

# UNIVERSITY OF BIRMINGHAM

University of Birmingham  
Research at Birmingham

## You are in sync with me

Cacioppo, S.; Zhou, H.; Monteleone, G.; Majka, E.a.; Quinn, Kimberly; Ball, A.b.; Norman, G.j.; Semin, G.r.; Cacioppo, J.t.

DOI:

[10.1016/j.neuroscience.2014.07.051](https://doi.org/10.1016/j.neuroscience.2014.07.051)

License:

Other (please specify with Rights Statement)

*Document Version*

Peer reviewed version

*Citation for published version (Harvard):*

Cacioppo, S, Zhou, H, Monteleone, G, Majka, EA, Quinn, K, Ball, AB, Norman, GJ, Semin, GR & Cacioppo, JT 2014, 'You are in sync with me: neural correlates of interpersonal synchrony with a partner', *Neuroscience*, vol. 277, pp. 842-858. <https://doi.org/10.1016/j.neuroscience.2014.07.051>

[Link to publication on Research at Birmingham portal](#)

### **Publisher Rights Statement:**

NOTICE: this is the author's version of a work that was accepted for publication in *Neuroscience*. Changes resulting from the publishing process, such as peer review, editing, corrections, structural formatting, and other quality control mechanisms may not be reflected in this document. Changes may have been made to this work since it was submitted for publication. A definitive version was subsequently published in *Neuroscience*, Volume 277, 26 September 2014, Pages 842–858 DOI: 10.1016/j.neuroscience.2014.07.051  
Checked for repository 28/10/2014

### **General rights**

Unless a licence is specified above, all rights (including copyright and moral rights) in this document are retained by the authors and/or the copyright holders. The express permission of the copyright holder must be obtained for any use of this material other than for purposes permitted by law.

- Users may freely distribute the URL that is used to identify this publication.
- Users may download and/or print one copy of the publication from the University of Birmingham research portal for the purpose of private study or non-commercial research.
- User may use extracts from the document in line with the concept of 'fair dealing' under the Copyright, Designs and Patents Act 1988 (?)
- Users may not further distribute the material nor use it for the purposes of commercial gain.

Where a licence is displayed above, please note the terms and conditions of the licence govern your use of this document.

When citing, please reference the published version.

### **Take down policy**

While the University of Birmingham exercises care and attention in making items available there are rare occasions when an item has been uploaded in error or has been deemed to be commercially or otherwise sensitive.

If you believe that this is the case for this document, please contact [UBIRA@lists.bham.ac.uk](mailto:UBIRA@lists.bham.ac.uk) providing details and we will remove access to the work immediately and investigate.

## Accepted Manuscript

You are in sync with me: Neural correlates of interpersonal synchrony with a partner

Stephanie Cacioppo, Haotian Zhou, George Monteleone, Elizabeth A. Majka, Kimberly A. Quinn, Aaron B. Ball, Gregory J. Norman, Gün. R. Semin, John T. Cacioppo

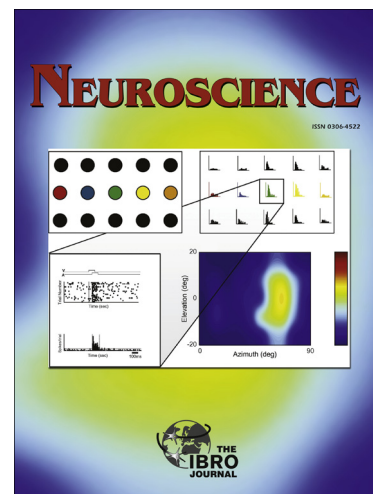
PII: S0306-4522(14)00624-1  
DOI: <http://dx.doi.org/10.1016/j.neuroscience.2014.07.051>  
Reference: NSC 15591

To appear in: *Neuroscience*

Accepted Date: 2 July 2014

Please cite this article as: S. Cacioppo, H. Zhou, G. Monteleone, E.A. Majka, K.A. Quinn, A.B. Ball, G.J. Norman, n.R. Semin, J.T. Cacioppo, You are in sync with me: Neural correlates of interpersonal synchrony with a partner, *Neuroscience* (2014), doi: <http://dx.doi.org/10.1016/j.neuroscience.2014.07.051>

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.



You are in sync with me:

## Neural correlates of interpersonal synchrony with a partner

Stephanie Cacioppo<sup>1,2</sup>; Haotian Zhou<sup>3</sup>, George Monteleone<sup>1</sup>; Elizabeth A. Majka<sup>3</sup>, Kimberly A. Quinn<sup>4</sup>, Aaron B. Ball<sup>1</sup>, Gregory J. Norman<sup>3</sup>, Gün. R. Semin<sup>5,6</sup>; John T. Cacioppo<sup>1,2,3</sup>

1. Center for Cognitive and Social Neuroscience, HPEN laboratory, University of Chicago, 940 East 57<sup>th</sup> Street, Chicago, IL 60637

2. Department of Psychiatry and Behavior Neuroscience, University of Chicago, A27 S. Maryland Avenue, Chicago, IL, 60637

3. Department of Psychology, University of Chicago, 5848 S. University Avenue, Chicago, IL, 60637

4. School of Psychology, University of Birmingham, Edgbaston, Birmingham, B15 2TT, United Kingdom; Department of Psychology, DePaul University, 2219 N. Kenmore Ave., Chicago, IL 60657

5. Faculty of Social and Behavioral Sciences, Utrecht University, Heidelberglaan 1, 3584 CS, Utrecht, Netherlands

6. Department of Psychology, Koç University, Istanbul, Turkey

---

Title Word Count: 14

Running Title Character Count: 44 (with spaces)

Abstract Word count: 273

Text Total Word Count: 8837

Number of pages: 45

Tables: 7

Figures: 5

---

**Conflict of interest:** The authors declare no competing financial interests.

**Acknowledgments:** GM was supported by a grant from the Swiss National Science Foundation (FNS\_PP00\_1\_128599/1 to SC) and by the Center for Cognitive and Social Neuroscience (CCSN). The authors thank John S. Irick for this technical assistance.

**Running Title:** Neural correlates of interpersonal synchrony

**Corresponding Author:** Dr. John T. Cacioppo, Ph.D. ([Cacioppo@uchicago.edu](mailto:Cacioppo@uchicago.edu)); The University of Chicago ; Department of Psychology, 5848 South University Avenue, Chicago, IL, 60637

---

## Abstract

Interpersonal synchrony is characterized by a temporary alignment of periodic behaviors with another person. This process requires that at least one of the two individuals monitors and adjusts their movements to maintain alignment with the other individual (the referent). Interestingly, recent research on interpersonal synchrony has found that people who are motivated to befriend an unfamiliar social referent tend to automatically synchronize with their social referent, raising the possibility that synchrony may be employed as an affiliation tool. It is unknown, however, whether the opposite is true; that is, whether the person serving as the referent of interpersonal synchrony perceives synchrony with their partner or experiences affiliative feelings towards the partner.

To address this question, we performed a series of studies on interpersonal synchrony with a total of 103 participants. In all studies, participants served as the referent with no requirement to monitor or align their behavior with their partner. Unbeknownst to the participants, the timings of their “partner’s” movements were actually determined by a computer program based on the participant’s (i.e., referent’s) behavior.

Overall, our behavioral results showed that the referent of a synchrony task expressed greater perceived synchrony and greater social affiliation toward a synchronous partner (i.e., one displaying low mean asynchrony and/or a narrow asynchrony range) than with an asynchronous partner (i.e., one displaying high mean asynchrony and/or high asynchrony range). Our neuroimaging study extended these results by demonstrating involvement of brain areas implicated in social cognition, embodied cognition, self–other expansion, and action observation as correlates of interpersonal synchrony (vs. asynchrony). These findings have practical implications for social interaction and theoretical implications for understanding interpersonal synchrony and social coordination.

**Keywords:** Social neuroscience; fMRI; Interpersonal synchrony; Dyads; Shared representations.

**Highlights:**

- First fMRI study on social consequences of synchrony where the participant served as referent.
- Referents recruit brain areas involved in social and embodied cognition during synchrony.
- Referents expressed greater feelings of affiliation toward synchronous partners.

## 1. Introduction

Early studies of synchrony focused on the mechanisms underlying a person's ability to synchronize movements with some *referent*, such as a metronome (cf, Repp, 2005). Interpersonal synchrony, the alignment in time of the periodic movements of two or more individuals, has also been investigated because of its putative social consequences. Interpersonal synchrony promotes an array of positive interpersonal outcomes, such as affiliation (Hove and Risen 2009), liking (Miles, Nind, Henderson, Macrae, 2009), rapport (Vacharkulksemsuk and Fredrickson, 2012), and emotional support satisfaction (Jones and Wirtz, 2007). Interpersonal synchrony also leads to outcomes that extend beyond individuals to promote groups, including cooperation (Wiltermuth and Heath, 2009) and compassion (Valdesolo and DeSteno, 2011). Functionalist accounts of synchrony posit that the primary purpose of synchrony is to foster social bonds (Semin, 2007; Semin and Cacioppo, 2008) and strengthen the collective (McNeill, 1995; Ehrenreich, 2006; Haidt, Seder, Kesibir, 2008; Haidt, 2012). McNeill (1995) argued that synchrony played an important role in the ascension of our species, and previous investigations have documented motivational factors that promote interpersonal synchrony and various social consequences of synchrony (Bernieri, 1988; Cappella, 1997; Lakin and Chartrand, 2003; Hove and Risen, 2009; Marsh et al., 2009; Wiltermuth and Heath, 2009; Miles et al., 2010; Paladino et al., 2010; Valdesolo and DeSteno, 2011; Vacharkulksemsuk and Fredrickson, 2012).

The research to date has focused on a particular type of interpersonal synchrony, in which the participants share the goal of synchronizing (either directly with their fellow participants, or with some other cue that results in their synchronization with each other). Interpersonal synchrony can take other forms, however, and individuals may find themselves being the referents for others' synchronization goals without sharing those goals for themselves. In the

1  
2  
3  
4 current research, we investigated experimentally whether being the *referent* for a partner who  
5  
6 responds in a more or less synchronous fashion (rather than an intentional contributor to the  
7  
8 synchrony produced by a partner) affects the referent's perceived synchrony with and affiliative  
9  
10 response toward the partner. Second, we investigated the neural correlates of interpersonal  
11  
12 synchrony (vs. asynchrony) in this referent.  
13  
14

### 15 16 17 18 19 **1. 1. Three processes underlying the emergence of interpersonal synchrony**

20  
21 The temporal relation between the movements of two or more individuals determines the  
22  
23 degree of interpersonal synchrony. However, the same state of synchrony may be the outcome  
24  
25 of any of three distinct production processes, which we refer to as orchestration, reciprocal  
26  
27 entrainment, and unilateral entrainment. In orchestration, synchrony is achieved when two or  
28  
29 more individuals entrain their movements to an external pacesetter (e.g., the pacing sound of a  
30  
31 metronome) that “directs” the shared movement pattern, much like a conductor leading scores of  
32  
33 musicians. For example, Hove and Risen (2009) manipulated interpersonal synchrony by having  
34  
35 participants tap to beats created by a metronome.  
36  
37  
38

39  
40 In reciprocal entrainment, synchrony is achieved through a give-and-take process in  
41  
42 which individuals within a system (e.g., dyad) monitor each other and adjust their own  
43  
44 movement in a mutual fashion. For example, Oullier and colleagues (2008) found that dyadic  
45  
46 interpersonal synchrony reflected movements that were distinct from individuals' movements  
47  
48 prior to the interaction, suggesting that participants shifted their movement in response to their  
49  
50 partners' movement.  
51  
52  
53

54  
55 Finally, in unilateral entrainment, one individual within a dyad (the “synchronizer”)  
56  
57 unilaterally adjusts his or her movements to entrain to the movements of the other individual (the  
58  
59  
60  
61

1  
2  
3  
4 referent) within the dyad – an individual who moves periodically but does not adjust his or her  
5  
6 movements in reciprocation to promote synchrony. Previous work has focused on interpersonal  
7  
8 synchrony achieved through orchestration or reciprocal entrainment (e.g., Delaherche et al.,  
9  
10 2012; Repp and Su, 2013). Our focus here is on the social effects and neural correlates of  
11  
12 unilateral entrainment. In a pilot study (Study I) and Study II, we sought to establish the extent  
13  
14 to which a referent, who is subjected to a partner who behaves in a relatively synchronous or  
15  
16 asynchronous fashion, *perceives* the former partner's movements to be more synchronous or  
17  
18 the latter partner's movements, and feels greater affiliation toward the former than latter partner.  
19  
20 In other words, we sought to ascertain whether (or not) unilateral synchrony promoted a sense of  
21  
22 liking and rapport, thereby extending previous investigations centered on assessing the relative  
23  
24 movement of those with a heightened motivation to socially connect with a target (e.g., Miles et  
25  
26 al., 2010, 2011). In Study III, we investigated the neural correlates of perceived synchrony in the  
27  
28 referent.  
29  
30  
31  
32  
33  
34

## 35 36 37 38 **1.2. Social functions of synchrony**

39  
40 Over the past decades, two main bodies of literature have developed to better understand  
41  
42 interpersonal synchrony. The literature on sensorimotor synchronization (SMS) focuses on an  
43  
44 *action* that leads to synchrony by means of temporary coordination with a predictable external  
45  
46 event (the referent). Among the findings in this field are that error correction is required to  
47  
48 maintain SMS (see review by Repp, 2005), and stability is greater for synchronous than  
49  
50 asynchronous inter-limb (e.g., arm or leg) movements within an individual (e.g., Yamanishi et  
51  
52 al., 1980; Kelso, 1984) and between individuals (e.g., Schmidt et al., 1990; Richardson et al.,  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

1  
2  
3  
4 2005), with the result being an increased likelihood of entrainment (e.g., Engström et al., 1996;  
5  
6 Schmidt and O'Brien, 1997).

7  
8  
9 A second literature focuses on the *social* functions of interpersonal synchrony. Hatfield,  
10 Cacioppo and Rapson (1993) hypothesized that interpersonal synchrony enhances the moment-  
11  
12 by-moment tracking of other people's feelings (even when individuals are not explicitly  
13  
14 attending to this information), thereby promoting emotional alignment between interacting  
15  
16 individuals. Relatedly, as described above, McNeill (1995) posited that synchrony contributes to  
17  
18 group solidarity. Since the 1990s, a large number of studies have reinforced these hypotheses  
19  
20 and showed that performing actions that are similar to, and coordinated with, those of an  
21  
22 interacting partner enhances feelings of connectedness, affiliation, interpersonal rapport, and a  
23  
24 blurring of self–other boundaries (Bernieri, 1988; Tickle-Dengen and Rosenthal, 1990; Bernieri  
25  
26 et al., 1994; Cappella, 1997; Lakin and Chartrand, 2003; Hove and Risen, 2009; Miles et al.,  
27  
28 2010, 2011; Paladino et al., 2010; Vacharkulksemsuk and Fredrickson, 2012), liking (e.g., Hove  
29  
30 and Risen, 2009; Miles et al., 2009), perceived similarity and compassion (Valdesolo and  
31  
32 DeStano, 2011), joint action (Valdesolo et al., 2010), cooperation and enhanced altruistic  
33  
34 behavior (Wiltermuth and Heath, 2009; Valdesolo and DeStano, 2011), better negotiation  
35  
36 outcomes (Maddux, Mullen, and Galinsky, 2008), emotional empathy (Chartrand & Bargh,  
37  
38 1999; Sonnby-Borgström, 2002; Marzoli et al., 2011), person memory (Macrae et al., 2008;  
39  
40 Miles et al., 2010), group cohesion (McNeil, 1995), and prosocial behavior (van Baaren,  
41  
42 Holland, Steenaert, and van Knippenberg, 2003; van Baaren, Holland, Kawakami, van  
43  
44 Knippenberg, 2004; Marsh et al., 2009; Valdesolo and DeStano, 2011; Müller, Maaskant, van  
45  
46 Baaren, Dijksterhuis, 2012). In sum, interpersonal synchrony is a foundation for effective social  
47  
48 interaction and enhanced sociality (Miles et al., 2009; Delaherche, et al., 2012; Lumsden et al.,  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65



2012). Little is known, however, about the social consequences of synchrony by unilateral entrainment.

