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### You are in sync with me

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## 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

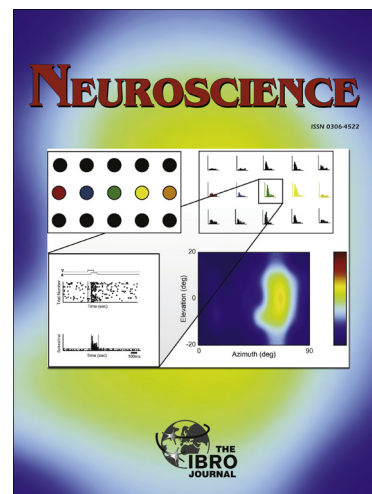
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You are in sync with me:

## Neural correlates of interpersonal synchrony with a partner

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## 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

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4 current research, we investigated experimentally whether being the *referent* for a partner who  
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6 responds in a more or less synchronous fashion (rather than an intentional contributor to the  
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8 synchrony produced by a partner) affects the referent's perceived synchrony with and affiliative  
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10 response toward the partner. Second, we investigated the neural correlates of interpersonal  
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12 synchrony (vs. asynchrony) in this referent.  
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### 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  
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25 of any of three distinct production processes, which we refer to as orchestration, reciprocal  
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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  
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31 metronome) that “directs” the shared movement pattern, much like a conductor leading scores of  
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33 musicians. For example, Hove and Risen (2009) manipulated interpersonal synchrony by having  
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35 participants tap to beats created by a metronome.  
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39 In reciprocal entrainment, synchrony is achieved through a give-and-take process in  
40  
41 which individuals within a system (e.g., dyad) monitor each other and adjust their own  
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43 movement in a mutual fashion. For example, Oullier and colleagues (2008) found that dyadic  
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45 interpersonal synchrony reflected movements that were distinct from individuals' movements  
46  
47 prior to the interaction, suggesting that participants shifted their movement in response to their  
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49 partners' movement.  
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54 Finally, in unilateral entrainment, one individual within a dyad (the “synchronizer”)  
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56 unilaterally adjusts his or her movements to entrain to the movements of the other individual (the  
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4 referent) within the dyad – an individual who moves periodically but does not adjust his or her  
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6 movements in reciprocation to promote synchrony. Previous work has focused on interpersonal  
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8 synchrony achieved through orchestration or reciprocal entrainment (e.g., Delaherche et al.,  
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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  
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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.  
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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  
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24 movement of those with a heightened motivation to socially connect with a target (e.g., Miles et  
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26 al., 2010, 2011). In Study III, we investigated the neural correlates of perceived synchrony in the  
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28 referent.  
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## 35 36 37 38 **1.2. Social functions of synchrony**

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40 Over the past decades, two main bodies of literature have developed to better understand  
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42 interpersonal synchrony. The literature on sensorimotor synchronization (SMS) focuses on an  
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44 *action* that leads to synchrony by means of temporary coordination with a predictable external  
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46 event (the referent). Among the findings in this field are that error correction is required to  
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48 maintain SMS (see review by Repp, 2005), and stability is greater for synchronous than  
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50 asynchronous inter-limb (e.g., arm or leg) movements within an individual (e.g., Yamanishi et  
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52 al., 1980; Kelso, 1984) and between individuals (e.g., Schmidt et al., 1990; Richardson et al.,  
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4 2005), with the result being an increased likelihood of entrainment (e.g., Engström et al., 1996;  
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6 Schmidt and O'Brien, 1997).

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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  
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14 attending to this information), thereby promoting emotional alignment between interacting  
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16 individuals. Relatedly, as described above, McNeill (1995) posited that synchrony contributes to  
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18 group solidarity. Since the 1990s, a large number of studies have reinforced these hypotheses  
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20 and showed that performing actions that are similar to, and coordinated with, those of an  
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22 interacting partner enhances feelings of connectedness, affiliation, interpersonal rapport, and a  
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24 blurring of self–other boundaries (Bernieri, 1988; Tickle-Dengen and Rosenthal, 1990; Bernieri  
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26 et al., 1994; Cappella, 1997; Lakin and Chartrand, 2003; Hove and Risen, 2009; Miles et al.,  
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28 2010, 2011; Paladino et al., 2010; Vacharkulksemsuk and Fredrickson, 2012), liking (e.g., Hove  
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30 and Risen, 2009; Miles et al., 2009), perceived similarity and compassion (Valdesolo and  
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32 DeStano, 2011), joint action (Valdesolo et al., 2010), cooperation and enhanced altruistic  
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34 behavior (Wiltermuth and Heath, 2009; Valdesolo and DeStano, 2011), better negotiation  
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36 outcomes (Maddux, Mullen, and Galinsky, 2008), emotional empathy (Chartrand & Bargh,  
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38 1999; Sonnby-Borgström, 2002; Marzoli et al., 2011), person memory (Macrae et al., 2008;  
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40 Miles et al., 2010), group cohesion (McNeil, 1995), and prosocial behavior (van Baaren,  
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42 Holland, Steenaert, and van Knippenberg, 2003; van Baaren, Holland, Kawakami, van  
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44 Knippenberg, 2004; Marsh et al., 2009; Valdesolo and DeStano, 2011; Müller, Maaskant, van  
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46 Baaren, Dijksterhuis, 2012). In sum, interpersonal synchrony is a foundation for effective social  
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48 interaction and enhanced sociality (Miles et al., 2009; Delaherche, et al., 2012; Lumsden et al.,  
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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.,

