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Beyond physical entrainment: competitive and cooperative mental stances during identical joint-action tasks differently affect inter-subjective neural synchrony and judgments of agency

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Abstract: Little work has examined how mental stance alone, apart from physical entrainment, affects between-participant neural synchrony during joint social interaction. We report the first findings on how cooperative and competitive mental stances, even during identical visuomotor joint-action tasks, result in distinct neural oscillatory signatures in low beta and theta band between-participant phase synchrony. Two participants jointly controlled a cursor and were instructed to either compete or cooperate to move it to one of three targets. The visuomotor output was identical for both the compete and cooperate conditions because participants were privately given the same target for experimental trials. Cooperation enhanced theta band between-participant phase-locking value (PLV) midtrial at 1-2 seconds, reflecting activation of systems for social coordination to move the cursor in a shared direction. Competition enhanced low beta between-participant PLV, shifting from temporal to frontal regions, indicating that participants focused only on their target and later evaluated self-agency as winner or loser. This interpretation of the neural signature was corroborated by participants' greater post-trial ratings of the degree of control over the cursor during competition. Top-down cooperative and competitive mental stances shape perceptions of social context and affect interpersonal neural synchrony important for representation of self and others' actions.

Keywords: Competition, cooperation, mental stance, interpersonal neural synchrony, agency

Introduction

A growing number of studies have shown how top-down mental stance shapes perceptions of social context and affects neural representation of self and others' actions. Mental stance is the attitude toward others during social interaction that can affect the deployment of attention and self-referential processes based on the mentalizing of shared or divergent beliefs, goals and future actions. For example, Koban, Pourtois, Vocat, and Vuilleumier (2010) found that a cooperative but not competitive mental stance during a go/no-go task resulted in early (125–145 ms) evoked-potential negativity in observers when viewing co-participant actors' errors. Hommel, Colzato, and van den Wildenberg (2009) likewise found cooperative but not competitive attitude in a Simon task selectively enhanced the recruitment of shared representations. They proposed that cooperation fostered self-other merging and monitoring from a first-person perspective by enhancing shared motor representation in the mirror neuron system. This

suggested that competition between participants may involve a more self-centered perspective without merging with others. These studies strongly suggest that cooperative and competitive mental stance may affect perceptions and inter-participant neural synchrony during joint action. Although interbrain synchronization has been well established as an underlying mechanism for joint-action and social interaction, little work has examined just how much mental stance alone, apart from physical entrainment, influences the perception of social context and supporting neurological responses. A shift in mental stance from cooperation to competition is perhaps the most salient contrast in how the same social event can be differently perceived and how attentional resources are subsequently allocated. Studies of competition and cooperation often employ different experimental protocols making it difficult to

discern whether contrasting neural patterns are the result of the tasks or mental stance. Cooperative and competitive activity both involve attention, anticipation and reaction to another actor's intentions and actions (Tsoi, Dungan, Waytz, & Young, 2016). However, the two are generally investigated using different experimental paradigms. Interbrain synchrony studies of cooperation usually involve joint action, while those on competition generally use strategic turn-taking games (Balconi & Vanutelli, 2017). No study has examined how the mental stance of cooperation or competition in identical tasks affects between-participant neural synchrony and the sense of agency.

Recent EEG hyperscanning studies have shown that cooperative joint-action synchronizes brain activity between participants compared to competitive conditions. For example, studies of airplane copilots have found greater between-brain phase synchrony in frontal regions for theta band and parietal regions for alpha band during take-off and landing, when increased risk would demand enhanced attention to interpersonal coordination and cooperation (Astolfi et al., 2011, 2012; Toppi et al., 2016). In a Pong-type game, participants had higher inter-brain correlation in alpha and beta bands when they cooperatively played as a team on one side of the screen against the computer, as compared to when they played competitively against each other on opposite sides of a screen (Sinha, Maszczyk, Zhang, Tan, & Dauwels, 2016). These studies are consistent with well established literature showing between-participant neural synchronization during joint-action and joint-attention tasks (Hu, Hu, Li, Pan, & Cheng, 2017; Liu et al., 2018; Wallot, Mitkidis, McGraw, & Roepstorff, 2016; Cheng et al., 2015; Dumas et al., 2010).

In contrast, EEG hyperscanning studies of strategic decision-making games find that spectral power is enhanced during competition as compared to cooperation. Experiments using games such as Bridge, Chicken, and Prisoner's Dilemma found greater spectral power in frontal regions for beta and theta bands for the competitive defect or defeat conditions compared to cooperative conditions (Astolfi et al., 2009, 2010; Babiloni et al., 2007). In one study, this greater power was elicited within the first second of activity by the sudden decision to compete (Fallani et al., 2010).

These contrasting neural patterns and experimental protocols highlight the importance of examining the mental stance of cooperation and competition during joint-action. However, mental stances of cooperation and competition are particularly difficult to isolate from differences in the motor tasks for each condition. Cooperative joint-action involves shared perspective, attention, and motor behavior toward a common goal. In contrast, competition is usually directed toward divergent goals and motor

behavior. This leads to distinct patterns of attentional and motor responses. When comparing both mental stances these different responses can confound underlying differences in the neural correlates that undergird these mental stances irrespective of their physical actions.

The present study aims to address these methodological challenges and the lack of direct comparisons in the literature, by examining the neural correlates of the mental stances of cooperation and competition, while employing the same task of seeming joint control over a computer cursor. We tested whether the mental stance of competition or cooperation during joint control of a cursor affected between-participant neural oscillation patterns. Two participants and a third computer-controlled player used joysticks in separate rooms to share equally weighted control over a single cursor. Prior to each trial, the two participants were given the instruction to compete or cooperate to move the cursor to one of three possible targets. Participants were instructed that each of the three participants might be given the same target and that one or both of the other participants, or all three participants, might be given separate targets. The cursor supposedly would move according to the vector sum, presumably directing participants to move in the same or different targets. In experimental trials, however, both participants were privately told the same target. Thus, in experimental trials, the only difference was the mental stance to compete or cooperate, while the motor output and visual feedback would be identical.