### 1.3. The neural correlates of interpersonal synchrony

There is an extensive body of research on the underlying brain mechanisms for sensorimotor synchronization with an external stimulus. Briefly, brain areas known to be involved in movement timing, temporal prediction, error correction and internal modeling of sensorimotor dynamics (such as the basal ganglia, cerebellum, and prefrontal regions; e.g., Strick et al., 1993; Rao et al., 1997; Salman, 2002; Krause et al., 2010; Bijsterbosch et al., 2011; cf. also reviews by Rao et al., 1997; Lewis et al., 2004; Repp, 2005) are activated during synchrony. This brain network highlights the importance of temporary coordination with a predictable external event (the referent) during synchrony. For instance, Lewis et al. (2004) investigated the neural correlates of rhythmic movement complexity to investigate error monitoring and correction. Among the brain regions that varied with movement complexity during sensorimotor synchronization (but not during similar self-paced movements) were the premotor cortex (PMC), supplementary motor cortex (SMA), and right dorsolateral prefrontal cortex (cf. Rao et al., 1997).

The literature on the neural correlates of the perception and social consequences of interpersonal synchrony is smaller (Tognoli et al., 2007; Kelso et al., 2009; Konvalinka et al., 2010; Fairhurst et al., 2012). To date, the social consequences of behavioral interpersonal synchrony have been mostly documented following both the mimicry of discrete bodily movements (e.g., foot shaking, face touching; van Baaren, Holland, Steenaert, and van Knippenberg, 2003) and the synchronization of more continuous sequences of action (e.g.,

1  
2  
3  
4 postural movements, facial expressions, gestures; Bernieri, 1988; Cappella, 1997; for review cf.  
5  
6 Miles et al., 2009). For instance, a meta-analysis of studies of a related social motor action—  
7  
8 imitation—indicates activation of parietal and frontal regions including the superior parietal  
9  
10 lobule, inferior parietal lobule, and dorsal premotor cortex (Molenberghs et al., 2009). Guionnet  
11  
12 et al. (2011) extended this work in an fMRI study of participants as they imitated or were  
13  
14 imitated by another person. Results revealed activation in the primary sensorimotor cortex,  
15  
16 premotor and supplementary motor areas, left inferior frontal gyrus, left IPL, and left insula,  
17  
18 whether imitating or being imitated. In addition, activation was found in the dorsal anterior  
19  
20 cingulate (dACC), pre-supplementary motor area (pre-SMA), and a rostral part of the  
21  
22 dorsolateral prefrontal cortex (DLPFC) in all conditions except during instructed imitation. The  
23  
24 contrast of imitating or being imitated revealed that being imitated by another person led to  
25  
26 greater activation in the dACC, pre-SMA, and DLPFC, and the dorsal region of the left anterior  
27  
28 insular cortex, whereas imitating led to greater activation in the visual cortex, medial frontal  
29  
30 cortex, posterior cingulate gyrus, precuneus, bilateral IPL, para-hippocampus, and hippocampus  
31  
32 than being imitated.  
33  
34  
35  
36  
37  
38  
39

40 Many of these regions constitute the default mode network (DMN; Raichle et al., 2001;  
41  
42 Fox et al., 2005), a network that is more active during self-referential, social, and affective  
43  
44 processing (Raichle and Snyder, 2007; van Overwalle and Baetens, 2009). Fairhurst et al.  
45  
46 (2012) performed an fMRI study of sensorimotor synchronization with a virtual partner using a  
47  
48 finger-tapping paradigm in which the virtual partner varied in adaptivity, which also  
49  
50 corresponded to differing degrees of coupling between the virtual partner and participant.  
51  
52  
53 Participants were instructed to synchronize with the virtual partner while also maintaining the  
54  
55 initial tempo, thereby establishing the goals of maintaining the periodicity of the finger tapping  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

1  
2  
3  
4 and minimizing the phase differences in the finger tapping task. Objective synchrony was  
5  
6 operationalized in terms of phase relations, whereas the feeling of being synchronized was  
7  
8 operationalized as (lower) perceived task difficulty. Regression analyses identified different  
9  
10 networks whether the participants were objectively in synchrony with the virtual partner  
11  
12 (positive correlation with increased midline activation of structures including the ventromedial  
13  
14 prefrontal cortex, vmPFC; hippocampus, supplementary motor area, SMA; primary  
15  
16 somatosensory cortex, S1 extending into primary motor cortex, M1; posterior cingulate; and  
17  
18 precuneus) or subjective perception of synchrony (i.e., reduced task difficulty was correlated  
19  
20 with greater activation of the right IFG, right anterior insula, posterior dmPFC, bilateral  
21  
22 ventrolateral prefrontal cortex, superior frontal gyrus, and inferior parietal activity in the region  
23  
24 of the temporo-parietal junction for perceived synchronization difficulty, and SMA, S1/M1,  
25  
26 vmPFC and hippocampus; Fairhurst et al., 2013).

27  
28  
29  
30  
31  
32  
33  
34 Although this body of research is on the perception and social consequences of  
35  
36 interpersonal synchrony (e.g., Tognoli et al., 2007; Kelso et al., 2009; Konvalinka et al., 2010;  
37  
38 Fairhurst et al., 2012), these studies have focused primarily on the neural correlates of one's  
39  
40 synchronizing their behavior with a referent. Little is known about the neural bases of  
41  
42 interpersonal synchrony from the perspective of the referent. Thus, in the present study, we used  
43  
44 fMRI to investigate how regional brain activity was modulated by differences in synchronous  
45  
46 stimuli during a tapping-based interactive task compared to asynchronous stimuli with a  
47  
48 synchronizer. Moreover, little is known about the neural regions that might be correlated with  
49  
50 subjective perceptions of synchrony and corresponding feelings of affiliation between a referent  
51  
52 and a synchronizer. Therefore, we also ran correlational analyses to explore this relationship  
53  
54 (see Method section for details). To the best of our knowledge, this is the first empirical  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

1  
2  
3  
4 investigation of the neural correlates of the participants' perception of interpersonal synchrony  
5  
6 and their feelings of affiliation with a virtual co-acting partner when the participant is the  
7  
8 referent (rather than the synchronizer).  
9

## 10 11 **2. General experimental procedures**

### 12 13 **2.1. Participants**

14  
15 All participants were native English speakers with normal or corrected-to-normal vision,  
16  
17 and were not taking antidepressant medication. As ascertained by an anamnesis, none of the  
18  
19 participants reported prior or current neurological or psychiatric disorders (e.g., traumatic brain  
20  
21 injury with loss of consciousness, epilepsy, neurological impairment or degenerative  
22  
23 neurological illness). All participants provided written informed consent to participate in the  
24  
25 experiment, which was approved by the University of Chicago Health Sciences Institutional  
26  
27 Review Board. All participants received monetary compensation for their participation.  
28  
29  
30  
31  
32  
33

### 34 35 **2.2. General experimental task**

36  
37 The experimental task was presented to participants as a computer-mediated  
38  
39 communication task that involved simple back-and-forth keyboard tapping between members of  
40  
41 a dyad. Specifically, the task was described as an abstract simulation of cell-phone texting,  
42  
43 where a beat (i.e., a single tap on the computer keyboard) replaced actual text—actions described  
44  
45 as “*bexting*,” short for beat-based texting (Figure 1).  
46  
47  
48  
49

50  
51 Throughout the session, the message board at the top of the screen displayed various  
52  
53 information and instructions about the task. Participants were informed that the circle labeled  
54  
55 “I” was their own avatar, which would immediately pulse each time they would send a beat (i.e.,  
56  
57 pressed the keyboard once). The pulse was visually represented by a short animation of the  
58  
59  
60  
61  
62  
63  
64  
65

1  
2  
3  
4 circle transforming into a square and then back into the circle. Participants were also told that  
5  
6 the central server would pair them up with randomly selected fellow participant in the room, one  
7  
8 of whom would be represented by an avatar labeled “A” or “B”. It was emphasized to the  
9  
10 participants that the specific avatar (i.e., “A” or “B”) chosen to represent their partner on the  
11  
12 screen was randomly determined after the partner was selected, thus bearing no relationship to  
13  
14 the partner’s true identity. Once the dyad was formed, participants’ avatar and the partner’s  
15  
16 avatar entered the “*bexting*” zone represented by the rectangular box surrounding the two avatars  
17  
18  
19  
20  
21 (Figure 1).  
22

23  
24 The participant was told that their task was simply to generate a series of beats at a  
25  
26 designated frequency (e.g., 1 beat/sec), regardless of their partner’s beat frequency (i.e.,  
27  
28 unencumbered by any need to coordinate their beats with their partner’s beats). Participants  
29  
30 were also informed that the task of their partner was to respond to each one of their beats with  
31  
32 another beat—with no time constraint to respond except that they had to send a beat back to each  
33  
34 beat prior the occurrence of the referent’s  $n+1$ st beat. Although the participant served as the  
35  
36 referent, no mention was made of this and no mention was made of synchrony. The two dyadic  
37  
38 members bexted with each other for an extended period of time, called a bexting round  
39  
40  
41 (described below), which consisted of multiple equal-length trials separated by short breaks.  
42  
43  
44

45  
46 At the end of a bexting round, the participants reported their impression of their partner  
47  
48 by answering a short questionnaire displayed on the message board. After completing the  
49  
50 questionnaire, participants were led to believe that the server would form a new pairing between  
51  
52 themselves and another randomly selected fellow participant and that a new bexting round would  
53  
54 then ensue. This made it possible to manipulate partner synchrony using a within-subjects  
55  
56 design, which is especially important if the paradigm is also to be used to investigate the neural  
57  
58  
59  
60  
61  
62  
63  
64  
65

1  
2  
3  
4 correlates of perceived interpersonal synchrony. Due to the presence of at least three other  
5  
6 fellow participants, the use of cubicles, rubber keyboards to ensure key presses could not be  
7  
8 heard, and the supposedly random pairing scheme implemented by the central server, it was  
9  
10 impossible for the participants to map their ostensible partners to any particular individual in the  
11  
12 room. As a result, the only reliable information about a given partner accessible to the  
13  
14 participants was the timings of that partner's beat series. Objective synchronicity by definition is  
15  
16 contingent on the alignment of timing per se, so this feature of the paradigm allowed us to  
17  
18 examine whether timing information was sufficient to influence perceived synchrony and social  
19  
20 affiliation.  
21  
22  
23  
24  
25  
26  
27  
28

### 29 **2.3. General manipulation of unilateral entrainment**

30  
31 The participant and their partner correspond, respectively, to the referent and  
32  
33 synchronizer involved in unilateral entrainment. Unbeknownst to the participants, the  
34  
35 "partner's" beat series were generated by a computer program, which made it possible to  
36  
37 experimentally manipulate the degree to which the partner's beats were entrained to the  
38  
39 referent's beats. More precisely, the partner's beat latency (i.e., the interval between the  
40  
41 referent's beat and the partner's beat) was sampled from a uniform distribution with pre-  
42  
43 determined mean and range (described below). Because prior research has manipulated  
44  
45 synchrony using latency ranges varying between 0 and 90 degrees, beat latencies in the present  
46  
47 research were manipulated within the same range. By manipulating the means and range of the  
48  
49 distribution of partner's response latency, different levels of synchrony could be produced. This  
50  
51 feature ensured that the variation in synchrony was determined solely by the unilateral  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

1  
2  
3  
4 entrainment on the part of the ostensible synchronizer rather than through mutual entrainment or  
5  
6 orchestration.  
7  
8  
9

### 10 11 **3. Study I (Pilot study)** 12

13  
14 Because the present experimental tapping task differs from existing paradigms, we first  
15  
16 conducted a pilot study to test whether the cover story for the tapping task was believable and  
17  
18 whether the task instructions were easy for participants to understand.  
19  
20  
21  
22

#### 23 24 **3.1. Participants** 25

26 Forty-seven community residents (19 women) participated in this pilot study.  
27

28 Participants ranged from 19 to 52 years of age ( $M = 25.10$ ,  $SD = 7.19$ ). No participants were  
29  
30 excluded from the analyses. Data collection started at a beginning of an academic quarter and  
31  
32 stopped at the end of that academic quarter.  
33  
34  
35  
36  
37  
38

#### 39 40 **3.2. Experimental procedure** 41

42 Participants were tested in groups of four in the same testing room. This procedure was  
43  
44 used to ensure that participants did not know with whom they would be bexting during any given  
45  
46 task period. Each participant was seated in a separate cubicle, which was equipped with one  
47  
48 computer. Participants were free to adjust the position of their chairs to their utmost comfort  
49  
50 level. Participants were told that all the four computers in the room were connected to a central  
51  
52 server. Each bexting round consisted of six 12-second trials. The asynchrony (i.e., response  
53  
54 latency) distributions of the partners were experimentally manipulated such that the interaction  
55  
56 with one partner was more synchronous than the other. Specifically, the mean asynchrony and  
57  
58  
59  
60  
61  
62  
63  
64  
65

1  
2  
3  
4 asynchrony range were 220 ms and  $\pm 110$  ms for the low-synchronous partner and 110 ms and  
5  
6  $\pm 10$  ms for the high-synchronous partner. The order in which participants bexted with a  
7  
8 synchronous or asynchronous partner was counterbalanced across participants. The bexting  
9  
10 program was coded in Adobe ActionScript 3 and ran through Adobe Flash Player.  
11  
12

13  
14 Participants' instruction was the following: "Using the spacebar, tap at a slow rate  
15  
16 (approximately 1 beat per 2 sec) [a moderate rate (approximatley 1 beat per sec)/ a fast rate  
17  
18 (approximately 2 beats per second)]". In each experimental block, all three suggested tempos for  
19  
20 beat generation appeared twice (thus six trials in total), with the order randomly determined. The  
21  
22 variation of the suggested tempos was to investigate generalizability.  
23  
24

25  
26 At the end of each tapping experimental block, participants answered six items  
27  
28 concerning the degree of social affiliation they felt toward the ostensible partner in that tapping  
29  
30 experimental block. Specifically, participants were to indicate on a seven-point scale anchored  
31  
32 by 1 (*not at all*) and 7 (*very much*), (1) How much rapport they felt with the partner, (2) How  
33  
34 much they trusted the partner, (3) How much they liked the partner, (4) How much they would  
35  
36 like to work with the partner, (5) How much they would like to confide in the partner, and (6)  
37  
38 how close they felt to the partner. These six items showed high internal consistency across both  
39  
40 conditions ( $\alpha > .92$ ) and were thus averaged to yield a *social affiliation* score.  
41  
42  
43  
44

45  
46 Embedded among these affiliation items was a *perceived synchrony* item, which asked  
47  
48 participants to indicate how synchronized they were with the partner on the same seven-point  
49  
50 scale (How synchronized was the communication between you and Partner A?). The inclusion  
51  
52 of this measure was motivated primarily by one main consideration. Although our experimental  
53  
54 manipulation objectively created two levels of synchrony, it was unclear whether participants  
55  
56 would subjectively map the difference in their experiences with the two partners on the  
57  
58  
59  
60  
61  
62  
63  
64  
65