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4 postural movements, facial expressions, gestures; Bernieri, 1988; Cappella, 1997; for review cf.  
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6 Miles et al., 2009). For instance, a meta-analysis of studies of a related social motor action—  
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8 imitation—indicates activation of parietal and frontal regions including the superior parietal  
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10 lobule, inferior parietal lobule, and dorsal premotor cortex (Molenberghs et al., 2009). Guionnet  
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12 et al. (2011) extended this work in an fMRI study of participants as they imitated or were  
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14 imitated by another person. Results revealed activation in the primary sensorimotor cortex,  
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16 premotor and supplementary motor areas, left inferior frontal gyrus, left IPL, and left insula,  
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18 whether imitating or being imitated. In addition, activation was found in the dorsal anterior  
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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  
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28 insular cortex, whereas imitating led to greater activation in the visual cortex, medial frontal  
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30 cortex, posterior cingulate gyrus, precuneus, bilateral IPL, para-hippocampus, and hippocampus  
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32 than being imitated.  
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40 Many of these regions constitute the default mode network (DMN; Raichle et al., 2001;  
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42 Fox et al., 2005), a network that is more active during self-referential, social, and affective  
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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  
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48 finger-tapping paradigm in which the virtual partner varied in adaptivity, which also  
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50 corresponded to differing degrees of coupling between the virtual partner and participant.  
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53 Participants were instructed to synchronize with the virtual partner while also maintaining the  
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55 initial tempo, thereby establishing the goals of maintaining the periodicity of the finger tapping  
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4 and minimizing the phase differences in the finger tapping task. Objective synchrony was  
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6 operationalized in terms of phase relations, whereas the feeling of being synchronized was  
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8 operationalized as (lower) perceived task difficulty. Regression analyses identified different  
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10 networks whether the participants were objectively in synchrony with the virtual partner  
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12 (positive correlation with increased midline activation of structures including the ventromedial  
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14 prefrontal cortex, vmPFC; hippocampus, supplementary motor area, SMA; primary  
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16 somatosensory cortex, S1 extending into primary motor cortex, M1; posterior cingulate; and  
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18 precuneus) or subjective perception of synchrony (i.e., reduced task difficulty was correlated  
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20 with greater activation of the right IFG, right anterior insula, posterior dmPFC, bilateral  
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22 ventrolateral prefrontal cortex, superior frontal gyrus, and inferior parietal activity in the region  
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24 of the temporo-parietal junction for perceived synchronization difficulty, and SMA, S1/M1,  
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26 vmPFC and hippocampus; Fairhurst et al., 2013).

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34 Although this body of research is on the perception and social consequences of  
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36 interpersonal synchrony (e.g., Tognoli et al., 2007; Kelso et al., 2009; Konvalinka et al., 2010;  
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38 Fairhurst et al., 2012), these studies have focused primarily on the neural correlates of one's  
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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  
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44 fMRI to investigate how regional brain activity was modulated by differences in synchronous  
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46 stimuli during a tapping-based interactive task compared to asynchronous stimuli with a  
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48 synchronizer. Moreover, little is known about the neural regions that might be correlated with  
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50 subjective perceptions of synchrony and corresponding feelings of affiliation between a referent  
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52 and a synchronizer. Therefore, we also ran correlational analyses to explore this relationship  
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54 (see Method section for details). To the best of our knowledge, this is the first empirical  
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4 investigation of the neural correlates of the participants' perception of interpersonal synchrony  
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6 and their feelings of affiliation with a virtual co-acting partner when the participant is the  
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8 referent (rather than the synchronizer).  
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## 10 11 **2. General experimental procedures**

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

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15 All participants were native English speakers with normal or corrected-to-normal vision,  
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17 and were not taking antidepressant medication. As ascertained by an anamnesis, none of the  
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19 participants reported prior or current neurological or psychiatric disorders (e.g., traumatic brain  
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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  
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25 experiment, which was approved by the University of Chicago Health Sciences Institutional  
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27 Review Board. All participants received monetary compensation for their participation.  
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### 36 37 **2.2. General experimental task**

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39 The experimental task was presented to participants as a computer-mediated  
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41 communication task that involved simple back-and-forth keyboard tapping between members of  
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43 a dyad. Specifically, the task was described as an abstract simulation of cell-phone texting,  
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45 where a beat (i.e., a single tap on the computer keyboard) replaced actual text—actions described  
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47 as “*bexting*,” short for beat-based texting (Figure 1).  
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51 Throughout the session, the message board at the top of the screen displayed various  
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53 information and instructions about the task. Participants were informed that the circle labeled  
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55 “I” was their own avatar, which would immediately pulse each time they would send a beat (i.e.,  
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57 pressed the keyboard once). The pulse was visually represented by a short animation of the  
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4 circle transforming into a square and then back into the circle. Participants were also told that  
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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  
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16 avatar entered the “*bexting*” zone represented by the rectangular box surrounding the two avatars  
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21 (Figure 1).  
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23  
24 The participant was told that their task was simply to generate a series of beats at a  
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26 designated frequency (e.g., 1 beat/sec), regardless of their partner’s beat frequency (i.e.,  
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28 unencumbered by any need to coordinate their beats with their partner’s beats). Participants  
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30 were also informed that the task of their partner was to respond to each one of their beats with  
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32 another beat—with no time constraint to respond except that they had to send a beat back to each  
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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  
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38 members bexted with each other for an extended period of time, called a bexting round  
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41 (described below), which consisted of multiple equal-length trials separated by short breaks.  
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46 At the end of a bexting round, the participants reported their impression of their partner  
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48 by answering a short questionnaire displayed on the message board. After completing the  
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50 questionnaire, participants were led to believe that the server would form a new pairing between  
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52 themselves and another randomly selected fellow participant and that a new bexting round would  
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54 then ensue. This made it possible to manipulate partner synchrony using a within-subjects  
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56 design, which is especially important if the paradigm is also to be used to investigate the neural  
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4 correlates of perceived interpersonal synchrony. Due to the presence of at least three other  
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6 fellow participants, the use of cubicles, rubber keyboards to ensure key presses could not be  
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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  
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12 room. As a result, the only reliable information about a given partner accessible to the  
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14 participants was the timings of that partner's beat series. Objective synchronicity by definition is  
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16 contingent on the alignment of timing per se, so this feature of the paradigm allowed us to  
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18 examine whether timing information was sufficient to influence perceived synchrony and social  
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20 affiliation.  
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### 29 **2.3. General manipulation of unilateral entrainment**

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31 The participant and their partner correspond, respectively, to the referent and  
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33 synchronizer involved in unilateral entrainment. Unbeknownst to the participants, the  
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35 "partner's" beat series were generated by a computer program, which made it possible to  
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37 experimentally manipulate the degree to which the partner's beats were entrained to the  
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39 referent's beats. More precisely, the partner's beat latency (i.e., the interval between the  
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41 referent's beat and the partner's beat) was sampled from a uniform distribution with pre-  
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43 determined mean and range (described below). Because prior research has manipulated  
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45 synchrony using latency ranges varying between 0 and 90 degrees, beat latencies in the present  
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47 research were manipulated within the same range. By manipulating the means and range of the  
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49 distribution of partner's response latency, different levels of synchrony could be produced. This  
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51 feature ensured that the variation in synchrony was determined solely by the unilateral  
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4 entrainment on the part of the ostensible synchronizer rather than through mutual entrainment or  
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6 orchestration.  
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### 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  
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18 whether the task instructions were easy for participants to understand.  
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#### 23 24 **3.1. Participants** 25

