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**Why Do We Fall into Sync with Others? Interpersonal Synchronization and the Brain's
Optimization Principle**

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Abstract

Spontaneous interpersonal synchronization of rhythmic behavior such as gait or clapping is a ubiquitous phenomenon in human interactions, and is potentially important for social relationships and action understanding. Although several authors have suggested a role of the mirror neuron system in interpersonal coupling, the underlying brain mechanisms are not well understood. Here we argue that more general theories of neural computations, namely predictive coding and the Free Energy Principle, could explain interpersonal coordination dynamics. Each brain minimizes coding costs by reducing the mismatch between the representations of observed and own motor behavior. Continuous mutual prediction and alignment result in an overall minimization of free energy, thus forming a stable attractor state.

Keywords

Social interaction; prediction; optimization; social bonding; synchronization

Introduction

Arriving at the airport and rushing from the gate to the exit with the crowd from the plane, my boots go clack-clack-clack... - and then I realize that my steps, and those of the strangers walking next to me are perfectly synchronized, at least until the very moment I notice it. How do we get in such perfect synchronization with others, sometimes with complete strangers, and why?

Thus far, individual brains and social cognition have been mostly studied in isolation. Recently, several authors have called for understanding cognition and brain function from a framework that assumes multiple interacting brains, arguing that mechanisms underlying social cognition are fundamentally different during interaction as opposed to typical social observation-based experiments (Hasson & Frith, 2016; Schilbach et al., 2013). Consequently, studying the neural underpinnings of multi-person interactions has become increasingly popular (for reviews see Hasson, Ghazanfar, Galantucci, Garrod, & Keysers, 2012; Keller, Novembre, & Hove, 2014; Konvalinka & Roepstorff, 2012; Sanger, Lindenberger, & Muller, 2011; Schilbach et al., 2013; Tognoli & Kelso, 2015).

One of the most fascinating areas of investigation concerns ‘interpersonal coordination’, and in particular ‘synchronization’, with its purported links to different aspects of relationship and social behavior. As opposed to social *coordination*, which we use as a more general term for mutual behavioral or physiological adjustments in social interactions, *synchronization* is more specifically defined as the “adjustment of rhythms of self-sustained periodic oscillators” as a result of their weak interaction with each other, in terms of their phase and frequency locking (Boker & Laurenceau, 2007; Helm, Sbarra, & Ferrer, 2012; Pikovsky & Rosenblum, 2007). Spontaneous synchronization is a widespread and fascinating phenomenon found in non-

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biological oscillators such as swinging pendulum clocks, which become coupled via the small movements of the clocks' common support frame (Bennett, Schatz, Rockwood, & Wiesenfeld, 2002), as well as in biological systems such as fireflies and neural cell assemblies (Glass, 2001; Strogatz, 2004). Similarly, *spontaneous* synchronization of rhythmic motor behavior between two or more interacting individuals has been shown across a wide range of movements and effectors, leading to the emergence of social coordination dynamics as a growing area of research (Oullier, de Guzman, Jantzen, Lagarde, & Kelso, 2008; Tognoli & Kelso, 2015).

While interpersonal motor and physiological synchronization have evoked great interest recently (Dumas, Nadel, Soussignan, Martinerie, & Garnero, 2010; Hasson & Frith, 2016; Konvalinka et al., 2011; Müller & Lindenberger, 2011; Noy, Dekel, & Alon, 2011; Palumbo et al., 2016), plausible computational or mechanistic accounts of behavioral synchronization have been explored less, and an explanatory account that bridges the social system level with the underlying brain functions is still lacking (Hasson & Frith, 2016; Keller et al., 2014; Konvalinka & Roepstorff, 2012). Human interpersonal synchronization can be both spontaneous (unintentional) and intentional. Intentional synchronization refers to instances where motor synchronization is intended or instructed, for example during military marching or when singing and playing music together (Keller et al., 2014). Here we focus especially on the putative brain mechanisms of *spontaneous* motor synchronization (for a model of intentional synchronization, see Keller et al., 2014). Spontaneous motor synchronization is typically consciously accessible (e.g., becoming aware that gait is synchronized), but often happens without conscious awareness, thus people don't need to intend or be aware for synchronization to occur (Néda, Ravasz, Brechet, Vicsek, & Barabási, 2000). We argue that the general principle of optimization in neural computation, such as the reduction of prediction errors, could explain spontaneous motor

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synchronization between individuals. Simply put, being in sync with other social agents might be computationally more efficient.

