Rhythm Breaks: A Wearable EEG Setup for Interbrain Synchrony in Remote Collaboration

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Abstract. Remote teamwork lacks the natural physiological coordination cues present in co-located settings. Inter-brain synchrony (IBS)—the degree of neural signal similarity between interacting individuals—is positively associated with team performance. However, no hyperscanning study has examined whether IBS can be induced or detected in remote collaboration. This study investigates whether a three-minute interactive joint breathing intervention can increase IBS and improve cooperative task synchrony in remote dyads. We present a setup for real-time EEG measurement across remote locations using consumer-grade sensors. Using a within-subject crossover design with ten dyads, we test four hypotheses: (H1) the breathing intervention increases task synchrony; (H2) it increases inter-brain synchrony; (H3) it increases perceived synchrony; and (H4) inter-brain synchrony predicts task performance.

Keywords: Interpersonal Synchrony · Interbrain Synchrony · Hyperscanning · EEG · Physiological Entrainment · Remote Collaboration

1 Introduction

1.1 Inter-Brain Synchrony and Team Performance

Remote collaboration has become a central mode of professional teamwork, yet it fundamentally removes the physiological context that supports natural coordination. When people work in physical proximity, shared sensory experiences and co-regulated physiological rhythms—such as coordinated breathing and movement—contribute to interpersonal alignment that supports joint action [10].

One neurophysiological marker of interpersonal alignment is inter-brain synchrony (IBS), defined as the degree of similarity between the brain signals of multiple individuals interacting with each other [10]. IBS is measured using hyperscanning, a methodology in which multiple participants' brain activity is recorded simultaneously while they interact. A systematic review and meta-analysis of 41 hyperscanning studies covering 1,326 teams finds that IBS is positively associated with team performance, with the effect being strongest for synchronization tasks [10].

Research establishes that IBS emerges from cooperative tasks with shared goals [3], coordinated breathing and physiological entrainment [4], and active real-time co-regulation [5].

Cui et al. [3] demonstrate that cooperative tasks with shared goals reliably elicit inter-brain synchrony, particularly in the frontal region. They used a coordinated task paradigm in which dyads responded to shared stimuli under a success criterion tied to temporal proximity of responses—a design used in later IBS studies and which directly inspired the Dolphin Task used in this study. Reinero et al. [9] further demonstrate that inter-brain synchrony in teams predicts collective performance across a range of group activities.

1.2 Inducing Inter-Brain Synchrony: Physiological Entrainment and Real-Time Feedback

Research identifies physiological entrainment as a pathway to IBS [11]: joint meditation and breathing can induce inter-brain synchrony [4], [1] and feelings of interconnectedness [2].

Additionally, Dinh et al. [5] show that real-time external feedback (visual, auditory, and haptic)of IBS intensity may amplify synchrony during collaborative tasks. While their results show a marginal, non-significant trend toward enhanced IBS with feedback ($p = 0.064$), the work motivates the design principle of making synchrony states visible and salient to participants during collaboration. This informed the decision to implement an interactive breathing protocol in which both participants actively signal their breathing state via keypresses, creating deliberate real-time co-regulation of a shared physiological rhythm rather than passively following a fixed animation.

Together, these works identify the remote setting as a gap in the hyperscanning literature and jointly inform both the choice of intervention and the cooperative task used for performance measurement.

1.3 Research Gap and Question

Despite these findings, no hyperscanning study has yet examined whether IBS can be detected or deliberately induced in remote collaboration settings. If short physiological synchronization rituals can induce IBS in remote dyads, this offers a practical, wearable-compatible mechanism for enhancing remote teamwork. This paper addresses the following research question:

> *Can synchronized interactive breathing induce inter-brain synchrony and improve cooperative task synchrony in remote teams?*

To answer this question, the study employs a within-subject crossover design in which pairs of participants perform a cooperative synchronization task after either an interactive joint breathing intervention or a passive control condition.