26 Forty-seven community residents (19 women) participated in this pilot study.  
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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  
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32 stopped at the end of that academic quarter.  
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#### 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  
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56 with one partner was more synchronous than the other. Specifically, the mean asynchrony and  
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4 asynchrony range were 220 ms and  $\pm 110$  ms for the low-synchronous partner and 110 ms and  
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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.  
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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  
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18 (approximately 2 beats per second)]". In each experimental block, all three suggested tempos for  
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20 beat generation appeared twice (thus six trials in total), with the order randomly determined. The  
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22 variation of the suggested tempos was to investigate generalizability.  
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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  
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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.  
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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  
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54 manipulation objectively created two levels of synchrony, it was unclear whether participants  
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56 would subjectively map the difference in their experiences with the two partners on the  
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4 dimension of synchronicity. Given the apparent non-rhythmic nature of the synchronizer's task,  
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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.  
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### 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.  
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#### 34 3.3.2. Participants' behavioral performance

35  
36 To determine whether the participants' performance was influenced by the experimental  
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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 ( $F(1,46) = 0.24$ ,  $p = .63$ ,  $\eta^2_{\text{partial}} = .01$ ).  
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### 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

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4 production of the synchrony<sup>1</sup> and the synchrony was unrelated to their task performance. We  
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6 nevertheless found a significant effect on perceived synchrony and a stronger affiliative response  
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8 toward the synchronous than asynchronous partner. This suggests the effects of interpersonal  
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10 synchrony are not dependent on the synchrony being task-relevant or to the participant actually  
11  
12 contributing to the observed synchrony.  
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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.  
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##### 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  
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49 distributions with unique mean-range combinations obtained by crossing two levels of  
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51 asynchrony mean (120 ms versus 220 ms) with two levels of response latency ranges ( $\pm 10$  ms  
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59 <sup>1</sup> The computer algorithm used to manipulate the degree of synchrony ensured that the experimental manipulation of  
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61 synchrony was orthogonal to the participant's beat series.

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4 versus  $\pm 110$  ms). The order in which participants bexed with the four partners was manipulated  
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6 using a Latin Square design, yielding 10 different orders. As in the pilot study, the six items  
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8 measuring social affiliation exhibited a high level of internal consistency across all four  
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10 conditions ( $\alpha s > .97$ ) and hence were combined.  
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### 15 16 4.3. Results

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

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21 A 2 (Mean response latency: 120 ms or 220 ms) x 2 (Response latency range:  $\pm 10$  ms or  
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23  $\pm 110$  ms) x 2 (Gender) ANOVA was performed to determine whether the participant's (i.e.,  
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25 referent's) responses were influenced by their partner's behavior. No significant differences  
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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  
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31 response latency ( $F(1,39) = 0.006, p = .94, \eta^2_{\text{partial}} = 0$ ). The response latency range  
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33 manipulation, however, did affect the referents' tap-to-tap variability. Specifically, participants'  
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35 tap-to-tap variability was smaller when interacting with narrow-ranges partners ( $\pm 10$  ms) than  
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37 with broad-range partners ( $\pm 110$  ms) ( $M_s = 14.29$  ms and 82.34 ms, respectively;  $F(1,39)$   
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39  $= 162.1, p < .001, \eta^2_{\text{partial}} = .81$ ).  
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#### 48 4.3.2. Participants' perceived synchrony

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50 The perceived synchrony ratings were subjected to a 2 (Mean response latency: 120 ms  
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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.  
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56 Results indicated that both main effects were significant. Partners who responded with short  
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(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

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4 not influence the referents' tap-to-tap variability. Although the range (variability) of response  
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6 latencies did affect the referents' tap-to-tap variability, the participants' tapping responses were  
7  
8 not correlated with the perceived synchrony ( $r(40) = -0.22$ ,  $p = .17$ ) or affiliative responses  
9  
10 toward the partner ( $r(40) = -0.25$ ,  $p = .12$ ), suggesting that the social affiliation effect cannot be  
11  
12 explained by the effect of the experimental manipulation on the referents' tapping behavior.  
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14 These findings are generally consistent with prior research (Miles et al., 2009) in which  
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16 observers perceived higher levels of rapport between members of a dyad when the mean  
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18 temporal difference between their strides while they were walking decreased.  
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## 26 **5. Study III (Neuroimaging study)**

### 27 **5.1. Participants**

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31 A total of 16 volunteers (7 women) were recruited via e-mail and subsequently screened  
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33 and qualified with a follow-up telephone interview. All participants were right-handed, ranging  
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35 from 19–25 years old ( $M = 21.44$ ,  $SD = 1.63$ ), and were healthy with no medical history of  
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37 neurological, psychiatric or psychological disorders as ascertained by an anamnesis. Data from  
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39 three volunteers out of the 16 could not be included in the analyses because the volunteers did  
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41 not complete entirely the task as they were too slow and took too long during the instruction  
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43 periods in between bexting rounds. The design was self-paced, and those subjects appeared to  
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45 have trouble with the task and did not complete it before the set scanning time was complete (the  
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47 scanner had a finite period in which it could run for each scan). The final fMRI results, thus,  
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49 include 13 subjects.  
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### 58 **5.2. Experimental procedure**

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4 A similar procedure to the one described in the above behavioral study was used in this  
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6 neuroimaging study. The main difference was that stimuli were presented while the participants  
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8 were lying down in the scanner. Visual stimuli were projected from a PC located in the  
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10 experimenter room to a back projection screen located in the scanner room. Stimuli were viewed  
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12 using binocular goggles mounted on the head coil approximately 2 inches above the participants'  
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14 eyes.  
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19 The entire task consisted of five blocks. Four of the experimental blocks involved the  
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21 participant tapping at 1 Hz with an ostensible partner, and one block involved the participant  
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23 tapping at 1 Hz with no partner (self-pacing). This latter block was included in order to evaluate  
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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.  
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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  
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53 using the middle finger (moving to the left, selecting lower values) and ring finger (moving to  
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55 the right, selecting higher values), and the answer selection was done using the index finger.  
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4 Before performing the actual behavioral experimental task, the participants and  
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6 confederates (research assistants who did not participate in the study) performed a practice block  
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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  
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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  
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16 would then see during the experimental task were actually generated by a human partner.  
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18 Following the practice block, the participant was prepared for fMRI scanning, where they  
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20 performed the experimental task.  
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### 29 5.3. Magnetic resonance imaging recordings

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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  
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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  
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45 suppressed).  
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### 53 5.4. Functional image processing and analyses

