INTER-BRAIN SYNCHRONIZATION DURING MONASTIC DEBATE

Bachelor's Project Thesis

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Abstract: Debate is an essential component of Tibetan scholastic training. This practice is notable in that it has a specific physical form, and the debate is focused on finding contradictions rather than convincing the opponent of your position. Our study examines how inter-brain synchronization, which is thought to reflect social connectedness, varies as a function of two features in the debate. First we analyzed the synchronization between debaters to find neural evidence of joint attention during periods subjectively marked as "agreement" versus periods marked as "disagreement". The second analysis was if a change in the synchronization took place on the moment a debater clapped his hands. The results of both analyses indicated a change in inter-brain synchronization located at the temporoparietal cortex. The results were not significant after correction for multiple comparisons on 32 locations on the scalp.

1. Introduction

Monastic debate is a Buddhist contemplative practice involving at least a challenger and a defender arguing on a topic. Debating plays an important role in monastic education and enhances the monks' understanding of studied material. It is expected to require critical thinking and reasoning. In monastic debate, the challenger tries to attack a statement that the defender tries to uphold. This monastic debate has a quite specific form that is different from what is known as debate in the West. Specifically, the challenger attempts to find a flaw in the logic of the defender (Dreyfus, 2008), instead of in Western debate, where the credibility of the arguments are more important. The truth of the facts stated is not the subject of the debate. In this paper we aim to study the cognition during social interaction of the debate.

The social interaction between the challenger and the defender during debate is determined in part by the following rules that define monastic debate. The challenger tries to show that the defender is wrong by posing a consequence to the defender. This consequence contains a thesis and a reason, to which the defender replies. An example of a debate is from "a Brief Introduction to science debate", Sera Jay Sience center. When the consequence is 'it follows that light is not particle because it is wave', the defender has three options. He can agree on it, disagree on the thesis ('it doesn't follow'), or on the reason ('it is not a wave'). Alternatively he/she can say that he/she agrees on the consequence. The challenger attempts to win by making the defender contradict himself/herself, after which he/she says 'Tsa', which means, 'You are finished.' In this case, the challenger has tricked the defender into conflicting his response on an earlier statement. More principles on monastic debate involve that the debaters should avoid pauses, staying silent indicates him/her as at a loss of words. (Dreyfus, 2008)

Theatrical gestures by the challenger occur often, such as clapping in his hands at the end of a statement. These movements are likely used to affirm the argument made and capture attention of the defender.

Activities with mutual interaction, like monastic debate, require joint attention. Joint attention is suggested to play a part of social interaction so that representations of objects and events can be shared. This form of attention involves linking actualities and predicting the effects of the others' actions. (Sebanz, Bekkering, & Knoblich, 2006)

Research on joint attention showed neuronal inter-brain synchronization during eye contact. (Saito et al., 2010) This synchronization is thought to occur during maintained joined attention and may involve tuning neural circuits to oscillate with the same frequency and locked phase. (Hasson, Ghazanfar, Galantucci, Garrod, & Keysers, 2012) We suspect that this tuning of inter-brain synchrony in neural circuits between

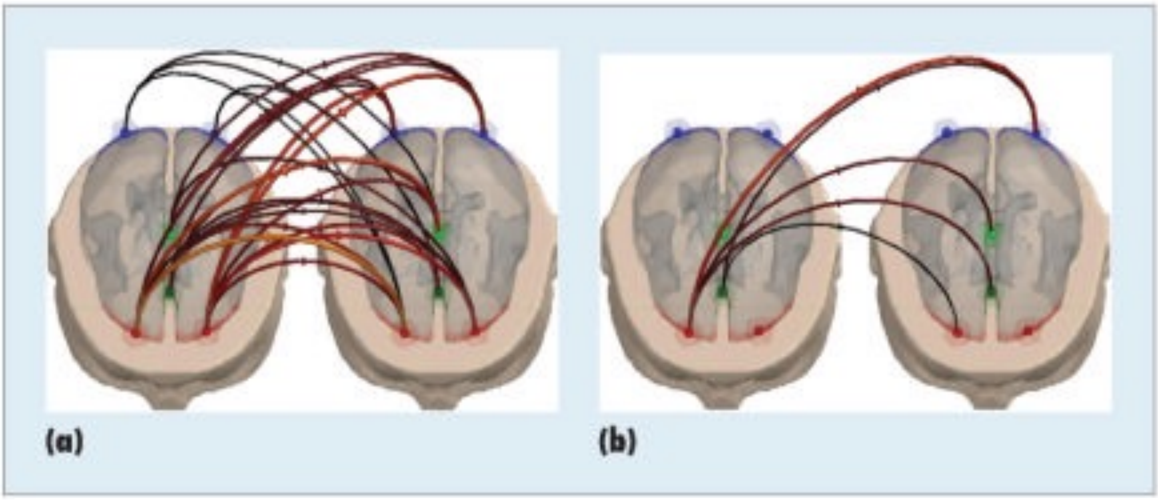

Figure 2: Increased number of synchronized electrodes in (a) cooperative relative to (b) defect behavior from (Astolfi L. et al, 2011)

both brains of the participants occurs during monastic debate. As it involves turn-taking and physical movement during social interaction. This is posed as a basis for synchronous actions during social interaction. (Hari & Kujala, 2009)

We used hyper-scanning methods to research the inter-brain synchronization of social interaction during monastic debate. With this method, data is collected from two participants at the same time, simultaneously recording the signals from the of both subjects. (Acquadro, Congedo, & De Riddeer, 2016)By analyzing comparing the data on neuronal activity in both brains, the inter-brain synchronization between the monks can be determined. Specifically, we attempt to find if changes in the debate change the inter-brain synchronizations of the monks. It is suspected that this works by neuronal circuits in the brain, which fire regularly.

