw EEG signal, this might give an indication that the clap indeed causes a phase reset. The handclaps do not seem to effect the raw EEG signal based on visual inspection.

Time-lock analyses:

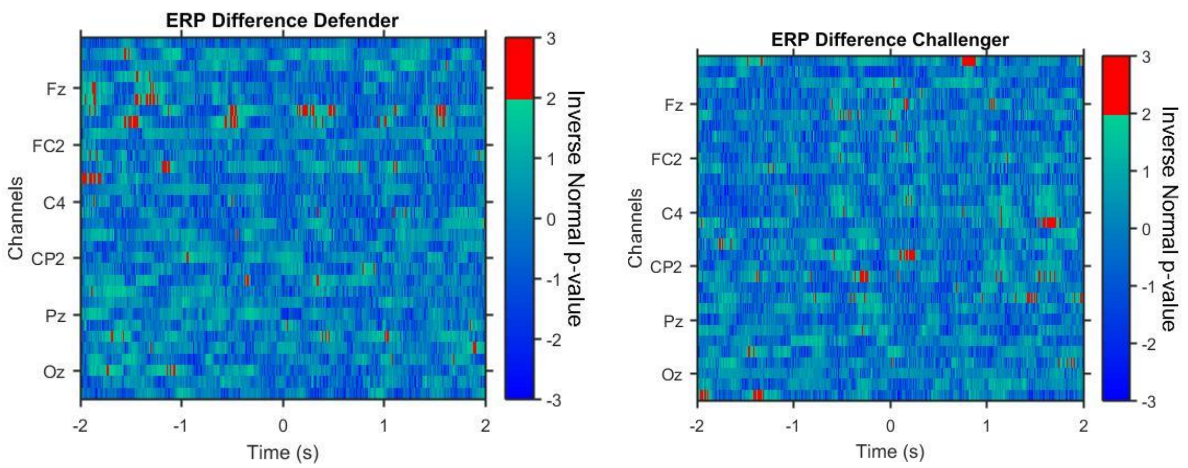

Figure 1. Scaled color image of the inverse normal p-value of the difference in ERP between segments time-locked to a clap and segments time-locked to a random moment for the defender and challenger. An inverse normal p-value can be interpreted as a z-score where values >2 are significant. The x-axis presents time in seconds. The y-axis presents the electrode channels. All the significant values (uncorrected for multiple comparisons) are presented in red. The figure shows the entire segment of 2s before and 2s after the clap and the moment a clap takes place is centered at 0.

We examined whether the sound of the handclap causes a phase reset that is visible in the event-related potential. Our hypothesis was that if the sound of a handclap is salient, it will indeed manifest in the event-related potential. Figure 1 shows the uncorrected inverse normal p-values of the differences in ERP between segments time-locked to a handclap and randomly selected segments over time for all the channels for the defender and challenger. The inverse normal p-value can be interpreted as a z-score where values >2 are significant. Unfortunately, none of these p-values survive correcting for multiple comparisons using false discovery rate. This is not really surprising. In order to manifest in an ERP, the EEG signal needs to be time-locked to the stimulus very precisely or else the signal might average out. In this case, it is not possible to determine the moment of a clap that exact since the timeline of the video data and EEG data was matched by hand.

Since we could not determine the clap time precisely, we also examined the data using more lenient uncorrected significance thresholds. Figure 1 shows that for the defender, the largest differences seem to take place during the first second mostly at the frontal and frontal central electrodes. Furthermore, especially in channel 7(F8), there seems to be a difference right after the clap till 0.5 seconds after a clap. The ERP's of channel F8 for the segments surrounding a clap and the non-clap segments were plotted to examine what this difference looks like. Figure 2 shows that the difference in ERP between the clap segments and non-clap segments indeed seems to be present at the time interval from the clap to 0.5 seconds after the clap. Whether this difference is indeed due to phase-locking to the clap or due to random fluctuations in the EEG signal remains unclear. To examine the scalp distribution of the difference in ERPs, a topographical plot was made (Figure 3) that presents how the t- values are distributed over the scalp. The figure shows that the most positive differences for the clap segments seem to be present at the electrodes on the right at the frontal and temporal side of the scalp. The most negative differences for the clap segments seem to be present at frontal, central and central parietal electrodes on the mid-left side of the scalp.

