Report

Current Biology

# Brain-to-Brain Synchrony Tracks Real-World Dynamic Group Interactions in the Classroom

## Highlights

- We report a real-world group EEG study, in a school, during normal class activities
- EEG was recorded from 12 students simultaneously, repeated over 11 sessions
- Students' brain-to-brain group synchrony predicts classroom engagement
- Students' brain-to-brain group synchrony predicts classroom social dynamics


## Authors

Suzanne Dikker, Lu Wan, Ido Davidesco, ..., Jay J. Van Bavel, Mingzhou Ding, David Poeppel

## Correspondence

sdikker@gmail.com (S.D.), david.poeppel@gmail.com (D.P.)



## In Brief

Dikker, Wan, et al. follow a group of high school seniors for a semester and record their brain activity during their regular biology class. They find that students' brainwaves are more in sync with each other when they are more engaged during class. Brain-to-brain synchrony is also reflective of how much students like the teacher and each other.


Dikker et al., 2017, Current Biology *27*, 1375–1380
May 8, 2017 
http://dx.doi.org/10.1016/j.cub.2017.04.002

Current Biology
Report



# Brain-to-Brain Synchrony Tracks Real-World Dynamic Group Interactions in the Classroom

Suzanne Dikker,[1,2,7,8,*] Lu Wan,[3,7] Ido Davidesco,[1] Lisa Kaggen,[1] Matthias Oostrik,[5] James McClintock,[6] Jess Rowland,[1] Georgios Michalareas,[4] Jay J. Van Bavel,[1] Mingzhou Ding,[3] and David Poeppel[1,4,*]
[1]Department of Psychology, New York University, 6 Washington Place, New York, NY 10003, USA
[2]Department of Language and Communication, Utrecht Institute of Linguistics OTS, Utrecht University, Trans 10, 3512 JK Utrecht, the Netherlands
[3]J. Crayton Pruitt Family Department of Biomedical Engineering, University of Florida, 1275 Center Drive, Gainesville, FL 32611, USA
[4]Max Planck Institute for Empirical Aesthetics, Grüneburgweg 14, 60322 Frankfurt am Main, Germany
[5]Leidekkerssteeg 1, 1012 GH Amsterdam, the Netherlands
[6]New York, NY 10024, USA
[7]These authors contributed equally
[8]Lead Contact
*Correspondence: sdikker@gmail.com (S.D.), david.poeppel@gmail.com (D.P.)
http://dx.doi.org/10.1016/j.cub.2017.04.002

## SUMMARY

**The human brain has evolved for group living [1]. Yet we know so little about how it supports dynamic group interactions that the study of real-world social exchanges has been dubbed the "dark matter of social neuroscience" [2]. Recently, various studies have begun to approach this question by comparing brain responses of multiple individuals during a variety of (semi-naturalistic) tasks [3–15]. These experiments reveal how stimulus properties [13], individual differences [14], and contextual factors [15] may underpin similarities and differences in neural activity across people. However, most studies to date suffer from various limitations: they often lack direct face-to-face interaction between participants, are typically limited to dyads, do not investigate social dynamics across time, and, crucially, they rarely study social behavior under naturalistic circumstances. Here we extend such experimentation drastically, beyond dyads and beyond laboratory walls, to identify neural markers of group engagement during dynamic real-world group interactions. We used portable electroencephalogram (EEG) to simultaneously record brain activity from a class of 12 high school students over the course of a semester (11 classes) during regular classroom activities (Figures 1A–1C; Supplemental Experimental Procedures, section S1). A novel analysis technique to assess group-based neural coherence demonstrates that the extent to which brain activity is synchronized across students predicts both student class engagement and social dynamics. This suggests that brain-to-brain synchrony is a possible neural marker for dynamic social interactions, likely driven by shared attention mechanisms. This study validates a promising new method to investigate the neuroscience of group interactions in ecologically natural settings.**

## RESULTS AND DISCUSSION

The classroom is an ideal starting point for real-world neuroscience: it provides a practically important and ecologically naturalistic context but also a semi-controlled environment, governed by a sequence of activities led by a teacher. This allowed us to measure brain activity and behavior in a systematic fashion over the course of a full semester as students engaged in a series of predetermined class activities (repeated across 11 50-min classes, students followed lectures, watched instructional videos, and participated in group discussions). We explored the hypothesis that synchronized neural activity across a group of students predicts (and possibly underpins) classroom engagement and social dynamics. When students feel connected or engaged with the material or each other, are their brains in fact "in sync" in a formal, quantifiable sense? To investigate these questions, we used low-cost portable electroencephalogram (EEG) systems ([16]; Supplemental Experimental Procedures, section S2) paired with a novel analysis technique to characterize the synchronization of brain activity between individuals: total interdependence (TI; [17]; Supplemental Experimental Procedures, section S3). Figures 1C and 1D lay out how TI is operationalized.