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55 Image pre-processing and analyses were performed using Analysis of Functional  
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57 NeuroImages software (AFNI version AFNI\_2011\_12\_21\_1014, Medical College of  
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4 Wisconsin). For each subject, motion detection and correction were undertaken using a six-  
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6 parameter, rigid-body transformation. Functional images were co-registered and spatially  
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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  
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14 of the four experimental conditions were convolved with a gamma-variate waveform using the  
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16 AFNI program Waver, and the resulting model was fit voxelwise to preprocessed time-series  
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18 data with a linear least-squares model using the AFNI program 3dDeconvolve, generating a map  
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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)  
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30 stereotaxic coordinate space and interpolated to 3 mm<sup>3</sup> isometric voxels for group analysis.  
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39 Our fMRI analysis aimed to identify how regional brain activity was modulated by  
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41 differences in synchronous stimuli during a tapping-based interactive task compared to  
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43 asynchronous stimuli with a synchronizer. To this purpose, we first identified the brain regions  
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45 sensitive to differences in synchrony and asynchrony using a voxelwise 2 (task/response period)  
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47 x 2 (small/large range) x 2 (small/large lag) factorial ANOVA. Then, to assess the relationship  
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49 of these regions to corresponding perceptions of synchrony and feelings of social affiliation, we  
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51 correlated BOLD activity in each identified cluster with each respective behavioral measure.  
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56 The self-pacing blocks were modeled in the fMRI GLM and were not treated as residuals. In  
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4 terms of our contrasts, they were treated as regressors of non-interest. The cluster threshold was  
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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.  
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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.  
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## 50 51 **5.5. Results**

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

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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  $\pm 110$   
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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

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4 responding. Figure 2 and Table 5 display the main effects for Response Latency Range during  
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6 the experimental tapping task. The synchrony minus asynchrony contrast revealed a significant  
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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)  
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12 parahippocampal gyrus extending to the amygdala and iii) the ventro-medial prefrontal cortex  
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14 (vmPFC) and anterior cingulate cortex (ACC; Table 5). No significant results were found for  
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16 which asynchronous stimuli elicited a larger BOLD response than synchronous stimuli.  
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### 23 *Correlation analyses*

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26 Correlational analyses were first performed between the participants' ratings and each of  
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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,  $t(11) = 2.84$ ;  $p = 0.016$ ;  $R$   
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34  $= 0.65$ , and feelings of social affiliation,  $t(11) = 2.44$ ,  $p = 0.03$ ;  $R = 0.59$ ; Figure 3).  
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39 Next, whole-brain voxelwise correlation analyses were performed between the dBOLD  
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41 and the corresponding differences between conditions in perceived synchrony. Results revealed a  
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43 positive correlation in the right cerebellar tonsil, and negative correlations in the right anterior  
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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  
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51 change of the synchronous and asynchronous conditions separately for the two groups (see  
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56 Figure 4C).

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4 Similar negative correlations were observed for the feelings of affiliation in the right  
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6 lingual gyrus, and right inferior parietal lobule (Figure 5A & B, Table 7). We again calculated a  
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8 median split and analyzed the percent signal change of the synchronous and asynchronous  
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10 conditions separately for the two groups (Figure 5C).  
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## 15 16 **6. Discussion**

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19 In the present series of three studies, we first sought to experimentally investigate an  
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21 individual's *social perceptions* of a partner who responds in a more or less synchronous fashion  
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23 in a unilateral entrainment paradigm. Behavioral results across all three studies revealed that  
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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  
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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  
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37 synchronously rather than asynchronously, even though all partners (actually, a programmed  
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39 series of responses) performed the assigned experimental task equally well.  
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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  
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50 studies using orchestration or reciprocal synchrony paradigms (cf. Bernieri, 1988, Tickle-Dengen  
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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;  
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56 Vacharkulksemsuk and Fredrickson, 2012) or in studies using mimicry (e.g., van Baaren,  
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4 Holland, Steenaert, and van Knippenberg, 2003; Maddux, Mullen, and Galinsky, 2008; van  
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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  
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12 when they are not aware of it. Like mimicry, interpersonal synchrony increases the social  
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14 connection felt between individuals through an automatic process of “mimicry” that is described  
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16 in the literature as a “by-product in interaction” (e.g., Chartrand and Bargh, 1999; van Baaren et  
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18 al., 2009). This process is in line with a large body of evidence suggesting that the affiliative  
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20 effects are not dependent on an individual’s awareness of the interpersonal synchrony (e.g., see  
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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  
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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  
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32 individuals and interpersonal mimicry refers to the similarity in form of the actions between  
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34 individuals, they both feature similarities in the temporal alignment of the actions and in their  
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36 social consequences (Semin and Cacioppo, 2009; Cacioppo and Cacioppo, 2012). As illustrated  
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38 by the social cognition model (from Semin and Cacioppo, 2009), synchronization and mimicry  
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40 are “time-locked to the observed stimulus.” Like mimicry, interpersonal synchrony also  
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42 increases the social connection felt between individuals.  
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53 Our fMRI results extend these behavioral results by revealing the recruitment of brain  
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55 areas involved in social cognition, embodied cognition, self—other information processing, and  
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57 action observation as correlates of interpersonal synchrony (vs. asynchrony). More precisely, the  
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4 synchrony minus asynchrony contrast revealed greater response in three brain regions: i) left IPL  
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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)  
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10 extending to the anterior cingulate cortex. No significant results were found for which  
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12 asynchronous stimuli elicited a larger BOLD response than synchronous stimuli.  
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16 The recruitment of BA 40 is consistent with previous studies showing the recruitment of  
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18 this brain region while participants integrate visuo-motor information during observation and  
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20 evaluation of actions (Grafton et al., 1996; Rizzolatti and Craighero, 2004; Desmurget et al.,  
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22 2009; Grafton, 2009; Ortigue et al., 2009, 2010) and perception of elementary mechanical  
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24 causality events (Blakemore et al., 2001). This action observation brain system is also known to  
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26 sustain embodied cognitive mechanisms, meta-representation of the bodily self, detection of  
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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  
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32 and imagined actions (e.g., inferior parietal lobule; Grafton et al., 1996; Shimada et al., 2005;  
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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  
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48 embodied mechanisms are not a pre-requisite to act, connect or understand others, embodied  
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50 behaviors offer new ways to investigate social perception, cognition, and behavior (e.g., Semin  
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4 and Smith, 2002; Semin and Cacioppo, 2009; Cacioppo and Cacioppo, 2012). In line with Aron  
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6 and Aron's (1986) self-expansion model which posits that others toward whom one feels a close  
7  
8 social bond can be incorporated into the representation of one's self, and the relational model of  
9  
10 communal sharing and cognitive interdependence (see Fiske, 2004; Smith, 2007; IJzerman and  
11  
12 Semin, 2010; ]Cacioppo and Cacioppo, 2012).