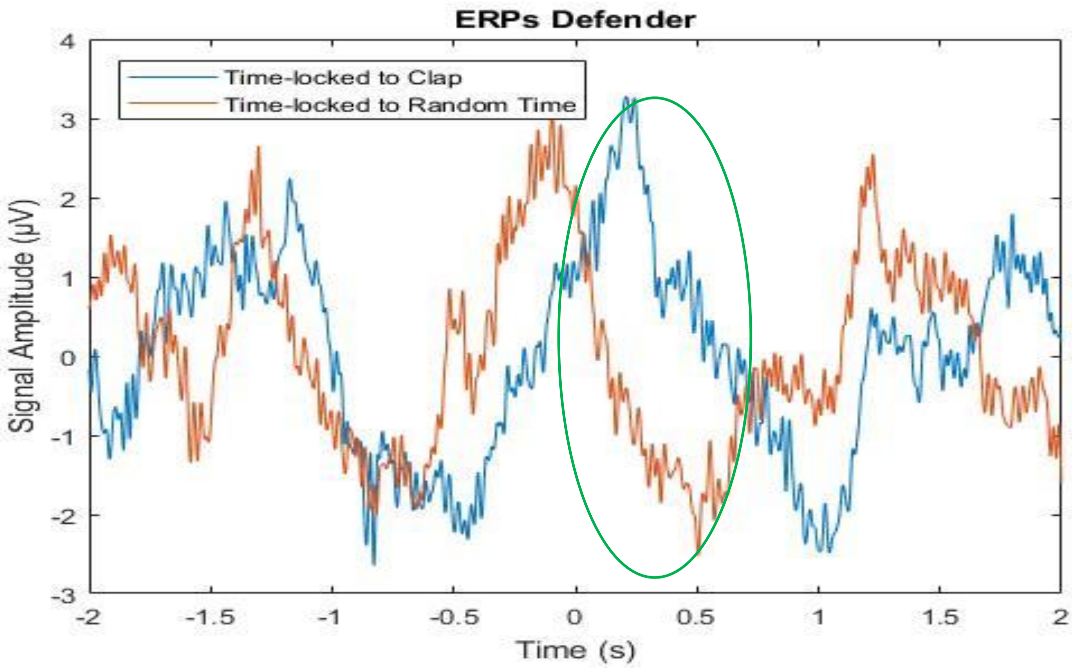

Figure 2. ERPs in channel F8, the channel showing the most significant differences (uncorrected for multiple comparisons) right after the clap, for segments time-locked to a clap (blue) and segments time-locked to a random time point (red) for the defender. The x-axis shows time in seconds and the clap takes place at 0.

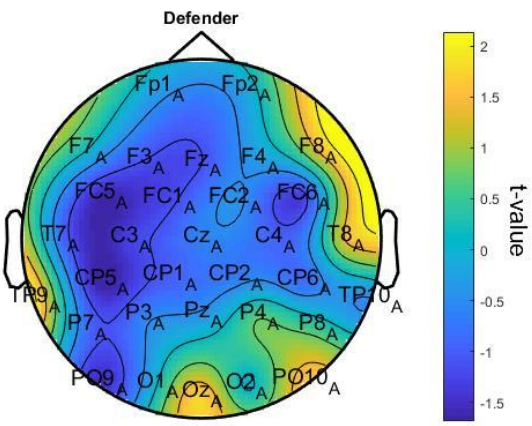

Figure 3. Topographical plot showing how the t-values of the difference in ERPs between segments time-locked to a handclap and randomly selected segments are distributed over the scalp for the defender for the time interval from the moment a clap took place till 0.6 seconds after the clap.

Time-frequency analyses:

The second hypothesis was that if handclaps help debaters to focus, attention will increase after a handclap. This may manifest in an increase in power in theta frequencies and a decrease in power in the alpha frequencies (Klimesch, 2012; Ishii et al., 2014). Time-frequency analysis was done for alpha and theta frequencies for a time interval of 1.5 s before and after the handclap. Power in alpha and theta was compared between the time periods after a handclap and the time period before a handclap using a t-test (figure 4). There were a few time bins and channels for which there was a difference in oscillatory power between the clap and no-clap conditions. However, after correction for multiple comparisons, no significant differences in power of alpha or theta between time periods after a handclap and time period before a handclap were found for either the defender or the challenger.