2 Methods

2.1 Experimental Design

The study employs a within-subject crossover design to compare task performance and IBS under two conditions: a breathing intervention condition (*With Intervention*) and a passive control condition (*Without Intervention*). Ten dyads are divided into two groups to counterbalance condition order. Group A receives

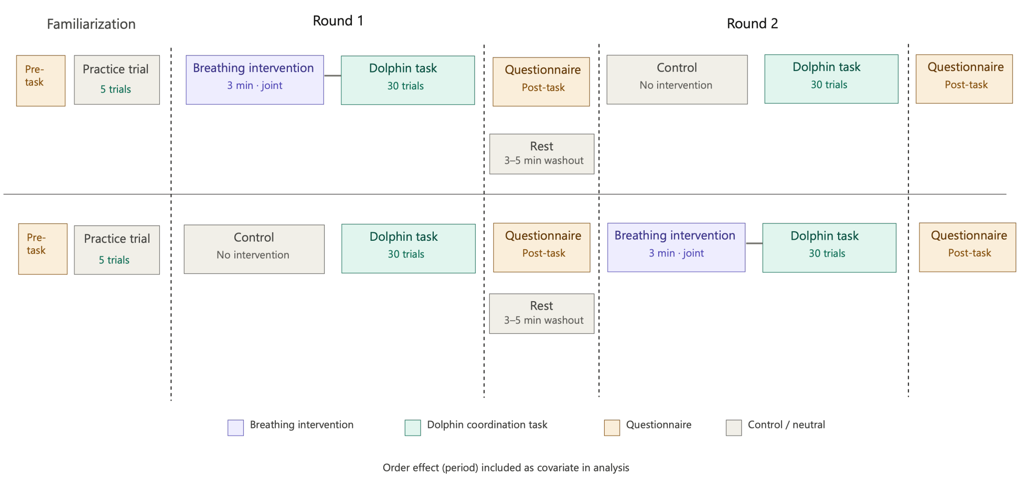


Fig. 1: Overview of Study Setup

the breathing intervention in Round 1 and the control condition in Round 2. Group B receives the reverse order. Each round consists of the respective condition followed immediately by 30 trials of the Dolphin coordination task and a post-task questionnaire. A washout period of 3–5 minutes separates the two rounds. Both groups begin with a familiarisation phase comprising a pre-task questionnaire and five practice trials. The crossover structure counterbalances for order effects, which are also included explicitly as a statistical covariate.

2.2 Participants

Twelve individual participants (ages 24–39) recruited from the university community took part in the study. Ten dyads were formed from these participants; some individuals were paired with multiple partners. Participants had normal or corrected-to-normal vision, no neurological disorders, and provided written informed consent in accordance with GDPR requirements. Participation was voluntary with the right to withdraw at any time.

2.3 Sample Composition

The dyad was the statistical unit of analysis ($N = 10$ dyads for behavioral and questionnaire analyses). One EEG session was excluded due to data capture failure; EEG-based analyses used $N = 9$ dyads.

Table 1: Dyad composition of the study sample.

Sample level	**Count**
Unique individual participants	12
Analysed dyads	10
Dyads in EEG analyses	9

2.4 Interactive Breathing Synchronization Protocol

The breathing intervention is a three-minute interactive co-regulation protocol. Each participant presses dedicated keyboard keys to signal their current state of breathing (left key, inhale, & right key, exhale). Both participants' states are displayed in real time on each screen: each participant sees two coloured circles, one representing their own breathing phase and one representing their partner's, enabling them to observe and match their partner's rhythm.

The interactive design is inspired by Dinh et al. [5], who demonstrate that real-time external feedback during collaborative tasks actively enhances IBS. Rather than presenting a fixed automatic animation, participants actively signal their breathing state via keypresses, creating deliberate real-time co-regulation of a shared physiological rhythm — the mechanism theorised to generate physiological entrainment and, in turn, IBS.

2.5 Dolphin Task for Cooperative Performance

The Dolphin Task is a validated IBS-performance paradigm adapted from Cui et al. [3]. Two participants each control a dolphin avatar. A ball drops from the top of the screen and both participants must press their key simultaneously to catch it. Both response times are displayed after each trial, making the synchrony goal transparent to the dyad.