Systems used to study the brain during social interaction are MRI and EEG. MRI scanners have the highest spatial resolution, but require persons to be lying inside the scanner, making MRI unsuitable for the movements involved in monastic debate. EEG is of a higher temporal resolution than MRI, and does not limit the physical actions of the participants much. (Koike, Tanabe, & Sadato, 2015) A cap with wired electrodes and backpack with the splitter boxes for the EEG device allows the monks to move relatively unconstrained.

Research on mutual interaction using hyper-scanning methods showed inter-brain synchronization in diverse social tasks. Game theory based experiments that required decision making and predicting strategies of their opponents (Fallani et al., 2010), movement imitation in finger tapping (Konvalinka, Vuust, Roepstorff, & Frith, 2010), and a simulated combat scenario (Dodel et al., 2011). The researchers successfully showed changes in the inter-grain synchronization predicting features in the tasks. The brain regions in which results were found are diverse, but consistently present is inter-brain synchronization located in the prefrontal and centro-parietal brain areas of the interacting participants.
The synchronization occurs in several frequency bands. In research on hand movement imitation (Dumas, Nadel, Soussignan, Martinerie, & Garnero, 2010), synchronization between the brains was found in the alpha band (8-12 Hz).

As far as we know, there is no comparable hyper-scanning research on inter-brain neural dynamics during conversations. A research that predicts on the prisoner's dilemma by (Astolfi et al., 2011)The pairs of subjects in this research played the prisoner's dilemma game, that involves them to choose between working together with their opponent or defect, for a possibly higher solitary reward. Analysis on inter-brain synchronization showed that when the subjects chose to defect they showed higher cortical activity and lower synchronization in distributed among several

brain areas. Cooperation elicited a weaker activation but a higher synchronization. They established functional links between brain regions when synchronization was found for cooperative and defect conditions.
These are shown in figure 1. The most often occurring functional connections are located at the parietal and occipital lobe.

During monastic debate there are moments when the defender agrees on the consequence of the challenger, and other moments when they are disagreeing. We suspect similar decision making as in game theory experiments This may be similar to the decision of cooperating or defecting in the prisoner's dilemma. If this holds, then this predicts that when the monks agree, there is a relatively high measure of inter-brain synchronization. (Astolfi et al., 2011) If the monks disagree there will be a relatively low measure of inter-brain synchronization. These effects are expected to be found using EEG hyper-scanning the centro-parietal brain areas and the alpha (8-12) frequency band, consistent with findings in earlier research on social interaction.

2. Method

The participants of the experiment were five monks of age 30 to 36 years. The debates took place in the Science center of Sera Jay monastery in Bylakuppe in a room with several monks and lay people as spectators. For each debate the participants debated relatively unconstrained, but were wearing an EEG cap. The challenger, who was standing, had a backpack with the splitter boxes of the EEG system. The defender was sitting on the ground. Nine debates were recorded with a varying number of participants. Five debates involved two monks, with EEG measurements of the challenger and the defender. Two debates involved EEG measurements on two defenders, debating against one or two challengers. Another two debates involved EEG measurements on two challengers, debating against one defender. The duration of the debates varied between 9 and 17 minutes.

For an analysis on differences in inter-brain synchronization during the debate, trigger events are determined. These trigger events are moments during the debate on which we suspect a change in the level inter-brain synchronization. For the first analysis, the moments on which the challenger claps his hands are labeled as trigger events. There occurred 100 claps during the debate. These were labeled as trigger events, as well as a pre-clap event 4 seconds before each hand clap. These pre-clap triggers are the events to which the inter-brain synchronization on the clap trigger. The analysis on the clapping was performed only on the second debate, due to time constraints to manually label all clapping events in further debates.

To obtain a general description on the social interaction involved in the debate, notes were made of how it proceeded. During the debate a third monk was watching and from time to time pressed a trigger button to indicate that "something interesting" happened. Each button press was associated by a verbal description, which was written down by one of the researchers. These descriptions contain remarks on the pacing of the debate, whether the monks agree or disagree and when the challenger finds a contradiction. The number of triggers per debate varies from 5 to 23.
On the basis of these descriptions, the trigger events are divided in two groups for expected inter-brain synchronization between the debaters. One group for a difficult, unpredictable state of the debate in which we expect less synchronization, and one easier, more predictable state of the debate in which we expect more synchronization. The keywords used are shown in table 1.

Agreement	Disagreement
Consistent	'Tsa'
Focus	Excitement
Flow	Tense
Harmony	Heated
Agreement	Disagreement
Same Direction	Hard time

Table 1: Keyword from debate notes, dividing trigger events in Agreement and Disagreement.

