Bodies and Minds in Sync:
Forms and Functions of Interpersonal Synchrony in Human Interaction.

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Abstract

Interpersonal Synchrony (IPS) is a ubiquitous phenomenon in social interactions characterized by the rhythmic entrainment of movement behavior as well as neurophysiological processes. While there is evidence that IPS supports social bonding and facilitates group formation and collaboration, definitions within communication research are vague and mechanisms remain elusive. Starting from basic definitions of synchrony in physics and biology, the current chapter discusses the particularities of IPS in humans and reflects on possible explanations, presents existing research evidence for its effects, and addresses open methodological challenges.

Keywords: Interpersonal synchrony, nonverbal behavior, emergent, dynamic, social
Bodies and Minds In-Sync.

Forms and Functions of Interpersonal Synchrony in Human Interaction.

Humans are fundamentally social. We live in groups and our survival and life achievements very much depend on our ability to communicate and coordinate our actions with others. A very basic constituent of this ability is the evolutionary deeply rooted tendency to attune our movements to our conspecifics. Whenever two or more humans show some kind of repetitive motion, and they can perceive each other, they are prone to engage in a shared rhythm: they synchronize. Interpersonal Synchrony (IPS) occurs for people walking together, sitting in rocking chairs, rowing boats, cheering their teams, and, more subtly, in our everyday conversations. Not only in a phylogenetic but also in an ontogenetic perspective IPS appears to be foundational for bonding and social learning. IPS can be observed in early mother-infant interactions and has been posited as a mechanism through which infants develop language capabilities (Delaherche et al., 2012; Feldman, 2007) and self-control mechanisms (Feldman 1999).

IPS is an emergent phenomenon and a widely automatic, uncontrolled and unconscious process comprising the mutual entrainment of at least two individuals. In this sense, we can conceive IPS as a core mechanism of group formation, action coordination and collaboration. It has been shown that simple rhythmic alignment of body movements is closely tied to cooperativeness and perceived group entitativity (Lakens & Stel, 2011; Wiltermuth & Heath, 2009), relational quality and rapport (Ramsayer & Tschacher, 2011) and a variety of other social outcomes (cf. Rennung & Göritz, 2016). Cultural practices as present in religion, sports, military, arts, etc. make use of this seemingly hardwired connection between synchrony and the sense of communality to strengthen the bonds between the group members (Reddish, Fischer, & Bulbulia, 2013; Noy, Levit-Binun, & Golland, 2015; Tuncgenc & Cohen, 2016).
Despite growing attention synchrony has received across various disciplines in the last decade, the concept as applied to human communication remains somehow elusive. Varied definitions in social science and metaphorical uses of the term have led to some confusion and a watering down of a powerful concept. For instance, defining synchrony as “…the temporal linkage of the nonverbal behavior of two or more interacting individuals” (Won, Bailenson, Statathos, & Dai, 2014, p.390) leads to confusions with other concepts referring to movement coordination and postural similarity, such as imitation, mirroring, or mimicry. In contrast to these phenomena, synchrony is an emergent interpersonal phenomenon that does not require a leader and a follower (Strogatz 2003; Strogatz & Stewart, 1993). As Noy, Dekel, and Alon (2011) showed, joint movement improvisation without designated leaders and followers generates even better results in temporal alignment and less jitter (i.e. corrective micro-movements) than leader-follower scenarios (see also Fairhurst, Janata, & Keller, 2014; Konvalinka et al., 2014). To preserve the potential explanatory power of the concept, we suggest to stay close to definitions of synchrony as formulated in the natural sciences, physics and biology, and to examine how far the concept can be stretched to match the particularities of human communication without losing its boundaries and becoming fuzzy and meaningless.

The current chapter conceives synchrony as a ubiquitous “force of nature” and approaches the special case of interpersonal synchrony (IPS) as an essential component in human communication and collaboration. We will start with a line-up of the major constituents of synchrony as they appear in physics and biology and ask how these can be utilized to understand IPS in humans. This implies the questions, why higher-developed beings show behavioral synchrony, and how this might be functional for individual and group survival. We then turn towards the distinction of various types and instances of synchrony and scientific ways to look at these. The focus here is on those features relevant to communication research and not on
completeness as a research review. Excellent overviews and meta-analyses can be found in Chetouani, Delaherche, Dumas, and Cohen (2017), as well as in Rennung and Göritz (2016). We follow this by discussing the effects of synchrony, including positive as well as potentially negative outcomes. Finally, our concluding sections examine methodological challenges and novel research perspectives that have emerged from new technologies.