1  
2  
3  
4 dimension of synchronicity. Given the apparent non-rhythmic nature of the synchronizer's task,  
5  
6 the participants might have parsed the partner's behaviors into a series of independent local  
7  
8 events (i.e., whether the partner responded in time on a given trial) instead of integrating these  
9  
10 local events across the temporal span of the tapping experimental block. Thus, the participants  
11  
12 might not perceive the synchronizer as engaging in periodic movement and thereby might not  
13  
14 construe their interaction in terms of synchronicity.  
15  
16  
17  
18  
19  
20

### 21 3.3. Results

#### 22 3.3.1. Participants' feedback about the task instruction

23  
24 Results from this pilot study revealed that none of the participants reported being  
25  
26 confused regarding the task instruction. Furthermore, none of the participants suspected that  
27  
28 their partners were actually a computer program rather than two of their fellow participants.  
29  
30  
31  
32  
33

#### 34 3.3.2. Participants' behavioral performance

35  
36 To determine whether the participants' performance was influenced by the experimental  
37  
38 manipulation, their performance was subjected to a 2 (Partner's type: low synchrony or high  
39  
40 synchrony) x 2 (Order) x 2 (Gender) x 3 (Tapping pace: 2/sec, 1/sec, .5/sec) mixed ANOVA.  
41  
42 Neither the main effect of synchrony manipulation nor any of the interactive effects involving  
43  
44 synchrony manipulation was significant. Of all the interactive effects, the one with the largest  
45  
46 effect size was the interaction between synchrony manipulation and tapping pace ( $F(2,86) = 1.72$ ,  
47  
48  $p = .02$ ,  $\eta^2_{\text{partial}} = .04$ ). As for the main effect of synchrony manipulation, we found no evidence  
49  
50 of our manipulation influencing tap-to-tap variability ( $F(1,46) = 0.24$ ,  $p = .63$ ,  $\eta^2_{\text{partial}} = .01$ ).  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

### 3.3.3. Participants' perceived synchrony

The perceived synchrony scores were subjected to a 2 (Partner's type: low synchrony or high synchrony) x 2 (Order) x 2 (Gender) mixed ANOVA. No significant results involving gender, order or tapping were observed, so we collapsed across these factors. Results showed that participants rated their interaction with the high-synchronous partner as being more synchronized ( $M = 5.91$ ,  $SD = 1.47$ ) than their interaction with the low-synchronous (i.e., asynchronous) partner ( $M = 5.13$ ,  $SD = 1.81$ ;  $F(1, 46) = 6.45$ ,  $p = .02$ ,  $\eta^2_{\text{partial}} = .03$ ; Table 1).

### 3.3.4. Participants' social affiliation

The social affiliation scores were also subjected to a 2 (Partner type: low synchrony or high synchrony) x 2 (Order) x 2 (Gender) mixed ANOVA. No effects involving gender, order were found, so we collapsed across these factors. Results showed that participants felt greater social affiliation with the high-synchronous partner ( $M = 4.91$ ,  $SD = 1.59$ ) than the low-synchronous (asynchronous) partner ( $M = 4.54$ ,  $SD = 1.67$ ;  $F(1, 46) = 4.32$ ,  $p = .004$ ,  $\eta^2_{\text{partial}} = .02$ ; Table 2).

## 3.4. Interim Conclusion

The results from this pilot study suggest that the tapping task is a viable paradigm for studying interpersonal synchrony achieved through unilateral entrainment. The cover story is believable and the instructions are easy to understand. The difference in perceived synchrony across the two conditions suggests that participants were influenced by interpersonal synchrony achieved through unilateral entrainment even though the participants played no role in the

1  
2  
3  
4 production of the synchrony<sup>1</sup> and the synchrony was unrelated to their task performance. We  
5  
6 nevertheless found a significant effect on perceived synchrony and a stronger affiliative response  
7  
8 toward the synchronous than asynchronous partner. This suggests the effects of interpersonal  
9  
10 synchrony are not dependent on the synchrony being task-relevant or to the participant actually  
11  
12 contributing to the observed synchrony.  
13  
14

#### 15 16 17 18 19 **4. Study II (Behavioral study)**

##### 20 21 4.1. Participants

22  
23 Forty community residents (20 women) participated in this behavioral study. Participants  
24  
25 ranged in age from 19 to 43 years ( $M = 23.9$ ,  $SD = 6.87$ ) and were tested in a similar setting as  
26  
27 the pilot study. No participants were excluded in the analyses. Data collection stopped at the end  
28  
29 of an academic quarter.  
30  
31

##### 32 33 34 35 4.2. Experimental procedure

36  
37 A similar procedure to that used in the pilot study (Study I) was used in Study II. Each  
38  
39 participant played one tapping experimental block with each of four ostensible partners. Each  
40  
41 experimental block consisted of eight 12-second trials followed by the series of questions on  
42  
43 perceived synchrony and affiliation. The suggested tapping tempo for the referent (i.e., the  
44  
45 participant) was kept the same throughout the experimental session at one beat per second. The  
46  
47 asynchronies of the four ostensible partners were sampled respectively from four uniform  
48  
49 distributions with unique mean-range combinations obtained by crossing two levels of  
50  
51 asynchrony mean (120 ms versus 220 ms) with two levels of response latency ranges ( $\pm 10$  ms  
52  
53  
54  
55  
56  
57

---

58  
59 <sup>1</sup> The computer algorithm used to manipulate the degree of synchrony ensured that the experimental manipulation of  
60  
61 synchrony was orthogonal to the participant's beat series.

1  
2  
3  
4 versus  $\pm 110$  ms). The order in which participants bexed with the four partners was manipulated  
5  
6 using a Latin Square design, yielding 10 different orders. As in the pilot study, the six items  
7  
8 measuring social affiliation exhibited a high level of internal consistency across all four  
9  
10 conditions ( $\alpha s > .97$ ) and hence were combined.  
11  
12  
13  
14

### 15 16 4.3. Results

#### 17 18 4.3.1. Participants' behavioral performance

19  
20  
21 A 2 (Mean response latency: 120 ms or 220 ms) x 2 (Response latency range:  $\pm 10$  ms or  
22  
23  $\pm 110$  ms) x 2 (Gender) ANOVA was performed to determine whether the participant's (i.e.,  
24  
25 referent's) responses were influenced by their partner's behavior. No significant differences  
26  
27 involving gender were observed, so we collapsed across this factor. The ANOVA revealed no  
28  
29 significant interaction ( $F(1,39) = 0.002, p = .97, \eta^2_{\text{partial}} = 0$ ), and no main effect for mean  
30  
31 response latency ( $F(1,39) = 0.006, p = .94, \eta^2_{\text{partial}} = 0$ ). The response latency range  
32  
33 manipulation, however, did affect the referents' tap-to-tap variability. Specifically, participants'  
34  
35 tap-to-tap variability was smaller when interacting with narrow-ranges partners ( $\pm 10$  ms) than  
36  
37 with broad-range partners ( $\pm 110$  ms) ( $M_s = 14.29$  ms and 82.34 ms, respectively;  $F(1,39)$   
38  
39  $= 162.1, p < .001, \eta^2_{\text{partial}} = .81$ ).  
40  
41  
42  
43  
44  
45  
46  
47

#### 48 4.3.2. Participants' perceived synchrony

49  
50 The perceived synchrony ratings were subjected to a 2 (Mean response latency: 120 ms  
51  
52 or 220 ms) x 2 (Response latency range:  $\pm 10$  ms or  $\pm 110$  ms) x 2 (Gender) ANOVA. No  
53  
54 significant differences involving gender were observed, so we collapsed across this factor.  
55  
56 Results indicated that both main effects were significant. Partners who responded with short  
57  
58  
59  
60  
61  
62  
63  
64  
65

(120 ms) mean lags were rated as being more synchronized ( $M = 5.10$ ) than partners who responded with long (220 ms) mean lags ( $M = 4.59$ ;  $F(1, 39) = 3.79$ ,  $p = .06$ ,  $\eta^2_{\text{partial}} = .09$ ; Table 3), and partners with narrow ( $\pm 10$  ms) ranges were rated as being more synchronized than partners with broad ( $\pm 110$  ms) ranges ( $M_s = 5.20$  and  $4.59$ , respectively;  $F(1, 39) = 8.21$ ,  $p = .007$ ,  $\eta^2_{\text{partial}} = .17$ ; Table 3). The two-way interaction was not significant ( $F(1, 39) = 0.02$ ,  $p = .88$ ,  $\eta^2_{\text{partial}} = .01$ ).

#### 4.3.3. Participants' social affiliation

The social affiliation scores were subject to a 2 (Mean response latency: 120 ms or 220 ms) x 2 (Response latency range:  $\pm 10$  ms or  $\pm 110$  ms) x 2 (Gender) ANOVA. No tests involving gender were significant, so we also collapsed across this factor. The main effects for both aspects of partner's timing were significant: The participants expressed more social affiliation with the partners characterized by mean response latencies of 120 ms rather than 220 ms ( $M_s = 4.53$  and  $4.06$ , respectively;  $F(1, 39) = 5.02$ ,  $p = .03$ ,  $\eta^2_{\text{partial}} = .10$ ; Table 4), and with partners characterized by 10 ms than 110 ms response latency ranges ( $M_s = 4.61$  and  $3.98$ , respectively;  $F(1, 39) = 9.54$ ,  $p = .01$ ,  $\eta^2_{\text{partial}} = .20$ ; Table 4). The two-way interaction did not reach significance ( $F(1, 39) = 0.65$ ,  $p = .42$ ,  $\eta^2_{\text{partial}} = .02$ ).

#### 4.4. Interim Conclusion

Participants serving as referents in the current study perceived partners as more synchronous when they showed relatively short response latencies (i.e., relatively small phase shifts) and when the variability of these response latencies was relatively small. Furthermore, and as in the pilot study, the mean response latency manipulation of interpersonal synchrony did

not influence the referents' tap-to-tap variability. Although the range (variability) of response latencies did affect the referents' tap-to-tap variability, the participants' tapping responses were not correlated with the perceived synchrony ( $r(40) = -0.22, p = .17$ ) or affiliative responses toward the partner ( $r(40) = -0.25, p = .12$ ), suggesting that the social affiliation effect cannot be explained by the effect of the experimental manipulation on the referents' tapping behavior. These findings are generally consistent with prior research (Miles et al., 2009) in which observers perceived higher levels of rapport between members of a dyad when the mean temporal difference between their strides while they were walking decreased.

## 5. Study III (Neuroimaging study)

### 5.1. Participants

A total of 16 volunteers (7 women) were recruited via e-mail and subsequently screened and qualified with a follow-up telephone interview. All participants were right-handed, ranging from 19–25 years old ( $M = 21.44, SD = 1.63$ ), and were healthy with no medical history of neurological, psychiatric or psychological disorders as ascertained by an anamnesis. Data from three volunteers out of the 16 could not be included in the analyses because the volunteers did not complete entirely the task as they were too slow and took too long during the instruction periods in between bexting rounds. The design was self-paced, and those subjects appeared to have trouble with the task and did not complete it before the set scanning time was complete (the scanner had a finite period in which it could run for each scan). The final fMRI results, thus, include 13 subjects.

### 5.2. Experimental procedure

1  
2  
3  
4 A similar procedure to the one described in the above behavioral study was used in this  
5  
6 neuroimaging study. The main difference was that stimuli were presented while the participants  
7  
8 were lying down in the scanner. Visual stimuli were projected from a PC located in the  
9  
10 experimenter room to a back projection screen located in the scanner room. Stimuli were viewed  
11  
12 using binocular goggles mounted on the head coil approximately 2 inches above the participants'  
13  
14 eyes.  
15  
16  
17

18  
19 The entire task consisted of five blocks. Four of the experimental blocks involved the  
20  
21 participant tapping at 1 Hz with an ostensible partner, and one block involved the participant  
22  
23 tapping at 1 Hz with no partner (self-pacing). This latter block was included in order to evaluate  
24  
25 participants' motor movements per se. Each experimental block consisted of eight 12-second  
26  
27 trials. The order of the experimental conditions was varied across participants using a Latin  
28  
29 Square design. Button-press responses were made with the index finger on an fMRI-compatible  
30  
31 response box. As in the behavioral studies, a tap of the button during an experimental block  
32  
33 caused the "I" avatar to pulse momentarily from a circle to a square, and the partner's response  
34  
35 beat was depicted likewise.  
36  
37  
38  
39

40  
41 After each one of the four experimental tapping blocks, the participants were also asked  
42  
43 to answer the series of questions on perceived synchrony and affiliation with their ostensible  
44  
45 partner. As in the previous two behavioral studies described above, these seven questions  
46  
47 included one question about perceived synchronization and six questions about affiliation with  
48  
49 their partner. Answers to the other six questions were again averaged into one composite index  
50  
51 of interpersonal affiliation because of the high Cronbach alpha ( $> .8$ ). Answers were navigated  
52  
53 using the middle finger (moving to the left, selecting lower values) and ring finger (moving to  
54  
55 the right, selecting higher values), and the answer selection was done using the index finger.  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

1  
2  
3  
4 Before performing the actual behavioral experimental task, the participants and  
5  
6 confederates (research assistants who did not participate in the study) performed a practice block  
7  
8 in which they were asked to interact with a computer (rather than with a human). In contrast to  
9  
10 the actual experimental task, the computer's response during practice lacked variability and had a  
11  
12 constant inter-beat interval of 100 ms. This was intended to not only allow participants to  
13  
14 familiarize themselves with the task, but also to enhance their perception that the beats they  
15  
16 would then see during the experimental task were actually generated by a human partner.  
17  
18 Following the practice block, the participant was prepared for fMRI scanning, where they  
19  
20 performed the experimental task.  
21  
22  
23  
24  
25  
26  
27  
28

### 29 5.3. Magnetic resonance imaging recordings

30  
31 Imaging was performed on a 3-T Philips Achieva Quasar Dual 16 Ch scanner with  
32  
33 quadrature head coil used for spin excitation and signal reception. High-resolution volumetric  
34  
35 T1-weighted spoiled gradient-recalled (SPGR) images were obtained for each participant in one  
36  
37 hundred eighty-one 1.0-mm sagittal slices with 8° flip angle and 24 cm field of view (FOV) for  
38  
39 use as anatomical images. Functional images were acquired using an echo-planar acquisition  
40  
41 with Z-Shimming with 32 x 4-mm coronal slices with an inter-slice gap of 0.5 mm spanning the  
42  
43 whole brain (TR = 2 sec, TE = 30 ms, flip angle = 80°, FOV = 22 cm, 64 x 64 matrix size, fat  
44  
45 suppressed).  
46  
47  
48  
49  
50  
51  
52

### 53 5.4. Functional image processing and analyses

54  
55 Image pre-processing and analyses were performed using Analysis of Functional  
56  
57 NeuroImages software (AFNI version AFNI\_2011\_12\_21\_1014, Medical College of  
58  
59  
60  
61  
62  
63  
64  
65