We first briefly review findings on social synchronization and its bidirectional links to social and affective factors. We then introduce basic principles of optimization to develop the idea that synchronization of motor behavior is computationally more efficient and energetically less costly, and therefore arises automatically.

Bodies in sync

A pioneering study (Schmidt, Carello, & Turvey, 1990) showed that two persons sitting next to each other spontaneously synchronized the swinging of their legs, generalizing the dynamical principles of intrapersonal coordination (such as bilateral leg swinging) to the interpersonal domain. The finding of spontaneous interpersonal motor synchronization has since been replicated in different settings such as joint pendulum swinging (Schmidt & O'Brien, 1997), hand clapping during concerts (Néda et al., 2000), human gait coordination (Nessler & Gilliland, 2009), finger movement (Oullier et al., 2008), and people sitting next to each other in rocking chairs (Richardson, Marsh, Isenhower, Goodman, & Schmidt, 2007).

Much of this previous work has grounded spontaneous interpersonal synchronization in a coordination dynamics framework, showing that when engaging in intra- and interpersonal temporal synchronization, two stable states emerge, in-phase and anti-phase synchronization, as predicted by the Haken-Kelso-Bunz (HKB) model (Haken, Kelso, & Bunz, 1985). While much work has been done to understand spontaneous interpersonal coordination as a self-organizing phenomenon (Schmidt & Richardson, 2008), whereby degrees of freedom of people's movement systems become coupled, hence establishing interpersonal synergies (Riley, Richardson,

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Shockley, & Ramenzoni, 2011), the brain mechanisms underlying this phenomenon remain poorly understood.

Unlike physical systems such as coupled pendulums, in the case of interpersonal synchronization, information is exchanged via direct or technically mediated perceptual links (e.g. online video display, auditory coupling). In experimental settings where no direct haptic, visual, or auditory perception of the other person's movement is possible (i.e. eyes and ears closed), synchronization does not occur, indicating that perception constitutes the coupling medium and hence perceptual information transfer is crucial for interpersonal motor synchronization (Oullier et al., 2008; Repp & Su, 2013; Schmidt et al., 1990; Schmidt & O'Brien, 1997). Evidence also suggests that information about the other person must not only be perceived, but also attended to, for maximal synchronization to be achieved (Richardson et al., 2007). Taken together, this shows that interpersonal motor synchronization cannot be explained purely on the level of the agents' musculoskeletal systems or based on bodily constraints (as sufficient in the case of swinging pendulums and other non-biological oscillators), but happens on the basis of interpersonal information exchange (Repp & Su, 2013; Schmidt et al., 1990). Thus, interpersonal synchronization must be linked to brain processes of action and perception.

Links Between Social-Affective Factors and Interpersonal Synchronization

One reason for the increased interest in social synchronization is its link to aspects of relationship and bonding (reviewed recently by Hasson et al., 2012; Keller et al., 2014). Interpersonal synchronization might be a desirable state between people (Müller & Lindenberger, 2014) and has been associated with activity in reward-processing brain regions such as the ventral striatum (Kokal, Engel, Kirschner, & Keysers, 2011). It has been

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demonstrated that synchronized behavior fosters cooperation (Kokal et al., 2011; Wiltermuth & Heath, 2009) and promotes rapport between people (Bernieri, 1988), and conversely, strong relational ties modulate physiological synchronization (Konvalinka et al., 2011). Consequently, various authors have suggested that synchronization might be functionally important for affiliation, bonding, and group cohesion, potentially by merging representations of self and others (Chartrand & Bargh, 1999; Cohen, Ejsmond-Frey, Knight, & Dunbar, 2010; Hove & Risen, 2009; Konvalinka et al., 2011; Miles, Lumsden, Richardson, & Neil Macrae, 2011; Wiltermuth & Heath, 2009). Others have pointed at a possible functional role of behavioral coordination and synchronization in predicting others' behavior and for successful joint action and communication (Hasson & Frith, 2016; Keller et al., 2014; Sanger et al., 2011; Sebanz, Bekkering, & Knoblich, 2006; Wilson & Knoblich, 2005).