**Principles: What Metronomes, Fireflies and Humans Have in Common**

Synchrony is a ubiquitous phenomenon, which can be observed in the inanimate and animated nature. It occurs when two or more oscillators are weakly coupled. An oscillator is any system that shows periodic behavior. Of particular interest in our case are oscillators with an inherent energy source, which controls frequency and amplitude of the periodic behavior. This is true for some manufactured devices, such as metronomes or clockwork pendulums, but most importantly for all biological systems with some kind of pacemaker that drives periodic behaviors, such as our heartbeat, breathing activity, hormone cycles, walking steps and more (Strogatz, 2003; Strogatz & Stewart, 1993). It is important to note that synchrony is not identical with simultaneity. Oscillating systems can synchronize in-phase or anti-phase, or with a certain phase shift. This is true for metronomes or the flashing of fireflies, but also for intentional, goal directed synchrony in human behavior. For instance, in-phase synchrony can enable the accumulation of forces in service of maximal impact at a point in time (e.g., pulling a rope) while anti-phase synchrony can enable the iterative application of forces in service of a continuous impact (e.g. moving a two-handed saw back and forth). In both cases, the behaviors of the two agents are phase-locked, and both might be equally functional. In-phase synchrony appears to be the more stable state though, which is more difficult to influence by perturbation (Schmidt, Carello, & Turvey, 1990).

Weak coupling means that two or more oscillating systems are connected in a way that energy, respectively information, can travel between the systems. The term “weak coupling”
distinguishes a synchronized system of independent oscillators from two components that are forced into mutual rhythm, such as the rotation of two wheels that share an axis (Pikovsky & Rosenblum, 2007). For instance, placing two metronomes on a moving board that can pick up and transmit the kinetic energy of the metronomes will lead to synchronized movements (see https://www.youtube.com/watch?v=yysnkY4WHyM). A prominent example for coupled oscillators in living organisms is the unison flashing of fireflies (see https://www.youtube.com/watch?v=ZGvtnE1Wy6U). This only requires a light sensor with limited range and a neural connection between the visual input and the pacemaker’s output to synchronize the flashing of the neighboring individuals. Synchronization then can spread over a large population without each individual necessarily perceiving each other. As Strogatz and Stewart (1993) hold: “Synchronization emerges cooperatively. If a few oscillators happen to synchronize, their combined, coherent signal rises above the background din, exerting a stronger effect on the others” (p 107). Importantly, in contrast to the metronomes, the coupling between biological systems, as well as between more complex machines, such as for instance robots, relies on sensing and some kind of processing. To understand synchrony in human interactions, we have to take into account that beyond mere exposure of the periodic behavior to a perceptual channel, there must be some attention devoted to this channel and the transmitted signal (Koban, Ramamoorthy & Konvalinka, 2019). Moreover, entrainment might depend on cognitive representations that relate behavioral synchrony to specific situational contexts, task demands, social norms, and values.

Whereas simple motor coordination exists in many social species, including humans (Nagasaka, Zenas, Hasegawa & Fujii, 2013), we might expect synchrony at higher behavioral complexity levels to occur only in humans. Hence, it might be important to distinguish different types or instances of synchrony within the human species. Koban et al. (2019), for instance,
differentiate two types of IPS, one being unintentional or spontaneous and the other being intentional or instructed/induced (see also Keller, Novembre, & Hove, 2014). A more specific example for spontaneous synchrony is the entrainment of body sway in conversations (Shockley, Richardson, & Dale, 2009). With a few exceptions though, behaviors that tend to show spontaneous synchrony, such as marching in stride, clapping in concert, bending down in prayers, or the unison movements of side-by-side rocking chairs, can also be induced by social rules or instructed by an experimenter. Whether these different instantiations are processed in our brains in similar or distinct ways, and whether they produce differential socio-emotional effects, is still an open research question. Another differentiation, which refers to different types of entrainment that entails interpersonal synchrony, has been suggested by Cacioppo et al. (2014). The first type, “unilateral entrainment,” involves one person becoming entrained to the behavior of another in the sense of a leader-follower relationship. The second type, “orchestral entrainment,” involves actors entraining their behavior to an external pacing driver, such as a ticking clock or metronome (e.g., Hove & Risen, 2009). The third type, “reciprocal entrainment,” involves two actors mutually adapting to each other’s behavior, such that the person acting as the referent continuously switches during the interaction (Noy et al., 2011; Oullier, De Guzman, & Jantzen, 2008). Referring to the basic definitions above, one might question whether the term synchrony in interpersonal contexts should be preserved for the emergent phenomenon described as type 3 while excluding types 1 and 2. In fact, we still know too little about the underlying neural processes that might group these phenomena together or afford a clear separation. It is important to note though, that these types of entrainment are not mutually exclusive. It might well be that IPS in a motor task, which might also occur spontaneously, is just supported by an orchestration. This is putatively the case in songs that once were sung during harvests. In this example, the visually perceived motor behavior is overlaid by a rhythm in the auditory channel that can help stabilize IPS as it makes it independent from
visual attention demanded by the task. We might also find examples of leader-supported IPS in cultural practices where a central figure serves as pacemaker, as seen for instance is the role of the imam during prayers in a mosque. Most likely, the worshiping community would also synchronize in their bending movements spontaneously, but by facing the same direction and avoiding visual distraction, the imam makes it easier to stay in sync.

