Human brain correlates of strong anticipation in motor coordination between dyads

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Introduction

Interpersonal motor coordination happens all the time in our daily activities. As individuals interact with each other in coordinated movements two types of coordination dynamics of mutual adaptation have been observed in previous studies [Marmelat et al., 2012]. **Weak anticipation** is the result of local adjustments to motor behavior by one individual by perception of the other individual. Weak anticipation often will give rise to leader-follower dynamics, where the leader sets a pace and the other individual continuously adapts to the variability of the other individual, correcting perceived errors. **Strong anticipation** reflects the ability of individuals to learn the long-range statistics of their environment in order to predict future events. In the motor system, strong anticipation is grounded in the observation that repetitive rhythmic motor behaviors such as tapping exhibit long-range correlations or complexity. An open question is whether complexity is an adaptive motor behavior, where individuals can match complexity to facilitate coordination. The purpose of the present study is to examine whether motor coordination between dyads can reflect such strong anticipation. We investigated two finger tapping coordination tasks, synchronization and syncopation between dyads, by means of hyperscanning with simultaneous behavioral and EEG recordings.

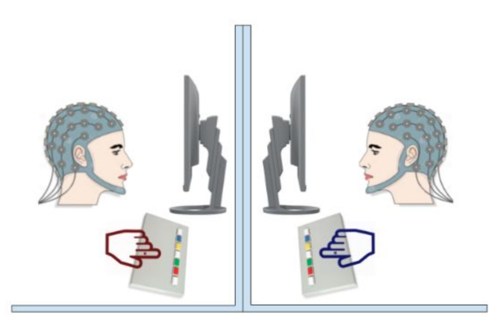

Fig 1: Experimental Setup

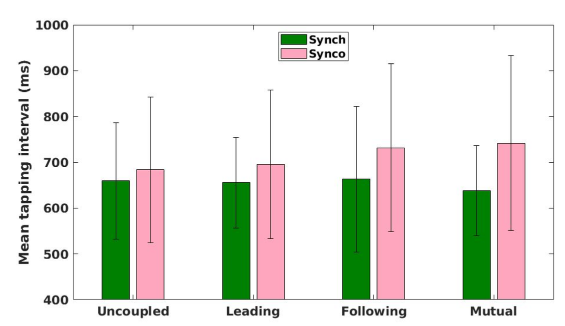

Fig 2: Average tapping intervals

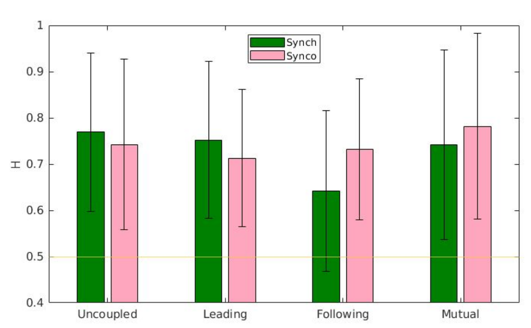

Fig 3: Average DFA H exponents

Experimental Design

Six pairs of subjects (from a pool of 11 total, 4 M and 7 F), each performed one session of synchronized tapping and one session of syncopated tapping with each other in separated space isolated from the other participant (Fig 1: Experimental Setup)

There were four conditions in each session:

1) Independent tapping (Uncoupled)

In the synchronized tapping session: the dyads tapped independently on their own following a sequence of 30-tap pacing stimulus (1.3Hz). They each received visual feedback of their own individual taps (with a self-feedback signal (colored dot) on the screen). The trial ended when one of the participants reached 230 taps.

In the syncopated tapping session: the dyads attempted to tap in between visual feedback of a tapping sequence generated by themselves during the previous synchronization session. Thus, they are syncopating with a random signal generated independently from their own tapping history in the synchronized tapping session.

2) Unidirectional coordination (Leader->Follower)

In the synchronized tapping session, one subject (Leader) received the 30-tap pacing stimulus, then tapped independently (self feedback), in the same way as in the Uncoupled condition. The other subject (Follower) tried to synchronize with real-time visual feedback of the tapping sequence by the Leader.