In experimental trials when participants reached their target, we expected greater between-brain phase synchrony, measured as phase-locking value (PLV), during cooperation than competition in alpha and theta bands. These are markers for enhanced attention and social coordination found by Astolfi et al. (2011, 2012) and Toppi et al. (2016). Baird, Smallwood, Lutz, and Schooler (2014) also found a significant increase in theta-band phase locking to visual events during task focus compared to mind-wandering, which may relate to participants' greater task focus during our cooperate condition to coordinate with others. We also predicted enhanced spectral power in beta and theta bands during competition compared to cooperation, especially during the first second of trials, as noted by studies of competitive decision tasks. (Astolfi et al., 2009, 2010; Babiloni et al., 2007; Fallani et al., 2010).

The experimental conditions thus tested specifically for the neural correlates of competitive and cooperative mental stances using an identical visuomotor joint-action task. As a secondary post-trial behavioral judgment, we examined whether the mental stances of competition and cooperation also affect the sense of agency during joint action. As proposed by prior research, cooperative mental stance

may enhance shared representation and self-other integration (Hommel et al., 2009; Koban et al., 2010) to reduce the sense of individual agency, while competitive mental stance attenuates self-other integration to accent first-person perspective (Ruissen & de Bruijn, 2016).

Studies of the sense of agency have primarily focused on the low-level visuomotor feedback that bind action intentions as the perceived cause of events. A sense of agency arises from the correspondence or predictability between self-generated motor action and the observed effects. This sense of agency decreases when control over the movement of an object is perceived to be shared. However, Dewey, Pacherie, and Knoblich (2014) and van der Wel (2015) have shown that perceived agency increases when two participants jointly move an object, but each person controls a distinct dimension of the movement, such as horizontal or vertical movement. The sense of agency during this sort of complementary control also increases when the pair shares an intended goal compared to when they do not.

If the mental stances of cooperation and competition alone influence the post-trial sense of agency, this would strongly suggest that sense of agency is also influenced by social attitude, even when the motor output and feedback in both conditions are identical. Hence, after each trial, we had participants rate their perceived degree of control to examine whether high-level cognitive processes underlying competitive and cooperative mental stances also altered their perception of agency. We predicted that competitive mental stance alone may enhance participants' perception of agency because they would believe their successfully reaching the target was the result of their action, not that of other participants who presumably had different goals.

Materials and methods

Participants

Forty-two participants (21 females) were recruited for the experiment. Data from two participants were excluded because they did not comply with task instructions. This left 40 participants (20 females) with average age 22.5 (SD = 1.4). Two additional participants were excluded from power analysis because of missing triggers, and eight participants were excluded from PLV analysis, because of equipment errors with data recording leading to a mismatch in trials between subjects or too few usable matched trials.

Procedure

Two participants and one confederate, posing as a third participant, were seated together in a waiting room

where they filled out forms and had their heads measured. The two participants were then each seated in two separate rooms with a CRT monitor and joystick. The confederate was presumably led to a third room. The two participants were shown the same display on each of their screens and informed of this. They were instructed that all three of them (including the confederate) would use the joysticks to jointly control a circular cursor, which would appear at the center of the screen at the beginning of each trial. The three joystick inputs would be equally weighted, and vector summed to control the direction of the cursor, but not the cursor speed, which would remain constant. So, if two participants moved in the same direction, their inputs would outweigh the third, and the cursor would move at a constant speed in the direction controlled by the majority of participants. If all three participants moved in different directions, the cursor movement could jitter or cancel out.

Once these instructions were understood, the participants were informed that they were to use their hand on the joystick to move the jointly controlled cursor to one of three targets. The participants were instructed to point their joysticks to the target as soon as the target was given. The targets would appear on the outer edge of the screen, equidistant from the cursor starting position, at the center. Each participant would then be given the same or different targets by auditory instruction over earphones. At the beginning of each trial, the words "compete" or "cooperate" would appear on the screen. In the compete condition, participants were to point their joysticks at their given target till the end of the trial, regardless of the direction the cursor moved. In the cooperate condition, participants were to initially point their joysticks in the direction of their given target; however, if the cursor started to move toward a different target, the participant was to immediately switch direction and point their joystick to this different target; thus cooperating with the other two participants who were presumably aiming at that target.

Material and trial timeline

The order of the stimuli presentation for each trial was as follows. Each trial began with both participants seeing the same word, "compete" or "cooperate" for 1.5 s at the center of their screen to inform them of the trial condition. Three targets would then appear for 3 s, randomly positioned at a same distance from the center of the screen. The three targets were small circles labeled inside with the numbers 1, 2, or 3. While the targets were on the screen, participants were simultaneously given the auditory instruction "one", "two", or "three" for their target. The target numbers then disappeared, and the cursor appeared at the center of the screen

indicating the start of the trial. As soon as the target appeared, the joysticks were activated. Each trial ended once the cursor reached a target or timed out after 4 s.

At the end of each trial, participants were asked to use their other hand to rate their degree of control over the cursor using a 10-point scale, which evaluated their sense of agency. Response and joystick hands were counterbalanced across participants. The genders of the participants were also counterbalanced.

Experimental design

Participants were exposed to 120 experimental and filler trials. There were 84 experimental trials, subdivided into 42 trials for the compete and 42 trials for the cooperate conditions. In the experimental trials, the two participants were each instructed to aim at the same number target, but could not hear the target given to the other participant. Both participants also had control over the cursor movement. Hence, in both the compete and cooperate conditions, the visual feedback and motor output during the experimental trials were comparable. The only difference was the participants' goal to either compete or cooperate.