A trial is scored as a success if the absolute difference between the two response times does not exceed one quarter of their mean response time:

$$|RT_1 - RT_2| \; < \; \frac{RT_1 + RT_2}{8} \tag{1}$$

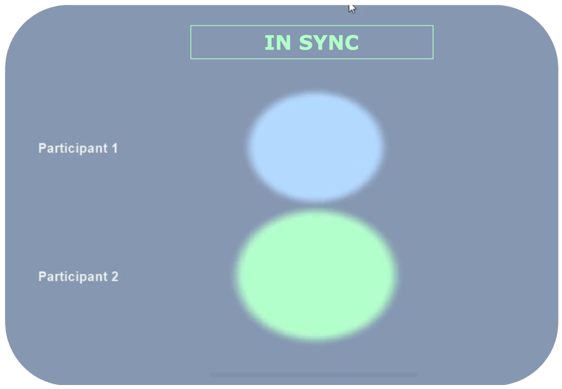
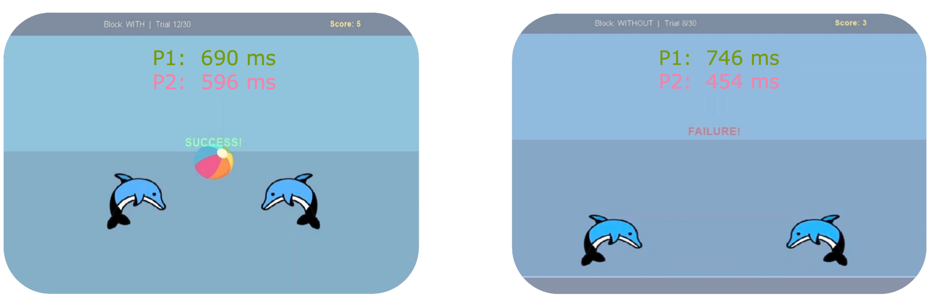


Fig. 2: Interactive breathing protocol interface: the circles expand on inhale and contract on inhale. Each participant sees two circles representing their own and their partner's breathing state in real time.

This threshold ensures that success depends on *relative* temporal coordination rather than absolute speed. Slower pairs receive a proportionally wider acceptance window; faster pairs receive a tighter one. Success is determined exclusively by how well a dyad matches each other, never by individual reaction speed. The Dolphin Task measures the behavioural outcome of IBS: whether physiological synchrony translates into coordinated motor action.



(a) Successful trial: both participants press simultaneously, the ball is caught.

(b) Failed trial: the response time difference exceeds the threshold.

Fig. 3: The Dolphin Task interface. Participants must press their key simultaneously when the ball drops, success depending on temporal alignment as opposed to reaction time.

2.6 Technical Setup

Each participant runs the PsychoPy stimulus application on a dedicated computer. EEG is recorded via two EMOTIV headsets managed through the EmotivPro software. Marker streams from each PsychoPy instance and EEG data streams from both EmotivPro instances are synchronised using the Lab Streaming Layer (LSL) framework and captured centrally by a LAB Recorder operated by the experimenter. The two PsychoPy instances exchange timing markers via LSL to align task events across both participants' machines.

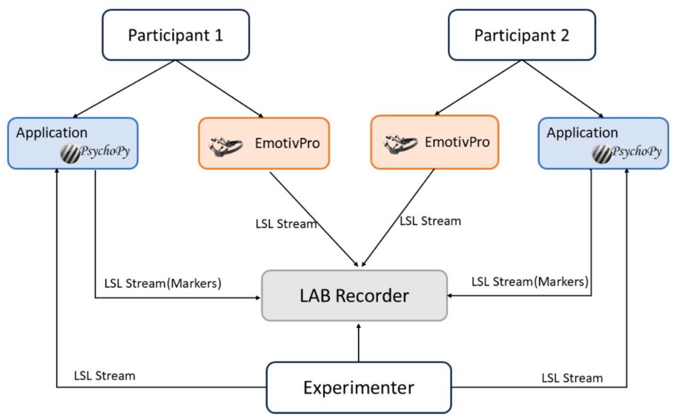


Fig. 4: Overview of the Technical Setup

2.7 EEG Preprocessing

EEG data were preprocessed offline in Python using MNE-Python. The pipeline consisted of: offline average referencing to reduce common noise, bandpass filtering (1–45 Hz) to remove slow drifts and high-frequency noise, Independent Component Analysis (ICA) to separate neural activity from non-neural artefacts, visual inspection of ICA components, and removal of identified artefact components to yield clean EEG signals.