To measure the inter-brain synchronization, EEG data is recorded during the entire debate. In particular, the neuro-electric activity of the two participants was recorded using 32 channels arranged according to the 10-20 system for both participants. In this way the EEG device recorded the neuro-electric activity across most of the scalp. The sampling was done at a frequency of 500 Hz. The channels were re-referenced to the within-participant average. Data acquisition was performed using actiCAPs from the mobile Brainproduct System. This device contains active electrodes, with amplifiers. In this way the movements the monks make do not create much interference. Since both electrode caps were connected to the same EEG recording system, there was no need to send triggers back and forth to align the two datasets. In this way it was possible to do an analysis using EEG hyper-scanning.

The specific analyses are performed using Matlab and FieldTrip (Oostenveld, 2011). A low frequency band pass was performed to filter out frequencies higher than 45 Hz. For artifact rejection, ICA was used to find and remove artifacts from the EEG dataset. These artifacts are mostly from movements and eye blinks. The window size was 0.5 seconds, with steps of 0.01 second. The frequencies of interest are in the theta band (4-7 Hz) and the alpha band (8-12 Hz). Synchrony was computed on 2-second intervals and just prior to the button presses, to account for the expected delay between when the event occurred and when the spectator pressed the button.

Synchrony between both participants was computed using the Phase Synchronization Index (PSI). First a frequency analysis was performed using a multitaper time-frequency transformation using a hanning window. The Phase Synchronization Index was used to define synchronization between the brains, defined by

$$\mathrm{PSI}_{\phi}(f_i) = \left|\langle e^{j\Delta\phi^{k}(f_i)}\rangle\right|, j = \sqrt{-1}$$

The PSI measures if the oscillations in the data are in phase, without influence from the amplitude of the signal. It is a measure of locking of the phase of both oscillations. The PSI is 1 if the of the oscillating signals are in phase. It measures the stability of the phase across time within a trial. A high PSI for the period indicates that there is a period of phase synchronization of the brain area between the participants. This is a used as a reliable measure for the strength of inter-brain synchronization comparing two EEG electrodes. (Mizuhara, Wang, Kobayashi, & Yamaguchi, 2005)

For every debate an unpaired t-test with different sample size was used to compare the two clapping events. For the comparison on agreement and disagreement all debates are analyzed. A linear mixed model was used to combine the information of the several types of debates. A rejection of the null hypothesis was accepted with a $p>0.05$.

To find if there is a correlation in the data from multiple trials we need to combine the PSI from the varying debate types; challenger-defender, two defenders, two challengers. The Linear Mixed Effects Model can be fitted to the data with coefficients for the trials and the different setups. (Davidson, 2009) The Linear Mixed Effects Model uses the formula:

$$y = X\beta + Zb + \varepsilon, \varepsilon \sim N(0, \sigma I), b \sim N(0, \Psi), \\ \varepsilon \perp b$$

For the model y are N samples of the response variable, that is the measure of the synchronization, the PSI. X is the design matrix of fixed effects and β the fixed-effect coefficients. The fixed effects are type of the trigger as clap/pre-clap or for the second analysis agreement/disagreement. Z is the design matrix of random-effects and b are the coefficients of the random-effects. The random effects are the debate instance and the kind of debate, one challenger or two challengers or two defenders. Differences not fitted by the model are represented by the residual error ε. The mixed model is used to calculate the statistical significance of fixed effect on the predictor. This way, it can be determined if the difference in PSI between the groups of trigger events (clap/pre-clap or agreement/disagreement) is a relevant predictor for the measure of synchronization.

3. Results

Before performing the analysis, we needed to observe if the distribution of inter-brain synchronization between the monks in different debates is similar enough to perform statistical tests. In order to find if statistical analyses can be performed. There are different types of debates (with two participants or with two defenders/two challengers) the debates were also on different topics. To examine the inter-brain synchronization in different debates we computed the distribution of the PSI in the debates.