Two types of filler trials were included to give the impression that there was a third person. These filler trials were also subdivided into compete and cooperate conditions. In the first type of filler trial (24/120), neither participant had control over the cursor and each participant was given a different target. Both participants' joysticks were deactivated. Instead, the computer controlled the cursor to move to the third target, which was unassigned to the two participants. Each participant would have the impression that their joystick input was outweighed by the other two participants controlling the cursor to a different target. In the cooperate condition, both participants would change their initial target to cooperate with the group.

In the second type of filler trial (12/120), both participants had control over the cursor and were given different targets from each other. In addition, the computer simulated a third participant by adding vector input to move the cursor toward the third target, which was unassigned to the participants. In the compete condition, the two participants and computer would be aiming at different targets. The cursor would jitter but not reach any target before the trial timed out. In the cooperate condition, this mimics a situation where participants would have to change their initial direction until a common group target emerged.

EEG data recording and preprocessing

Electroencephalographic data was recorded from 19 Ag/AgCl scalp electrodes mounted in an elastic cap according to the modified 10/20 system. EEG signal was recorded at

256 Hz referenced to the nose. Horizontal EOG (electrooculogram) was recorded from the outer canthi of the eyes. Vertical EOG was recorded using electrodes above and below the left eye. Electrodes covered the left and right hemispheres at the frontal (Fp1, F3, F7; Fp2, F4, F8), central-lateral (C3, T3; C4, T4), posterior (P3, T5, O1; P4, T6, O2), and midline (Fz, Cz, Pz) regions. The EEG signal was preprocessed with EEGLAB (Decety, Jackson, Somerville, Chaminade, & Meltzoff, 2004). It was filtered off-line using high-pass (passband edge frequency: 0.1 Hz; 6-dB cutoff: 0.05 Hz; filter order: 8449; transition band: 0.1 Hz) and low-pass sinc filters (passband edge frequency: 100 Hz; 6-dB cutoff: 112.5 Hz; filter order: 35; transition band: 25 Hz). EEG continuous data was visually examined and segments with slow drifting and muscle artifacts were removed. After data rejection, the average number of trials remaining for analysis was 40.0 (SD = 2.5) for the compete condition and 40.2 (SD = 1.7) for the cooperate condition; all participants had at least 78% of trials remaining. Data were then epoched time-locked to stimulus onsets with a 2 s pre-stimulus interval and 4.5 s post-stimulus interval. The baseline was subtracted from a 4.5 s post-stimulus interval. ICA (Independent Component Analysis) was run to remove eye artifacts and cardiac activities (Jung et al., 2000). After ICA decomposition, independent components that captured artefactual activity were visually identified and pruned, and data back-projected.

For between-participant analysis, we were concerned by the potential confound of 50 Hz power line noise because participants were recorded simultaneously and the amplifiers connect to the same 50 Hz power source. In our previous work, we found that line noise could result in spurious phase synchrony between simultaneously recorded participants at this frequency (Cho et al., 2018). To control for this, we applied a notch filter (48–52 Hz band-cut edges, filter order: 424) before time wavelet transform.

EEG wavelet decomposition

EEG epochs were subjected to continuous wavelet transform as implemented in EEGLAB (Decety et al., 2004). We used a set of wavelets that captured frequencies from 4 Hz to 80 Hz ($c = 3-24$, increasing linearly; $of = 2.6-6.7$ Hz; $\sigma t = 136-942$ ms). This covered our frequency bands of interest: theta (4.0 to 7.5 Hz), alpha (8.0 to 12.5 Hz), low beta (13.0 to 20.5 Hz), and high beta (21.0 to 30.5 Hz).

EEG power and phase synchrony analysis

Raw power was computed from the wavelet transform at each frequency and data point. Individual trial values were normalized by the mean power from -0.8 s to

–0.3 s pre-trial onset, and transformed to a decibel scale ($10 \cdot \log(\text{signal})$). The baseline interval was chosen to prevent overlap with stimulus onset activity.

Phase synchrony was investigated to assess the degree of temporal alignment of brain activity within and between channels. This was performed both within and across participants. For each frequency band of interest phase values were first derived from wavelet parameters. The degree of phase synchrony between channels was assessed across trials using the phase locking factor (Lachaux, Rodriguez, Martinerie, & Varela, 1999). The PLV quantifies the degree of time-locking of oscillatory phase of two channels at each frequency and time point. It varies between 0 and 1, with higher value reflecting increased phase synchrony between channels. The PLV at time (t) was computed as

$$\text{PLV}_t = \frac{1}{N} \left| \sum_{n=1}^N e^{i\theta(t,n)} \right|$$

where $\theta(t,n)$ is the phase difference between the two channels at time t and trial n.

For within-participant analyses, within-participant PLV was calculated between channels pairs in each participant.

For between-participant analyses, channels pairs were taken between participants. For each pair of participants, we computed the phase-locking value between all possible pairings of the 19 channels of the participants.

EEG statistical analysis

Before analysis, all data were aggregated over a series of 1 s time windows from 0 s to 4 s, and over 4 frequency bands of interest.

For power, within subject ANOVA were carried out on separate frequency bands theta (4.0 to 7.0 Hz), alpha (8.0 to 12.0 Hz), low beta (13.0 to 20.0 Hz), and high beta (21.0 to 30.0 Hz) with factors Condition (compete, cooperate), Channel (C3, C4, Cz, F3, F4, F7, F8, Fp1, Fp2, Fz, O1, O2, P3, P4, Pz, T3, T4, T5, T6), and Time Window (0–1 s, 1–2 s, 2–3 s, 3–4 s).

For within-participant PLV, we first attempted within subject ANOVA on separate frequency bands with factors Condition (2 levels), Channel Pairs (171 levels), and Time Window (0–1 s, 1–2 s, 2–3 s, 3–4 s). However, the size of the model matrix exceeded the computational capacity of the statistical package R. To overcome this limitation, we decided to use k-means clustering to decrease the size of the Channel Pairs factor by grouping cluster pair with similar PLV response profile (for further details on this method see Cho et al., 2018). Eight clusters were selected to group 171 channel pairs based on

within clusters sum of squares. Within-participant ANOVA was then carried out on separate frequency bands with factors Condition (2 levels), Channel Pair Clusters (8 levels) and Time Window (4 levels).