We focused on the relationship between TI and classroom engagement, on the one hand, and social dynamics, on the other—both of which are critical for student learning [18]. Classroom engagement was quantified as student appreciation ratings of different teaching styles (Figure 1B) and student day-by-day self-reported focus. Classroom social dynamics were quantified in terms of socially relevant personality traits (group affinity [19, 20] and empathy [21]) and as social closeness during class interactions (between students and with the teacher; see Supplemental Experimental Procedures, section S1 for details).

### Brain-to-Brain Synchrony and Class Engagement

We first examined the relationship between brain-to-brain synchrony (indexed by TI) and student ratings of four different

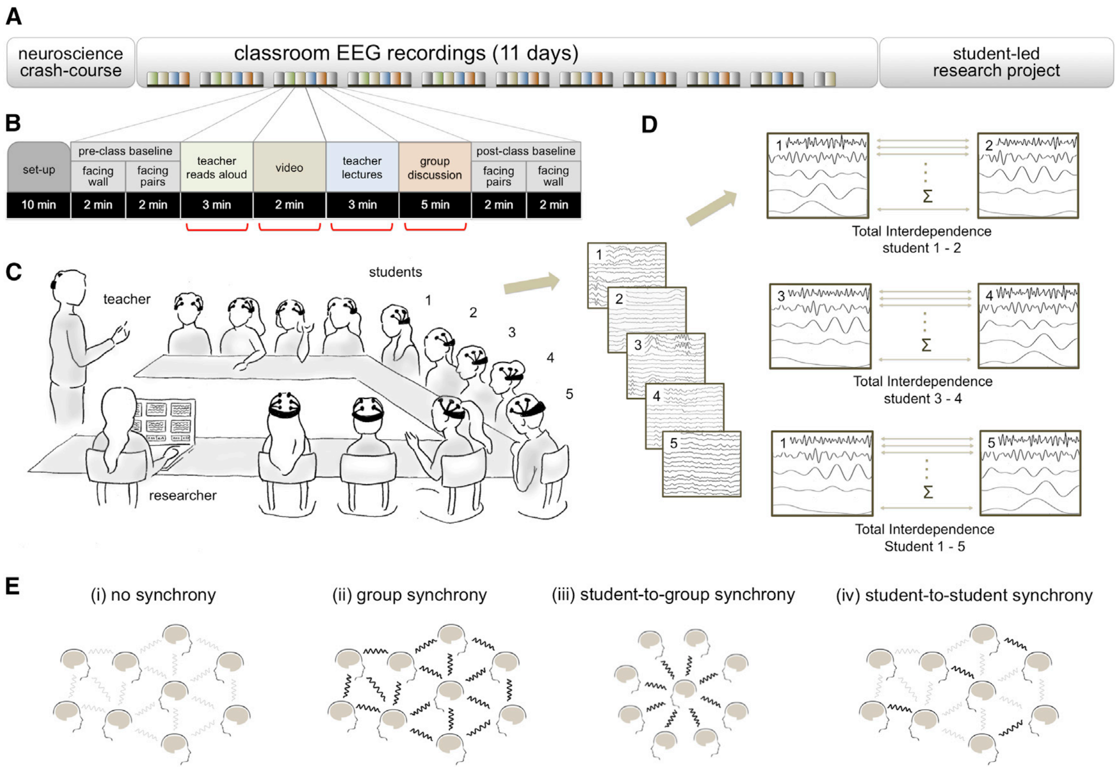


**Figure 1. Experimental Setup, Procedure, and Rationale**

(A) Timeline of the experiment. The fall semester started with a crash course in neuroscience, followed by 11 recording days distributed over a 3-month period. In the spring semester, students designed, executed, and carried out their own original research projects (see Supplemental Experimental Procedures, section S1).

(B) Sample experimental procedure of a typical recording day: EEG activity was recorded during video, lecture, and discussion teaching styles separately, which were consistently carried out across all 11 recording days. Other tasks were alternated (Supplemental Experimental Procedures, section S1). TI values were averaged for each teaching style separately (marked in red; Supplemental Experimental Procedures, section S3).

(C) Illustration of experimental setup in the classroom with 12 students wearing the EMOTIV EPOC headset (Supplemental Experimental Procedures, section S2). These portable devices offer a rich opportunity to involve students both as participants and as experimenters (Supplemental Experimental Procedures, section S1).

(D) Brain-to-brain synchrony (TI) was computed by taking each student's raw EEG signal, decomposing it into frequency bins (1–20 Hz, 0.25 Hz resolution), and calculating the sum of the inter-brain coherence between pairs of students for each bin. Thus, TI quantifies the inter-brain coherence across the frequency spectrum, allowing a data-driven identification of the brain signals of interest (see Figure S3 for further details).