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16 Differences in activation were also found in the parahippocampal area—a region shown  
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18 previously to be involved in temporal discrimination and interval comparison (Harrington et al.,  
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20 2002), and learning of adaptive events (Fairhurst et al., 2013; Grossberg, 2013). These findings  
21  
22 are in line with adaptive resonance theory, a cognitive and neural theory of how the brain  
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24 automatically learns to identify, categorize, and predict events in a changing world (Grossberg,  
25  
26 2013).

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31 Finally, several investigators have found the ventral part of the medial PFC is relatively  
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33 activated when processing information about the self or similar others, whereas the dorsal part of  
34  
35 the medial PFC is relatively activated when processing information about others (Mitchell et al.,  
36  
37 2005; Amodio and Frith, 2006; Keysers and Gazzola, 2007; Epley et al., 2009). Consistent with  
38  
39 synchrony increasing the perception of similarity, Fairhurst et al. (2013) found greater activity in  
40  
41 the vmPFC region when participants were in relative synchrony with a virtual partner. We also  
42  
43 found greater activity in the vmPFC in the synchronous than asynchronous condition, and  
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45 correlational analyses further revealed that the greater the difference in the BOLD signal in the  
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47 vmPFC between the synchronous and asynchronous conditions, the greater the corresponding  
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49 difference in the ratings of perceived synchrony and affiliation.

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



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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  
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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  
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18 asynchronous partner. This pattern was reversed and weaker in participants who perceived  
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20 relatively little difference in synchrony between their synchronous and asynchronous partners.  
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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  
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30 synchronous partner as being more similar to themselves and thought about the asynchronous  
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32 partner as being more dissimilar to themselves, than the participants who less distinguished  
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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  
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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  
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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  
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46 but is not rated as being synchronous who may evoke greater attention and mentalizing to  
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48 understand and predict. Consistent with this reasoning, the correlational analyses between the  
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50 BOLD differential synchrony scores (dBOLD: synchrony minus asynchrony) and reported  
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52 feelings of perceived synchrony revealed negative correlations for the right lateral prefrontal  
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4 cortex (BA 46), the right lingual gyrus (BA18/19), and the right middle occipital gyrus (BA 19;  
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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  
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14 when the participants whose ratings of perceived synchrony most distinguished between the  
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16 conditions were performing with a synchronous partner and the highest levels of activation when  
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18 these participants were performing with an asynchronous partner, whereas this pattern was  
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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  
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24 differences between their synchronous and asynchronous partners and show evidence of relative  
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26 vmPFC activation and self-other overlap with the synchronous partner, it is the asynchronous  
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28 partner who activates brain regions involved in attention, visual discrimination, and cognitive  
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30 control, whereas for participants who see relatively little difference between these partners in  
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32 terms of perceived synchrony and show little difference in vmPFC activation and little self-other  
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34 overlap with the synchronous partner, it is the synchronous partner who activates these regions  
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36 more than the asynchronous partner.  
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46 For the participants who show relatively large differences in perceived synchrony across  
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48 conditions (and relatively large differences in vmPFC activity), the assimilation of the  
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50 synchronous (in contrast to the asynchronous) partner to the self should result in the application  
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52 of an abstract trait representation of the self to the synchronous partner, thereby diminishing the  
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54 need for continued attention and mentalizing. For the participants who show relatively little  
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56 difference in perceived synchrony across conditions (and relatively small differences in vmPFC  
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4 activity), both the synchronous and the asynchronous partner may be regarded as dissimilar  
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6 others; as such, the temporal aspects of the asynchronous partner's behavior would be congruent  
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8 with the abstract trait inference that this partner is dissimilar (e.g., outgroup homogeneity) and  
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10 may therefore elicit little additional attention or mentalizing, whereas the temporal aspects of the  
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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  
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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  
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22 being formed (and attention, cognitive control, and mentalizing being truncated) for synchronous  
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24 partners in the former group of participants and for asynchronous partners in the latter group of  
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26 participants.  
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33 Finally, whole brain correlational analyses based on differences in reported feelings of  
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35 affiliation for synchronous versus asynchronous partners, two regions emerged: the right lingual  
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37 gyrus (BA 19) and in the inferior parietal/supramarginal gyrus (BA 40; see Figure 5). As noted  
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39 above, the right lingual gyrus is involved in third person perspective taking, and the inferior  
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41 parietal/supramarginal gyrus is involved in sensorimotor mirroring. These results suggest that  
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43 for participants who perceive the synchronous partner as relatively more likable than the  
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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  
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49 participants who perceive the synchronous and asynchronous partners as being more equivalent  
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51 in likability, these regions are more active when the partner's behavior is synchronous rather  
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53 than asynchronous.  
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4           Limitations of the current study include the exploratory nature of the correlational  
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6 analyses and the relatively small sample size of the fMRI study in contrast to the behavioral  
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8 studies. Among the strengths of the current paradigm is the experimental control that it affords.  
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10 For instance, rather than relying on natural variations in synchrony between two participants, the  
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12 current paradigm permits the temporal parameters used to experimentally manipulate  
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14 interpersonal synchrony to be standardized and precisely controlled using computer programs.  
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16 Second, the task does not require face-to-face interactions, so characteristics of the ostensible  
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18 partner (e.g., age, gender, attractiveness, group identity) that may prove to be moderator  
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20 variables can be experimentally controlled. Third, participants can be an actor (e.g., trials on  
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22 which participants bext with a partner) or an observer (e.g., trials on which they watch two  
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24 partners bext), making it possible to examine the observational effects of interpersonal  
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26 synchrony. Finally, the task involves minimal movement (finger tapping) so that the bexting  
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28 paradigm can be used in neuroimaging studies.  
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### 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.