For between subject PLV, ANOVAs were then carried out on the same frequency bands, with factors Condition (compete, cooperate), Channel pairs (190 pairs of channels from C3, C4, Cz, F3, F4, F7, F8, Fp1, Fp2, Fz, O1, O2, P3, P4, Pz, T3, T4, T5, T6), and Time Window (0–1 s, 1–2 s, 2–3 s, 3–4 s). Model complexity did not lead to complication for between-participant analysis, so we did not employ a clustering strategy.

Multiple comparisons were dealt with by controlling the false discovery rate (FDR) at 5% over two-sided t-tests that were run in the study. Unless otherwise noted, tests had a q-value lower than or equal to 0.05 (Storey, 2002). The minimum and maximum range of q-values were presented.

Results

Behavioral ratings

Participants' sense of agency, rated as the degree of control over the cursor movement, was greater in the compete over cooperate conditions (Figure 1). Ratings for the 84 experimental trials were standardized for each participant by subtracting mean rating and dividing by each participant standard deviation. T-tests on scaled ratings indicated a significant difference between compete and cooperate conditions with an enhanced sense of agency in the Compete condition [$t(39) = 3.59$, $p < .001$, $\eta^2 = 0.568$]. Further Wilcoxon rank sum test was performed on scaled ratings to test for the sign of compete and cooperate differences. Compete ratings were significantly greater than cooperate ratings [$W = 649$, $p < 0.001$].

This result was as predicted and confirmed that the task was effective in eliciting different mental stances as planned, which was reflected in a change of sense of agency.

EEG power

In theta band, there was a significant Condition by Channel interaction [$F(18, 666) = 2.31$, $p = .002$, $\eta^2 = 0.015$] (Figure 2). Follow up two-sided t-tests showed a significant Condition effect, in which EEG power for the cooperate condition was higher than for the compete condition in channel Fp1 [$t(37) = -2.83$, $p = .008$, $\eta^2 = -0.459$, $q = 0.373$], but the compete condition was significantly higher than the cooperate condition in channel F4 [$t(37) = 2.32$, $p = .026$,

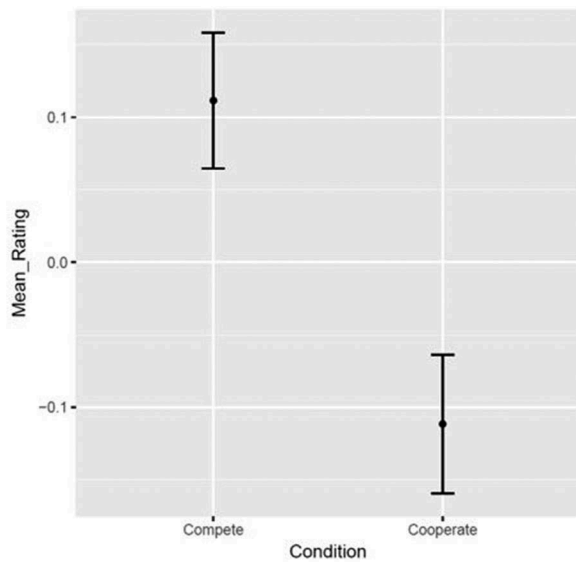


Figure 1. Perceived degree of control on the cursor as rated after each task, scaled within participant and used as a proxy for the sense of agency, as a function of condition. Individuals' scores are z-transformed. Errors bar represent the 95% within-participant confidence intervals.

$\eta^2 = 0.376$, $q = 0.373$]; However, these results did not pass FDR correction as indicated by the q -values. Other channels were not significant ($ps > .100$). The main effect

of Condition was not significant [$t(37) = 0.33$, $p = .741$, $\eta^2 = 0.054$].

In the alpha band, there was no significant Condition by Channel effect [$F(18, 666) = 1.25$, $p = .214$, $\eta^2 = 0.005$], the main effect of Condition was not significant [$F(1, 37) = 0.097$, $p = .757$, $\eta^2 = 0.000$].

In low beta band, there was a significant Condition by Channel interaction [$F(18, 666) = 1.98$, $p = .009$, $\eta^2 = 0.009$]. Follow up two-sided t -tests showed a significant Condition effect, in which low beta power for the compete condition was higher than the cooperate condition in channels F4 [$t(37) = 2.49$, $p = .017$, $\eta^2 = 0.404$, $q = 0.373$], and F8 [$t(37) = 2.10$, $p = .043$, $\eta^2 = 0.340$, $q = 0.487$], but did not pass FDR correction. Other channels ($ps > 0.10$). The main effect of Condition was not significant [$F(1, 37) = 2.09$, $p = .157$, $\eta^2 = 0.010$].

In the high beta band, there was a significant Condition by Channel interaction [$F(18, 666) = 1.72$, $p = .032$, $\eta^2 = 0.007$]. Follow up two-sided t -tests indicated that high beta power was greater in the compete cooperate condition as compared to the condition in channel Cz [$t(37) = -2.34$, $p = .025$, $\eta^2 = -0.379$, $q = 0.373$], but did not pass FDR correction. There was no other significant condition effect ($p > .053$). The main effect of Condition was not significant [$F(1, 37) = 0.04$, $p = .843$, $\eta^2 = 0.000$].