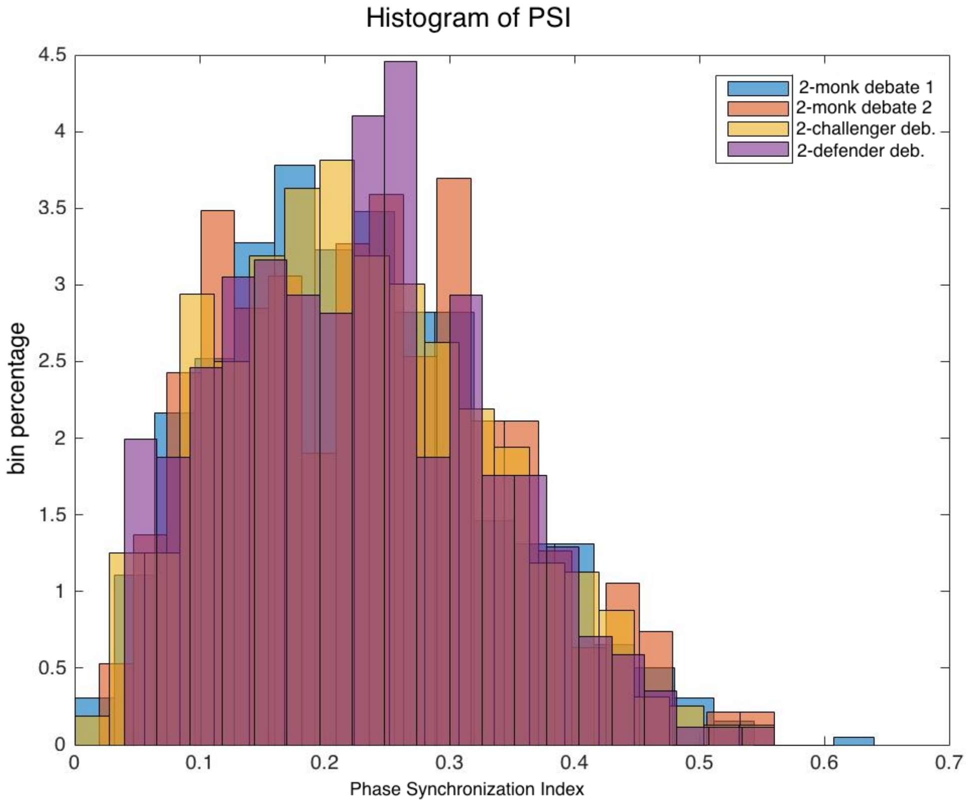

Figure 3: Histogram of PSI on continuous data, the measure in synchronization, y is percentage in the respective bin.

The phase synchronization index (PSI) was calculated over two-second intervals on the continual EEG data. It is shown for two participants in the debate. A histogram is shown for different debates in figure 2. A selection from the nine debates debates is included in the figure. It contains the first two debates with two participants and the first debate with two defenders and first debate with two challengers. The histograms show that the distributions of inter-brain synchronization between the debates are comparable. For the different debate types, the distribution of phase synchronization is comparable and seem to be normally distributed.

We used a linear mixed effects model to find if the synchronization differed between moments of agreement and disagreement in the debates. The results in the linear model show if there is a significant difference in agreement and disagreement for comparisons of all debates. The topography of these p-values for all the electrodes on the scalp in the three frequency bands are shown in Figure 3. The frontal lobe is at the top and parietal bottom, green indicates a low p-value (high significance) and red indicates a high p-value (low significance).

In the 4-7 Hz theta band, one frontal electrode showed a significant decrease in inter-brain synchronization for agreement compared to disagreement. In the 8-12 Hz alpha band one right parietal electrode showed a significant increase (p=0.04) for agreement. In the 13-30 Hz beta band, electrodes showed a significant (p=0.048) increase for agreement on the right parietal region on the scalp. A significant decrease (p=0.02, p=0.003) was found both on the left parietal and center of the scalp for agreement. Because of performing the statistical tests for all 32 channels, we needed to correct for multiple comparisons. When using a false discovery rate of 0.05, there were no p-values that were higher than the corrected threshold.

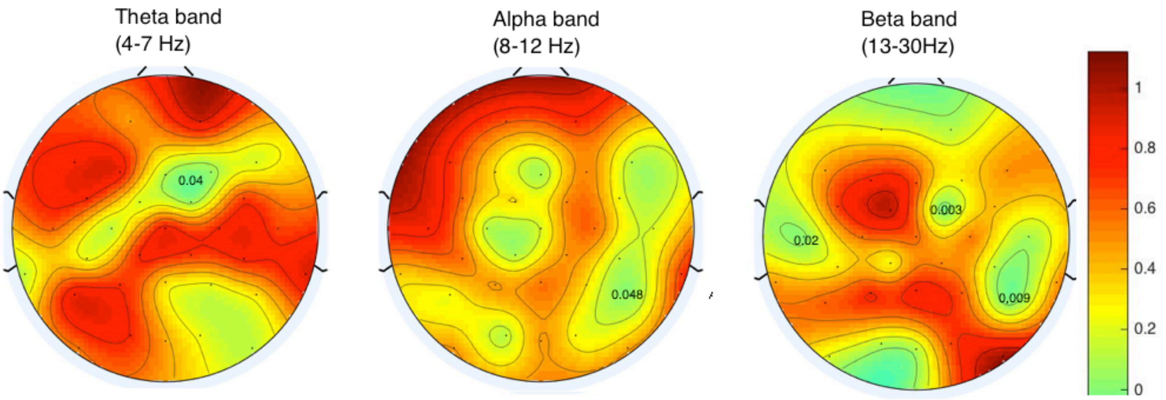

Figure 4: Plot of p-value from model on phase synchronization Index vs trigger group. Numbers indicate the p-values of electrodes that show an uncorrected significant difference (p<0.05) in inter-brain synchronization between the different debates.

After this general analysis of the debate, we focused on analyzing more clearly observable events during the debate. At various points during the debates, the challenger claps his hand to emphasize a consequence. We performed statistical analysis on these events to find out whether the inter-brain synchronization differed between just after the hand clap and four seconds before the clap. The analysis was performed on the second debate with two monks, a challenger and a defender. Results from the t-test show if there was a significant difference in the PSI between pre- and post-clap moments for various electrodes in the theta, alpha and beta frequency bands. The topography of the significance for all of the channels are shown in figure 4. The topography plot shows that in the 4-7 Hz theta band, one frontal electrode showed a significant decrease (p=0.027) in synchronization and one on the right parietal region of the scalp showed a significant increase (p=0.03) on the clap. In the 8-12 Hz alpha band, one electrode in the right parietal and one near the center of the scalp showed a significant increase (p=0.01, p=0.03) on the clap. In the 13-30 Hz beta band, a right frontal electrode showed a significant increase (p=0.04) in inter-brain synchronization on the clap.