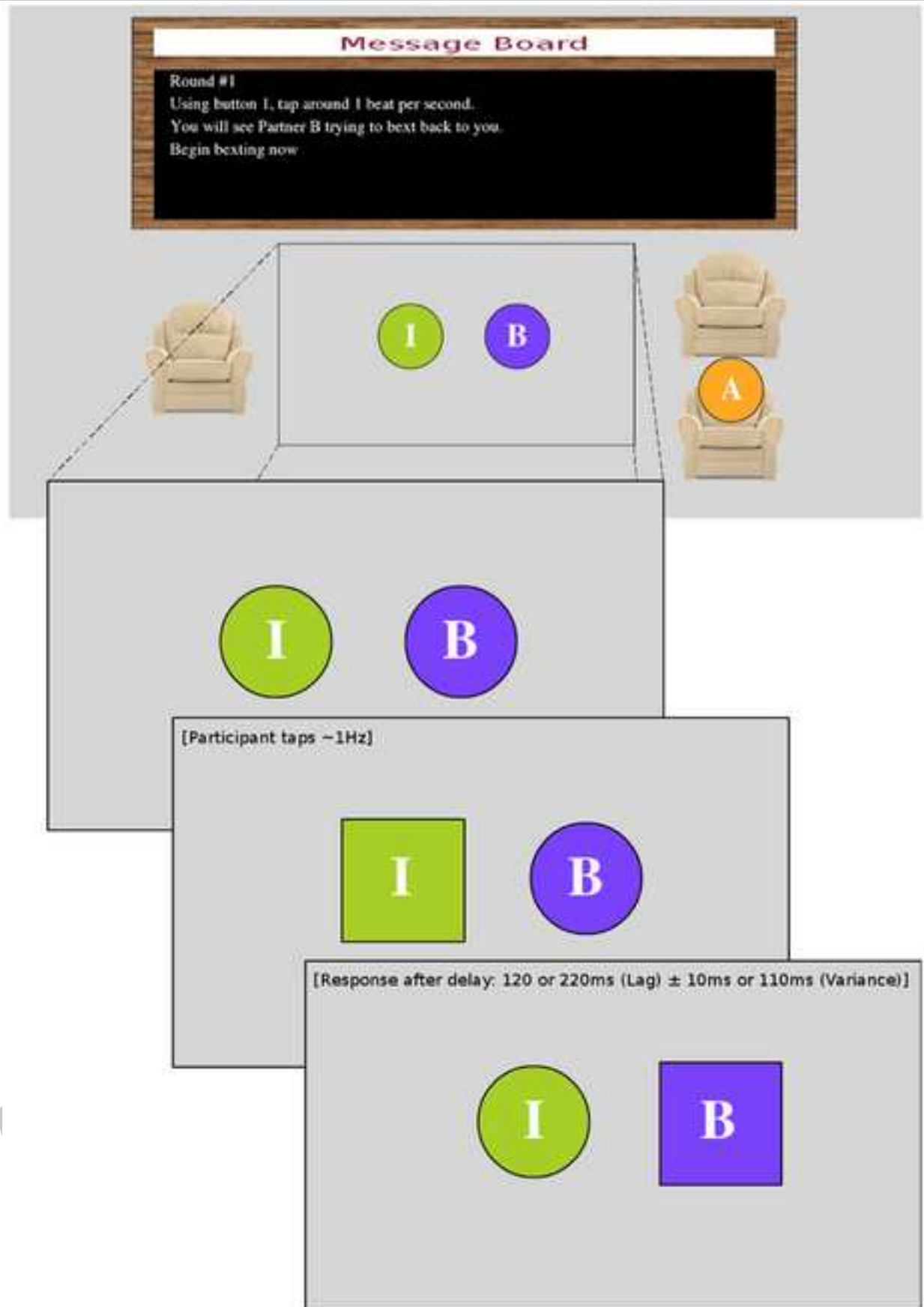
Figure 3. Correlations between neural activity and behavioral measures in the ventromedial prefrontal cortex (vmPFC). The BOLD effect for synchrony found in vmPFC (see Figure 2) significantly correlated with measures of perceived synchrony and feelings of affiliation. The ordinate indicates behavioral 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

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4 synchrony projected onto a slice from the MNI atlas (left,  $z = -42$ ) and mapped on the Caret  
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6 AFNI Colin brain right hemisphere, lateral view (center) and medial view (right). B. Scatter  
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8 plots for each respective cluster, from left to right: cerebellar tonsil, right middle occipital gyrus  
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10 (BA 19), right lateral prefrontal cortex (BA 46), dorsomedial prefrontal cortex (BA 9), and right  
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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  $\alpha < .05$ .  
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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.  
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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  
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36 behavioral median. Results were obtained with a voxelwise cluster threshold of  $p < .025$ ,  
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38 corrected for multiple comparisons to  $\alpha < .05$ .  
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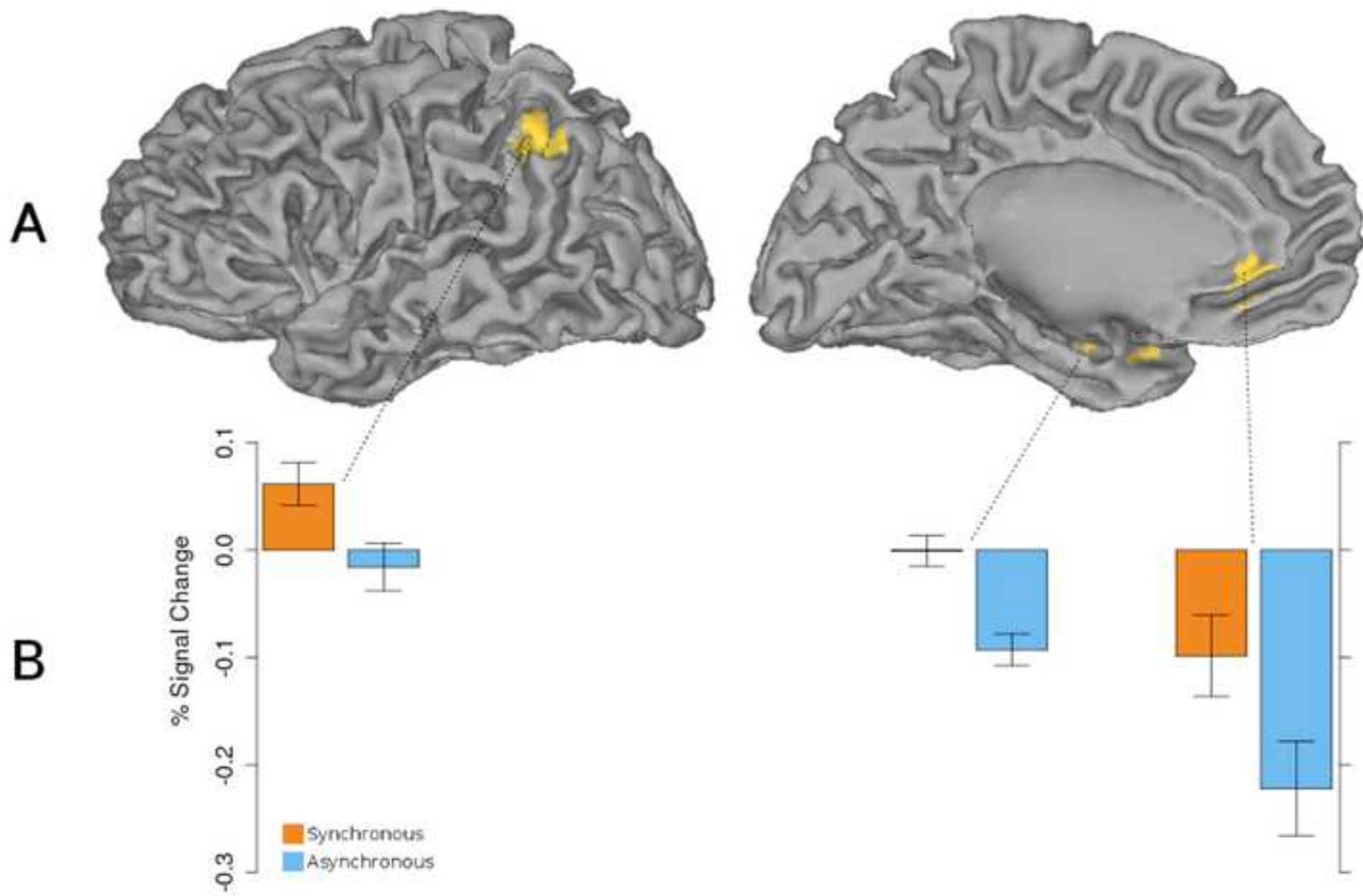
Figure 1