1  
2  
3  
4 Wisconsin). For each subject, motion detection and correction were undertaken using a six-  
5  
6 parameter, rigid-body transformation. Functional images were co-registered and spatially  
7  
8 smoothed using a 5-mm full width at half maximum Gaussian filter. Individual-subject analyses  
9  
10 were conducted using the general linear model to generate estimates of blood oxygenation level-  
11  
12 dependent (BOLD) signal on a voxelwise basis (Ward, 2002). Stimulus timing vectors for each  
13  
14 of the four experimental conditions were convolved with a gamma-variate waveform using the  
15  
16 AFNI program Waver, and the resulting model was fit voxelwise to preprocessed time-series  
17  
18 data with a linear least-squares model using the AFNI program 3dDeconvolve, generating a map  
19  
20 consisting of beta coefficients (fit values) at each voxel for each modeled condition--short lag /  
21  
22 synchronous variance; long lag / synchronous variance; short lag / asynchronous variance; and  
23  
24 long lag / asynchronous variance --as well as a baseline coefficient. Output from the  
25  
26 deconvolution analysis for each subject was scaled voxelwise to percent signal change from  
27  
28 baseline, and each subject's data were spatially transformed to Talairach and Tournoux (1988)  
29  
30 stereotaxic coordinate space and interpolated to 3 mm<sup>3</sup> isometric voxels for group analysis.  
31  
32  
33  
34  
35  
36  
37

38  
39 Our fMRI analysis aimed to identify how regional brain activity was modulated by  
40  
41 differences in synchronous stimuli during a tapping-based interactive task compared to  
42  
43 asynchronous stimuli with a synchronizer. To this purpose, we first identified the brain regions  
44  
45 sensitive to differences in synchrony and asynchrony using a voxelwise 2 (task/response period)  
46  
47 x 2 (small/large range) x 2 (small/large lag) factorial ANOVA. Then, to assess the relationship  
48  
49 of these regions to corresponding perceptions of synchrony and feelings of social affiliation, we  
50  
51 correlated BOLD activity in each identified cluster with each respective behavioral measure.  
52  
53  
54

55  
56 The self-pacing blocks were modeled in the fMRI GLM and were not treated as residuals. In  
57  
58  
59  
60  
61  
62  
63  
64  
65

1  
2  
3  
4 terms of our contrasts, they were treated as regressors of non-interest. The cluster threshold was  
5  
6 at  $p < .01$  corrected to  $\alpha < .05$ .  
7  
8

9 Finally, because little is also known about the overall network of neural regions that  
10 might be correlated with subjective perceptions of synchrony and corresponding feelings of  
11 social affiliation between a referent and a synchronizer, we ran voxelwise correlation analyses in  
12 the same respect. To further elucidate what was driving voxelwise correlation effects, BOLD  
13 activity within voxelwise correlation regions was assessed according to a median split of  
14 behavioral measures. Voxelwise fMRI analyses were performed at the group level, the results of  
15 which were corrected for multiple comparisons using a Monte Carlo simulation to determine  
16 minimum cluster sizes corresponding to an alpha value of .05 for voxelwise threshold of  $p < .01$   
17 (729  $\mu$ l) for the ANOVA analysis (Nichols, 2012). An additional corrected voxelwise  
18 threshold of  $p < .025$  (1080  $\mu$ l), was also used for the BOLD:behavior analysis, as  $p < .01$   
19 yielded no results for BOLD:Affiliation and limited results for BOLD:Synchrony.  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34

35  
36 Difference scores (Synchrony minus Asynchrony) of BOLD signal and the corresponding  
37 behavioral data were also calculated for each subject, and these values were entered into a group-  
38 level, whole-brain voxelwise Pearson correlation to identify regions in which differential BOLD  
39 activity in response to the stimulus conditions was associated with the same contrast patterns in  
40 the behavioral responses.  
41  
42  
43  
44  
45  
46  
47  
48  
49

## 50 51 **5.5. Results**

### 52 53 **5.5.1. Behavioral results**

54  
55 The participants' ratings of perceived synchrony and affiliative responses were subjected  
56 to a 2 (Mean response latency: 120 ms or 220 ms) x 2 (Response latency range:  $\pm 10$  ms or  $\pm 110$   
57  
58  
59  
60  
61

ms) x 2 (Gender) ANOVA. A gender effect was observed in this sample for ratings of perceived synchrony ( $M_{\text{male}} = 5.25$ ,  $M_{\text{female}} = 3.50$ ,  $F(1,11) = 7.08$ ,  $p = .02$ ,  $\eta^2 = .39$ ), and a marginal effect was observed for ratings of social affiliation ( $M_{\text{male}} = 4.98$ ,  $M_{\text{female}} = 3.59$ ,  $F(1,11) = 4.40$ ,  $p = .06$ ,  $\eta^2 = .29$ ). However, neither gender effects showed a significant interaction with mean response latency or latency range, so we collapsed across the gender factor. Analyses revealed that participants perceived greater interpersonal synchrony ( $M_{+/-10\text{ms}} = 5.19$ ,  $M_{+/-110\text{ms}} = 3.42$ ,  $F(1,12) = 13.45$ ,  $p = .004$ ,  $\eta^2 = .40$ ) and greater social affiliation ( $M_{+/-10\text{ms}} = 4.74$ ,  $M_{+/-110\text{ms}} = 3.72$ ,  $F(1,12) = 7.46$ ,  $p = .02$ ,  $\eta^2 = .16$ ) when the response latency range was small than large. No other tests approached statistical significance. No behavioral interaction effects were statistically significant for measures of perceived synchrony (Gender x Mean response latency:  $F(1,11) = .011$ ,  $p = .92$ ,  $\eta^2 = .0001$ ; Gender x Response latency range,  $F(1,11) = 4.04$ ,  $p = .07$ ,  $\eta^2 = .05$ ; Mean response latency x Var:  $F(1,11) = 2.07$ ,  $p = .18$ ,  $\eta^2 = .01$ ; Gender x Mean response latency x Response latency range:  $F(1,11) = 1.15$ ,  $p = .31$ ,  $\eta^2 = .007$ ) or for feelings of social affiliation. No behavioral interaction effects were statistically significant for measures of perceived synchrony (Gender x Mean response latency:  $F(1,11) = 3.17$ ,  $p = .10$ ,  $\eta^2 = .011$ ; Gender x Response latency range:  $F(1,11) = 2.99$ ,  $p = .11$ ,  $\eta^2 = .04$ ; Mean response latency x Response latency range:  $F(1,11) = .43$ ,  $p = .52$ ,  $\eta^2 = .002$ ; Gender x Mean response latency x Response latency range:  $F(1,11) = .06$ ,  $p = .81$ ,  $\eta^2 = .0002$ ).

### 5.5.2. Functional neuroimaging results

#### *Synchrony vs. Asynchrony contrast*

Based on the above results we collapsed across the Mean Response Latency factor to investigate the neural effects of variations in a partner's perceived synchrony with one's

1  
2  
3  
4 responding. Figure 2 and Table 5 display the main effects for Response Latency Range during  
5  
6 the experimental tapping task. The synchrony minus asynchrony contrast revealed a significant  
7  
8 main effect of synchrony, which was characterized by a greater response in three brain regions: i)  
9  
10 left inferior parietal lobule (IPL) extending to the angular gyrus, portions of the left ii)  
11  
12 parahippocampal gyrus extending to the amygdala and iii) the ventro-medial prefrontal cortex  
13  
14 (vmPFC) and anterior cingulate cortex (ACC; Table 5). No significant results were found for  
15  
16 which asynchronous stimuli elicited a larger BOLD response than synchronous stimuli.  
17  
18  
19  
20  
21  
22

### 23 *Correlation analyses*

24  
25  
26 Correlational analyses were first performed between the participants' ratings and each of  
27  
28 the three areas depicted in Figure 2. The BOLD differential synchrony scores (dBOLD for  
29  
30 synchrony minus asynchrony) in the vmPFC was the only region to be significantly correlated  
31  
32 with the comparable difference in the ratings of perceived synchrony,  $t(11) = 2.84$ ;  $p = 0.016$ ;  $R$   
33  
34  $= 0.65$ , and feelings of social affiliation,  $t(11) = 2.44$ ,  $p = 0.03$ ;  $R = 0.59$ ; Figure 3).  
35  
36  
37

38  
39 Next, whole-brain voxelwise correlation analyses were performed between the dBOLD  
40  
41 and the corresponding differences between conditions in perceived synchrony. Results revealed a  
42  
43 positive correlation in the right cerebellar tonsil, and negative correlations in the right anterior  
44  
45 prefrontal cortex/lateral prefrontal cortex (BA 46), left dMPFC, right lingual gyrus and right  
46  
47 middle occipital gyrus (Figure 4 A & B; Table 6). To better understand this effect, we calculated  
48  
49 a median split of our groups based on the rating difference and then analyzed the percent signal  
50  
51 change of the synchronous and asynchronous conditions separately for the two groups (see  
52  
53  
54  
55  
56 Figure 4C).  
57  
58  
59  
60  
61  
62  
63  
64  
65

1  
2  
3  
4 Similar negative correlations were observed for the feelings of affiliation in the right  
5  
6 lingual gyrus, and right inferior parietal lobule (Figure 5A & B, Table 7). We again calculated a  
7  
8 median split and analyzed the percent signal change of the synchronous and asynchronous  
9  
10 conditions separately for the two groups (Figure 5C).  
11  
12  
13  
14

## 15 16 **6. Discussion**

17  
18  
19 In the present series of three studies, we first sought to experimentally investigate an  
20  
21 individual's *social perceptions* of a partner who responds in a more or less synchronous fashion  
22  
23 in a unilateral entrainment paradigm. Behavioral results across all three studies revealed that  
24  
25 synchrony by the partner enhanced a participant's ratings of perceived interpersonal synchrony  
26  
27 of and social affiliation with the partner. Specifically, the participants felt greater synchrony  
28  
29 toward a synchronous partner than with an asynchronous partner. These results indicate that  
30  
31 neither the perception of interpersonal synchrony nor the affiliative consequences of synchrony  
32  
33 are contingent on an individual's behavioral intentions or explicit goal to synchronize. In all  
34  
35 three studies, referent participants felt more social affiliation with partners who responded  
36  
37 synchronously rather than asynchronously, even though all partners (actually, a programmed  
38  
39 series of responses) performed the assigned experimental task equally well.  
40  
41  
42  
43  
44

45  
46 The current findings suggest that interpersonal synchrony achieved through unilateral  
47  
48 entrainment may produce the same array of social consequences as has been found previously in  
49  
50 studies using orchestration or reciprocal synchrony paradigms (cf. Bernieri, 1988, Tickle-Dengen  
51  
52 and Rosenthal, 1990; Hatfield et al., 1993; Bernieri et al., 1994, Cappella, 1997; Lakin and  
53  
54 Chartrand, 2003; Hove and Risen, 2009; Miles et al., 2009, 2010, 2011; Paladino et al., 2010;  
55  
56 Vacharkulksemsuk and Fredrickson, 2012) or in studies using mimicry (e.g., van Baaren,  
57  
58  
59  
60  
61  
62  
63  
64  
65

1  
2  
3  
4 Holland, Steenaert, and van Knippenberg, 2003; Maddux, Mullen, and Galinsky, 2008; van  
5  
6 Baaren, Janssen, Chartrand and Dijksterhuis, 2009; Stel et al., 2010; Muller, Maaskant, van  
7  
8 Baaren, and Dijksterhuis, 2012). One possible interpretation for such social consequences may  
9  
10 rely on the automatic (or nonconscious) human tendency to act in synchrony with others even  
11  
12 when they are not aware of it. Like mimicry, interpersonal synchrony increases the social  
13  
14 connection felt between individuals through an automatic process of “mimicry” that is described  
15  
16 in the literature as a “by-product in interaction” (e.g., Chartrand and Bargh, 1999; van Baaren et  
17  
18 al., 2009). This process is in line with a large body of evidence suggesting that the affiliative  
19  
20 effects are not dependent on an individual’s awareness of the interpersonal synchrony (e.g., see  
21  
22 review by Hatfield et al., 1994; Cacioppo and Cacioppo, 2012). Another possible interpretation,  
23  
24 which is related to the latter, is an interaction between feelings of liking and the activation of  
25  
26 shared motor representations between the self and the other in several tasks, as it has been  
27  
28 reported in interpersonal somatic mimicry (Sonnby-Borgström, 2002; Marzoli et al., 2011).  
29  
30 Although interpersonal synchrony refers to the coordination of movement that occurs between  
31  
32 individuals and interpersonal mimicry refers to the similarity in form of the actions between  
33  
34 individuals, they both feature similarities in the temporal alignment of the actions and in their  
35  
36 social consequences (Semin and Cacioppo, 2009; Cacioppo and Cacioppo, 2012). As illustrated  
37  
38 by the social cognition model (from Semin and Cacioppo, 2009), synchronization and mimicry  
39  
40 are “time-locked to the observed stimulus.” Like mimicry, interpersonal synchrony also  
41  
42 increases the social connection felt between individuals.  
43  
44  
45  
46  
47  
48  
49  
50  
51

52  
53 Our fMRI results extend these behavioral results by revealing the recruitment of brain  
54  
55 areas involved in social cognition, embodied cognition, self—other information processing, and  
56  
57 action observation as correlates of interpersonal synchrony (vs. asynchrony). More precisely, the  
58  
59  
60  
61  
62  
63  
64  
65

1  
2  
3  
4 synchrony minus asynchrony contrast revealed greater response in three brain regions: i) left IPL  
5  
6 (BA 40) extending to the angular gyrus, ii) portions of the left parahippocampal gyrus (BA 38)  
7  
8 extending to the amygdala; and iii) the ventro-medial prefrontal cortex (vmPFC; BA 32)  
9  
10 extending to the anterior cingulate cortex. No significant results were found for which  
11  
12 asynchronous stimuli elicited a larger BOLD response than synchronous stimuli.  
13  
14

15  
16 The recruitment of BA 40 is consistent with previous studies showing the recruitment of  
17  
18 this brain region while participants integrate visuo-motor information during observation and  
19  
20 evaluation of actions (Grafton et al., 1996; Rizzolatti and Craighero, 2004; Desmurget et al.,  
21  
22 2009; Grafton, 2009; Ortigue et al., 2009, 2010) and perception of elementary mechanical  
23  
24 causality events (Blakemore et al., 2001). This action observation brain system is also known to  
25  
26 sustain embodied cognitive mechanisms, meta-representation of the bodily self, detection of  
27  
28 movements of others, self–other expansion, monitoring of others’ intentions, perspective taking,  
29  
30 and perception of a synchrony between visual and proprioceptive feedbacks, as well as observed  
31  
32 and imagined actions (e.g., inferior parietal lobule; Grafton et al., 1996; Shimada et al., 2005;  
33  
34 Rizzolatti and Sinigaglia, 2007; Ortigue et al., 2009; van Overwalle and Baetens, 2009; Fairhurst  
35  
36 et al., 2013). The recruitment of this brain network is in line with theories of embodied cognition  
37  
38 and simulation, which suggest that people may understand actions of others, without any  
39  
40 inferential reasoning, through a direct matching process that occurs via an automatic mapping  
41  
42 between observed and performed actions, and via the reactivation of the bodily states that were  
43  
44 originally active during past self-related experiences (Grafton, 2009; Niedenthal, 2007;  
45  
46 Niedenthal, et al., 2005; Rizzolatti and Craighero, 2004; Rizzolatti, et al., 2001). Although  
47  
48 embodied mechanisms are not a pre-requisite to act, connect or understand others, embodied  
49  
50 behaviors offer new ways to investigate social perception, cognition, and behavior (e.g., Semin  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

1  
2  
3  
4 and Smith, 2002; Semin and Cacioppo, 2009; Cacioppo and Cacioppo, 2012). In line with Aron  
5 and Aron's (1986) self-expansion model which posits that others toward whom one feels a close  
6 social bond can be incorporated into the representation of one's self, and the relational model of  
7 communal sharing and cognitive interdependence (see Fiske, 2004; Smith, 2007; IJzerman and  
8 Semin, 2010; ]Cacioppo and Cacioppo, 2012).