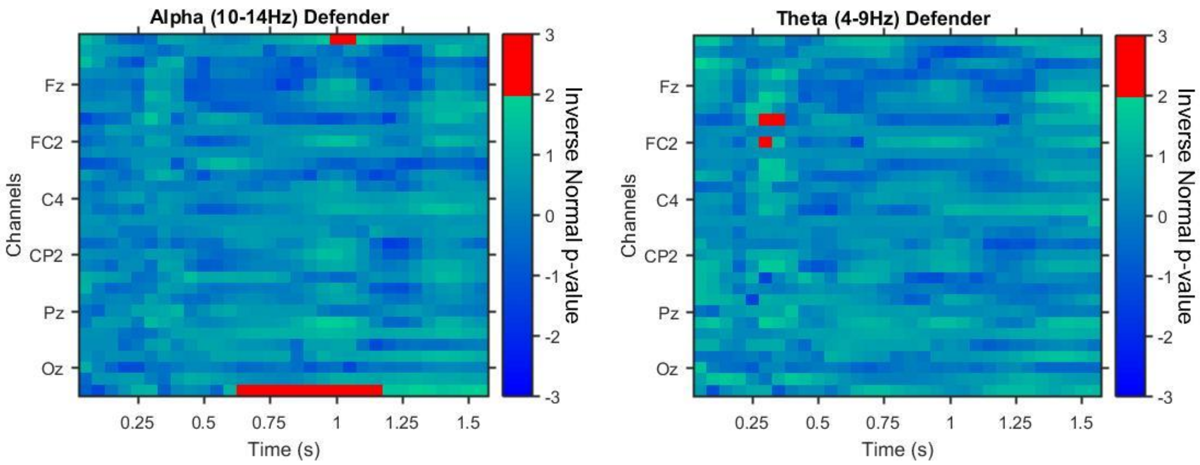

Figure 4. Scaled color image of the inverse normal p-value over time of the difference in power for alpha and theta frequencies between time periods after a clap and time periods before a clap. An inverse normal p-value can be interpreted as a z-score where values >2 are significant. All the significant values (uncorrected for multiple comparisons) are presented in red. The x-axis presents time where a clap took place at timepoint 0. The y-axis presents the electrode channels.

Inter-brain synchronization analyses:

The last hypothesis was that since the handclap seems to play a communicational role, increased inter-brain synchronization can be expected after a clap for theta as well as alpha frequencies. Inter-brain synchronization was calculated for the time interval of 0.5 seconds after the clap and for the time interval of -1.5 to -1 before the clap. For each channel, a t-test was done to compare inter-brain synchronization in time periods after a handclap versus time periods before a clap.

Figure 5 presents a topographical plot showing the distribution of the t-values of the difference in inter-brain synchronization between the time segments before a clap and after a clap for alpha and theta frequencies. The areas in which the t-values are significant (uncorrected for multiple comparisons) are outlined in red. After correction for multiple comparisons, no significant differences remain. The uncorrected significant differences in inter-brain synchronization for theta frequencies show that an increase in inter-brain synchronization seems to be present at the right temporal area and left central and parietal area.