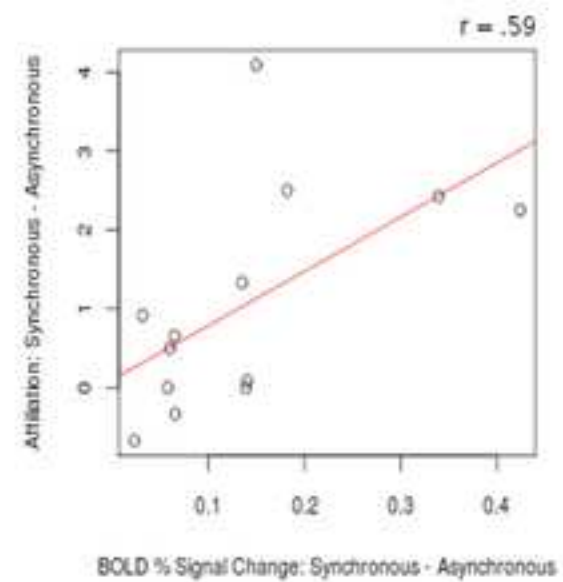
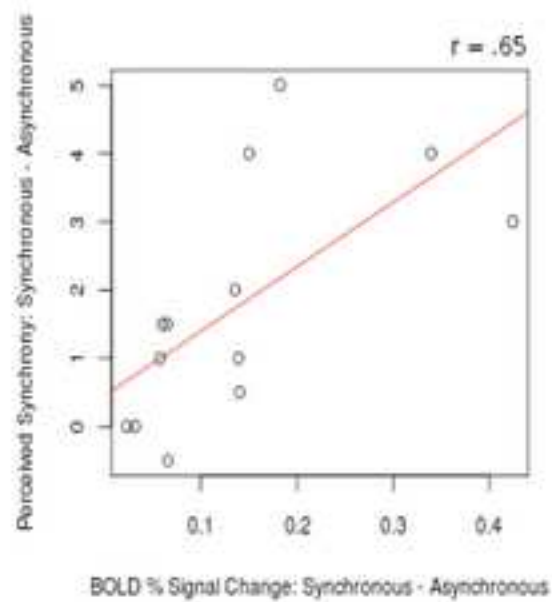
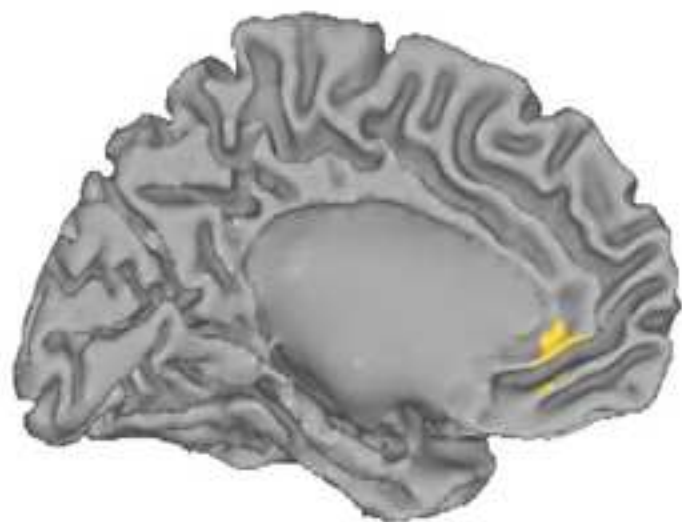