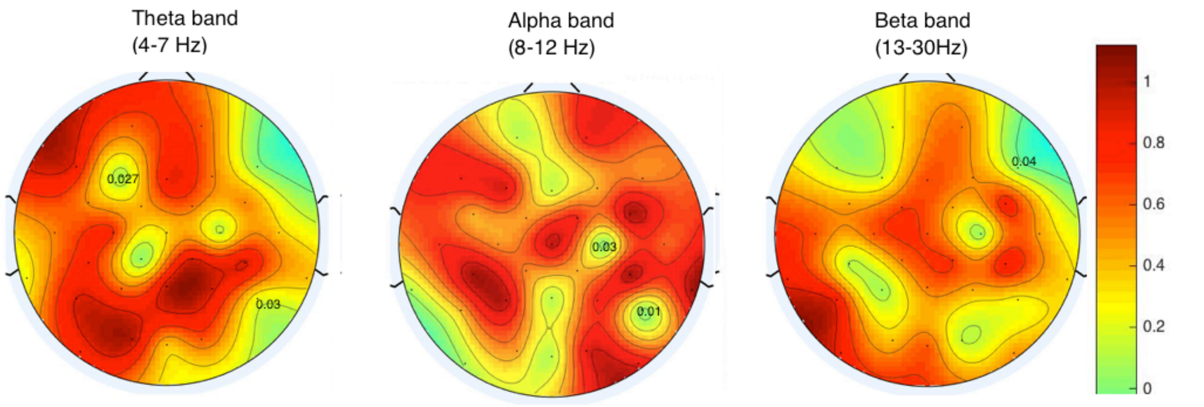

Figure 5: Plot of p-value from t-test on PSI clapping moment vs before clapping. Numbers indicate the p-values of electrodes that show an uncorrected significant difference (p<0.05) in inter-brain synchronization between the different debates.

After correcting for multiple comparisons, using a false discovery rate of 0.05, there were no p-values that were above the corrected threshold.

In summary, we observed relatively weak evidence for increased synchronization between the brains of both monks on agreement relative to disagreement, and right after the challenger had made a hand-clap relative to before. In all cases, this inter-brain synchronization occurred mostly in right parietal cortex. This result was found in the theta, alpha, and beta frequency bands.

4. Discussion

Our study provides some evidence that during a social task involving verbal turn-taking oscillatory synchronization occurred between the brains of the monks that depended on task parameters. Specifically, we showed an increase in inter-brain synchronization after a clearly timed cue during the interaction (a handclap), as well as during agreement compared to disagreement on the verbal content of the debate. This inter-brain synchronization was found in the right temporoparietal region on the scalp. The temporoparietal junction is suggested to have an essential role in integration of information for social interaction. (Decety & Lamm, 2007)

These results tie into a larger literature of EEG hyper-scanning research on social interaction. Synchronization of the timing and pace of physical movements are expected to be encoded in the right parietal region. For example, inter-brain synchronization during social interaction in the right parietal region is found in studies on imitation of hand movements (Dumas et al., 2010) and imitation of finger movement (Tognoli, Lagarde, DeGuzman, & Kelso, 2007). In those experiments, right parietal alpha oscillations (8-12 Hz) were shown to be increased during synchronous movements relative to asynchronous movements.

One may wonder why we observed an increase in inter-brain synchronization at the time of the clapping gesture. The clap by the challenger, to affirm a statement, is a clearly timed cue. The cue can serve as an object for both monks that captures joint attention. Specifically, the moment of a clap by the challenger showed a higher synchronization than four seconds before that moment. The change in synchronization was found in the theta (4-7 Hz) and alpha band (8-12 Hz) in the temporoparietal cortex. After correction for multiple comparisons on all 32 channels, the result is not significant. Further research is needed to verify this result.
Similarly, we observed an increase in synchronization the right parietal cortex between the two brains when the monks agreed relative to disagreement. This increase in synchronization when the monks agree, may be due to an increase in joined attention. During disagreement, attention may be directed more towards reasoning. This is expected to diminish the attention they can directed towards joined attention. This may be the cause for the decrease in synchronization.
The results on agreement showed a significant results in the alpha (8-12) and beta (13-30) band in the temporoparietal cotrex. On correction for multiple comparisons on all 32 EEG channels, the result was not significant. One possible explanation for the weakness of the effect could be uncertainty in the decision on the periods of agreement and disagreement in the debate. The moments of agreement and disagreement were identified subjectively by an observing monk, and therefore are subject to interpretation. Although we expect that the general descriptions provide an accurate representation of what occurs during the debate, the descriptions are an interpretation of what happens in the debate. The subjectivity of the descriptions can lead to wrong conclusions about the agreement between the monks. This could have lowered the significance of the results.