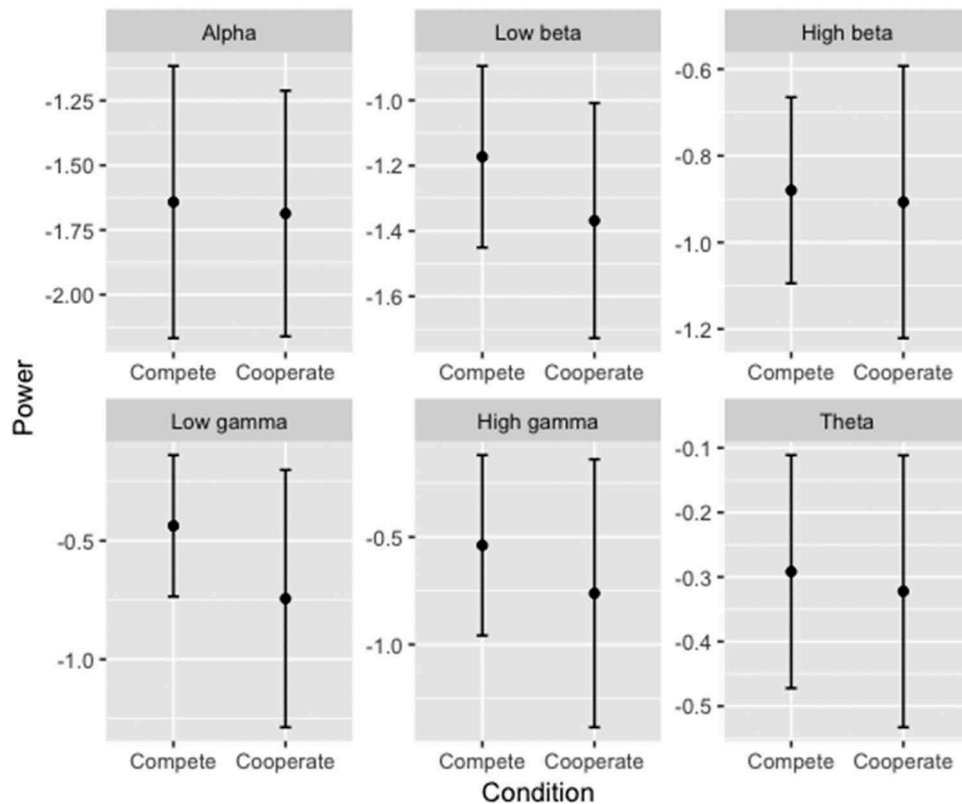


Figure 2. EEG Power in all examined frequency bands for the compete and cooperate conditions. Errors bar represent the 95% within-participant confidence intervals.

In addition, for all frequency bands there was a significant effect of Time Window on power [all $ps < .001$], there were significant main effects of Channels [$F(18, 666) = 3.0$, $p < .001$, $\eta^2 = 0.019$]. These effects were not of interest here and were not investigated further.

Within-participant PLV

In the theta band, there was a significant main effect of Condition [$t(37) = 2.15$, $p = .038$, $\eta^2 = 0.35$], with higher PLV in the compete as compared to the cooperate condition. There was also a significant Channel-Pair Cluster effect in all frequency bands ($p < .001$). This was not the focus of the work and was not investigated further. No other effects were significant ($ps > .076$) (Figure 3).

Between-participant PLV

Theta between-participant PLV

In theta band, there was a significant three-way interaction of Condition, Channel Pair and Time Window [$F(567, 8505) = 1.13$, $p = .023$, $\eta^2 = 0.025$]. Follow-up ANOVAs in separate time windows showed significant Condition by Channel Pair interaction in the 1–2s time window only [$F(189, 2835) = 1.28$, $p = .007$, $\eta^2 = 0.039$]. Further follow-up two-tailed t-tests of separate channels pairs in the theta 1-2s time window showed significantly higher between-participant PLV in the cooperate over the compete condition in C3_T5, F8_T4, O2_T5, T4_T4, F3_T4, Cz_T6, T4_T5, C3_P3, C4_Fz [all $ps < .047$]. After FDR correction, the significant channel pairs were: C3_T5 [$t(29.92) = -3.39$, $p = 0.002$, $\eta^2 = -0.61$, $q = 0.038$], T4_T4 [$t(28.84) = -2.59$, $p = 0.015$, $\eta^2 = -0.4742$, $q = 0.727$], and T4_T5 [$t(23.87) = -2.29$, $p = 0.031$, $\eta^2 = -0.46$, $q = 0.046$]. Nonsignificant pairs after FDR correction were F8_T4, O2_T5, F3_T4, C_T6, C3_P3 [$.115 < qs < .353$, $ps > .014$].

Follow-up two-tailed t-tests in separate channels pairs in the theta 1-2s time window also showed significantly higher between-participant PLV in the compete over cooperate condition in F7_Pz, F7_P3, Fp2_P3, F4_Pz, Fp2_Pz, [all $ps < .043$]. Interestingly, however, none of these channel pairs for which the between-participant PLV for compete was greater than cooperate passed a 5% FDR criterion [$0.090 < qs < 0.298$, $ps > .010$]. ANOVAs in other time windows did not reveal any significant interaction between Condition and Channel Pair ($ps > .119$) (Figure 4).

Low beta between-participant PLV

In the low beta band, there was a significant Condition by Channel Pair by Time Window interaction [$F(567, 8505) = 1.12$, $p = .029$, $\eta^2 = 0.024$]. Follow-up ANOVAs

were carried out in separate Time Windows. There was a significant Condition by Channel Pair interaction in the time windows 0–1 s [$F(189, 2835) = 1.21$, $p = .029$, $\eta^2 = 0.029$], 1–2 s [$F(189, 2835) = 1.37$, $p = .001$, $\eta^2 = 0.040$], and 2–3 s [$F(189, 2835) = 1.29$, $p = .006$, $\eta^2 = 0.039$], but not in the 3–4 s time window [$F(189, 2835) = 0.89$, $p = .859$, $\eta^2 = 0.029$].