9  
10  
11  
12  
13  
14  
15  
16 Differences in activation were also found in the parahippocampal area—a region shown  
17 previously to be involved in temporal discrimination and interval comparison (Harrington et al.,  
18 2002), and learning of adaptive events (Fairhurst et al., 2013; Grossberg, 2013). These findings  
19 are in line with adaptive resonance theory, a cognitive and neural theory of how the brain  
20 automatically learns to identify, categorize, and predict events in a changing world (Grossberg,  
21 2013).

22  
23  
24  
25  
26  
27  
28  
29  
30  
31 Finally, several investigators have found the ventral part of the medial PFC is relatively  
32 activated when processing information about the self or similar others, whereas the dorsal part of  
33 the medial PFC is relatively activated when processing information about others (Mitchell et al.,  
34 2005; Amodio and Frith, 2006; Keysers and Gazzola, 2007; Epley et al., 2009). Consistent with  
35 synchrony increasing the perception of similarity, Fairhurst et al. (2013) found greater activity in  
36 the vmPFC region when participants were in relative synchrony with a virtual partner. We also  
37 found greater activity in the vmPFC in the synchronous than asynchronous condition, and  
38 correlational analyses further revealed that the greater the difference in the BOLD signal in the  
39 vmPFC between the synchronous and asynchronous conditions, the greater the corresponding  
40 difference in the ratings of perceived synchrony and affiliation.

41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65  
66  
67  
68  
69  
70  
71  
72  
73  
74  
75  
76  
77  
78  
79  
80  
81  
82  
83  
84  
85  
86  
87  
88  
89  
90  
91  
92  
93  
94  
95  
96  
97  
98  
99  
100  
101  
102  
103  
104  
105  
106  
107  
108  
109  
110  
111  
112  
113  
114  
115  
116  
117  
118  
119  
120  
121  
122  
123  
124  
125  
126  
127  
128  
129  
130  
131  
132  
133  
134  
135  
136  
137  
138  
139  
140  
141  
142  
143  
144  
145  
146  
147  
148  
149  
150  
151  
152  
153  
154  
155  
156  
157  
158  
159  
160  
161  
162  
163  
164  
165  
166  
167  
168  
169  
170  
171  
172  
173  
174  
175  
176  
177  
178  
179  
180  
181  
182  
183  
184  
185  
186  
187  
188  
189  
190  
191  
192  
193  
194  
195  
196  
197  
198  
199  
200  
201  
202  
203  
204  
205  
206  
207  
208  
209  
210  
211  
212  
213  
214  
215  
216  
217  
218  
219  
220  
221  
222  
223  
224  
225  
226  
227  
228  
229  
230  
231  
232  
233  
234  
235  
236  
237  
238  
239  
240  
241  
242  
243  
244  
245  
246  
247  
248  
249  
250  
251  
252  
253  
254  
255  
256  
257  
258  
259  
260  
261  
262  
263  
264  
265  
266  
267  
268  
269  
270  
271  
272  
273  
274  
275  
276  
277  
278  
279  
280  
281  
282  
283  
284  
285  
286  
287  
288  
289  
290  
291  
292  
293  
294  
295  
296  
297  
298  
299  
300  
301  
302  
303  
304  
305  
306  
307  
308  
309  
310  
311  
312  
313  
314  
315  
316  
317  
318  
319  
320  
321  
322  
323  
324  
325  
326  
327  
328  
329  
330  
331  
332  
333  
334  
335  
336  
337  
338  
339  
340  
341  
342  
343  
344  
345  
346  
347  
348  
349  
350  
351  
352  
353  
354  
355  
356  
357  
358  
359  
360  
361  
362  
363  
364  
365  
366  
367  
368  
369  
370  
371  
372  
373  
374  
375  
376  
377  
378  
379  
380  
381  
382  
383  
384  
385  
386  
387  
388  
389  
390  
391  
392  
393  
394  
395  
396  
397  
398  
399  
400  
401  
402  
403  
404  
405  
406  
407  
408  
409  
410  
411  
412  
413  
414  
415  
416  
417  
418  
419  
420  
421  
422  
423  
424  
425  
426  
427  
428  
429  
430  
431  
432  
433  
434  
435  
436  
437  
438  
439  
440  
441  
442  
443  
444  
445  
446  
447  
448  
449  
450  
451  
452  
453  
454  
455  
456  
457  
458  
459  
460  
461  
462  
463  
464  
465  
466  
467  
468  
469  
470  
471  
472  
473  
474  
475  
476  
477  
478  
479  
480  
481  
482  
483  
484  
485  
486  
487  
488  
489  
490  
491  
492  
493  
494  
495  
496  
497  
498  
499  
500  
501  
502  
503  
504  
505  
506  
507  
508  
509  
510  
511  
512  
513  
514  
515  
516  
517  
518  
519  
520  
521  
522  
523  
524  
525  
526  
527  
528  
529  
530  
531  
532  
533  
534  
535  
536  
537  
538  
539  
540  
541  
542  
543  
544  
545  
546  
547  
548  
549  
550  
551  
552  
553  
554  
555  
556  
557  
558  
559  
560  
561  
562  
563  
564  
565  
566  
567  
568  
569  
570  
571  
572  
573  
574  
575  
576  
577  
578  
579  
580  
581  
582  
583  
584  
585  
586  
587  
588  
589  
590  
591  
592  
593  
594  
595  
596  
597  
598  
599  
600  
601  
602  
603  
604  
605  
606  
607  
608  
609  
610  
611  
612  
613  
614  
615  
616  
617  
618  
619  
620  
621  
622  
623  
624  
625  
626  
627  
628  
629  
630  
631  
632  
633  
634  
635  
636  
637  
638  
639  
640  
641  
642  
643  
644  
645  
646  
647  
648  
649  
650  
651  
652  
653  
654  
655  
656  
657  
658  
659  
660  
661  
662  
663  
664  
665  
666  
667  
668  
669  
670  
671  
672  
673  
674  
675  
676  
677  
678  
679  
680  
681  
682  
683  
684  
685  
686  
687  
688  
689  
690  
691  
692  
693  
694  
695  
696  
697  
698  
699  
700  
701  
702  
703  
704  
705  
706  
707  
708  
709  
710  
711  
712  
713  
714  
715  
716  
717  
718  
719  
720  
721  
722  
723  
724  
725  
726  
727  
728  
729  
730  
731  
732  
733  
734  
735  
736  
737  
738  
739  
740  
741  
742  
743  
744  
745  
746  
747  
748  
749  
750  
751  
752  
753  
754  
755  
756  
757  
758  
759  
760  
761  
762  
763  
764  
765  
766  
767  
768  
769  
770  
771  
772  
773  
774  
775  
776  
777  
778  
779  
780  
781  
782  
783  
784  
785  
786  
787  
788  
789  
790  
791  
792  
793  
794  
795  
796  
797  
798  
799  
800  
801  
802  
803  
804  
805  
806  
807  
808  
809  
810  
811  
812  
813  
814  
815  
816  
817  
818  
819  
820  
821  
822  
823  
824  
825  
826  
827  
828  
829  
830  
831  
832  
833  
834  
835  
836  
837  
838  
839  
840  
841  
842  
843  
844  
845  
846  
847  
848  
849  
850  
851  
852  
853  
854  
855  
856  
857  
858  
859  
860  
861  
862  
863  
864  
865  
866  
867  
868  
869  
870  
871  
872  
873  
874  
875  
876  
877  
878  
879  
880  
881  
882  
883  
884  
885  
886  
887  
888  
889  
890  
891  
892  
893  
894  
895  
896  
897  
898  
899  
900  
901  
902  
903  
904  
905  
906  
907  
908  
909  
910  
911  
912  
913  
914  
915  
916  
917  
918  
919  
920  
921  
922  
923  
924  
925  
926  
927  
928  
929  
930  
931  
932  
933  
934  
935  
936  
937  
938  
939  
940  
941  
942  
943  
944  
945  
946  
947  
948  
949  
950  
951  
952  
953  
954  
955  
956  
957  
958  
959  
960  
961  
962  
963  
964  
965  
966  
967  
968  
969  
970  
971  
972  
973  
974  
975  
976  
977  
978  
979  
980  
981  
982  
983  
984  
985  
986  
987  
988  
989  
990  
991  
992  
993  
994  
995  
996  
997  
998  
999  
1000

Correlational analyses involving the dmPFC showed the opposite pattern, as might be  
expected if interpersonal synchrony increases self—other overlap or egocentric information



1  
2  
3  
4 processing about the partner. To further investigate this result, a median split was performed to  
5  
6 create two groups of participants, those who rated the synchronous partner as much more  
7  
8 synchronous than they rated the asynchronous partner, and those who rated the synchronous and  
9  
10 asynchronous partner relatively similarly on perceived synchrony. Analyses of the dmPFC  
11  
12 showed the lowest levels of activation when the participants who most distinguished between the  
13  
14 conditions were performing with a synchronous partner and the highest levels of activation when  
15  
16 the participants who distinguished most between the conditions were performing with an  
17  
18 asynchronous partner. This pattern was reversed and weaker in participants who perceived  
19  
20 relatively little difference in synchrony between their synchronous and asynchronous partners.  
21  
22  
23  
24

25  
26 In sum, the analyses of the mPFC regions suggest that the participants, who most  
27  
28 distinguished between the synchronous and asynchronous partners, thought about the  
29  
30 synchronous partner as being more similar to themselves and thought about the asynchronous  
31  
32 partner as being more dissimilar to themselves, than the participants who less distinguished  
33  
34 between the synchronous and asynchronous partners. When a synchronous, relative to an  
35  
36 asynchronous, partner is assimilated to the self, it is the asynchronous partner who requires the  
37  
38 most attention and mentalizing to understand and predict. In contrast, for participants who show  
39  
40 relatively little difference in the perceived synchrony of the synchronous and the asynchronous  
41  
42 partners (and who show little difference in the activation of the vmPFC region; see Figure 3), it  
43  
44 is the (synchronous) partner whose temporal behavior is reflective of the participant's behavior  
45  
46 but is not rated as being synchronous who may evoke greater attention and mentalizing to  
47  
48 understand and predict. Consistent with this reasoning, the correlational analyses between the  
49  
50 BOLD differential synchrony scores (dBOLD: synchrony minus asynchrony) and reported  
51  
52 feelings of perceived synchrony revealed negative correlations for the right lateral prefrontal  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

1  
2  
3  
4 cortex (BA 46), the right lingual gyrus (BA18/19), and the right middle occipital gyrus (BA 19;  
5  
6 see Figure 4). The former is involved in control-related processes (Hare et al., 2009), the lingual  
7  
8 gyrus has been involved in third-person perspective-taking (Jackson et al., 2006), and the middle  
9  
10 occipital gyrus has been involved in visual attention and discrimination (Tu et al., 2013).  
11  
12 Exploratory analyses based on median splits further indicated the lowest levels of activation  
13  
14 when the participants whose ratings of perceived synchrony most distinguished between the  
15  
16 conditions were performing with a synchronous partner and the highest levels of activation when  
17  
18 these participants were performing with an asynchronous partner, whereas this pattern was  
19  
20 reversed in participants who reported relatively little difference in perceived synchrony between  
21  
22 their synchronous and asynchronous partners. In short, for participants who perceive large  
23  
24 differences between their synchronous and asynchronous partners and show evidence of relative  
25  
26 vmPFC activation and self-other overlap with the synchronous partner, it is the asynchronous  
27  
28 partner who activates brain regions involved in attention, visual discrimination, and cognitive  
29  
30 control, whereas for participants who see relatively little difference between these partners in  
31  
32 terms of perceived synchrony and show little difference in vmPFC activation and little self-other  
33  
34 overlap with the synchronous partner, it is the synchronous partner who activates these regions  
35  
36 more than the asynchronous partner.  
37  
38  
39  
40  
41  
42  
43  
44

45  
46 For the participants who show relatively large differences in perceived synchrony across  
47  
48 conditions (and relatively large differences in vmPFC activity), the assimilation of the  
49  
50 synchronous (in contrast to the asynchronous) partner to the self should result in the application  
51  
52 of an abstract trait representation of the self to the synchronous partner, thereby diminishing the  
53  
54 need for continued attention and mentalizing. For the participants who show relatively little  
55  
56 difference in perceived synchrony across conditions (and relatively small differences in vmPFC  
57  
58  
59  
60  
61  
62  
63  
64  
65

1  
2  
3  
4 activity), both the synchronous and the asynchronous partner may be regarded as dissimilar  
5  
6 others; as such, the temporal aspects of the asynchronous partner's behavior would be congruent  
7  
8 with the abstract trait inference that this partner is dissimilar (e.g., outgroup homogeneity) and  
9  
10 may therefore elicit little additional attention or mentalizing, whereas the temporal aspects of the  
11  
12 synchronous partner's behavior would be more reminiscent of the self and therefore may require  
13  
14 additional processing. Although speculative, the correlational analyses revealed a positive  
15  
16 correlation in the right cerebellar tonsil, a region involved in trait abstraction particularly based  
17  
18 on others' nonverbal behavior (van Overwalle et al., 2014). The median split analyses of  
19  
20 activation in the cerebellar tonsil region were entirely consistent with high-level abstractions  
21  
22 being formed (and attention, cognitive control, and mentalizing being truncated) for synchronous  
23  
24 partners in the former group of participants and for asynchronous partners in the latter group of  
25  
26 participants.  
27  
28  
29  
30  
31

32  
33 Finally, whole brain correlational analyses based on differences in reported feelings of  
34  
35 affiliation for synchronous versus asynchronous partners, two regions emerged: the right lingual  
36  
37 gyrus (BA 19) and in the inferior parietal/supramarginal gyrus (BA 40; see Figure 5). As noted  
38  
39 above, the right lingual gyrus is involved in third person perspective taking, and the inferior  
40  
41 parietal/supramarginal gyrus is involved in sensorimotor mirroring. These results suggest that  
42  
43 for participants who perceive the synchronous partner as relatively more likable than the  
44  
45 asynchronous partner, regions associated with third-person perspective-taking and mirroring are  
46  
47 more active when the partner's behavior is asynchronous than synchronous. In contrast, for  
48  
49 participants who perceive the synchronous and asynchronous partners as being more equivalent  
50  
51 in likability, these regions are more active when the partner's behavior is synchronous rather  
52  
53 than asynchronous.  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

1  
2  
3  
4 Limitations of the current study include the exploratory nature of the correlational  
5  
6 analyses and the relatively small sample size of the fMRI study in contrast to the behavioral  
7  
8 studies. Among the strengths of the current paradigm is the experimental control that it affords.  
9  
10 For instance, rather than relying on natural variations in synchrony between two participants, the  
11  
12 current paradigm permits the temporal parameters used to experimentally manipulate  
13  
14 interpersonal synchrony to be standardized and precisely controlled using computer programs.  
15  
16 Second, the task does not require face-to-face interactions, so characteristics of the ostensible  
17  
18 partner (e.g., age, gender, attractiveness, group identity) that may prove to be moderator  
19  
20 variables can be experimentally controlled. Third, participants can be an actor (e.g., trials on  
21  
22 which participants bext with a partner) or an observer (e.g., trials on which they watch two  
23  
24 partners bext), making it possible to examine the observational effects of interpersonal  
25  
26 synchrony. Finally, the task involves minimal movement (finger tapping) so that the bexting  
27  
28 paradigm can be used in neuroimaging studies.  
29  
30  
31  
32  
33  
34  
35  
36  
37