In both cases, the changes in inter-brain synchronization from the analyses on agreement and on clapping were located in the right temporoparietal cortex. In the EEG analysis the inter-brain synchronization is found in different frequency bands. The lower bands frequencies are from slow neural oscillations, the higher fast oscillations. The frequency band in which inter-brain synchronization is found for the clapping present in the theta (2-7 Hz) and alpha (8-12 Hz), in agreement in the alpha (8-12Hz) and beta (13-30 Hz). The theta band is found to be a marker for emotional processing (Knyazev, Slobodskoj-Plusnin, & Bocharov, 2009). The Alpha and Beta for the motor neurons and mirror neuron system. (Perry, Troje, & Bentin, 2010) The synchronization appears to be in a higher frequency band for the agreement vs disagreement. It is not clear why this difference is found.

Despite uncertainty on the results, this study indicates that there is inter-brain synchronization during monastic debate, and that this inter-brain synchronization is quite substantial (going up to a value of 0.6, where the maximum synchronization is 1.0).
Nevertheless, further research is required since the results are statistically weak. This can be due to artifacts in the EEG data due to the movement of the monks. During the debate, the challenger walked around and moved his arms. This is likely to create interference in the EEG recordings. It may be that despite artifact rejection and usage of active electrodes, movement artifacts still remained in the data.
Other events may be determined that change the inter-brain synchronization between the monks. This can confirm or deny the relevance of joined attention and social connectedness the debate.

Further research questions remain on the subject. We give some suggestions for further research on inter-brain synchronization during monastic debate.

Is there a difference between the challenger and the defender for the initiation of social interaction? During debate involving two monks, one of them is speaking at a time. The task of the monk that listens is different monk that speaks at that moment. Earlier research on directed synchronization used Granger Causalities statistics. This method can be used to show if a time series predicts another. In this experiment it is used to show if an neuronal oscillation forecasts an oscillation in the brain of the opponent. (Fallani et al., 2010)

Is there an observable change in inter-brain synchronization when the challenger finds an contradiction? When the defender contradicts himself, the challenger says “tsa”, indicating that he has found an inconsistency. Before this moment, the challenger tricks the defender into making a statement that is not correct. The challenger knows this, but the defender does not. This may require that the challenger reasons about the belief of the defender, which involves theory of mind. A research showed that the right parietal region is essential for theory of mind reasoning as well. (Apperly, Samson, Chiavarino, & Humphreys, 2004) In the moment of the contradiction a difference in brain activation in this region may be observed for the challenger compared to the defender.

How does the length of the pauses between turn-taking during the debate contribute to the measured inter-brain synchronization? Research on speech anticipation shows changes in activation of the parietal brain areas before is formulated a response (Wesselmeier & Müller, 2015) If turn-taking of the monks can be reliably labeled during the debate, an effect of speech anticipation may be observed. There are periods where the challenger and the defender alternate rapidly, and periods where they take more time between successive turns. We do suspect that there is less inter-brain synchronization in periods with longer pauses between the turns of the debaters.

While more research on the subject is needed, we have shown preliminary evidence that inter-brain synchronization is increased during periods of agreement and after hand-claps during monastic debate. Moreover, these results demonstrate that EEG hyper-scanning may be used to explore the neural basis for social interaction during the naturalistic practice of Tibetan monastic debate.