**Explanations: Why we Synchronize**

It is a plausible assumption that the urge to synchronize has evolved in humans because synchrony is adaptive, enabling coordination and collaboration in social groups and bringing about synergies in joint goal achievement (Sebanz, Bekkering, & Knoblich 2006; Valdesolo, Ouyang, & DeSteno 2010). In this sense, synchrony is seen as primarily motivated by external rewards, which putatively resonate in the activation of internal neural reward mechanisms (Kokal, Engel, Kirschner, & Keysers, 2011). But why then do we spontaneously attune our movements to the rhythms of others when no task at hand would benefit from synchrony and joint effort? This is the case in many cultural practices, such as in ritual dance or rhythmic praying movements, and we find it in many examples of mundane life. Consider two contrasting examples of types of synchrony that are evidently functional and “non”-functional. In one, two people are sitting in a rowboat, each holding one oar at opposite sides of the boat. Optimal speed, balance, straight movement and least effort will be achieved if they synchronize their strokes. Not only does such synchrony lead to higher efficiency on the dyad level, it also has rewarding effects on the individual level. As Cohen, Ejsmond-Frey, Knight, and Dunbar (2010) showed, synchronized rowing training, compared with a training regimen carried out alone, creates a heightened endorphin surge in the brain. Now imagine a second example of people sitting side-by-side in rocking chairs on a porch. They will also synchronize their rhythmic motion after a while, although there is no specific task that might benefit from synchrony (Richardson, Garcia, Frank, Gregor, & Marsh, 2012). Interestingly though,
it has been shown that the social effects of synchronized rocking generalized to upcoming group tasks, as it “…enhanced individuals’ perceptual sensitivity to the motion of other entities and thereby increased their success in a subsequent joint-action, that required the ability to dynamically detect and respond appropriately to a partner’s movements” (Valdesolo, Ouyang, DeSteno, 2010, p. 693).

The reason why synchrony occurs in the absence of specific task demands can be conceptualized in various ways. On one hand, we might assume that, because of its adaptive function and the paramount importance of synchrony for collaboration, the mere perception of emergent synchrony has become intrinsically rewarding. We might further speculate that beyond the rewarding experience of being in sync, experienced synchrony might have diagnostic value. For instance, synchrony achieved in simple conversations might indicate the ease or difficulty in synchronizing with a respective partner later, in face of collaborative task demands. The feeling of getting along well, liking each other, or in other words experiencing rapport, might be the socio-emotional consequence of a successful behavioral “conversational synchrony game,” which identifies the other as potential collaborator or even life partner when things become serious. Simply put, conversational synchrony might become a predictor for action coordination in future, sometimes already anticipated, collaborative tasks and consequently promote partner selection.