In the syncopated tapping session, one subject (Leader) attempted to tap in between the tapping sequence, generated by themselves during the synchronization session, in the same way as in the Uncoupled condition. The other subject (Follower) tried to syncopate with the real-time visual feedback of the tapping sequence of the Leader.

Both individuals in a dyad were placed in the role of Leader or Follower in separate trials.

4) Bidirectional coordination (Mutual)

In the synchronized tapping session: Following synchronization with a 30-tap pacing stimulus at 1.3 Hz, each participant in the dyad tried to synchronize with the other participant, while receiving real-time visual feedback of the other participant's tapping.

In the syncopated tapping session: Following syncopation with a 30-tap pacing stimulus at 1.3 Hz, each participant in the dyad tried to syncopate with the other participant, while receiving real-time visual feedback of the other participant's tapping.

Long-range statistics reveal complexity matching

Tapping intervals: There was no difference in tapping intervals across feedback conditions. Tapping intervals were longer in syncopation than synchronization, but not significant. (Fig 2: Average tapping intervals)

DFA Hurst Exponents (H):

Hurst exponents in all conditions were above 0.5 indicating complexity and long-range dependence in tapping behavior. No differences were found between conditions (Fig 3 : Average DFA H exponents).

We examined if complexity was adaptive, and found that the dyads aligned their complexity only when the participants underwent bidirectional coordination (Fig 4: Correlation of DFA Hurst exponents), indicating that **complexity matching** in motor behavior can be induced by sensory feedback. The correlation in a combined model is 0.7; when separately analyzed, synchronization has a correlation of 0.83 and syncopation has a correlation of 0.49. Thus, syncopation induces the strongest complexity matching.

EEG <-> Hurst Exponents:

When the participants are in bidirectional coordination (Mutual condition) theta activity in bilateral frontal regions is correlated with the Hurst Exponents (Fig 5: Correlation of EEG & Hurst exponents). Further investigation of the correlation of theta activity between the dyads also found strong correlation between participants bilaterally in Channel F3 and F4 of the frontal lobes (Fig 6: Correlation of theta power in Channels F3 & F4).