We note that the direction of causality can plausibly be inverted (Keller et al., 2014). Closer relationship, cooperation, or more interactive settings could increase the attention paid to the other's behavior, thereby enhancing the representation of their motor behavior (e.g., Koban, Pourtois, Vocat, & Vuilleumier, 2010). Individual differences in social value orientation have an impact on the extent of synchronization (Miles et al., 2011). Recent findings suggest that synchronization also can lead to more negative forms of social influence, e.g. by increasing the likelihood to comply with a partner's request or to aggress towards third persons (Wiltermuth, 2012). Synchronization therefore seems to enhance relationship-specific cohesion, not pro-social behavior in a general way (Wiltermuth, 2012), though there is some evidence to suggest otherwise (Reddish, Bulbulia, Fischer, 2014).

Potential Neurocomputational Mechanisms Underlying Behavioral Synchronization

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Various authors (Hasson & Frith, 2016; Macrae, Duffy, Miles, & Lawrence, 2008; Oullier et al., 2008; Tognoli, Lagarde, DeGuzman, & Kelso, 2007) have suggested that the mirror neuron system may help explain how humans synchronize their motor behavior. Putative mirror neurons code for both an agent's executed actions as well as observed actions in macaque monkeys (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996), and several studies have suggested a corresponding putative "mirror neuron system" in humans (Gallese, Keysers, & Rizzolatti, 2004; Mukamel, Ekstrom, Kaplan, Iacoboni, & Fried, 2010). This system has therefore been suggested to provide a common coding scheme for self-generated actions and perception of multiple agents' actions, subserving understanding of other individuals' actions and intentions (Gallese et al., 2004; Rizzolatti, Fogassi, & Gallese, 2001), which could be a basic mechanism underlying social motor synchronization.

Several studies have used neurophysiological measures to directly address the question of the brain mechanisms underlying synchronized versus non-synchronized social motor behavior. Tognoli and colleagues (2007) measured the EEG signals of two participants during phases of spontaneous synchronization and desynchronization in a finger movement task. Two frequency peaks in the alpha range (Phi1 and Phi2, 10-12 Hz), located over the centro-parietal cortex, were specifically enhanced for desynchronized and synchronized finger movement, respectively. Numerous studies since have investigated inter-brain mechanisms during various coordination tasks (for reviews see Dumas, Lachat, Martinerie, Nadel, & George, 2011; Konvalinka & Roepstorff, 2012). In particular, inter-brain synchronization has been reported in the alpha band over centroparietal regions of two participants when they engaged in synchronized behavior (Dumas et al., 2010), regions previously identified to play a role in social coordination. A more recent study by Szymanski and colleagues (2017) has also reported increased inter-brain phase

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synchronization during joint versus individual attention, and found an association between inter-brain synchronization and team performance. This suggests that inter-brain phase synchronization may be a functional mechanism underlying interpersonal motor synchronization, and importantly, may have a role in facilitating joint attention, which is necessary for intentional interpersonal synchronization to occur. However, it is still debated whether synchronized brain activity is causally related to synchronized motor behavior and if so, in which direction. Recent evidence that has investigated the causality between inter-brain and interpersonal motor synchronization suggests that inter-brain in-phase synchronization (but not anti-phase) in the beta frequency across motor cortices enhances interpersonal motor synchronization (Novembre, Knoblich, Dunne, & Keller, 2017). Whether there is a general tendency for brains to synchronize their activity to each other, and this is a necessary precondition for interpersonal coordination remains an open question. We note that it is hard to imagine a physical mechanism by which brains can synchronize with each other if there is no feedback via perceptual and motor interactions between the individuals involved.

Additional insight comes from recent studies that investigated brain activity associated with following versus leading behavior in motor synchronization. Konvalinka et al (2014) demonstrated stronger right frontal EEG alpha suppression in leaders compared to followers during synchronized finger tapping. Leaders in this study were defined as people who were less adaptive than their interactive partner. Given that the participants did not receive auditory feedback of self-produced taps, the leaders had to inhibit feedback of their partners' taps and increase monitoring of self-produced behavior, in order to take the lead. An fMRI study by Fairhurst, Janata, and Keller (2014) similarly found evidence for increased right prefrontal activity when perceiving leadership over an overly adaptive virtual partner. Together, these

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findings raise the possibility that leading at one's own rhythm (instead of following) requires inhibition of the representation of the other's motor action, or alternatively enhancement of the representation of one's own actions, and therefore is associated with *increased* effort and need for cognitive control. These findings support the notion that decoupling one's own actions from another's, and hence weakening the interpersonal synchronization, is more effortful and less rewarding than falling into sync with another (Kokal et al., 2011; Schilbach et al., 2009).