In the time window 0–1 s, the compete condition had significantly higher between-participant PLV than the cooperate condition for the Channel Pairs: C3_O1, F3_P4, F4_F4, F4_Fz, F8_T3, P4_P4, T6_T6, F3_O1 [all $ps < .044$]. After FDR correction, the remaining significant channel pair was T6_T6 [$t(28.62) = 2.18$, $p = 0.038$, $\eta^2 = 0.400$, $q = .038$], while the q-value range for the other channel pairs that did not pass the 5% FDR criterion was $.077 < qs < .507$ [all $ps > .005$]. Between-participant PLV for the cooperate condition was higher than for the compete condition for the Channel Pairs F8_Fp1, Fp1_Fp2 [all $ps < .048$]. Interestingly, none of these channel pairs in which the between-participant PLV for cooperate was greater than compete passed FDR correction [$.158 < qs < .427$, $ps > .023$].

In the 1–2 s time window, the compete condition had significantly higher between-participant PLV than cooperate in F8_T3, P4_P4, F7_Fp2, F4_P4, Fp2_T3, T3_T6, O2_T3 [all $ps < .032$]. After FDR correction, the significant channel pair was T3_T6 [$t(28.22) = 3.16$, $p = .004$, $\eta^2 = 0.58$, $q = .015$]. The q-value range for the channel pairs that did not meet FDR correction was $.090 < q < .333$, $ps > .008$. Cooperate had higher PLV than compete for P3_T6, C4_T6, Fp1_Fp2, Fp2_Fz, Fz_P3 [all $ps < .046$], but none of these channel pairs passed FDR correction [$.116 < q < .457$, $ps > .017$].

In the 2–3 s time window, compete had significantly higher between-participant PLV than cooperate in Fp2_T3, T3_T4, T5_T6, C4_T4, Fz_T3, Pz_T6, F3_T3, Fp1_T3, and F7_T3 [all $ps < .042$]. After FDR correction the significant channel pair was F7_T3 [$t(28.82) = 3.74$, $p = .008$, $\eta^2 = 0.685$, $q = .011$], while the significant channel pairs that did not satisfy FDR correction had a q-value range of $.061 < q < .055$, $ps > .015$. Cooperate had higher PLV than compete in C3_O2, F3_F3, [all $ps > .025$]. Interestingly, none of these channel pairs passed FDR correction [$.196 < q < .203$, $ps > .011$]. For the corresponding beta power scalp distributions over time see supplementary materials.

For other frequency bands, the interaction Condition by Channel Pair by Time Window was not significant [all $ps > .220$]. ANOVAs on separate frequency bands showed a significant time window effect in theta, alpha and high beta bands (all $ps < .011$), and no significant effect in low beta band [$F(3, 45) = 0.14$, $p = .935$, $\eta^2 = 0.000$] (Figure 4).

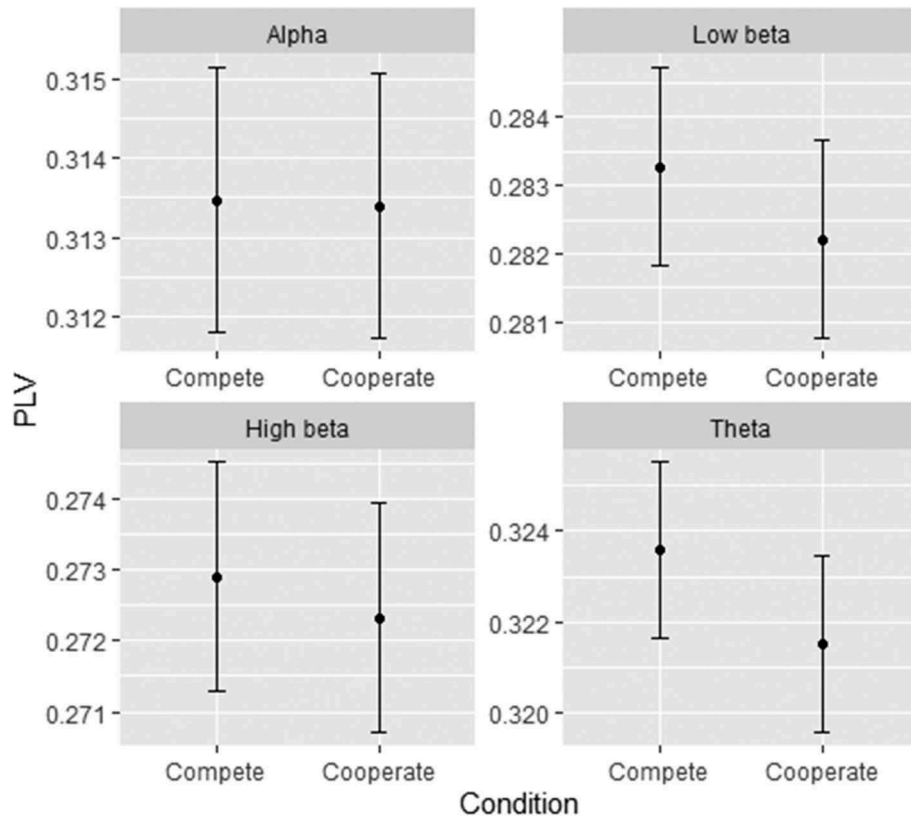


Figure 3. Within-Participant Phase Locking Value (PLV) for compete and cooperate conditions (alpha, low beta, high beta, and theta). Errors bar represent the 95% within-participant confidence intervals.