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Appendix A: code synchchonization analysis

```
function [eegData] = synchAllDebates()
%Main function execute agree/disagree analyses on all debates.
%clapping analysis part

    %the frequency band
    foi = 8:12;

    %open fieldtrip
    addpath /applications/fieldtrip;
    ft_defaults;

    %create a struct for the results of the analysis
    eegData = struct();
    eegData.ds = table();
    eegData.model = [];

    %read and analyse all eeg data
    for n=1:5
        if n ~= 4
         dataFileName = sprintf('dyadicdebate%d',n);
         eegData.(dataFileName) = addAnalysis(dataFileName,n,1);
        end
    end

    for n=1
        dataFileName = sprintf('Twodefender%d',n);
        eegData.(dataFileName) = addAnalysis(dataFileName,n+5,2);
    end

    for n=1
        dataFileName = sprintf('Twochallenger%d',n);
        eegData.(dataFileName) = addAnalysis(dataFileName,n+7,3);
    end

    %save frequencyanalysis and statistics in the struct
    function [dataName] = addAnalysis(dataName,t,g)
        %name of experiment, row for triglabels, experiment group
        %(dyadic, 2defender, 2challenger)
        longName = strcat(dataName, 'clean.mat');
        clapData = load(longName);
        %combine the data of both seperate EEG's
        dataFile =
 ft_appenddata([],clapData.data_iccleanedA,clapData.data_iccleanedB);
        %put it under the name as subfield
        dataName = struct();

        %add times of the triggers
        dataName.trigTimes = addTrigTimes(dataFile);

        %perform the frequency and synchronyanalysis
        dataName.freqAnalysis = freqSyncAnalysis(dataFile,foi, true);
```

```
        dataName.trigLabels = triggerLabels(t);

        nTrials = size(dataName.freqAnalysis);
        nTrials = nTrials(1);
        nTrigs = size(dataName.trigLabels);
        nTrigs = nTrigs(1);


        switch (nTrials-nTrigs)
             %remove last trial if 1 extra trial
            case {1}
                dataName.freqAnalysis =
dataName.freqAnalysis(1:nTrigs,:,:);
            %remove first trigger if 1 extra trigger
            case {-1}
                dataName.trigLabels = dataName.trigLabels(2:nTrigs,:);
                %normal data
            case {0}
            %error in file
            otherwise
                disp('Error, trial/trig numbers incompatible')
        end

        %add statistical analysis (mixed model)
        dataName.nTrigs = nTrigs(1);
        dataName.nTrials = nTrials(1);
        stats = tStat(dataName,t,g);
        dataName.stats = stats;

        eegData.ds = [eegData.ds;stats.dstable];

    end

    function [ trigsec ] = addTrigTimes(data)
        %returns trigger labels and timing
        sampleStart = data.sampleinfo(:,1);
        fsample = data.fsample;
        trigsec = sampleStart/fsample;
        trigsec = trigsec - trigsec(1);
        trigsec = trigsec/60;

    end

    function [ meanPhaseByTrial ] =
freqSyncAnalysis( combData,foi,off)
        % Calculate frequency for the data with given band foi and
offset
        % synchronization as the PSI

        cfg.output = 'powandcsd';
        cfg.method = 'mtmconvol';
        cfg.keeptrials = 'yes';
        cfg.taper = 'hanning';
        %cfg.channel = channels;
```

```
        cfg.channelcmb =
{'Fp1_A','Fp1_B';'Fp2_A','Fp2_B';'F7_A','F7_B';...

 'F3_A','F3_B';'Fz_A','Fz_B';'F4_A','F4_B';'F8_A','F8_B';...

 'FC5_A','FC5_B';'FC1_A','FC1_B';'FC2_A','FC2_B';'FC6_A','FC6_B';...

 'T7_A','T7_B';'C3_A','C3_B';'Cz_A','Cz_B';'C4_A','C4_B';'T8_A','T8_B';...

 'TP9_A','TP9_B';'CP5_A','CP5_B';'CP1_A','CP1_B';'CP2_A','CP2_B';...

 'CP6_A','CP6_B';'TP10_A','TP10_B';'P7_A','P7_B';'P3_A','P3_B';...

 'Pz_A','Pz_B';'P4_A','P4_B';'P8_A','P8_B';'PO9_A','PO9_B';...

 'O1_A','O1_B';'Oz_A','Oz_B';'O2_A','O2_B';'PO10_A','PO10_B'}
        cfg.foi = foi;
        cfg.t_ftimwin = 4./cfg.foi;

        if off
            cfg.toi = -3.5:.01:-3;
        else
            cfg.toi = 0:0.01:0.5;
        end

        freq = ft_freqanalysis(cfg,combData);
        % compute for every trial the average phase angle across all
time
        meanPhaseByTrial =
abs(nansum(exp(1i*angle(freq.crsspctrm)),4))...
            ./length(freq.time);
    end

    function [allTrigs] = triggerLabels(n)
        %return correct labels for the triggers events (1=agree, 2=dis
        trigName = 'allTriggersCorrect.csv';
        allTrigs = dlmread(trigName);

        allTrigs = allTrigs(find(allTrigs(:,1)==n),7);

    end

    function [result] = tStat(data, instance, group)
        %compute the results of a ttest
        %and add a table containing all synch results in one matrix

        freq = data.freqAnalysis;
        trig = data.trigLabels;
        n = length(trig);

        trial = [1:n]';
        %list of freqs nx31
        f = freq(1:n,:,2);
        instance = repmat(instance,n,1);
```

```
group = repmat(group,n,1);

%divide triggers: 1 is disagree, 0 agreement
agreeInd = find(~trig);
disagreeInd = find(trig);
result.agree = f((agreeInd),:);
result.disagree = f((disagreeInd),:);
result.ttest = [1:32];

%labels for the names of all channels
Fp1 = f(:,1);
Fp2 = f(:,2);
F7 =f(:,3);
F3=f(:,4);
Fz=f(:,5);
F4=f(:,6);
F8=f(:,7);
FC5=f(:,8);
FC1=f(:,9);
FC2=f(:,10);
FC6=f(:,11);
T7=f(:,12);
C3=f(:,13);
Cz=f(:,14);
C4=f(:,15);
T8=f(:,16);
TP9=f(:,17);
CP5=f(:,18);
CP1=f(:,19);
CP2=f(:,20);
CP6=f(:,21);
TP10=f(:,22);
P7=f(:,23);
P3=f(:,24);
Pz=f(:,25);
P4=f(:,26);
P8=f(:,27);
PO9=f(:,28);
O1=f(:,29);
Oz=f(:,30);
O2=f(:,31);
PO10=f(:,32);

%create a matrix with all results, for the lme model
result.dstable = table(instance,group,trig,Fp1,Fp2,F7,...

F3,Fz,F4,F8,FC5,FC1,FC2,FC6,T7,C3,Cz,C4,T8,TP9,CP5,CP1,CP2,...
    CP6,TP10,P7,P3,Pz,P4,P8,PO9,O1,Oz,O2,PO10);

%perform a ttest for all channels
for r= 1:32
    [h,result.ttest(r)] =
ttest2(result.agree(:,r),result.disagree(:,r));
end
```

```
 end

%add the variables to the dataset
eegData.ds.trig = nominal(eegData.ds.trig);
eegData.ds.group = nominal(eegData.ds.group);
eegData.ds.instance = nominal(eegData.ds.instance);


%create the lme model and add the results.
for i=4:35
    channel = char(eegData.ds.Properties.VariableNames(i));
    formula = strcat(channel,'~trig+(1|group)+(1|instance)');
    model = fitlme(eegData.ds,formula);
    anov = anova(model);
    slope = fixedEffects(model);
    eegData.model = vertcat(eegData.model, {channel, anov{2,2}, ...
        anov{2,5},slope(2)});
end

eegData.clapAnalysis = clapAnalysis();

%%%%%%%%%%%Clapping Analysis%%%%%%%%%%%%%%
 function [stats] = clapAnalysis()
     a = load('clapsTimepoints.mat');
     clapsTimepoints = a.clapsTimepoints;
     %correct for the offset for the first trial of 7 seconds
     %movie start point 7 seconds before debate
     clapsTimepoints = clapsTimepoints - 7;

     %create the config file for the claps
     %1000 sample trials, preclap 2000 samples (4 seconds) before
clap
     clapSamples = clapsTimepoints*500;

     preclaps = clapSamples - 2000;
     trials = [preclaps;clapSamples];
     trials = sort(trials);
     trials = trials(2:201);
     trials = int32(trials);
     trialEnd = trials+1000;
     offset = zeros(200,1);
     trl = [trials trialEnd offset];
     cfg = [];
     cfg.trl = trl;

     %redefine the trials for 2nd debate
     clapData = load('dyadicdebate2cleancont.mat');
     datacomb = ft_appenddata([],clapData.data_iccleanedA, ...
         clapData.data_iccleanedB);
     clapData = ft_redefinetrial(cfg,datacomb);

     foi = [8:12];
     clapData.freqAnalysis = freqSyncAnalysis(clapData,foi, false);
```

```
        %divide claptrials(1,3,5..) and non-claptrials(2,4,6..)
        %create a trigger label for on the clap a 1 (disagree), else a
 0 (agree)
        clapInd = 1:2:200;
        trig = zeros(200,1);
        trig(clapInd) = 1;
        clapData.trigLabels = trig;
        stats = tStat(clapData,1,1);
    end

end
```