Further evidence for this point comes from a behavioral study on joint rhythmic improvisation (Noy et al., 2011), which provides important insight into the potential mechanisms underlying behavioral synchronization. By comparing leader-follower interactions (unilateral imitation) with joint improvisation (mutual imitation), the authors showed that the latter condition resulted in more precise and smoother synchronization of highly complex rhythms, with less jitter than in the leader-follower interactions. This result is in line with the idea that mutual following is more efficient and less effortful than unilateral leading. Noy et al. (2011) extended their empirical findings with models of either a single or two coupled reactive-predictive control units. These units were designed to match their motor output to the (perceptual) input signal. The two-controller model, in which the output of the first constitutes the input of the second unit (and vice versa), yielded the best synchronization, corresponding to the joint improvisation condition.

Noy et al. (2011) did not interpret their findings in terms of putative neural mechanisms, but building upon previous suggestions (Macrae et al., 2008; Miles et al., 2011; Oullier et al., 2008; Tognoli et al., 2007), we hypothesize that their two-controller-model may potentially be implemented by mechanisms that compare and match an individual's own motor representation with the internal representation of another person's behavior (for a similar idea, c.f. Sängler et al.,

2011).

More support for merging of self-other representations on the neural level during synchronized action comes from a joint speaking study by Jasmin and colleagues (2016), which showed that when people engaged in synchronized and live speech with another person (which may be seen in chanting or prayers), the suppression of their auditory cortices, a marker of self-produced speech, diminished. This suggests that they processed self-produced speech as if it were produced by another, hence merging self-other representations.

However, this does not yet fully answer the question of why these two representations would be matched and aligned spontaneously, as seen in the large body of evidence on *spontaneously* emerging behavioral synchronization. We reason that better explanatory purchase could be obtained by focusing on the underlying neural computations. We propose that the brain's tendency for computational optimization may provide a plausible explanation.

Optimization Rules

Optimization and energy efficiency are central organizing principles of brain structure and function (Laughlin & Sejnowski, 2003). Optimization refers to the selection of the best possible element from a set of alternatives. In mathematical terms, optimization is achieved by maximizing or minimizing a pertinent quantity. A popular example of this would be the 'traveling salesman problem' (Applegate, Bixby, Chvátal, & Cook, 2006) in which a hypothetical salesman needs to find the shortest route to visit each city on a list exactly once (i.e. the most efficient route among several possible ones) before returning to the point of origin. There are several approaches to brain function that invoke optimization (Laughlin & Sejnowski, 2003). In this context optimization is achieved through the systematic reduction in discrepancy

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between a quantity computed/predicted by the brain and its actual value. Examples include reinforcement learning (Daw, Niv, & Dayan, 2005; Schultz, 2006), sensorimotor control (Todorov, 2004) and perceptual learning through predictive coding (Rao & Ballard, 1999). The minimization of reward prediction errors (actual reward – expected reward) in temporal-difference algorithms applied to study dopaminergic neurons in the striatum (Schultz, 2006), error minimization in models of motor control in the cerebellum (Dean, Porrill, & Stone, 2002), and minimization of response conflict in models of cognitive control (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Silvetti, Alexander, Verguts, & Brown, 2013) all facilitate optimization.

Friston (2010) expands upon this insight to propose a unified view of brain function with optimization at its core. In this framework, learning and control are viewed as processes that converge on optimal ways of representing the world and acting upon it, through a process of active inference. Percepts are optimized to correspond better to the physical environment, and actions are performed to both help refine percepts and to mine the environment for rewards. This is consistent with the actor-critic approach in reinforcement learning theory (Sutton & Barto, 1998) as well as Bayesian theories of cognition and control (Friston, Mattout, & Kilner, 2011; Knill & Pouget, 2004). More recently this “free-energy principle” has been proposed as a candidate neuronal gauge theory (Sengupta, Tozzi, Cooray, Douglas & Friston, 2016). The key idea here is that the minimization of variational free-energy (which bounds surprise) is invariant across scales of investigation (Sengupta, Tozzi, Cooray, Douglas, & Friston, 2016). If this were indeed a gauge-invariant principle of brain function, then it would be interesting to test whether it holds on an interpersonal level. Engaging with this hypothesis leads to interesting implications for interacting social agents and might offer a plausible mechanism to explain spontaneous as well as intentional interpersonal synchronization.