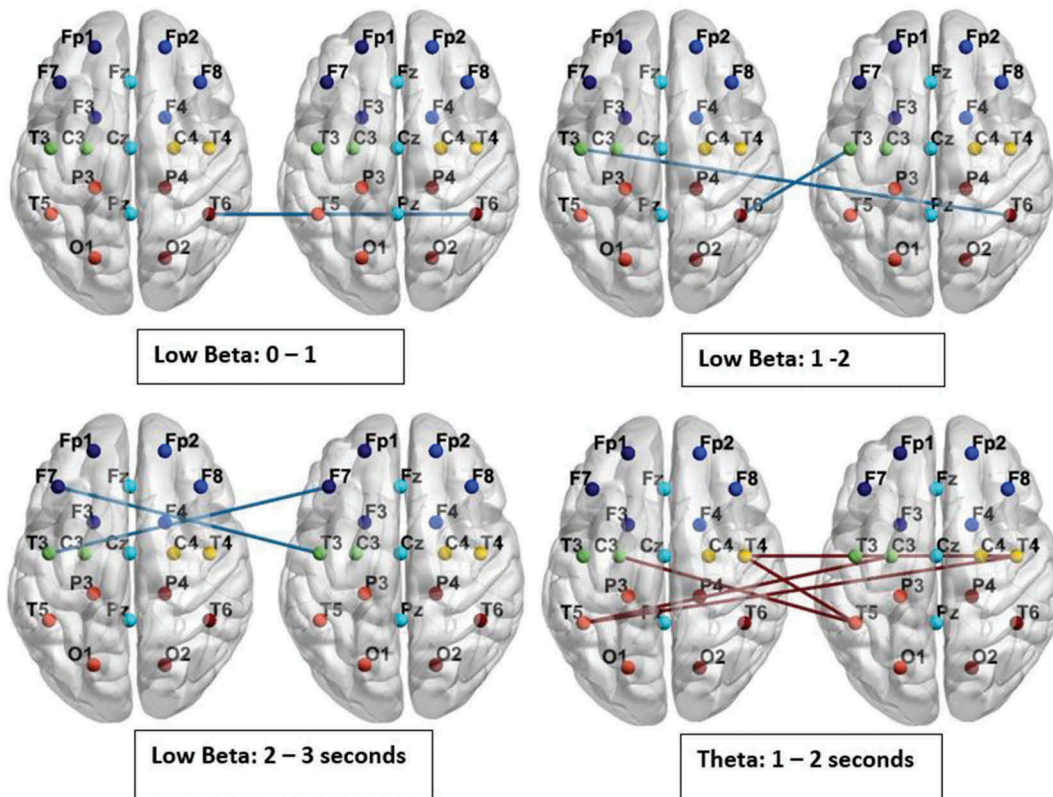


Figure 4. Between-Participant PLV connectivity between electrodes pairs passing 5% FDR criterion during compete and cooperate conditions. Magenta: Compete>Cooperate; Red: Cooperate>Compete.

Discussion

We present the first findings for how cooperative and competitive mental stances alone produce different neural oscillation patterns for between-participant phase synchrony and perceptions of agency. Cooperative mental stance enhanced theta band between-participant PLV while competitive mental stance enhanced low beta between-participant PLV and ratings of self-agency. This indicates that top-down mental stance shapes perceptions of social context and affects neural representation of self and others' actions not revealed by physical entrainment alone.

Two participants and a third computer-controlled player used joysticks in separate rooms to share equally weighted control over a single cursor. Prior to each trial, the two participants were given the instruction to either compete or cooperate to move the cursor to one of three possible targets without delay as soon as the targets were given. In the experimental trials, both participants were given the same target for both the compete and cooperate conditions. Only in the first type of filler trial did the computer move the cursor to a target other than the one initially given the participants, which would have required them to switch direction in the cooperate condition.

Hence, in the experimental trials, the visuomotor feedback was exactly the same for both participants in both conditions. The only difference was in the instruction to cooperate or compete, and the ensuing mental stance with which the task was performed. We discovered distinct patterns of brain synchrony for the compete and cooperate tasks in two of the oscillatory bands we examined, the low beta and the theta band.

Moreover, both the spectral power and PLV results indicated that participants complied with the instructions and did not delay action in the cooperate condition as a wait-and-see strategy. In the cooperate condition there was no significant power variation across time windows in beta or theta bands as a tell-tale sign of delayed motor response, nor enhancement of within-participant PLV as an indication of increased attention and suppression of distractor stimuli (Sacchet et al., 2015).

Competitive mental stance increased behavioral rating of self-agency

The differences in competitive and cooperative mental stance alone, strongly indicated that they may also affect related perceptions of an event, such as the sense of agency. Competitive mental stance may make a participant's self agency more salient, while cooperation

less so. The post-trial behavioral responses showed that this was the case. This points to future study on how differences in mental stance alone, above low-level visuo-motor feedback, can influence the sense of agency.

Behavioral results showed that the compete and cooperate conditions changed the perceived agency in the expected directions of increased self-agency during competition and decreased self-agency with cooperation. This indicated that task instructions were effective in shifting the mental stance of the participants as expected. Interestingly, competition also produced higher perceptual ratings of agency. This suggestibility of agency has been shown by Wegner and Wheatley (1999). He borrowed the idea of an Ouija board and had a subject and confederate jointly move a cursor to supposedly randomly stop on one of a number of available targets. Subjects believed they intentionally stopped at a target when they incidentally heard the name of the target, amid background music, 1 to 5 s before being forced to stop on it. This indicated that mental stance alone could influence the sense of agency even when the motor output and outcome were the same. Whereas Wegner used a suggestion at the end of the trial, the current experiment primed the mental stance, changing the social context, at the onset of the task.

Theta band between-participant phase synchrony supports cooperative mental stance

The theta band was examined because it has been implicated in social interaction and coordination processes (Dumas, Nadel, Soussignan, Martinerie, & Garnero, 2010; Yun, Watanabe, & Shimojo, 2012), and these were expected to be differentially engaged in the compete and cooperate conditions. Our results confirmed these predictions. Theta between-participant PLV was higher in the cooperate compared to the compete condition in temporal and central areas from 1 to 2 s. This increased PLV during the cooperate condition was not driven by spectral power, as theta power showed a contrasting pattern.