(E) TI enables us to analyze brain-to-brain synchrony at multiple socially relevant levels of investigation: group synchrony (averaging TI values across all possible pairs within a group) (i); student-to-group synchrony (averaging TI values between a given student and each of his/her peers) (ii); and student-to-student synchrony (TI values between pairs of students) (iii).

See also Figure S1.

teaching styles over time. Students rated each segment after every recording and were also asked to provide overall ratings of each teaching style after the semester was over (Figures 1A and 1B; Supplemental Experimental Procedures, section S1). Significant main effects of teaching style were observed on both student ratings (repeated-measures two-way ANOVA with teaching style and time as main factors [see Supplemental Experimental Procedures, section S4 for details]: day-by-day ratings: $F(3,24) = 16.85$; $p < 10^{-5}$; post-semester ratings: $F(3,27) = 33.29$; $p < 10^{-8}$) and brain-to-brain synchrony (group synchrony: $F(3,12) = 5.93$; $p < 0.0005$; student-to-group synchrony: $F(3,27) = 5.94$; $p < 0.005$; see Supplemental Experimental Procedures, section S2). Overall, students preferred watching videos and engaging in group discussions over listening to the teacher reading aloud or lecturing (Figure 2A, left panel), an effect that was even more pronounced in the post-semester ratings (Figure 2A, right panel). A strikingly similar pattern was observed for group synchrony (Figure 2B, left) as well as student-to-group synchrony (Figure 2B, right; see Table S2 for detailed statistics). Student-to-group synchrony exhibited a strong positive correlation with student ratings: the higher the post-semester student ratings, the stronger the student-to-group synchrony averaged across days ($r = .61$, $p < 0.0001$; Figure 2C; Figure 2A, right shows the same data, separated by condition and averaged across subjects). Day-by-day ratings and group synchrony were not correlated.

## Is Brain-to-Brain Synchrony Purely Stimulus Driven?

How much of brain-to-brain synchrony is explained by "mere" stimulus attributes (i.e., teaching style; cf. [6]), and how much do individual differences (cf. [7]) contribute to synchrony? To explore this, we performed a number of multiple regression

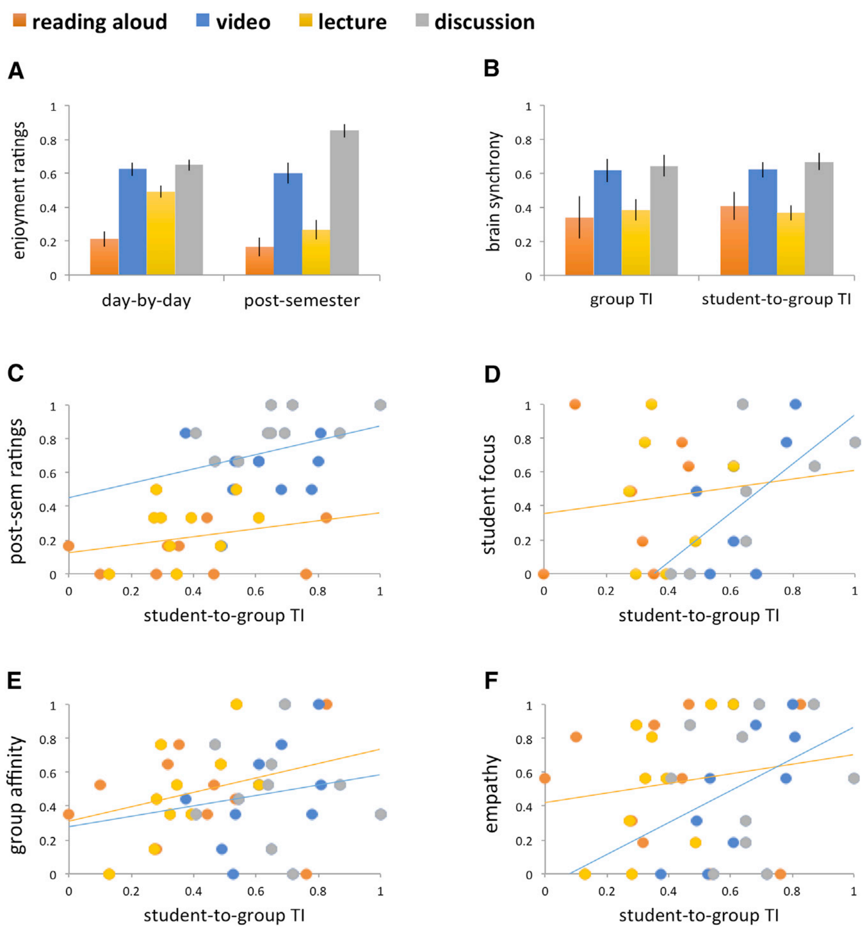


**Figure 2. Independent Contributions of Teaching Style and Individual Differences to Brain-to-Brain Synchrony**

(A) Average day-by-day (left) and post-semester (right) student appreciation ratings for four teaching styles: reading aloud, video, lecture, and discussion sessions. Error bars reflect standard errors over students.