Putting the Pieces Together

As discussed above, brains possess the machinery and tendency to optimize the representations of their environments (Friston, 2010). This environment often includes other brains and the behaviors they generate. Viewed in the light of the optimization principle, we surmise that the phenomenon of interpersonal motor synchronization occurs due to the tendency of brains to conserve computational resources (Laughlin & Sejnowski, 2003), thereby resulting in nearness of self and other representations. For example, spontaneous synchronized clapping after watching a good performance is achieved by audience members doubling their clapping periods (Neda et al., 2000), even at the expense of overall noise intensity (expected to reflect enthusiasm), which becomes lower as a result. This behavior could emerge out of an implicit desire for synchronization, or because the brain is optimizing energy, and hence minimizing both behavioral effort and differences in self/other representations. In other words, synchronized behavior results in *synchronized neural representations* for self- and other-generated behavior, which are reinforced as they are in line with the brain's general tendency to compress information and to reduce prediction errors (Friston, 2010; Laughlin & Sejnowski, 2003). This idea is also in line with the theory of coupled linear oscillators (Boker & Laurenceau, 2007), but importantly, we argue that this coupling and the resulting optimization of energy emerge at the level of synchronized *neural* representations for self- and other.

This proposed mechanism of interpersonal synchronization due to a general optimization principle could potentially be extended to account for higher-order phenomena as well. If spontaneous synchronization of motor behaviors is due to optimization of pertinent representations in interacting brains, then behavioral alignment in more complex social

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interactions, such as similar language use (Hasson & Frith, 2016) and joint action (Sebanz et al., 2006) may also be governed by this principle acting at different timescales. Future studies could investigate the relationships of spontaneous motor synchronization with these and other high-level social phenomena, such as conformity, social influence, or empathy.

Several testable predictions emerge from this proposal. We hypothesize that social prediction-error brain signals (e.g. in anterior cingulate or anterior insula cortex, Apps, Rushworth, & Chang, 2016; Koban & Pourtois, 2014; Silvetti et al., 2013) in interacting partners would decrease with increased synchronization and vice versa. Further, we predict that spontaneous synchronization (e.g. in gait, or hand clapping) is associated with less effort and energy consumption, and is therefore rewarding, which might offer one explanation for its link to increased positive affect. We also predict, that high cognitive load (such as during a demanding working memory task during hand clapping or walking together) would further push interacting individuals towards interpersonal synchronization.

Relationship to Other Accounts of Interpersonal Synchronization

Our contribution to the study of interpersonal synchronization is a hypothesis regarding the neuro-computational mechanisms at play in such interactions. Here we examine how this hypothesis relates to existing theoretical views on interpersonal synchronization.

The dynamical systems approach has yielded models of interpersonal synchronization in the behavioral domain (Dumas, de Guzman, Tognoli, & Kelso, 2014; Haken et al., 1985; Riley et al., 2011; Schmidt & Richardson, 2008). From the coordination dynamics perspective, interpersonal synchronization is an instance of coordination constrained by physical laws governing coupled oscillators. Given that human brains and bodies are subject to physical

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constraints, and the former generate oscillations, it stands to reason that the “coming together” of two such embodied brains in interaction can be described using the analysis of coupled oscillators, whereby in-phase and anti-phase synchronization correspond to attractors of the system. Within coordination dynamics, taking the paradigmatic case of coordinated finger movements (intra-personal or inter-personal), the HKB model (Haken et al., 1985) posits that the oscillatory system exhibits in-phase and anti-phase coordination patterns when the finger-movements are slow-paced, and increasing the frequency of motion pushes the system to exhibit only in-phase coordination beyond a critical threshold (the bifurcation point).

This is an elegant behavioral model that yields contact with the rich landscape of theoretical work on oscillatory phenomena. It provides a picture of the *necessary* conditions for such synchronization to occur, i.e., by examining the attractors associated with a physical system and their stability as a function of pertinent control parameters (in the case of limb coordination, finger-tapping etc, the frequency of the required motor movement). However, in our view, it is not *sufficient* to explain the phenomenon of interest given its focus on generating abstract mechanism-free models of behavior. Building on what we know to be physically available patterns to the interacting individuals, as described by the coordination dynamics framework, we develop our hypothesis to provide a mechanistic account of what occurs in the interacting brains.