This assumption is supported by a series of studies directly addressing synchronizations of brain activities and physiological activation patterns. Neural synchronization has been found in various interaction settings including face-to-face communication, motor coordination, and joint decision making tasks (Hasson, Ghanzanfar, Galantucci, Garrod, & Keysers, 2012; King-Casas, et al., 2005). Yun, Watanabe and Shimojo (2012) showed “spontaneous bi-directional improvisation (implicit synchrony) increased motor synchrony” (p. 5) as evidenced by increased inter-brain connectivity of beta and theta bands. It has also been shown that IPS of facial expressions correlates
with IPS in peripheral-physiological activation patterns in real-life communication as well as in virtual settings such as game interactions (Sovijärvi-Spapé et al., 2013; Chanel, Kivikangas, & Ravaja, 2012). Analyzing coordinated activity of singers, Müller and Lindenberger (2011) concluded that "oscillatory coupling of cardiac and respiratory patterns provide a physiological basis for interpersonal action coordination" (p. 1). IPS thus can be conceived as a crucial mechanism to establish cognitive and motivational readiness states, reflected in the entrainment of brain activity and physiological arousal, which prepares the interactors for coordinated perception and action. This position has been recently articulated in the concept of bio-behavioral synchrony (Atzil & Gendron, 2017; Feldman, 2017), which in our view holds transformational potential for theories of communication and social behavior.

Overall, this view holds that IPS is primarily functional for social groups, because it contributes to the optimization of shared attention and motor coordination in group efforts, and is secondarily functional in conversations, as it possesses signaling functions to this end, which are subjectively perceived as group entitativity or rapport (Lakens, 2010; Lakens & Stel, 2011). Although this perspective provides an interesting framework for communication research in itself, it does not fully explain why spontaneous synchrony happens in the absence of specific motor tasks or communication efforts and which basic biological mechanisms drive its occurrence. Koban et al. (2019) suggest an alternative explanation, which emphasizes the principle of energy optimization on the individual brain level instead of the optimization of motor energy on the group level. The authors 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” (p.13). In this view, the somehow “merged” cognitive representation of self and other is supposed to reduce complexity of the social environment and promote less effortful predictions of the conspecific’s behavior. It is important to
note that approaches focusing on the optimization of motor resources on the group level and those emphasizing the optimization of cognitive resources on the individual brain level are not mutually exclusive: both have the potential to spawn creative research in future communication research.

**Effects: How Synchrony Affects Social and Individual Outcomes.**

IPS has been studied mostly as an independent variable, with questions examining the effects of synchrony on a variety of outcome variables (e.g., Hove & Risen, 2009; Wiltermuth & Heath, 2009). Less frequently, IPS has been conceptualized as a dependent variable, (e.g., Miles, Lumsden, Richardson, & Macrae, 2011; Paxton & Dale, 2013). Also, most of the research has focused on social effects, whereas outcomes of synchrony for the individual have received much less attention (cf. Vicaria & Dickens, 2016). For instance, individual outcomes of IPS have been documented regarding enhancement of self-esteem (Lumsden, Miles, & Macrae, 2014) or improved memory for social information (Macrae, Duffy, Miles, & Lawrence, 2008). These effects were related to rewarding experiences of successful communication and to cognitive optimization resulting from merged other-self representation, respectively. Although established on the individual level, these variables clearly tie in to social functioning in more general terms.

Social outcomes of IPS in fact have been framed in multiple ways referring to constructs such as group entitativity, rapport, affiliation, cooperation, trust and others. There is insufficient space in this chapter to provide a comprehensive overview of the various research lines. Instead, we aim to sketch some of the major results to illustrate their common thread. As has been shown, the mere observation of people in sync causes the impression of group entitativity, or the perception that individuals constitute a social unit (Lakens, 2010). Using animated stick-figures or real people handwaving, this research found that only synchrony caused the impression of group entitativity, while other variables such as physical similarity did not. In follow-up studies, perceived entitativity led to the impression of relational quality in terms of rapport. These effects, however, were only
evident for dyads that supposedly showed spontaneously emerging synchrony (mutual entrainment) and not for induced synchrony of the leader-follower type (Lakens & Stel, 2011). Direct associations between synchrony and perceived rapport have been found repeatedly (Bernieri 1988; Vacharkulksemsuk & Fredrickson, 2012). Miles, Nind, and Macrae (2009) exposed participant observers to pairs of walking stick-figures that portrayed varying configurations of coordinated movement. These stimuli were manipulated such that the phase relationship between their strides varied from 0° to 360°. The authors discovered that the most stable phase relationship, or 0° difference (i.e., in-phase synchrony), led to the highest perceptions of rapport. This effect was duplicated in a second study where only the walkers’ audio cues were provided to participants.

Closely related to these results are findings regarding the influence of IPS on affiliation and liking. In a series of studies, Hove and Risen (2009) demonstrated that synchronized motor activity, in his case tapping to a metronome alongside with a confederate, increased affiliation and liking. Again, this effect only held when synchrony was interpersonal in nature and not orchestrated (attributed to the metronome) or led.