(B) Average group TI (left) and student-to-group TI (right) for four teaching styles. Error bars reflect standard errors over days (left) and students (right).

(C) Post-semester ratings, while exhibiting a main effect on student-to-group synchrony, did not independently predict student-to-group TI over teaching style.

(D–F) Student focus (D), group affinity (E), and empathy (F) did each predict student-to-group TI in addition to teaching style.

Trend lines are displayed by teaching style (blue: discussion and video; yellow: reading aloud and lecture). All values were normalized to a 0–1 scale (max-min) for presentation purposes, and each dot reflects one student's TI in one of four teaching styles averaged across days (see Figure S4 for data further separated by days).

See also Figures S2, S3, and S4 and Tables S1 and S2.

analyses to assess the relationship between TI and a number of individual variables (ratings, focus, group affinity, and empathic disposition), with teaching style included as a factor representing the stimulus attribute (see Supplemental Experimental Procedures, section S3).

Post-semester ratings, while exhibiting a main effect on student-to-group synchrony ($F(1,220) = 20.79$, $p < 0.0001$), did not independently predict synchrony over teaching style (post-semester ratings: $F(1,210) = 2.28$, $p = 0.1327$ and teaching style: $F(1,9) = 2.37$, $p = 0.1581$; Figure 2C). Student focus, in contrast, did predict student-to-group synchrony independent of teaching style: students who were more focused on a given day also showed higher synchrony for that day (focus: $F(1,126) = 4.64$, $p = 0.0331$ and teaching style: $F(1,9) = 29.23$, $p = 0.0004$; Figure 2D).

Next, we examined the relationship between brain-to-brain synchrony and students' personality traits, in particular their group affinity and empathic disposition ([20]; see Supplemental Experimental Procedures, section S1 for details). Both group affinity and empathy predicted student-to-group synchrony independently of teaching style (group affinity: $F(1,115) = 5.95$, $p = 0.0163$ and teaching style: $F(1,9) = 12.73$, $p = 0.0060$; empathy: $F(1,115) = 5.71$, $p = 0.0185$ and teaching style: $F(1,9) = 13.53$, $p = 0.0062$).

Together, these findings demonstrate that individual factors (focus and personality traits) contribute to synchrony above and beyond the nature of the stimulus itself.

## Brain-to-Brain Synchrony and Classroom Social Dynamics

Our findings suggest that brain-to-brain synchrony is driven by a combination of stimulus properties (teaching styles) and individual differences (student focus, teaching style preferences, teacher likeability, and personality traits). However, none of these factors speak directly to whether the presence of others had an effect on synchrony during class. For example, empathic disposition affects brain-to-brain similarities even in the absence of others [14].

To address classroom social dynamics directly, we collected social closeness ratings from students both toward the teacher and to the other students (Supplemental Experimental Procedures, section S1) and introduced manipulations that either did or did not involve direct social interaction. To investigate the effect of the teacher on student-to-group synchrony, we compared the two teaching styles in which the teacher was minimally involved (videos) and maximally involved (lectures). Figure 2D illustrates that, while students varied with respect to their overall student-to-group synchrony, synchrony was consistently higher for video than lecture sessions across students ($p = 0.007$; see Table S1). This difference was correlated with students' evaluations of the teacher: the more favorable a student's rating of the teacher, the smaller that student's difference in synchrony between video (where the teacher played no role) and lecture sessions (where the teacher played an integral role; Figure 2E; $r = 0.72$, $p = 0.018$ for data averaged across days).

We then tested whether pairwise student-to-student synchrony varied as a function of the classroom configuration (in each class, students were randomly assigned seats by the experimenters; see Supplemental Experimental Procedures,