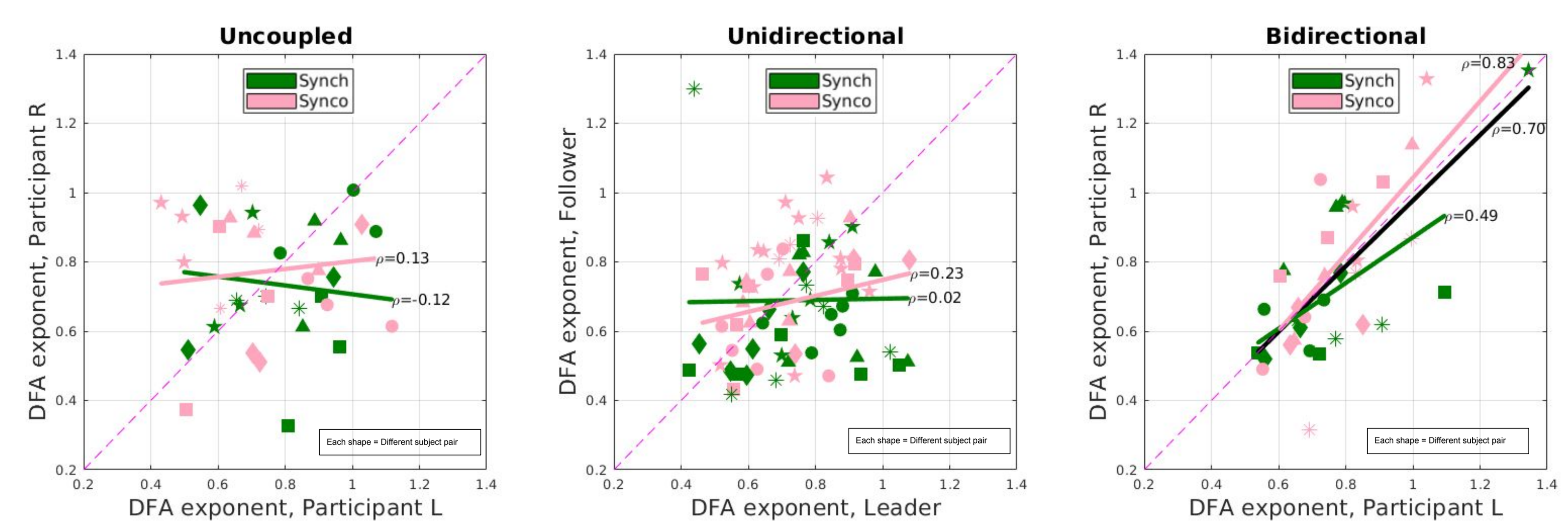

Fig 4: Correlation of DFA Hurst exponents (H)