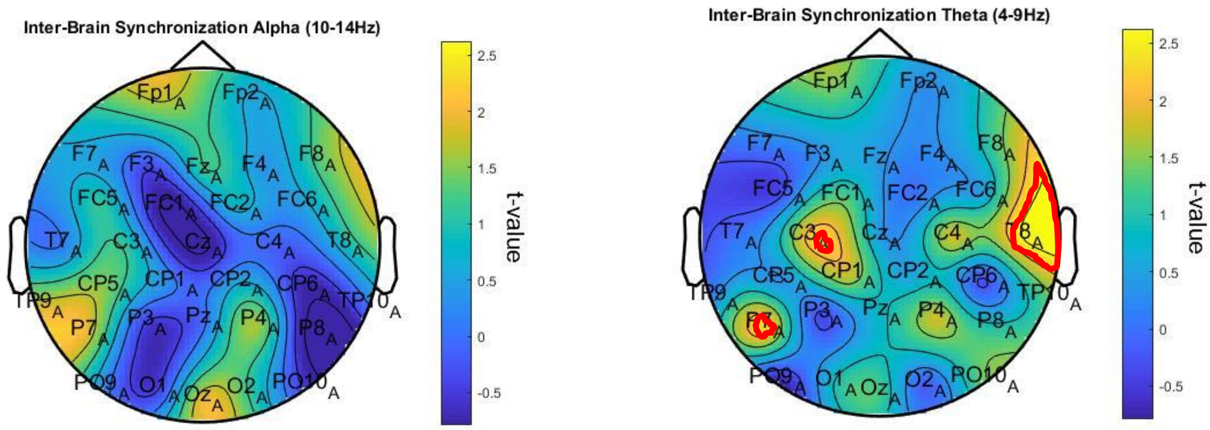

Figure 5. Topographical plots showing the distribution of the t-values of the difference in inter-brain synchronization for the time segments after a clap and the time segments before a clap for alpha and theta. The areas in which the t-values are significant (uncorrected for multiple comparisons) are outlined in red.

Discussion

In this study, we examined the function of a handclap on cognitive processes during monastic debate. On an intrapersonal level, it was expected that a clap would cause a phase reset manifesting in an ERP-like signal time-locked to the sound. Furthermore, an increase in theta power and a decrease in alpha power was expected. The results do not support these hypotheses. Because of the interactional nature of monastic debate, we also examined the effect of a handclap on neural oscillations on an interpersonal level using EEG hyperscanning. In agreement with our expectations, we found an increase in inter-brain synchronization after the occurrence of a clap compared to before the occurrence of a clap for alpha and theta frequencies. However, our results did not survive correction for multiple comparisons using false discovery rate.

A limitation of this study is the lack of accuracy in timing the handclaps. In contrast to most EEG studies on interpersonal processes, in this study, EEG hyperscanning was performed in a naturalistic setting. Therefore, we could not manipulate the moments at which a handclap would take place. As a consequence, we depended on video recordings that were made during the debates to later synchronize behavior and EEG signal. Unfortunately, the video recordings were started at the moment the start trigger in the EEG signal was pressed. That makes it likely that there is some delay in when the video recordings started with respect to the start trigger in the EEG signal. The delay is likely to differ for the different debates. This is problematic for testing the hypotheses that a clap would manifest in an ERP-like signal. For an ERP to occur, the signal needs to be time-locked to the stimulus very accurately or else differences in the signal will average out. Therefore, it is really likely that no difference in ERP between the segments surrounding a clap and the non-clap segments is found due to lack of accuracy on time-locking the clap. In the future, the accuracy of synchronizing video recordings with EEG data could be enlarged by recording the moment at which the start trigger of the EEG is sent instead of starting the recording at the moment of sending the trigger. For now, it is unclear whether no results were found because of inaccuracy in the time-locking of the handclap or because a clap does not cause a phase-reset in the ongoing oscillations.

No increase in power in theta frequencies and no decrease in power in alpha frequencies were found for the time period after the clap compared to before the clap. While imprecision in the temporal location of the clap could affect this analysis as well, in general, this is less likely to be an issue for induced brain oscillations. A further challenge for comparing power in the time interval after the clap with the time interval before the clap is the lack of a clear baseline period. In this study, we took a segment of 0.5 to 0.3 seconds before the clap as the baseline to make sure no claps were included in the baseline condition. However, due to the naturalistic setting of the experiment, it is very likely that the baseline is contaminated with artifacts from motor actions or speech. The handclap during monastic debate is a large motor action. Since the baseline was taken 0.5 to 0.3 seconds before the sound of a clap, the baseline is likely to overlap with the motor action of the clap. It is possible that we did not manage to filter out all the motion artifacts caused by this motor action. However, muscle activity is known to show up as an increased power in frequencies from 20 to 300Hz (Muthukumaraswamy, 2013). This makes it less likely that that baseline for alpha and theta frequencies is contaminated with motor artifacts. It is more plausible that the baseline is contaminated with speech artifacts. Theta frequencies seem to play an important role in speech perception (Giraud, Poeppel, 2012). Theta oscillations of the listener entrain to the speech signal when listening to speech and modulate higher neural frequencies. Theta oscillations of the speaker also entrain to the self-produced speech signal. Since the handclap punctuates a proposition, the baseline overlaps with speech. It is, therefore, possible that the baseline is contaminated with speech artifacts.