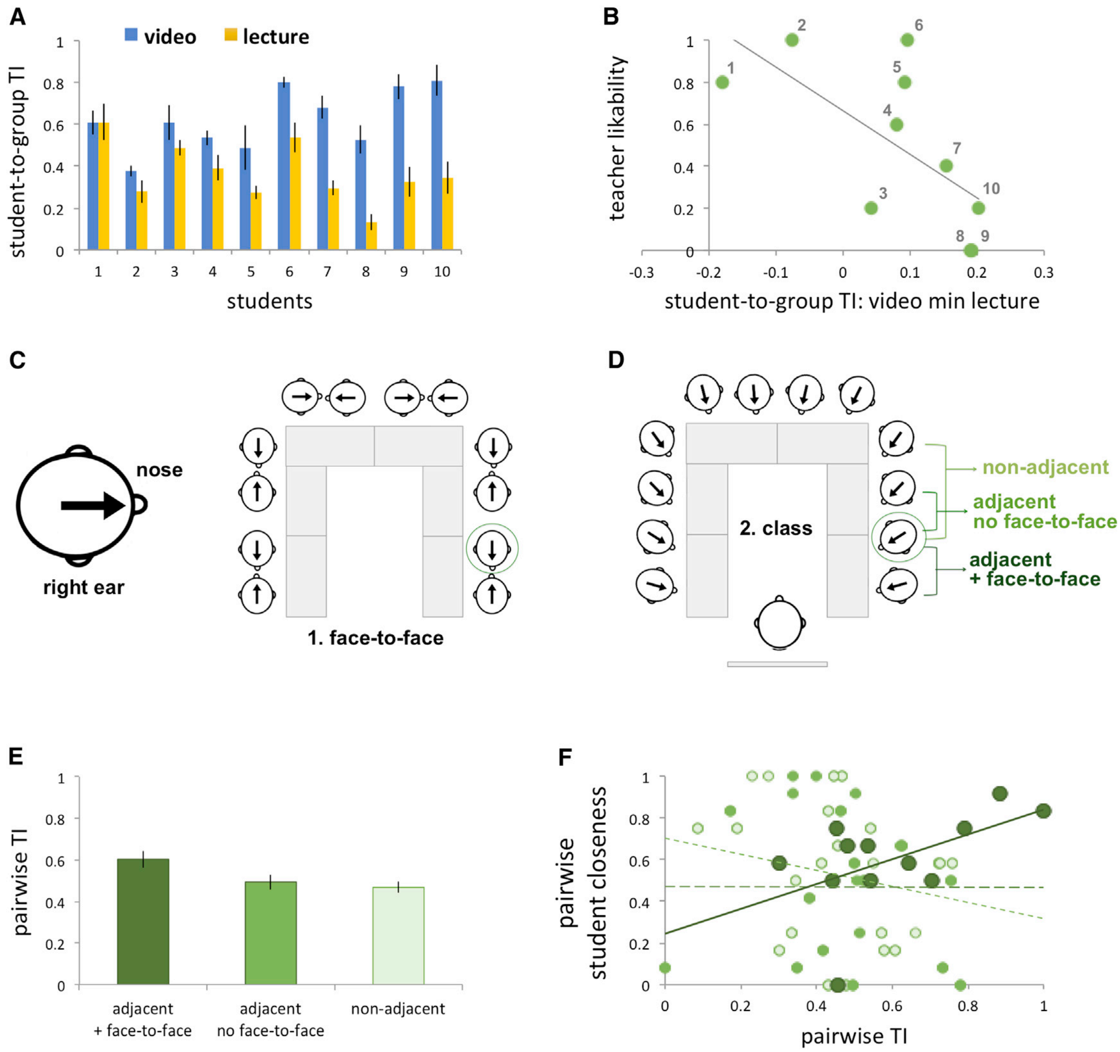


**Figure 3. Brain-to-Brain Synchrony Predicts Classroom Social Dynamics**

(A and B) The difference in student-to-group TI between video and lecture sessions across students (A) (error bars reflect standard errors over days) was negatively correlated with their ratings of the teacher (B) ($r = -.72$, $p = 0.018$; each dot represents one student; TI values are averaged across days; teacher likeability was recorded once for each student, after the semester was over).

(C) Before class, students sat face-to-face, engaging in eye contact for 2 min with one peer (Supplemental Experimental Procedures, section S1).

(D) An illustration for one student (green circle) of how the face-to-face baseline allowed a comparison of pairwise TI for three types of students: students who sat adjacent to each other and had engaged in silent eye contact prior to class (adjacent + face-to-face), students who sat next to each other but had not participated in a face-to-face baseline together (adjacent, no face-to-face), and students who were not sitting next to each other (non-adjacent).

(E) Students showed the highest pairwise synchrony during class with their face-to-face partner compared to the other two student pairings (error bars reflect standard errors over student pairs).

(F) Pairwise TI is correlated with mutual closeness ratings for adjacent + face-to-face pairs (solid dark green), but not for adjacent, no face-to-face pairs (solid light green) or non-adjacent pairs (no fill green). Each dot represents one student pair, averaged across teaching styles. All values were normalized to a 0–1 scale (max-min) for presentation purposes.