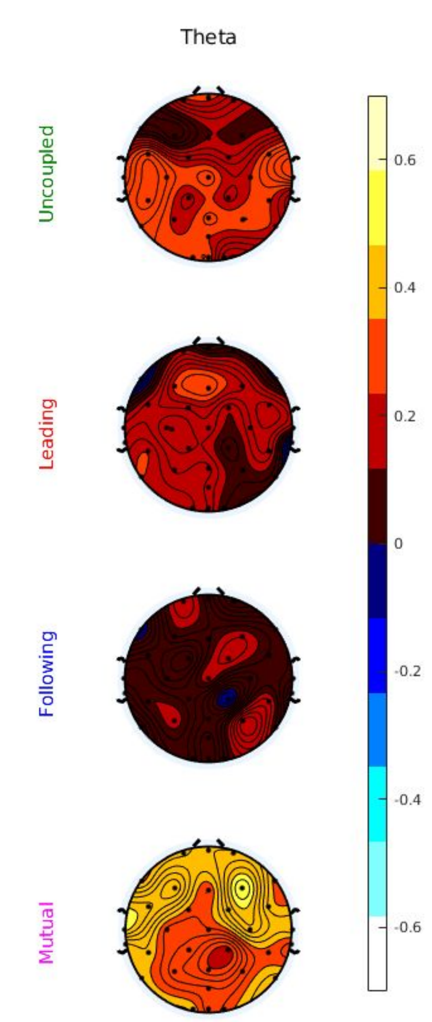

Fig 5: Correlation of EEG & H

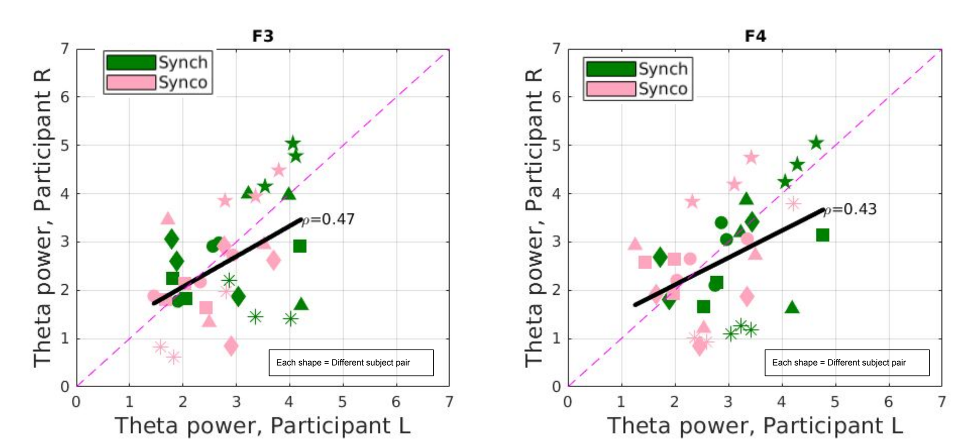

Fig 6: Correlation of theta power in Channels F3 & F4

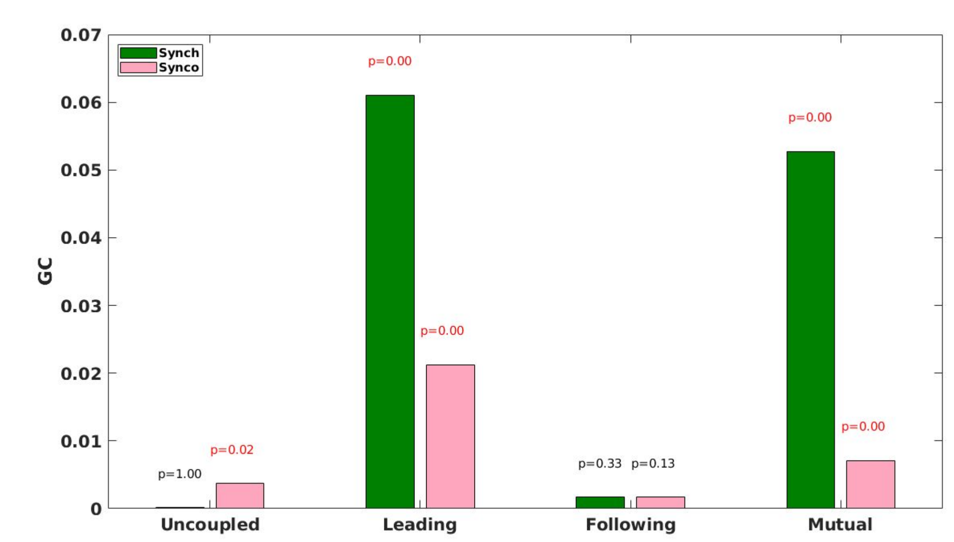

Fig 7: Granger Causality in tapping intervals

Leader-Follower dynamics in synchronization

Cross Correlation of Tapping Intervals. When the dyad was uncoupled, there was no cross-correlation in the tapping intervals. During synchronized tapping, follower lagged the leader by 1 tap in unidirectional coupling, indicating **weak anticipation** and local adjustment of tapping behavior. The same behavior was observed in bi-directional coupling in synchronization, with the role of leader and follower, differing between (and sometimes switching within blocks). In contrast, during syncopated tapping, peak of cross correlation was at 0 lag indicating that **strong prediction** of the dyads tapping behavior (Fig 6: Cross correlation of tapping intervals), produces matching tapping intervals with no lag.

Granger Causality of tapping intervals: GC is Highest from leader to follower during unidirectional coordination consistent with the cross-correlation. GC is bidrectional between the dyads during the bidirectional coordination (Fig 7: Granger Causality in tapping intervals)

GC was much stronger in synchronization than in syncopation.

EEG <-> Cross Correlation:

During synchronized tapping, in the mutual condition (bidirectional coordination), higher alpha activity was found with higher cross correlation at -/+1 lag. No such relationship was found in the uncoupled condition. The electrodes were over the right frontal, right premotor and visual cortices. During unidirectional coupling, beta and gamma power in the Leader was correlated with cross correlation at -/+1 lag at electrodes over the left frontal, left motor and left parietal cortices (Fig 8: Correlation of EEG and Xcorr(-1/+1) in synchronized tapping). No correlation was observed in the Follower.