Theta between-participant PLV has been associated with social interaction and coordination (Dumas et al., 2010; Lindenberger, Li, Gruber, & Muller, 2009; Yun et al., 2012). Notably, theta activity in centro-parietal regions has been implicated in non-verbal social coordination and the synchronization of one's movement with others (Dumas et al., 2010; Tognoli, Lagarde, DeGuzman, & Kelso, 2007). Furthermore, more lateral regions, including the temporal site observed here, are thought to support social processing including components of the theory of mind (Decety & Lamm, 2007). Together this

suggests that beyond the action monitoring linked to low beta oscillations during competition, theta-band oscillations during cooperative mental stance support processes for the representation of other's intentions and action, which contribute to effective social coordination during cooperative endeavors.

Interestingly, 5% FDR criterion which controlled tightly for false positives made more salient the contrast in between-participant PLV patterns for the compete and cooperate conditions. FDR criteria significantly qualified the pattern of between-participant PLV in two ways. First, in theta band, all significant channel pairs in which the between-participant PLV was greater in the compete condition than the cooperate condition were filtered out after FDR correction. Second, in low beta band, the opposite was true. All the significant channel pairs in which the between-participant PLV for cooperate was greater than compete were eliminated. Moreover, these patterns were not a result of spectral power changes. Cooperative mental stance was clearly supported by enhanced theta band between-participant phase synchrony and competitive mental stance was supported by enhanced low beta between-participant phase synchrony.

Low beta band between-participant phase synchrony supports competitive mental stance

Competition compared to cooperation enhanced between-participant PLV in the low beta band. Competition compared to cooperation enhanced low beta between-participant PLV in right temporal areas from 0 to 1 s, bilateral temporal areas from 1 to 2 s, and left frontal and temporal areas from 2 to 3 s. These phase effects were not driven by spectral power. These findings are consistent with the allocation of selective attention to different decision-making tasks for competition and cooperation in the current experimental protocol. This was reflective of mental stance as both conditions involved identical motor action. During cooperation, directional uncertainty is greater because the target initially given to the participant may not be the one to which the cursor moved. This was supposedly because the other two hypothetical participants (in actuality the computer) were pulling in the direction the cursor was moving. If the cursor moved to a target different than the one initially given, participants were to switch direction and cooperate. This creates greater uncertainty in the cooperate condition. But during competition, participants only focused on their given target and were not to be distracted by the direction other participants might attempt to move the cursor.

Previous research corroborates our findings. Tzagarakis, Ince, Leuthold, and Pellizzer (2010) used a similar protocol as the current experiment in which participants had to move a cursor from the center of the screen to one of three possible circular targets. They found that beta activity decreased depending on the number of possible targets, which increased the directional uncertainty. This is consistent with our findings of increased low-beta activity during the compete condition and decreased activity in the cooperate condition, when directional uncertainty was greater. Additionally, in a cued attention task Sacchet et al. (2015) found enhanced beta PLV between right inferior frontal cortex (rIFC) and somatosensory cortex acted as an inhibitory signal to take non-attended perceptual representation offline. The rIFC mediates top-down attentional inhibition of non-relevant sensory information and motor action as part of a stop-signaling pathway in motor control. This is consistent with our findings of consistently enhanced between-participant PLV under the compete condition when participants had to only focus on their target and ignore distractions. It is important to note that in experimental trials, the only difference was in the instruction to compete or cooperate. So the effect we reported should represent the difference in the mental stance of cooperation and competition.

This shift in low beta between-participant PLV over the course of trials may reflect a change in focus from monitoring self and other action to evaluating the outcome of performance as a winner or loser (Babiloni et al., 2002; Koelewijn, van Schie, Bekkering, Oostenveld, & Jensen, 2008). This pattern may be linked to increased emotional engagement and visual attention especially toward the end of the trial as participants ultimately reach their target during experimental trials and experience reward for "winning" (Quandt & Marshall, 2014; van Wijk, Beek, & Daffertshofer, 2012). Such enhanced positive emotions linked to performance have been well documented in studies of sports (Vast, Young, & Thomas, 2010).

Limitations

Although our results show distinct between-participant PLV patterns for competitive and cooperative mental stance, localizing the neural systems involved is still limited by the constraints of EEG hyperscanning. Knowing the precise areas of activation would be particularly important to differentiate the cognitive processes of each mental stance and any overlap with brain activity involved in perceptions of self and other agency. For example, Decety et al. (2004) have noted that cooperative and competitive states, compared to independent

playing, recruited common neural regions such as right superior parietal cortex, superior frontal gyrus, and anterior insula. However, they suggest that competition and cooperation lead to difference in self and other merging. So, greater activation of right inferior parietal cortex during competition compared to cooperation may be related to findings in other studies implicating this region in distinguishing between self-produced actions and actions generated by others (e.g., Farrer & Frith, 2002; Meltzoff & Decety, 2003). While providing precise localization, these studies are likewise limited to single-participant results. Further study is needed on the precise areas of between-participant synchrony to better understand the related cognitive processes underlying competition, cooperation, and agency perception.

Conclusion

We present the first neural signatures indicating that cooperative and competitive mental stances alone, apart from physical entrainment, affect inter-personal neural synchrony and perceptions of self-agency. In identical visuo-motor joint-action tasks, cooperative compared to competitive mental stance enhanced theta band between-participant phase-locking value midtrial at 1–2 s, reflecting activation of systems for social coordination. Cooperative mental stance may activate neural systems important for reacting midtrial to the greater uncertainty of coordinating with other participants' actions. Competitive mental stance, on the other hand, enhanced low beta between-participant phase-locking value, shifting from temporal regions at the start of trials to frontal regions by the end, indicating enhanced attention to movement and suppression of distracting stimuli at the start of trials and evaluation of self-agency as winner or loser. This interpretation is corroborated by the greater ratings of self-agency under the competitive mental stance condition. Top-down competitive and cooperative mental stances shape perceptions of social context and affect neural representation of self and others' actions.

Disclosure statement

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