See also Figures S2, S3, and S4 and Table S1.

section S1) and student interaction: as illustrated in Figures 1B and 3C, students engaged in eye contact (face-to-face) with an assigned peer for 2 min prior to class (see Supplemental Experimental Procedures, section S1 for details). This allowed us to compare the relationship between pairwise synchrony and students' self-reported closeness to each other for three types of student pairs: students who sat adjacent to each other and had engaged in silent eye contact prior to class (adjacent + face-to-face), students who sat next to each other but had not participated in a face-to-face baseline together (adjacent, no face-to-face), and students who were not sitting next to each other (non-adjacent; illustrated in Figure 3D). Students showed the highest pairwise synchrony during class with their face-to-face partner compared to the other two student pairings (Figure 3E; one-way ANOVA: $F(2,102) = 5.66$, $p = 0.0047$). In addition, brain-to-brain synchrony was correlated with students'

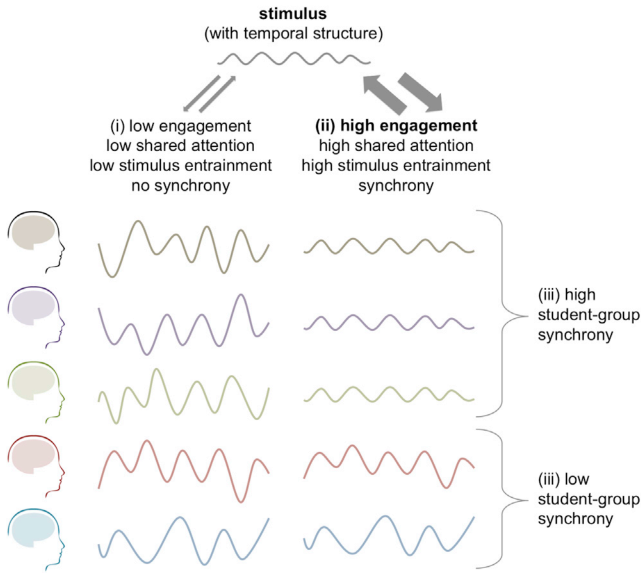


**Figure 4. Shared Attention as a Possible Account of Brain-to-Brain Synchrony**

Schematic illustration of a possible joint attention account of brain-to-brain synchrony. Neural entrainment to an external stimulus (video, teacher, or each other) is driven by a combination of stimulus properties (shown as arrows flowing down from "stimulus") and attention (arrows flowing up to the stimulus). Under "low attention" conditions, students' neural oscillations are not entrained to an external stimulus (video, teacher, or each other) (i). Under "shared attention" conditions, students' alpha oscillations are attenuated and entrained with an engaging external stimulus: a video, the teacher, or each other (ii). Some students are in a more attentive state, have more socially engaged personality traits, or have directly interacted, modulating the extent to which their neural oscillations are entrained with the stimulus (the teacher, a video, or each other) (iii).

mutual closeness ratings, but exclusively for adjacent + face-to-face pairs: student pairs who reported higher social closeness to each other exhibited stronger pairwise brain-to-brain synchrony during class activities, only if they had engaged in eye contact prior to class ($r = 0.5265$, $p = 0.0082$; solid green dots and solid line in Figure 3F; note that there was only a marginal main effect of condition on the TI × closeness correlation: $F(2,75) = 2.83$, $p = 0.0654$). In sum, face-to-face interaction prior to class not only increased brain-to-brain synchrony during class but also seemed to serve as an "activator" for interpersonal relationship features: actual joint attention, and not passive co-presence, predicted student-to-student synchrony.

## Shared Attention as a Likely Source of Brain-to-Brain Synchrony

It is important to emphasize that brain-to-brain synchrony is not a mechanism in itself. Instead, neural synchrony across participants is a measurable reflection of the underlying neural computations that underpin some of the psychological processes under investigation. To better understand the synchronization effects we observe, mental constructs like focus, empathy, and closeness need to be decomposed into basic psychological processes that provide more suitable linking hypotheses to neural metrics. As already briefly discussed above, the finding that student-to-student synchrony is correlated with mutual closeness ratings during class—but only for pairs of students who had engaged in eye contact prior to class—aligns with research suggesting that eye contact sets up a context for joint attention [22]. Joint attention (shared intentionality) has been proposed to form a scaffold for social cognition in a range of social-psychological contexts, including development [21, 23], and provides a plausible account for prior findings showing an increase in brain-to-brain synchrony during laboratory tasks that required dyads to coordinate visual attention (e.g., [3, 5, 8, 11]).

We speculate that stimulus properties (teaching style [13]), individual differences (focus, engagement, and personality traits [14]), and social dynamics (social closeness and social interaction) each mediate attention at the neural level. This, in turn, affects students' neural entrainment to their surrounding sensory input: the teacher, a video, or each other [24]. This ties directly to behavioral evidence showing that people physically (and typically subconsciously) entrain to each other when engaging in tasks that require joint attention (pupil dilation, gestures, walking; e.g., [25]). More broadly, student-to-group synchrony as a function of shared attention follows directly from a range of electrophysiological results showing that brain rhythms lock to the rhythms of auditory and audiovisual input, which is amplified when the input is attended [24, 26, 27].

To provide additional evidence that speaks to a shared attention account, we examined the relationship between student-to-group synchrony and alpha band power—a well-characterized index of attention [28, 29]. As predicted, a reduction in a student's alpha oscillatory activity was accompanied by an increase in student-to-group alpha coherence ($r = -0.64$, $p = 0.0044$).