Then on the interpersonal level, no differences in inter-brain synchronization were found after correction for multiple comparisons in alpha and theta frequencies for the time period after a clap compared to the time period before a clap. The uncorrected results for inter-brain synchronization showed a significant increase in inter-brain synchronization in theta for the right temporal area and left central and parietal area. Since inter-brain synchronization does not depend on accuracy in time-locking to behavioral markers, our results cannot be fully explained by lack of accuracy in determining the timing of the handclaps. However, since we calculated inter-brain synchronization over a time segment of just 0.5 seconds and the estimation of the time a clap took place could be off by maybe a second for some debates, the inaccuracy of clap detection could still have influenced the analysis.

If the observed increased inter-brain synchronization in theta frequencies in the right temporal area and left central and parietal area after a clap can be replicated in future studies, the increased inter-brain synchronization might represent shared auditory processing of the clap sound. Theta and alpha oscillations are known to be related to cortical communication (Bonnefond, Kastner & Jensen, 2017). The phase of alpha and theta modulates higher frequency oscillations that carry information about the stimulus. The left side of the auditory cortex is more involved in processing temporal information of sound, including speech processing whereas the right side is more specialized in processing spectral information of sound (Zatorre, Belin and Penhune,2002; Liégeois-Chauvel, de Graaf, Laguitton & Chauvel, 1999). Since a clapping sound does not contain complex temporal rhythms like speech, this might explain why increased synchronization is found in the temporal area at the right side, but not on the left side. This supports the theory that the observed increase in inter-brain synchronization reflects audio processing. However, the phase of theta oscillations has also been associated with communication of memories between the medial temporal lobe and medial prefrontal cortex (Kaplan et al., 2014). It is therefore impossible to distinguish memory retrieval from audio processing in our study. Nevertheless, there is no reason to believe that there is a difference in synchronized memory retrieval before and after a clap which makes it more likely that the increased inter-brain synchronization represents audio processing.

The observed increased inter-brain synchronization after a clap might indicate that handclaps increase the quality of the communication. The rhythm established by the claps is said to improve the clarity of the debater's communication (Liberman, 2015). This matches results from a study showing that increased inter-brain synchronization is related to higher quality in communication (Jiang et al., 2015). This study showed that more inter-brain synchronization arises between leaders and followers during a social interaction than between followers. They assumed that this finding is caused by leaders showing a better quality of communication than followers. Similar to our study, Jiang and colleagues found increased synchronization in the left temporal-parietal junction area. A study with brain-lesioned patients showed that this area seems to be necessary for reasoning about the beliefs of others (Samson, Chiavarino & Apperly, 2004). Reasoning about the beliefs of others and adjusting one's own behavior accordingly is known to improve communication (Dobbins, Long, Dedrick & Clemons, 1990). The clap might help to increase predictability of the others reasoning, thereby improving the clarity of communication.

The increased inter-brain synchronization after a clap could also reflect processes related to the timing of interpersonal coordination. A study by Lindenberger, Li, Gruber, and Müller (2009) showed that increased inter-brain synchronization is found in frequencies below 20Hz for frontal, central, temporal, and parietal arias at moments of importance for interpersonal timing for guitarists playing together. These moments were at the start of four metronome beats that set the tempo for the musicians and during the signal of the leading guitarist to start playing. The handclap might improve the timing of interpersonal coordination by signaling turn-taking in the conversation. However, the results of the study by

Lindenberger and colleagues could also be explained by increased shared attention. For our study, it is also likely that joint attention plays a role since both participants are engaged in a shared task and both need to pay attention to the content of the response of the other. The influence of shared attention on increased inter-brain synchronization can therefore not be separated from processes related to the timing of interpersonal coordination.

In conclusion, our findings do not support the expectations that a handclap during monastic debate enhances attention and plays a communicational role. However, it is impossible to determine whether this is due to the imprecision in timing the moment a clap took place or whether the clap indeed has no effect. Based on the uncorrected results, we hypothesize that a clap provokes processes related to interpersonal communication but future research is needed to assess whether this is true. The uncontrolled setting of this experiment makes it hard to determine the exact cognitive processes that are generated by the clap which in turn cause an increase in inter-brain synchronization. Therefore, studies with a more controlled research design are needed in the future to disentangle the processes causing a potential increase in inter-brain synchronization.

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