## 38 **References**

- 39  
40 Amodio DM, Frith CD (2006). Meeting of minds: The medial frontal cortex and social  
41  
42 cognition. *Nature Reviews Neuroscience* 7: 268-277.  
43  
44  
45 Bernieri FJ (1988). Coordinated movement and rapport in teacher-student interactions. *Journal*  
46  
47 *of Nonverbal Behavior* 12(2): 120-138.  
48  
49  
50 Bernieri FJ, Davis JM, Rosenthal R, Raymond Knee C (1994). Interactional synchrony and  
51  
52 rapport: Measuring synchrony in displays devoid of sound and facial affect. *Personality*  
53  
54 *and Social Psychology Bulletin* 20(3): 303-311. doi: 10.1177/0146167294203008.  
55  
56  
57  
58 Bijsterbosch JD, Lee KH, Hunter MD, Tsoi DT, Lankappa S, Wilkinson ID, Barker AT,  
59  
60  
61  
62  
63  
64  
65

- 1  
2  
3  
4 Woodruff PW (2011). The role of the cerebellum in sub-and supraliminal error correction  
5 during sensorimotor synchronization: evidence from fMRI and TMS. *Journal of*  
6  
7  
8  
9 *Cognitive Neuroscience*, 23(5): 1100-1112.
- 10  
11 Blakemore SJ, Fonlupt P, Pachot-Clouard M, Darmon C, Boyer P, Meltzoff AN, Segebarth C,  
12  
13  
14 Decety J (2001). How the brain perceives causality: an event-related fMRI study.  
15  
16 *Neuroreport* 12(17): 3741-3746.
- 17  
18  
19 Brown EC, Brüne M (2012). Evolution of social predictive brains? *Frontiers in psychology* 3: 1-  
20  
21 2.
- 22  
23  
24 Cacioppo JT, Cacioppo S (2012). Decoding the invisible forces of social connections. *Frontiers*  
25  
26 *in Integrative Neuroscience*, 6: 51.
- 27  
28  
29 Cappella JN (1997). Behavioral and judged coordination in adult informal social interactions:  
30  
31 Vocal and kinesic indicators. *Journal of Personality and Social Psychology* 72(1): 119.
- 32  
33  
34 Chartrand TL, Bargh JA (1999). The chameleon effect: The perception-behavior link and social  
35  
36 interaction. *Journal of Personality and Social Psychology*, 76(6): 893.
- 37  
38  
39 Delaherche E, Chetouani M, Mahdaoui A, Saint-Georges C, Viaux S, Cohen D (2012).  
40  
41 *Interpersonal Synchrony : A Survey Of Evaluation Methods Across Disciplines.*  
42  
43 *IEEE Transactions on Affective Computing*. 3(3): 349 - 365.
- 44  
45  
46 Desmurget M, Reilly KT, Richard N, Szathmari A, Mottolise C, Sirigu A (2009). Movement  
47  
48 intention after parietal cortex stimulation in humans. *Science* 324(5928): 811-813.
- 49  
50  
51 Ehrenreich B (2006). *Dancing in the streets: A history of collective joy*. New York, NY:  
52  
53 Metropolitan.
- 54  
55  
56 Engström DA, Kelso JAS, Holroyd T (1996). Reaction–anticipation transitions in human  
57  
58 perception–action patterns. *Human Movement Science* 15: 809–832.
- 59  
60  
61  
62  
63  
64  
65

- 1  
2  
3  
4 Epley N, Converse BA, Delbosc A, Monteleone GG, Cacioppo JT (2009). Believers' estimates  
5 of God's beliefs are more egocentric than estimates of other people's beliefs.  
6  
7 Proceedings of the National Academy of Sciences, 106(51): 21533-21538.  
8  
9  
10  
11 Fairhurst MT, Janata P, Keller PE (2013). Being and Feeling in Sync with an Adaptive Virtual  
12 Partner: Brain Mechanisms Underlying Dynamic Cooperativity. Cerebral Cortex 23(11):  
13  
14 2592-2600. doi: 10.1093/cercor/bhs243  
15  
16  
17  
18  
19 Fox MD, Snyder AZ, Vincent JL, Corbetta M, Van Essen DC, Raichle ME (2005). The human  
20 brain is intrinsically organized into dynamic, anticorrelated functional networks. Proc  
21  
22 Natl Acad Sci U S A 102: 9673-9678.  
23  
24  
25  
26 Grafton ST (2009). Embodied cognition and the simulation of action to understand others.  
27  
28 Annals of the New York Academy of Sciences 1156(1): 97-117.  
29  
30  
31 Grafton ST, Arbib MA, Fadiga L, Rizzolatti, G (1996). Localization of grasp  
32 representations in humans by positron emission tomography. Experimental Brain  
33  
34 Research 112(1): 103-111.  
35  
36  
37  
38 Grossberg S (2013). Adaptive resonance theory: How a brain learns to consciously attend, learn,  
39 and recognize a changing world. Neural Network 37: 1-47.  
40  
41  
42  
43 Guionnet S, Nadel J, Bertasi E, Sperduti M, Delaveau P, Fossati P (2011). Reciprocal imitation:  
44  
45 Toward a neural basis of social interaction. Cerebral Cortex 22(40): 971-978.  
46  
47  
48 Haidt J. (2012). The righteous mind: Why good people are divided by politics and religion. New  
49  
50 York, NY: Random House, Inc.  
51  
52  
53 Haidt J, Seder P, Kesebir S (2008). Hive psychology, happiness, and public policy. Journal of  
54  
55 Legal Studies, 37, S133-S156.  
56  
57  
58 Hatfield E, Cacioppo JT, Rapson RL (1994). Emotional contagion. Current Directions in  
59  
60  
61

- 1  
2  
3  
4 Psychological Science, 2, 96-99.  
5  
6  
7 Hare TA, Camerer CF, Rangel A (2009). Self-control in decision-making involves modulation of  
8  
9 the vmPFC valuation system. *Science* 324(5927): 646-648.  
10  
11 Harrington DL, Boyd LA, Mayer AR, Sheltraw DM, Lee RR (2002). Formulating  
12  
13 representations of time: an event-related fMRI study. In *Neural Information Processing,*  
14  
15 2002. ICONIP'02. Proceedings of the 9th International Conference on (Vol. 1, pp. 423-  
16  
17 427). IEEE.  
18  
19  
20  
21 Hove MJ, Risen JL (2009). It's all in the timing: Interpersonal synchrony increases affiliation.  
22  
23  
24 *Social Cognition* 27(6): 949-960.  
25  
26 IJzerman H, Semin GR (2010). Temperature perceptions as a ground for  
27  
28 social proximity. *Journal of Experimental Social Psychology* 46: 867-873.  
29  
30  
31 Jackson PL, Meltzoff AN, Decety J (2006). Neural circuits involved in imitation and  
32  
33 perspective-taking. *NeuroImage* 31(1): 429-439.  
34  
35  
36 Jones SM, Wirtz JG (2007). "Sad monkey see, monkey do": Nonverbal matching in emotional  
37  
38 support encounters. *Communication Studies*, 58, 71–86.  
39  
40  
41 Kelso JA (1984). Phase transitions and critical behavior in human bimanual coordination.  
42  
43 *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*  
44  
45 246(6): R1000-R1004.  
46  
47  
48 Kelso JAS, De Guzman GC, Reveley C, Tognoli, E (2009). Virtual partner interaction (VPI):  
49  
50 exploring novel behaviors via coordination dynamics. *PloS One* 4(6): e5749.  
51  
52  
53 Keyzers C, Gazzola V (2007). Integrating simulation and theory of mind: from self to social  
54  
55 cognition. *Trends in Cognitive Sciences* 11(5): 194-196.  
56  
57  
58 Konvalinka I, Vuust P, Roepstorff A, Frith CD (2010). Follow you, follow me: continuous  
59  
60  
61  
62  
63  
64  
65

- 1  
2  
3  
4 mutual prediction and adaptation in joint tapping. *The Quarterly Journal of Experimental*  
5  
6  
7 *Psychology* 63(11): 2220-2230.  
8
- 9 Krause V, Pollok B, Schnitzler A (2010). Perception in action: The impact of sensory  
10  
11 information on sensorimotor synchronization in musicians and non-musicians. *Acta*  
12  
13 *Psychologica* 133(1): 28-37.  
14
- 15  
16 Lakin JL, Chartrand TL (2003). Using nonconscious behavioral mimicry to create affiliation and  
17  
18 rapport. *Psychological Science* 14(4): 334-339.  
19
- 20  
21 Lewis PA, Wing AM, Pope PA, Praamstra P, Miall RC (2004). Brain activity correlates  
22  
23 differentially with increasing temporal complexity of rhythms during initialisation,  
24  
25 synchronisation, and continuation phases of paced finger tapping. *Neuropsychologia*  
26  
27 42(10): 1301-1312.  
28
- 29  
30  
31 Lumsden J, Miles LK, Macrae CN (2012). Perceptions of synchrony: Different strokes for  
32  
33 different folks? *Perception* 41: 1529-1531.  
34
- 35  
36 Maddux WW, Mullen E, Galinsky AD (2008). Chameleons bake bigger pies and take bigger  
37  
38 pieces: Strategic behavioral mimicry facilitates negotiation outcomes. *Journal of*  
39  
40 *Experimental Social Psychology*, 44(2): 461-468.  
41
- 42  
43 Macrae CN, Duffy OK, Miles LK, Lawrence J (2008). A case of hand waving: Action synchrony  
44  
45 and person perception. *Cognition* 109(1): 152-156.  
46
- 47  
48 Marsh KL, Richardson MJ, Schmidt RC (2009). Social connection through joint action and  
49  
50 interpersonal coordination. *Topics in Cognitive Science* 1(2): 320-339.  
51
- 52  
53 Marzoli D, Palumbo R, Di Domenico A, Penolazzi B, Garganese P, Tommasi L (2011). The  
54  
55 relation between self-reported empathy and motor identification with imagined agents.  
56  
57 *PloS One*, 6(1): e14595.  
58  
59  
60  
61



- 1  
2  
3  
4 McNeill WH (1995). *Keeping together in time: Dance and drill in human history*. Cambridge,  
5  
6 MA: Harvard University Press.  
7  
8  
9 Miles LK, Nind LK, Macrae CN (2009). The rhythm of rapport: Interpersonal synchrony and  
10  
11 social perception. *Journal of Experimental Social Psychology* 45(3): 585-589.  
12  
13  
14 Miles LK, Nind LK, Henderson Z, Macrae CN (2010). Moving memories: Behavioral synchrony  
15  
16 and memory for self and others. *Journal of Experimental Social Psychology* 46(2): 457-  
17  
18 460.  
19  
20  
21 Miles LK, Lumsden J, Richardson MJ, Macrae CN (2011). Do birds of a feather move together?  
22  
23 Group membership and behavioral synchrony. *Experimental Brain Research* 211: 1-9.  
24  
25  
26 Mitchell JP, Banaji MR, Macrae CN (2005). The link between social cognition and  
27  
28 self-referential thought in the medial prefrontal cortex. *Journal of Cognitive*  
29  
30 *Neuroscience* 17:1306–1315.  
31  
32  
33 Molenberghs P, Cunnington R, Mattingley JB (2009). Is the mirror neuron system involved in  
34  
35 imitation? A short review and meta-analysis. *Neuroscience & Biobehavioral Reviews*  
36  
37 33(7): 975-980.  
38  
39  
40 Müller BC, Maaskant AJ, van Baaren RB, Dijksterhuis AP (2012). Prosocial consequences of  
41  
42 imitation. *Psychol Rep.* 110(3): 891-898.  
43  
44  
45 Nichols T (2012) Multiple testing corrections, nonparametric methods, and random field theory.  
46  
47 *NeuroImage* 62(2): 811-5.  
48  
49  
50 Ortigue S, Thompson JC, Parasuraman R, Grafton, ST (2009). Spatio-temporal  
51  
52 dynamics of human intention understanding in temporo-parietal cortex: a combined  
53  
54 EEG/fMRI repetition suppression paradigm. *PloS One* 4(9): e6962.  
55  
56  
57 Ortigue S, Sinigaglia C, Rizzolatti G, Grafton ST (2010). Understanding actions of others: the  
58  
59  
60  
61  
62  
63  
64  
65

1  
2  
3  
4 electrodynamics of the left and right hemispheres. A high-density EEG neuroimaging  
5 study. PLOS ONE 5: e12160.  
6  
7

8  
9 Oullier O, De Guzman GC, Jantzen KJ, Lagarde J, Kelso JAS (2008). Social coordination  
10 dynamics: Measuring human bonding. Social Neuroscience 3(2): 178-192.  
11

12  
13 Paladino MP, Mazzurega M, Pavani F, Schubert TW (2010). Synchronous multisensory  
14 stimulation blurs self-other boundaries. Psychological Science 21(9): 1202-1207.  
15  
16

17  
18 Raichle ME, MacLeod AM, Snyder AZ, Powers WJ, Gusnard DA, Shulman GL (2001). A  
19 default mode of brain function. Proc Natl Acad Sci U S A 98(2): 676-682. doi:  
20 10.1073/pnas.98.2.676.  
21  
22

23  
24 Raichle ME, Snyder AZ (2007). A default mode of brain function: A brief history of an evolving  
25 idea. NeuroImage 37: 1083-1090.  
26  
27

28  
29 Rao AS, Georgeff MP (1997). Modeling rational agents within a BDI-architecture. Readings in  
30 Agents 317-328.  
31  
32

33  
34 Repp BH (2005). Sensorimotor synchronization: A review of the tapping literature.  
35 Psychonomic Bulletin & Review 12(6): 969-992.  
36  
37

38  
39 Repp BH, Su YH (2013). Sensorimotor synchronization: A review of recent research (2006-  
40 1012). Psychonomic Bulletin & Review 20(3):403-452. doi: 10.3758/s13423-012-0371-  
41  
42

43  
44 2  
45  
46 Richardson MJ, Marsh KL, Schmidt RC (2005). Effects of visual and verbal interaction on  
47 unintentional interpersonal coordination. Journal of Experimental Psychology: Human  
48 Perception and Performance 31(1): 62.  
49  
50

51  
52 Rizzolatti G, Craighero L (2004). The mirror-neuron system. Annual Review of Neuroscience  
53 27: 169-192.  
54  
55