In sum, this study suggests that brain-to-brain synchrony increases as shared attention modulates entrainment by "tuning" neural oscillations to the temporal structure of our surroundings. Individuals who are less engaged with the stimulus show lower brain-to-brain synchrony levels with the rest of the group (Figure 4), and people who have interacted face-to-face show increased entrainment to each other.

Simultaneously recording EEG data from a group of teenagers under naturalistic circumstances presents obvious challenges when compared to laboratory-generated EEG experiments. Although we could not attain the level of experimental rigor that characterizes laboratory studies, we imposed as much structured design as possible, while minimally limiting students to engage with each other and with the class content, as they would under normal circumstances. Second, we carried out EEG recordings on 11 different days with the same series of experimental conditions, essentially replicating the same experiment 11 times on the same group of students (Figure 1A). Finally, we carried out a series of experiments to verify that we obtained interpretable recordings and that TI reliably indexes the synchronization of the neural signal across individuals in both the laboratory and in a classroom context (Figure S2).

## Conclusions

We repeatedly recorded brain activity from a group of 12 students simultaneously as they engaged in natural classroom activities and social interactions. Over the course of 11 different school days distributed over one semester, we found that brain-to-brain synchrony between students consistently predicted class engagement and social dynamics. These findings suggest that brain-to-brain synchrony is a sensitive marker that can predict dynamic classroom interactions, and this relationship may be driven by shared attention within the group. The approach we describe provides a promising new avenue to investigate the neuroscience of group interactions under ecologically natural circumstances.

## ACCESSION NUMBERS

The raw data reported in this paper have been deposited in the Open Science Framework under ID code OSF: 10.17605/OSF.IO/NSUHJ.

## SUPPLEMENTAL INFORMATION

Supplemental Information includes Supplemental Experimental Procedures, four figures, and two tables and can be found with this article online at http://dx.doi.org/10.1016/j.cub.2017.04.002.

## AUTHOR CONTRIBUTIONS

S.D. and D.P. conceptualized the research. L.W., L.K., J.M., M.D., and D.P. designed the research. S.D., L.K., J.R., and I.D. performed the research. M.O. and S.D. designed custom software. L.W., S.D., L.K., J.R., and G.M. analyzed data. S.D., D.P., L.W., I.D., G.M., J.J.V.B., and M.D. wrote the paper.

## ACKNOWLEDGMENTS

This research was supported by NSF INSPIRE Track 1 Award 1344285 and Netherlands Organisation for Scientific Research Award 275-89-018. We thank the school staff and especially the Advanced Biology students for generously granting access to the school and for donating their time and resources (especially M. Schaffer and S. Dhanesar); M. Westerlund, S. Ashrafi, and M. Rabadi for co-facilitating the educational portion of the project; K. Du, G. Mackellar, and the rest of the EMOTIV team for hardware support; A. Flinker for technical consultation; and B. Tuller for comments. The research was approved by New York University's Committee on Activities Involving Human Subjects.

Received: October 20, 2016
Revised: February 27, 2017
Accepted: April 4, 2017
Published: April 27, 2017