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Appendix B: Code Histogram synchronization

```
function [ ] = syncHistoPlot()


    figure('Name','debateSync');
    Fz1 = syncHistogram('dyadicdebate1');
    hold on

    Fz2 = syncHistogram('dyadicdebate2');

    %syncHisto('dyadicdebate3')

    %syncHisto('dyadicdebate4')

    %syncHisto('dyadicdebate5')

    Fz2d = syncHistogram('Twodefender1');

    %syncHisto('Twodefender2')

    Fz2c = syncHistogram('Twochallenger1');

    %syncHisto('Twochallenger2')


 legend('dyadicdebate1','dyadicdebate2','Twodefender1','Twochallenger1');

    function [ ch ] = syncHistogram(fileName)
         longName = strcat(fileName,'cleancont.mat');
    load(longName);
    cfg = [];
    combData = ft_appenddata(cfg,data_iccleanedA,data_iccleanedB);

        % find a time-resolved method so we can look at within-trial
    % synchronization
    cfg = [];
    cfg.output = 'powandcsd';
    cfg.method = 'mtmconvol';
    cfg.keeptrials = 'yes';
    cfg.taper = 'hanning';
    %cfg.channel =
 {'Fp1_A','Fp2_A','F3_A','Fz_A','F4_A','PO9_A','O1_A',...

  'Oz_A','O2_A','PO10_A','Fp1_B','Fp2_B','F3_B','Fz_B','F4_B','PO9_B',...
        'O1_B','Oz_B','O2_B','PO10_B'};
    %cfg.channel = {'Fz_A','Fz_B','_A','Oz_B'};
      cfg.channelcmb =
 {'Fp1_A','Fp1_B';'Fp2_A','Fp2_B';'F7_A','F7_B';...
          'F3_A','F3_B';'Fz_A','Fz_B';'F4_A','F4_B';'F8_A','F8_B';...
          'FC5_A','FC5_B';'FC1_A','FC1_B';'FC2_A','FC2_B';'FC6_A',...
          'FC6_B';'T7_A','T7_B';'C3_A','C3_B';'Cz_A','Cz_B';'C4_A',...
          'C4_B';'T8_A','T8_B';'TP9_A','TP9_B';'CP5_A','CP5_B';...
          'CP1_A','CP1_B';'CP2_A','CP2_B';'CP6_A','CP6_B';...
```

```
            'TP10_A','TP10_B';'P7_A','P7_B';'P3_A','P3_B';...
            'Pz_A','Pz_B';'P4_A','P4_B';'P8_A','P8_B';...
            'PO9_A','PO9_B';'O1_A','O1_B';'Oz_A','Oz_B';...
            'O2_A','O2_B';'PO10_A','PO10_B'}

    cfg.foi = [8:12];
    cfg.t_ftimwin = 4./cfg.foi;
    cfg.toi = 0:0.01:2;
    freq = ft_freqanalysis(cfg,combData);

    meanPhaseByTrial = abs(nansum(exp(1i*angle(freq.crsspctrm))...
        ,4))./length(freq.time);
     ch = meanPhaseByTrial(:,27,2);
    h = histogram(ch,'Normalization','pdf');
    h.NumBins = 20;
    end
end
```

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