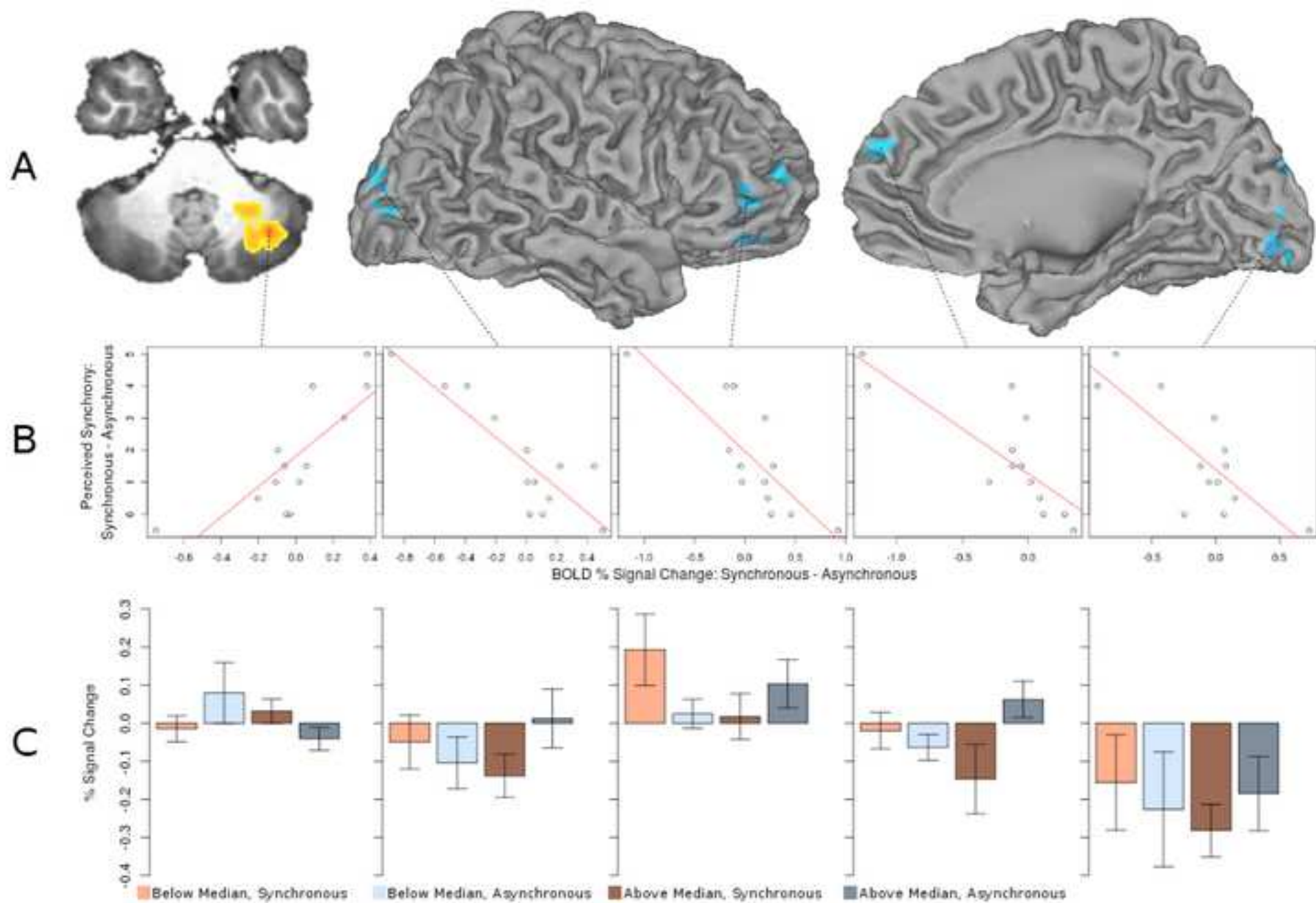
8s Bexting Block











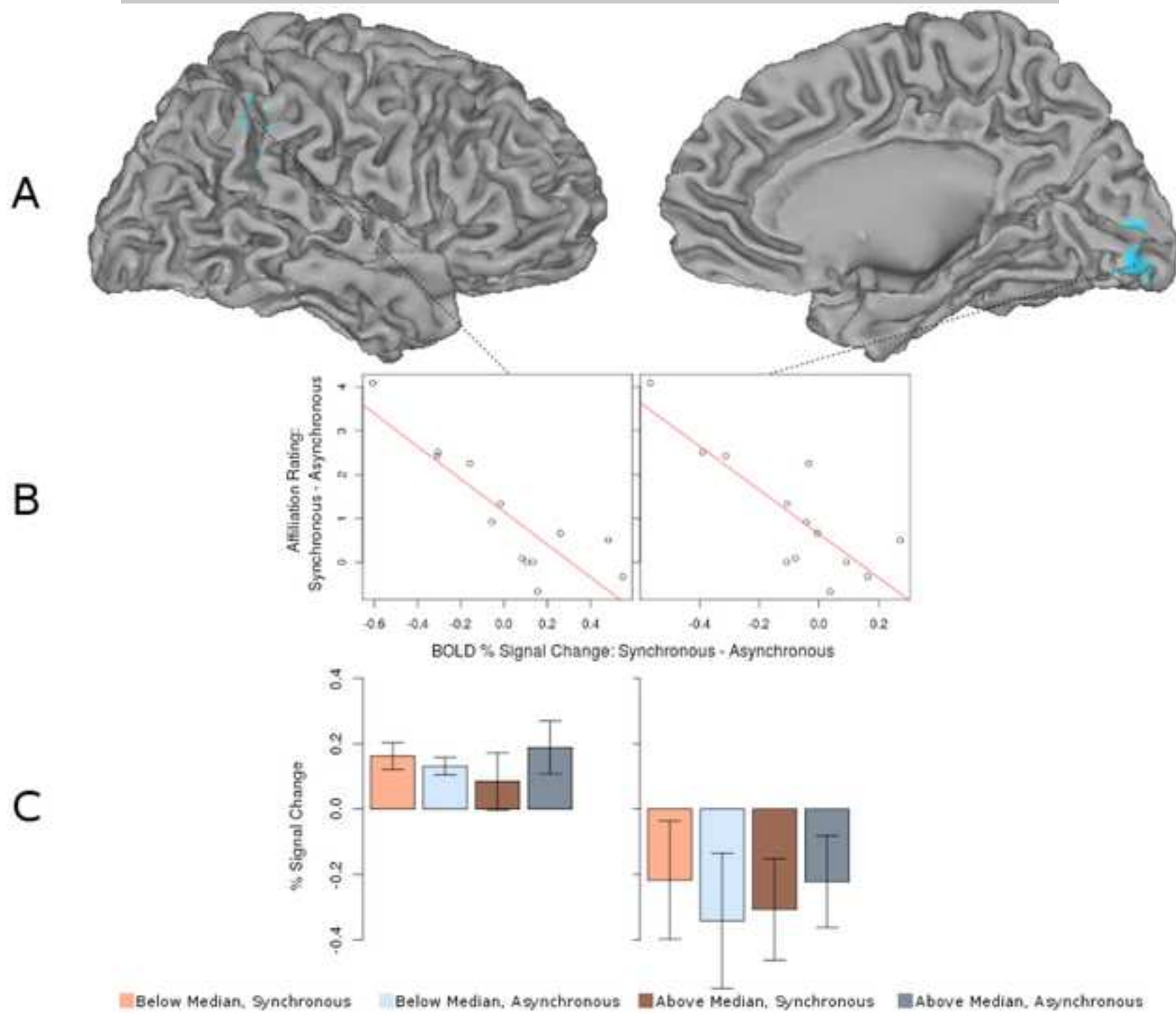


Table 1. Feelings of perceived synchrony with an adaptive partner

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.

ACCEPTED MANUSCRIPT