## REFERENCES

1. Dunbar, I.R. (2002). The social brain hypothesis. In Foundations in Social Neuroscience, J.T. Cacioppo, ed. (MIT Press), pp. 69–88.
2. Schilbach, L., Timmermans, B., Reddy, V., Costall, A., Bente, G., Schlicht, T., and Vogeley, K. (2013). Toward a second-person neuroscience. Behav. Brain Sci. *36*, 393–414.
3. Babiloni, F., and Astolfi, L. (2014). Social neuroscience and hyperscanning techniques: past, present and future. Neurosci. Biobehav. Rev. *44*, 76–93.
4. Dmochowski, J.P., Bezdek, M.A., Abelson, B.P., Johnson, J.S., Schumacher, E.H., and Parra, L.C. (2014). Audience preferences are predicted by temporal reliability of neural processing. Nat. Commun. *5*, 4567.
5. Dumas, G., Nadel, J., Soussignan, R., Martinerie, J., and Garnero, L. (2010). Inter-brain synchronization during social interaction. PLoS ONE *5*, e12166.
6. Hasson, U., Ghazanfar, A.A., Galantucci, B., Garrod, S., and Keysers, C. (2012). Brain-to-brain coupling: a mechanism for creating and sharing a social world. Trends Cogn. Sci. *16*, 114–121.
7. Hari, R., Himberg, T., Nummenmaa, L., Hämäläinen, M., and Parkkonen, L. (2013). Synchrony of brains and bodies during implicit interpersonal interaction. Trends Cogn. Sci. *17*, 105–106.
8. Jiang, J., Chen, C., Dai, B., Shi, G., Ding, G., Liu, L., and Lu, C. (2015). Leader emergence through interpersonal neural synchronization. Proc. Natl. Acad. Sci. USA *112*, 4274–4279.
9. Pfeiffer, U.J., Timmermans, B., Vogeley, K., Frith, C.D., and Schilbach, L. (2013). Towards a neuroscience of social interaction. Front. Hum. Neurosci. *7*, 22.
10. Stephens, G.J., Silbert, L.J., and Hasson, U. (2010). Speaker-listener neural coupling underlies successful communication. Proc. Natl. Acad. Sci. USA *107*, 14425–14430.
11. Babiloni, C., Buffo, P., Vecchio, F., Marzano, N., Del Percio, C., Spada, D., Rossi, S., Bruni, I., Rossini, P.M., and Perani, D. (2012). Brains "in concert": frontal oscillatory alpha rhythms and empathy in professional musicians. Neuroimage *60*, 105–116.
12. Duan, L., Dai, R.N., Xiao, X., Sun, P.P., Li, Z., and Zhu, C.Z. (2015). Cluster imaging of multi-brain networks (CIMBN): a general framework for hyperscanning and modeling a group of interacting brains. Front. Neurosci. *9*, 267.
13. Hasson, U., Nir, Y., Levy, I., Fuhrmann, G., and Malach, R. (2004). Intersubject synchronization of cortical activity during natural vision. Science *303*, 1634–1640.
14. Nummenmaa, L., Glerean, E., Viinikainen, M., Jääskeläinen, I.P., Hari, R., and Sams, M. (2012). Emotions promote social interaction by synchronizing brain activity across individuals. Proc. Natl. Acad. Sci. USA *109*, 9599–9604.
15. Dikker, S., Silbert, L.J., Hasson, U., and Zevin, J.D. (2014). On the same wavelength: predictable language enhances speaker-listener brain-to-brain synchrony in posterior superior temporal gyrus. J. Neurosci. *34*, 6267–6272.
16. Debener, S., Minow, F., Emkes, R., Gandras, K., and de Vos, M. (2012). How about taking a low-cost, small, and wireless EEG for a walk? Psychophysiology *49*, 1617–1621.
17. Wen, X., Mo, J., and Ding, M. (2012). Exploring resting-state functional connectivity with total interdependence. Neuroimage *60*, 1587–1595.
18. Reyes, M.R., Brackett, M.A., Rivers, S.E., White, M., and Salovey, P. (2012). Classroom emotional climate, student engagement, and academic achievement. J. Educ. Psychol. *104*, 700–712.
19. Balliet, D., Wu, J., and De Dreu, C.K. (2014). Ingroup favoritism in cooperation: a meta-analysis. Psychol. Bull. *140*, 1556–1581.
20. Saarela, M.V., Hlushchuk, Y., Williams, A.C.D.C., Schürmann, M., Kalso, E., and Hari, R. (2007). The compassionate brain: humans detect intensity of pain from another's face. Cereb. Cortex *17*, 230–237.
21. Mundy, P., and Newell, L. (2007). Attention, joint attention, and social cognition. Curr. Dir. Psychol. Sci. *16*, 269–274.
22. Farroni, T., Csibra, G., Simion, F., and Johnson, M.H. (2002). Eye contact detection in humans from birth. Proc. Natl. Acad. Sci. USA *99*, 9602–9605.
23. Tomasello, M. (1995). Joint attention as social cognition. In Joint Attention: Its Origins and Role in Development, C. Moore, and P. Dunham, eds. (Erlbaum), pp. 103–130.
24. Ki, J.J., Kelly, S.P., and Parra, L.C. (2016). Attention strongly modulates reliability of neural responses to naturalistic narrative stimuli. J. Neurosci. *36*, 3092–3101.
25. Knoblich, G., Butterfill, S., and Sebanz, N. (2011). Psychological research on joint action: theory and data. In The Psychology of Learning and Motivation, B. Ross, ed. (Academic Press), pp. 59–101.
26. Zion Golumbic, E.M., Ding, N., Bickel, S., Lakatos, P., Schevon, C.A., McKhann, G.M., Goodman, R.R., Emerson, R., Mehta, A.D., Simon, J.Z., et al. (2013). Mechanisms underlying selective neuronal tracking of attended speech at a "cocktail party". Neuron *77*, 980–991.
27. Lakatos, P., Karmos, G., Mehta, A.D., Ulbert, I., and Schroeder, C.E. (2008). Entrainment of neuronal oscillations as a mechanism of attentional selection. Science *320*, 110–113.
28. Haegens, S., Händel, B.F., and Jensen, O. (2011). Top-down controlled alpha band activity in somatosensory areas determines behavioral performance in a discrimination task. J. Neurosci. *31*, 5197–5204.
29. Palva, S., and Palva, J.M. (2007). New vistas for $\alpha$-frequency band oscillations. Trends Neurosci. *30*, 150–158.