- 1  
2  
3  
4 Rizzolatti G, Sinigaglia C (2007). Mirror neurons and motor intentionality. *Functional*  
5  
6 *Neurology* 22(4): 205-210.  
7  
8
- 9 Salman MS (2002). Topical Review: The Cerebellum: It's About Time! But Timing Is Not  
10  
11 Everything-New Insights Into the Role of the Cerebellum in Timing Motor and Cognitive  
12  
13 Tasks. *Journal of Child Neurology* 17(1): 1-9.  
14  
15
- 16 Schmidt RC, Carello C, Turvey MT (1990). Phase transitions and critical fluctuations in the  
17  
18 visual coordination of rhythmic movements between people. *Journal of Experimental*  
19  
20 *Psychology: Human Perception and Performance* 16(2): 227.  
21  
22
- 23 Schmidt RC, O'Brien B (1997). Evaluating the dynamics of unintended interpersonal  
24  
25 coordination. *Ecological Psychology*, 9: 189–206.  
26  
27
- 28 Semin GR (2007). Grounding communication: Synchrony. In A. W. Kruglanski & E. T. Higgins  
29  
30 (Eds.), *Social psychology: Handbook of basic principles* (2nd ed., pp. 630–649). New  
31  
32 York: Guilford.  
33  
34
- 35 Semin GR, Cacioppo JT (2008). Grounding social cognition: Synchronization,  
36  
37 coordination, and co-regulation. In G.R. Semin & E.R. Smith (Eds.), *Embodied*  
38  
39 *grounding: Social, cognitive, affective, and neuroscientific approaches* (pp. 119-147).  
40  
41 New York, NY: Cambridge University Press.  
42  
43
- 44 Semin GR, Cacioppo JT (2009). “From embodied representation to co-regulation,” in  
45  
46 *Mirror Neuron Systems: Role of Mirroring Processes in Social Cognition*, ed J. A. Pineda  
47  
48 (Totowa, NJ: The Humana Press), 107–120.  
49  
50
- 51 Semin GR, Smith E (2002). Interfaces of social psychology with situated and embodied  
52  
53 cognition. *Cogn. Syst. Res.* 3: 385–396.  
54  
55
- 56 Shimada S, Hiraki K, Oda I (2005). The parietal role in the sense of self-ownership with  
57  
58  
59  
60  
61  
62  
63  
64  
65

- temporal discrepancy between visual and proprioceptive feedbacks. *NeuroImage* 24(4): 1225-1232.
- Sonnby-Borgström M (2002). Automatic mimicry reactions as related to differences in emotional empathy. *Scandinavian Journal of Psychology*, 43(5): 433-443.
- Stel M, van Baaren RB, Blascovich J, van Dijk E, McCall C, Pollmann MM, van Leeuwen ML, Mastop J, Vonk R. (2010). Effects of a priori liking on the elicitation of mimicry. *Exp Psychol.* 57(6): 412-418.
- Strick PL, Hoover JE, Mushiake H (1993). Evidence for “output channels” in the basal ganglia and cerebellum. *Role of the cerebellum and basal ganglia in voluntary movement* 171.
- Talairach J, Tournoux P (1988). *Co-planar stereotaxic atlas of the human brain* (Vol. 147). New York: Thieme.
- Tickle-Degnen L, Rosenthal R (1990). The nature of rapport and its nonverbal correlates. *Psychological Inquiry*, 1: 285–293.
- Tognoli E, Magne C, de Guzman GC, Tuller B, Kelso JAS (2007). Brain rhythms underlying intentional social coordination. *Society for Neuroscience Itinerary Planner Program* 304.24, San Diego, USA, November 3rd-7th.
- Tu S, Qiu J, Martens U, Zhang Q (2013). Category-selective attention modulates unconscious processes in the middle occipital gyrus. *Conscious Cognition* 22(2): 479-485.
- van Baaren RB, Holland RW, Kawakami K, van Knippenberg A (2004). Mimicry and prosocial behavior. *Psychological Science* 15(1): 71-74.
- van Baaren RB, Holland RW, Steenaert B, van Knippenberg A (2003). Mimicry for money: Behavioral consequences of imitation. *Journal of Experimental Social Psychology*, 39(4): 393-398.

- 1  
2  
3  
4 van Baaren R, Janssen L, Chartrand TL, Dijksterhuis A. (2009). Where is the love? The social  
5  
6 aspects of mimicry. *Philos Trans R Soc Lond B Biol Sci.* 364(1528): 2381-2389.  
7  
8  
9 Vacharkulksemsuk T, Fredrickson BL (2012). Strangers in sync: achieving embodied rapport  
10  
11 through shared movements. *Journal of Experimental Social Psychology* 48(1): 399-402.  
12  
13  
14 Valdesolo P, Ouyang J, DeSteno D (2010). The rhythm of joint action: Synchrony promotes  
15  
16 cooperative ability. *Journal of Experimental Social Psychology* 46(4): 693-695.  
17  
18  
19 Valdesolo P, DeSteno D (2011). Synchrony and the social tuning of compassion.  
20  
21 *Emotion*,11(2): 262.  
22  
23  
24 van Baaren RB, Maddux WW, Chartrand TL, De Bouter C, van Knippenberg A (2003). It takes  
25  
26 two to mimic: behavioral consequences of self-construals. *Journal of Personality and*  
27  
28 *Social Psychology* 84: 1093–1102. doi:10.1037/0022-3514.84.5.1093.  
29  
30  
31 van Overwalle F, Baetens K (2009). Understanding others' actions and goals by mirror and  
32  
33 mentalizing systems: a meta-analysis. *NeuroImage* 48(3): 564-584. doi:  
34  
35 10.1016/j.neuroimage. 2009.06.009.  
36  
37  
38 van Overwalle F, Baetens K, Marien P, Vandekerckhove M (2014). Social cognition and the  
39  
40 cerebellum: a meta-analysis of over 350 fMRI studies. *NeuroImage* 86: 554-572. doi:  
41  
42 10.1016/j.neuroimage.2013.09.033  
43  
44  
45 Ward BD (2002). Deconvolution analysis of fMRI time series data. Milwaukee, WI:  
46  
47 Biophysics Research Institute, Medical College of Wisconsin.  
48  
49  
50 Wiltermuth SS, Heath C (2009). Synchrony and cooperation. *Psychological Science* 20(1): 1-5.  
51  
52  
53 Yamanishi JI, Kawato M, Suzuki R (1980). Two coupled oscillators as a model for the  
54  
55 coordinated finger tapping by both hands. *Biological Cybernetics* 37(4): 219-225.  
56  
57  
58 Yun K, Watanabe K, Shimojo S (2012). Interpersonal body and neural synchronization as a  
59  
60  
61  
62  
63  
64  
65

marker of implicit social interaction. Scientific Reports 2:959. doi: 10.1038/srep00959.

### Figure Captions

Figure 1. Screenshot of the computer interface of the “*bexting*” task.

Figure 2. BOLD responses obtained for synchrony compared to asynchrony. A. Synchrony > asynchrony is shown in yellow on lateral views of the fiducial left side of the brain (A). Brain activities were mapped on the AFNI Colin brain using Caret 5.65 software (Van Essen, 2005). (B). Plots of percent (%) signal change were extracted for the three significant regions (IPL, left; parahippocampal region, center; and vmPFC, right) between synchrony (orange) and asynchrony (blue). All clusters were significant at  $p < .01$  corrected to alpha  $< .05$ .

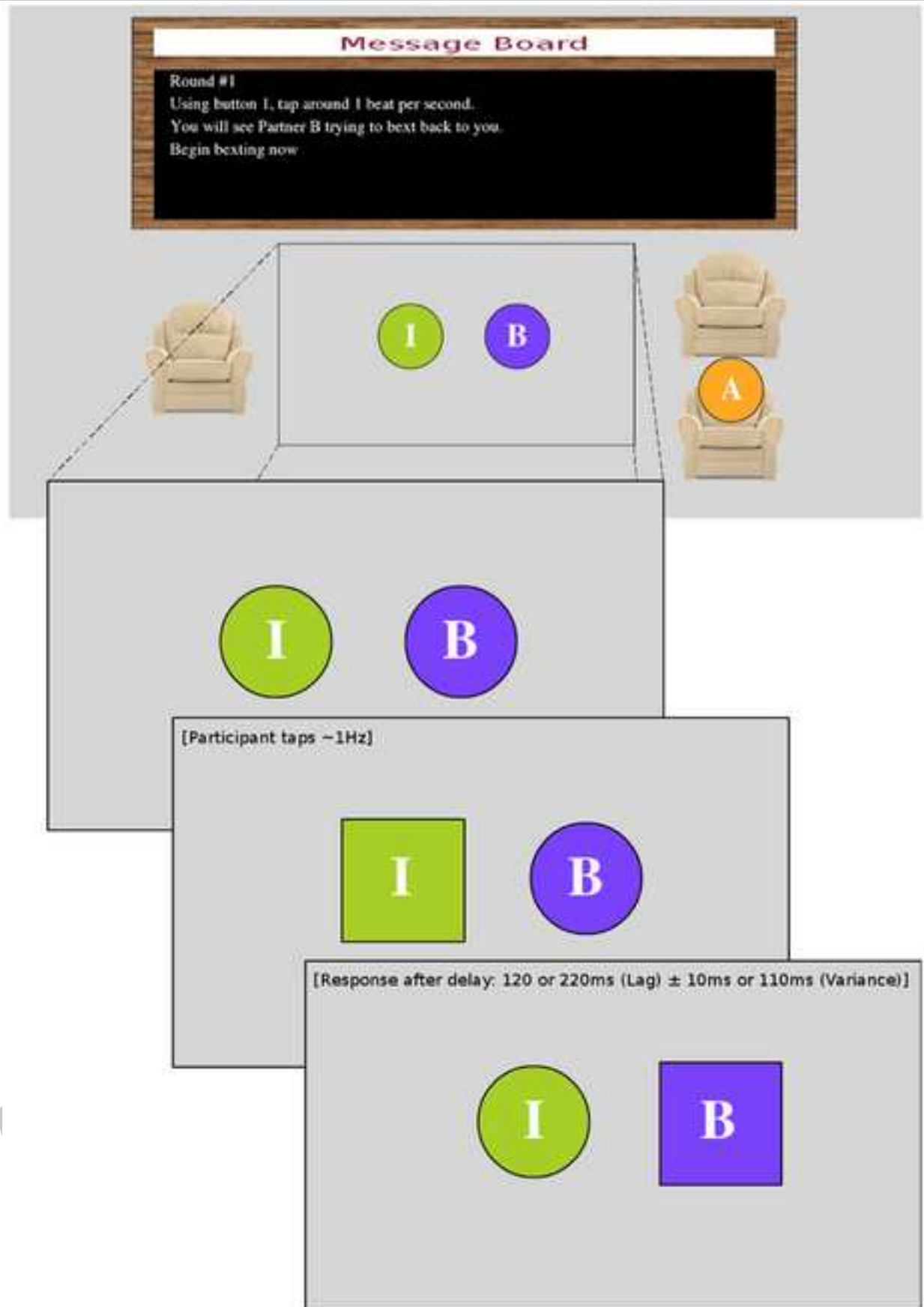
Figure 3. Correlations between neural activity and behavioral measures in the ventromedial prefrontal cortex (vmPFC). The BOLD effect for synchrony found in vmPFC (see Figure 2) significantly correlated with measures of perceived synchrony and feelings of affiliation. The ordinate indicates behavioral difference scores for synchronous - asynchronous trials; the abscissa indicates difference scores in BOLD activity (dBOLD). Participants reporting higher perception of synchrony and feelings of affiliation for synchronous items also showed greater corresponding vmPFC activity. Results were obtained with a voxelwise cluster threshold of  $p < .025$ , corrected for multiple comparisons to alpha  $< .05$ .

Figure 4. A. Results of voxelwise correlation analyses between the BOLD differential synchrony scores (dBOLD: synchrony minus asynchrony) and reported feelings of perceived

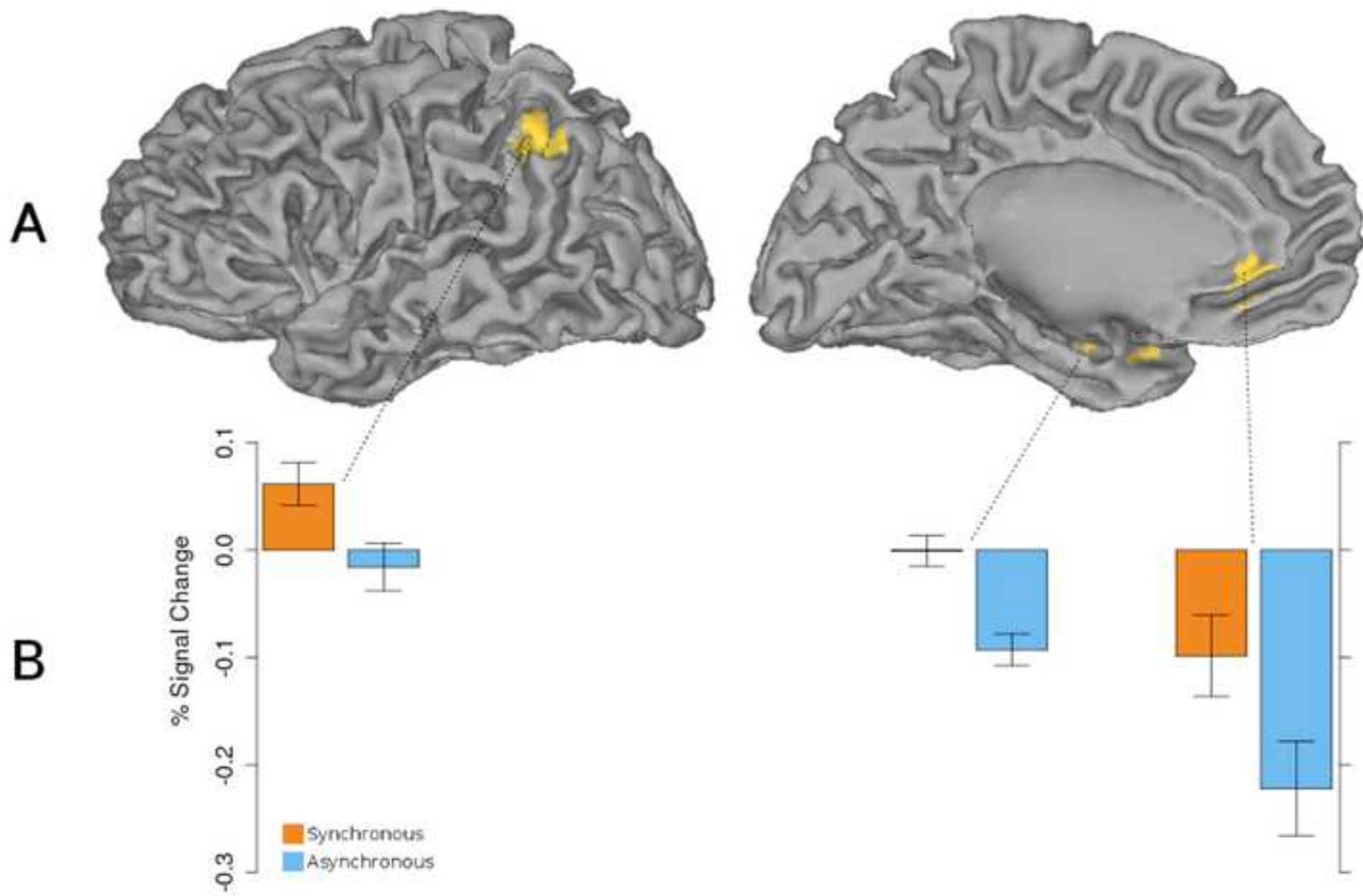
1  
2  
3  
4 synchrony projected onto a slice from the MNI atlas (left,  $z = -42$ ) and mapped on the Caret  
5  
6 AFNI Colin brain right hemisphere, lateral view (center) and medial view (right). B. Scatter  
7  
8 plots for each respective cluster, from left to right: cerebellar tonsil, right middle occipital gyrus  
9  
10 (BA 19), right lateral prefrontal cortex (BA 46), dorsomedial prefrontal cortex (BA 9), and right  
11  
12 lingual gyrus (BA18/19). C. Median split plots indicating each cluster's BOLD activity in each  
13  
14 condition for the subsamples above and below the behavioral median. Results were obtained  
15  
16 with a voxelwise cluster threshold of  $p < .025$ , corrected for multiple comparisons to  $\alpha < .05$ .  
17  
18  
19  
20  
21  
22