It is entirely conceivable that both in-phase and anti-phase patterns afford greater predictability (with attendant reduction in prediction errors). We propose that the physical constraints (i.e., environmental regularities), which scaffold the patterns predicted by coordination dynamics would be acquired by the brain via predictive learning, and thus the jointly produced patterns would lead to a reduction in prediction errors.

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This hypothesis is not necessarily inconsistent with the dynamical systems approach. Specifically, as the brain's coding costs are minimized to reduce the mismatch of self and other motor representations, it is quite plausible that it may settle on in-phase and anti-phase stable states, in line with the coordination dynamics account, as they are both states of alignment. Anti-phase, for example, may be perceived as aligned motor representations (i.e. I step with my left foot when you step with your right foot as we walk side-by-side, and vice versa) much the same way as in-phase (while at a strictly motoric, lower-level they may seem different, at a higher level of representation, they are both patterns of systematic coordinated behavior). In addition, consistent with the coordination dynamics approach, in this case the brains of two people interacting are building synergies, as their motor systems are coupled via perception; while each brain works independently, they are coupled perceptually to work as part of a common inseparable system that gives rise to coordination. This proposal and previous work on inter-brain synchronization paves the way for much future work. For example, future research could investigate the link between individual brain mechanisms (at the level of reducing prediction errors to minimize differences in self-other motor representations) and inter-brain coupling at the level of oscillations, which we believe are inherently linked.

Perspectives and Prospects

The view proposed here suggests several potential mechanisms of how synchronization influences social relationships. First, given that spontaneous synchronization is automatic and linked to less effort, it might be associated with more positive affect and therefore have an indirect effect on social rapport and bonding. Second, being closer or acting as a team might enhance motor representation by paying more attention to each other and therefore drive the

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system to enhanced synchronization. We speculate that, when controlling for the amount of attention to others' motor behavior and for positive affect, the link between social rapport and motor synchronization may be reduced. Further, this view may even suggest that being synchronized with others is computationally less costly than being alone—and idea that is in accordance with other recent theories on the benefits of social relationships (Beckes & Coan, 2011).

This proposal admittedly leads to many open questions. For example, if synchronization is computationally efficient, why don't we synchronize with others all the time? Obviously, other factors influence costs and rewards of behavior, including others' goals and environmental states. Certain tasks are more optimally achieved in the absence of synchronized behaviors, and rather via complementary motor actions (Sebanz et al., 2006) or coupled (but not mirrored) interaction dynamics (Hasson & Frith, 2016), or in the absence of symmetric roles (i.e. when participants have asymmetric task demands, see Skewes, Skewes, Michael, & Konvalinka, 2015). For example, a conversation would be difficult to carry out if both people spoke at the same time. Further, being mimicked too much can lead to feelings of discomfort or embarrassment in the communication partners (Boker & Rotondo, 2002), whereas breaking of symmetry in nonverbal expressions during a conversation may be a way to reduce redundancy and thereby increase the communicated information (Boker & Rotondo, 2002). There might still be alignment across different scales during dialog (Fusaroli, Rączaszek-Leonardi, & Tylén, 2014; Hasson & Frith, 2016), which could synchronize brain activations between people (Menenti, Pickering, & Garrod, 2012), but these would not be locked to individual motor outcomes, but rather achievement of joint outcomes (e.g. production-comprehension) (see also Loehr, Kourtis, Vesper, Sebanz, & Knoblich, 2013). Further, it might be best to not synchronize completely, in

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order to be optimally distinct (Brewer, 2003). In other words, being completely in sync with others would diminish our capacity to be distinguishable as individual agents. The overall optimum of interpersonal synchronization may be well below the energetic optimum, and reflect a tradeoff between energy optimization and retained information and individualization. Future work should further investigate how synchronization varies across different contexts and cultures in which individualistic versus collectivistic agency is more or less important (see also Pacherie, 2014).

In conclusion, we have proposed that behavioral synchronization observed in interacting human agents is a consequence of individual brains in interaction with each other operating under a general optimization principle. Once established, this phenomenon appears to work bi-directionally, with greater optimization improving coordination and greater coordination promoting optimization. Yet, the origin appears to rest in individual brains and their coming together for an interaction. This is a simplified account, for the phenomenon is allied with numerous others of interest that we approach with measured agnosticism. As mentioned in preceding sections, interpersonal coordination appears to have social ramifications. Ranging from dyadic relationships, to teamwork in sports, combat and other domains, interpersonal synchronization and coordination has a pervasive influence that remains to be understood in terms of its underlying neural and computational mechanisms.

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