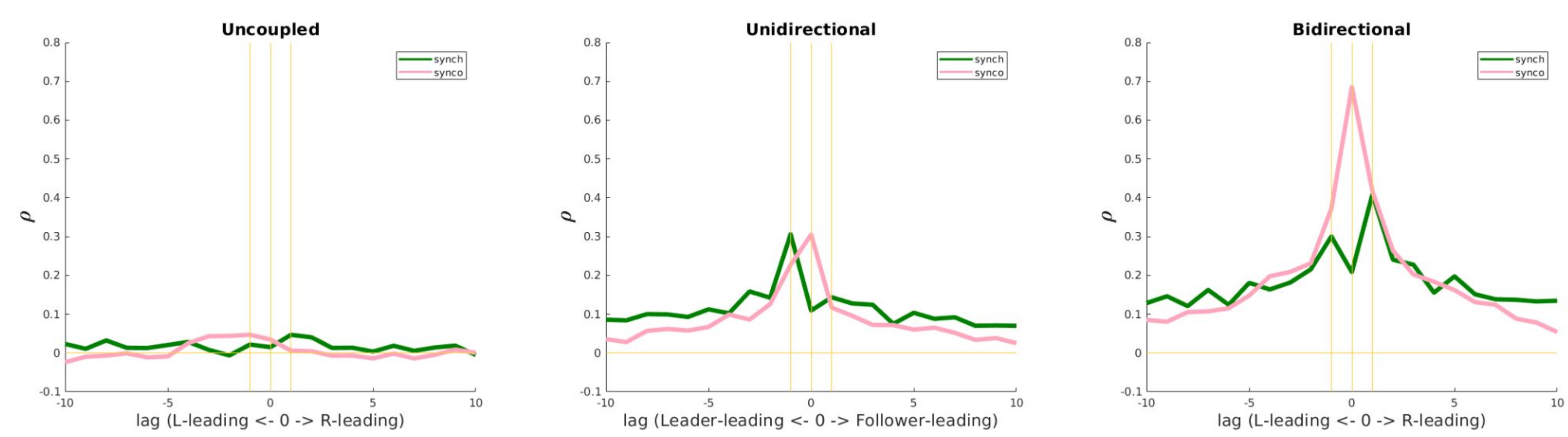

Fig 6: Cross correlation of tapping intervals

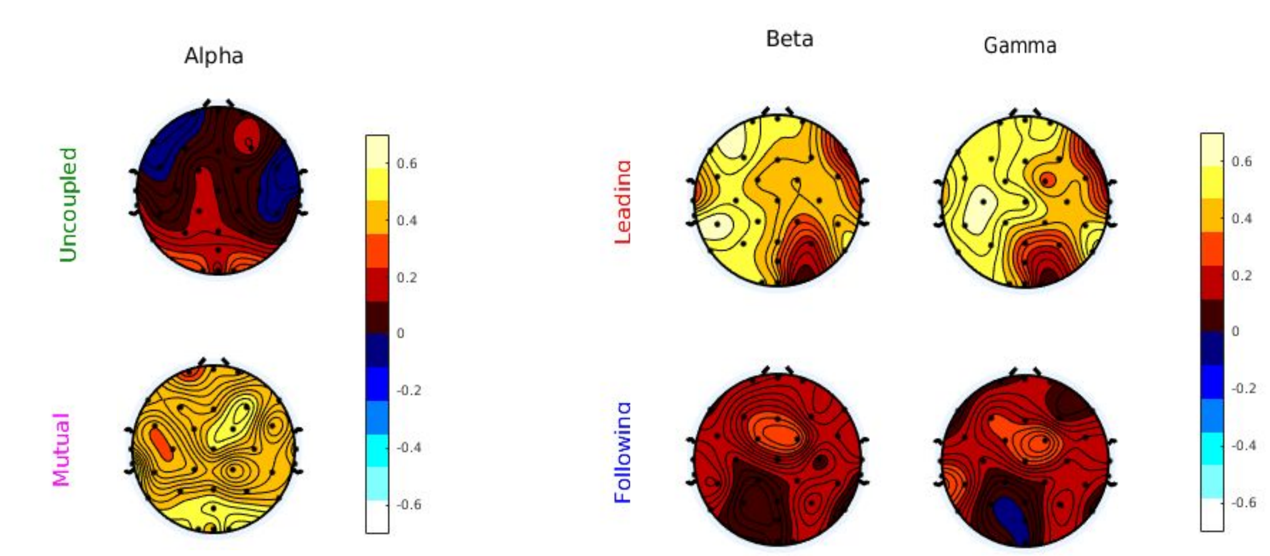

Fig8: Correlation of EEG and Xcorr(-1/+1) in synchronized tapping

Conclusion and implications

Long-range statistics such as Hurst exponents from motor actions are internally generated but can be coupled during mutual motor coordination. Such coupling reflects complexity matching in coordination and is most likely related with the theta activities from frontal regions centered around F3 and F4. Strong anticipation is more prominent in syncopated than synchronized motor coordination.

The relationship between EEG and cross correlation of dyads' motor actions can reveal whether the coordination exist and also the directionality of the coordination.

Reference

Marmelat, V., & Delignières, D. (2012). Strong anticipation: Complexity matching in interpersonal coordination. Experimental Brain Research, 222(1–2), 137–148. https://doi.org/10.1007/s00221-012-3202-9