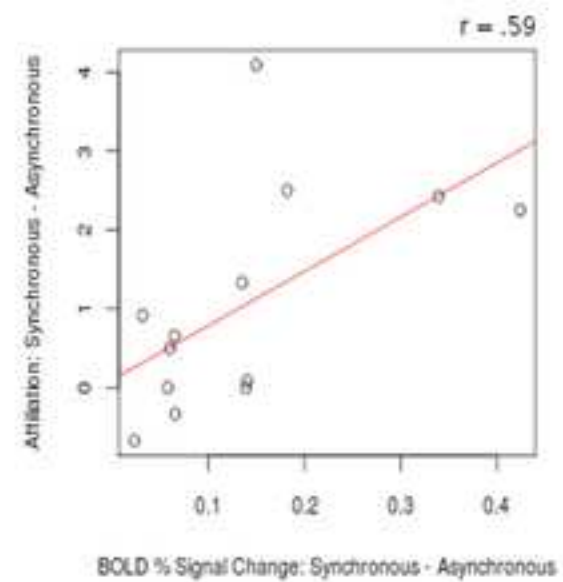
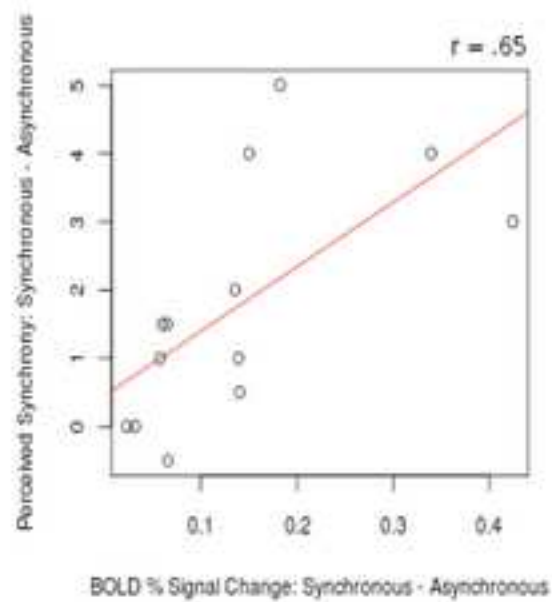
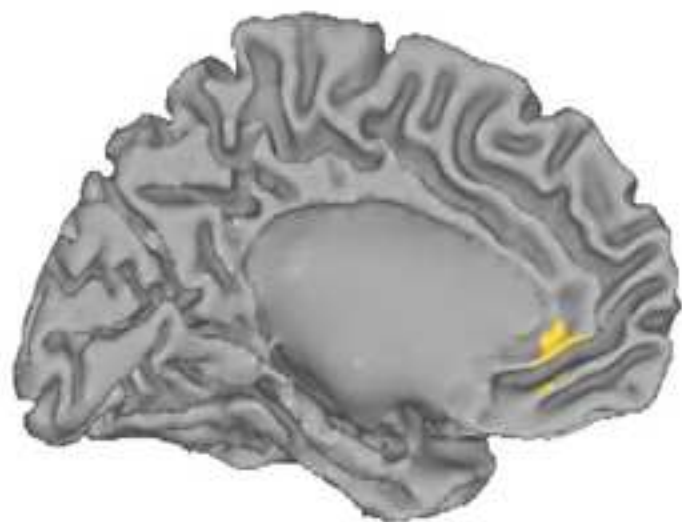
23  
24 Figure 5. Results of correlation analyses between the BOLD differential synchrony scores  
25  
26 (dBOLD between synchrony minus asynchrony) and reported feelings of affiliation. A.  
27  
28 Correlation clusters mapped onto the Caret AFNI Colin brain right hemisphere, lateral view (left)  
29  
30 and medial view (right). B. Scatter plots for each respective cluster from left to right: inferior  
31  
32 parietal / supramarginal gyrus (BA40), lingual gyrus (BA 19). C. Median split plots indicating  
33  
34 each cluster's BOLD activity in each condition for the subsamples above and below the  
35  
36 behavioral median. Results were obtained with a voxelwise cluster threshold of  $p < .025$ ,  
37  
38 corrected for multiple comparisons to  $\alpha < .05$ .  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

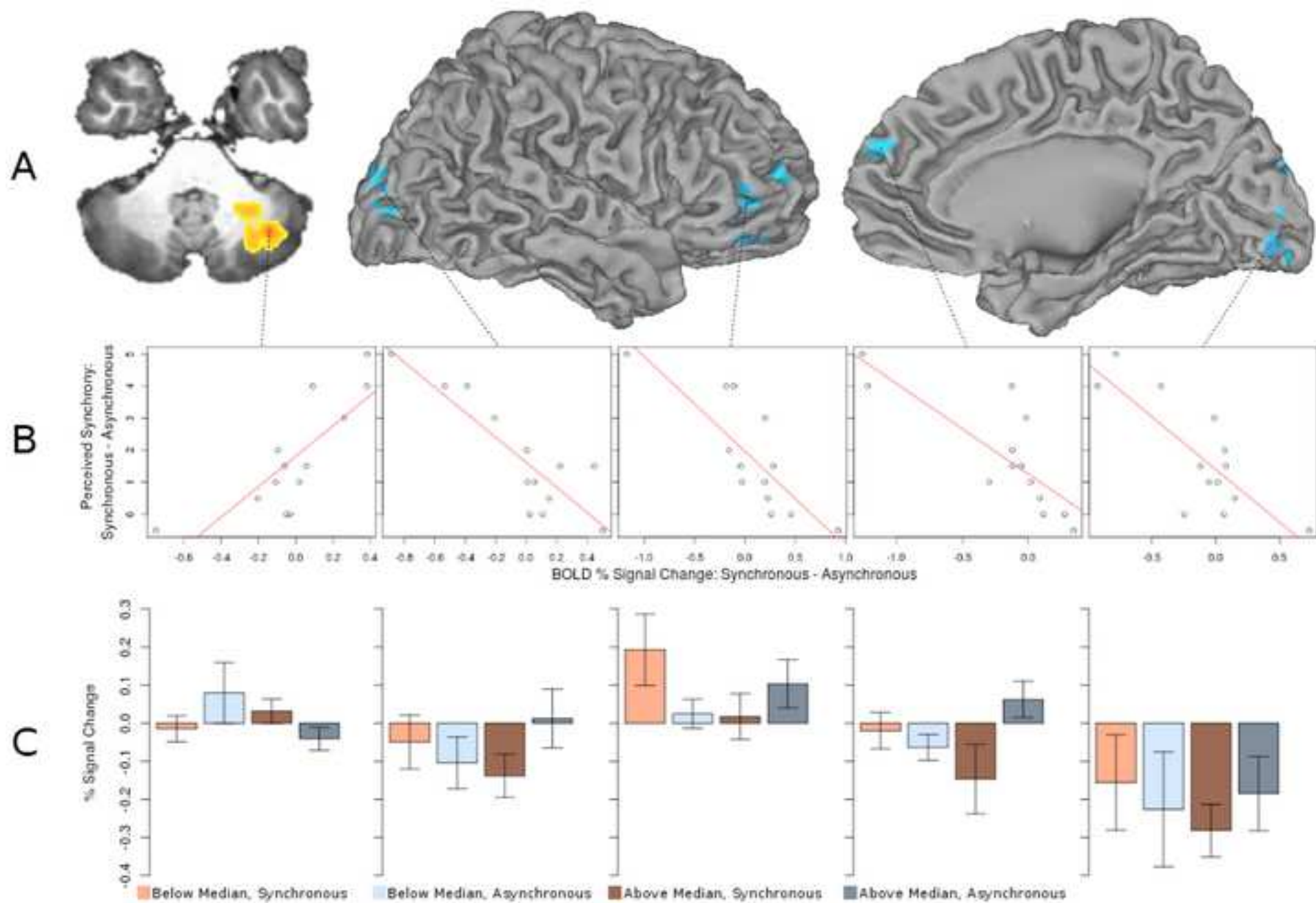
Figure 1











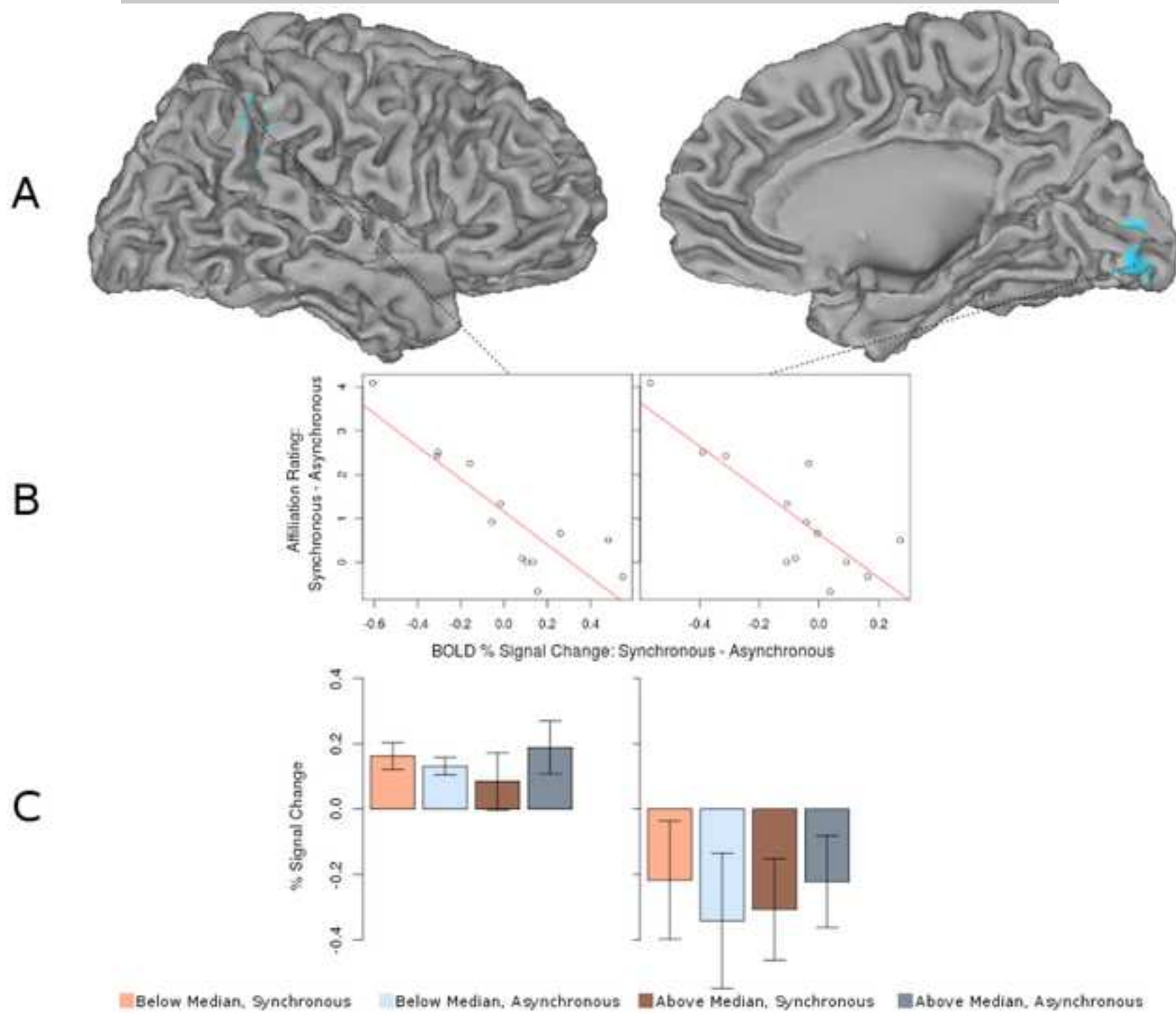


Table 1. Feelings of perceived synchrony with an adaptive partner

Condition	Mean	STD	SE	95% CI	
				Lower bound	higher bound
Synchrony	5.91	1.47	.22	5.48	6.35
Asynchrony	5.13	1.81	.26	4.60	5.66

Table 2. Feelings of social affiliation with an adaptive partner

Condition	Mean	STD	SE	95% CI Lower bound	95% CI higher bound
Synchrony	4.91	1.59	.23	4.45	5.38
Asynchrony	4.54	1.67	.24	4.05	5.03

Table 3. Feelings of perceived synchrony with an adaptive partner

Condition	Mean	STD	SE	95% CI Lower bound	95% CI higher bound
Small range + small lag	5.48	1.89	.30	4.87	6.08
Large range + small lag	4.73	2.10	.33	4.05	5.40
Large range + large lag	4.25	2.21	.35	3.54	4.96
Small range + large lag	4.93	2.06	.33	4.27	5.58

Table 4. Feelings of social affiliation with an adaptive partner

Condition	Mean	STD	SE	95% CI Lower bound	95% CI higher bound
Small range + small lag	4.92	1.76	.29	4.35	5.48
large range + small lag	4.15	1.76	.28	3.58	4.71
large range + large lag	3.81	1.89	.30	3.21	4.42
Small range + large lag	4.30	1.79	.28	3.73	4.88



Table 5. Variance range main effect results of the whole-brain factorial ANOVA. All clusters were significant at  $p < .01$  corrected to alpha  $< .05$ . Regions are indexed with MNI coordinates; Brodmann areas are indicated for appropriately located clusters.

		<b>Vol(<math>\mu</math>l)</b>	<b>x</b>	<b>y</b>	<b>z</b>	<b>t</b>
Left	Inferior Parietal Lobule, IPL (BA 40)	2565	-48	-57	38	3.87
	Supramarginal Gyrus					
	Angular Gyrus					
Left	Parahippocampal Gyrus (BA 38)	945	-28	-3	-19	3.52
	Amygdala					
Left	vmPFC/Anterior cingulate (BA 32)	918	-3	38	2	3.45

Table 6: Clusters resulting from the voxelwise analysis correlating BOLD signal during task period and behavioral ratings of perceived synchrony. Results were obtained with a voxelwise cluster threshold of  $p < .025$ , corrected for multiple comparisons to  $\alpha < .05$ . Regions are indexed with MNI coordinates; Brodmann areas are indicated for appropriately located clusters.

		Vol( $\mu$ l)	x	y	z	r
<i>Positive Correlation</i>						
Right	Cerebellar Tonsil	1269	27	-55	-49	.64
<i>Negative Correlations</i>						
Right	Anterior prefrontal cortex (BA 10)	2808	38	46	10	-.69
	Lateral prefrontal cortex (BA 46)					
	Dorsomedial prefrontal cortex (BA 9)	1566	-1	53	33	-.60
Right	Lingual Gyrus (BA18/19)	1107	10	-89	-14	-.66
Right	Middle Occipital Gyrus (BA 19)	1080	29	-89	9	-.68

Table 7. Clusters resulting from the voxelwise analysis correlating BOLD signal during task period and behavioral ratings of feelings of affiliation. Results were obtained with a voxelwise cluster threshold of  $p < .025$ , corrected for multiple comparisons to  $\alpha < .05$ . Regions are indexed with MNI coordinates; Brodmann areas are indicated for appropriately located clusters.

		Vol( $\mu$ l)	x	y	z	r
<i>Negative Correlations (No Positive Correlations Found)</i>						
Right	Lingual Gyrus (BA 19)	1431	9	-87	-1.5	-.68
Right	Inferior Parietal Lobule/Supramarginal gyrus (BA 40)	1323	59	-49	34	-.6

**Highlights:**

- First fMRI study on social consequences of synchrony where the participant served as referent.
- Referents recruit brain areas involved in social and embodied cognition during synchrony.
- Referents expressed greater feelings of affiliation toward synchronous partners.