Other studies have more directly investigated the behavioral outcomes of IPS. For instance, Launay, Dean, and Bailes (2013) found that participants instructed to tap synchronously as compared to asynchronously with a beat given through headphones contributed more money to their partner in a subsequent economic game. In the same sense, Cirelli, Einarson, and Trainor (2014) found that infants who were bounced by an adult synchronously (versus asynchronously) to music were more likely to subsequently help an assistant when she dropped objects on the floor. This effect was shown even when the movements were in anti-phase synchrony, suggesting that even a less stable form of synchrony can have prosocial effects. A number of studies also established a connection between IPS and collaboration, respectively cooperativeness (Cohen, Mundry, & Kirschner, 2013; Reddish, Fischer, & Bulbulia, 2013; Wiltermuth & Heath 2009).
Wiltermuth and Heath (2009) conducted a series of studies in which participant triads synchronized their steps while walking, or their voices and hand movements while singing and swinging a cup. Across these studies, groups who synchronized (whether it was movements, voices, or both) were more likely to choose the “best for the group” option in economic games than asynchronous triads. Reddish et al. (2013) found that the effect of synchrony on cooperation is magnified when there is shared intentionality among interactants, as opposed to incidental synchrony or intentional asynchrony (another form of coordination). Not only does IPS increase the motivation to cooperate, but it also increases one’s ability to cooperate (Valdesolo, Ouyang, & DeSteno, 2010), suggesting a preparatory mechanism for later collaboration as mentioned in our introduction.

Across these results covering a variety of psychological constructs, the common thread is that IPS promotes group formation and strengthens the social bonds within. Yet, where there is an ingroup there is also an outgroup, and it is an interesting question whether synchrony can be observed with outgroup members at all, and how ingroup synchrony relates to feelings and behaviors towards the respective outgroup. Using a minimal group paradigm, Miles, Lumsden, Richardson, and Macrae (2011) found, counter-intuitively, that synchronization worked even better with designated outgroup members. They attributed this result to attentional factors as well as the motivation to bridge intergroup differences. In line with this, Tuncgenç and Cohen (2016) showed that biases towards outgroup members can be mitigated by behavioral synchrony. A more complex and potentially negative relation between group membership and social outcomes of IPS, however, emerged in one of our own studies (Tamborini, et al. 2018). Using a dance videogame, we asked participants to synchronize dance moves with a black or white in-game character. We measured the influence of group membership and synchrony on trust towards other in-group and out-group members using a standard online trust game (cf. Bente, Baptist, & Leuschner, 2012). Results suggested that synchrony with an ingroup member can decrease general trust towards outgroup
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members. Further, it has been shown that synchrony with an authority figure can promote destructive obedience toward other living things, such as killing insects on command (Wiltermuth, 2012). Thus, it appears that synchrony can be socially beneficial as well as detrimental, depending on the salience of the respective reference group.

**Methods: How to Assess IPS in Natural Interactions.**

A major challenge in identifying signatures of IPS lies in the measurement and statistical modeling of the mutual interdependencies and temporal dynamics in free running human interactions, such as conversations. Human interactions unfold as a continuous, dynamic, and multi-level phenomenon among dyads or groups (Poyatos, 1983). Such interactions are characterized by (a) high dimensional complexity and (b) high processual complexity (Vogeley & Bente, 2010). Dimensional complexity relates to the fact that various channels, such as facial expressions, gaze, gestures, body postures, and movements show multiple interactions within and across the communicators. This includes idiosyncratic channel preferences and different levels of information density in the nonverbal signals (Chovil, 1991). Processual complexity implies that meaningful information is coded in dynamic aspects of the nonverbal behavior, as for instance in response delays, recurrence patterns, movement durations, etc. (Krumhuber, Manstead, & Kappas, 2007; Provost, Troje, & Quinsey, 2008). This is particularly important when looking at emergent dyadic interaction patterns such as IPS.