2.8 IBS Feature Extraction

IBS was operationalised as the Phase Locking Value (PLV), which quantifies the consistency of the phase relationship between neural oscillations across trials [6], [7].

Feature extraction was restricted to an a priori frontal/fronto-central ROI (AF3, F7, F3, FC5, FC6, F4, F8, AF4), consistent with prior hyperscanning evidence [6], [12], [9], [8], [13]. This ROI was also methodologically appropriate for the wearable EMOTIV setup: restricting analysis to predefined frontal channels reduced noise and the number of comparisons, which was particularly important given the small pilot sample and remote setup.

PLV was computed for all inter-subject electrode pairs within this ROI in the delta (1–4 Hz) and theta (4–8 Hz) bands [8], [6], [1], then spatially and spectrally averaged to yield a single IBS metric per trial.

3 Hypotheses and Analysis

Four hypotheses were tested: (H1) the breathing intervention increases task synchrony (game success rate); (H2) it leads to higher inter-brain synchrony (PLV, delta + theta bands, frontal electrodes); (H3) it increases perceived synchrony (post-task questionnaire); and (H4) higher inter-brain synchrony is associated with higher task synchrony.

Due to the small sample size ($N = 10$ dyads for behavioural/questionnaire data, $N = 9$ for EEG), non-parametric Wilcoxon signed-rank tests were used to compare intervention and control conditions. Effect sizes are reported as $r = |Z|/\sqrt{N}$. Control analyses examined practice effects (within-condition round comparisons) and order effects (crossover group comparisons).

4 Results

No significant effects of the breathing intervention were found on task synchrony ($W = 19.0$, $p = 0.422$, $r = 0.27$; H1), inter-brain synchrony ($W = 17.0$, $p = 0.570$, $r = 0.22$; H2), or perceived synchrony ($W = 13.0$, $p = 0.539$, $r = 0.47$; H3). However, an order effect emerged for H3: every dyad in Group B (intervention second) reported higher perceived synchrony after the intervention compared to their control round, while this pattern was absent in Group A (intervention first; Mann-Whitney $U = 0$, $p = 0.021$).

No relationship was found between inter-brain synchrony and task performance ($W = 21.0$, $p = 0.910$, $r = 0.06$; H4). Despite null primary findings, H2 showed a directional upward trend in PLV for 5 of 9 dyads in the intervention condition, suggesting a possible effect at larger sample sizes.

Table 2: Hypothesis test results. $^*p < .05$; n.s. = not significant.

Hypothesis	Test Statistic	p	r	Outcome
H1 (Task synchrony)	$W = 19.0$	.422	.27	n.s.
H2 (Inter-brain synchrony)	$W = 17.0$	.570	.22	n.s.
H3 (Perceived synchrony)	$W = 13.0$	.539	.47	n.s.
Order effect (H3)	$U = 0.0$	.021*	–	*
H4 (Synchrony–performance link)	$W = 21.0$	.910	.06	n.s.

5 Discussion

5.1 Limitations

This study has four principal limitations. First, the sample size of ten dyads limits statistical power and makes it difficult to detect small-to- moderate effect sizes reliably. Second, the three-minute intervention duration may be insufficient to produce lasting physiological entrainment that persists through subsequent task performance. Third, EEG data from wearable EMOTIV headsets is susceptible to motion and contact artefacts, which reduce signal quality, particularly in a remote setup where continuous electrode monitoring is difficult. Fourth, the Dolphin Task captures reactive motor synchronization but does not reproduce the cognitive and communicative complexity of genuine remote collaboration.

5.2 Future Work

Future studies should increase the sample to at least 30 dyads to achieve adequate statistical power for detecting small-to-moderate effects. The intervention duration should extend beyond three minutes, or be repeated across multiple sessions, to evaluate whether physiological entrainment accumulates over time. Incorporating additional physiological measures — particularly heart rate variability (HRV), which is less susceptible to EEG artefacts — would provide a complementary and more robust signal of physiological synchrony. Finally, replacing the Dolphin Task with a collaborative task involving naturalistic communication would better approximate real-world remote teamwork and test whether any induced IBS generalises beyond reactive motor synchronization.

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