Previous approaches to understanding the dynamics of IPS in natural human interactions are limited in their explanatory value, as they all start with complexity reduction at the level of data collection, either taking a restrictive or a generic measurement perspective on the interaction behavior. Restrictive approaches reduce the complex interaction behavior to specific and easily measurable rhythmic movement phenomena with a characteristic form. In fact, a majority of studies on IPS has focused on simple repetitive movements such as marching in stride (Wiltermuth
& Heath, 2009), waving (Lakens, 2010), swinging a pendulum (Schmidt & O’Brien, 1997), rocking chairs (Richardson, Marsh, Isenhower, Goodman, & Schmidt, 2007), body sway (Reynolds & Osler, 2014), or jointly moving sliders in the so-called mirror game (Noy et al., 2011). Schmidt, Morr, Fitzpatrick, and Richardson (2012) summarize: “The disadvantage of these studies is that the interactions between participants were not very natural. All the tasks involved having the subjects produce stereotyped rhythmic movements, which are obviously not present in everyday interactions. Moreover, the social interactions prescribed in the tasks were artificial” (p. 268). As such, the existing approaches are often a pale resemblance of the truly social phenomenon they were designed to study.

While restrictive approaches select one behavioral aspect to study IPS, generic approaches are based on aggregates of communication behavior, for instance representing the multichannel nonverbal interaction behavior as a single activity vector. An example of this approach is Motion Energy Analysis (MEA), which has been suggested as a possibility to track synchrony in free running conversations (Ramseyer & Tschacher, 2011). In MEA, the movement activity of interaction partners is automatically extracted from video recordings by essentially quantifying pixel changes between pre-filtered sequential video frames. Although an updated approach includes a method to separate body and head movement within MEA (Ramseyer & Tschacher, 2014), nonverbal behavior remains constricted to global activity measures that miss out on postural dynamics, specific gestures, variations in distance and orientation. Furthermore, MEA is based on 2D data and ignores depth information, a key reason why this approach has been limited to seating dyads.

As a powerful alternative to restrictive as well as generic approaches in communication research, we have suggested motion capture technology (see for a comprehensive overview Bente, 2019), which generates detailed protocols of body movement consisting of rotation and translation
information for all joints. While the resulting data protocols can be aggregated to produce a one-dimensional activity time-series as does MEA, they also allow for a micro-analysis of the various nonverbal subsystems such as gestures, head and body movements, body orientation, locomotion etc. and their interpersonal crosstalk. Accurate motion capture systems (e.g., OptiTrack) are still dependent on markers and/or special cameras, which restricts their application to experimental studies in the lab. Current progress in motion analysis based on video, using deep machine learning, can be expected to help overcome these constraints in the near future (Neverova, 2016).

It is important to note, that capturing the processual and dimensional complexity of human communication is a necessary but not a sufficient precondition for the study of IPS. A second most important requirement concerns the analytical methods to detect entrainment patterns and to quantify the level of synchrony, which is particularly challenging when studying natural interactions. Various solutions have been suggested, such as cross-lagged correlation analysis (Ramseyer & Tschacher, 2014), cross-recurrence analysis (Coco & Dale, 2014), cross-spectral analysis (Schmidt et al., 2012) and wavelets (Fujiara & Daibo, 2016), to name a few. Cross-recurrence quantification (CRQ), for instance, has been used to study coupled postural sway patterns (Shockley, 2005). CRQ extends the general idea of recurrence analysis where signals are embedded with their own time-shifted versions, by embedding the motions of one person with those of another at some time shift. Because recurrence methods are comprehensive and flexible with regards to assumptions, Marwan, Romano, Thiel, and Kurths (2007) argue that these methods can be considered as a generalized form of the linear cross-correlation function. However, at least in part due to the higher mathematical complexity compared to MEA (for example), their application in practice remains scarce. In addition to time-domain methods (MEA, cross-lagged correlation, CRQ), researchers have also adapted frequency-domain methods (e.g., Pikovsky et al., 2003). Frequency-domain methods have been mainly applied to simple motor trajectories such as
swinging a pendulum and moving a rocking chair (e.g., Schmidt & O’Brien, 1997; Richardson et al., 2007). To quantify IPS effects, movement data are transformed using Fourier analysis, or using the more potent wavelet approach. Fujiwara and Daibo (2016) applied cross-wavelet coherence analysis to movement data, extracted from video recordings of dyadic conversations. Movement protocols of the real pairings were compared to random combinations of individual protocols in a so-called pseudo-synchrony paradigm. They found higher values of cross-wavelet coherence in the real than in the pseudo dyads, specifically in the frequency band under 0.5 Hz. Although the modeling approach appears promising, the input data is rather crude, using an aggregate of movement activity based on the spatial differences of extracted nose and hand positions and ignoring the potential crosstalk between different nonverbal subsystems. The different approaches show specific advantages and downsides. As such, it is important that future approaches provide comparative data on their predictive value regarding the occurrence and various social outcome of IPS.

**Outlook: Where to go from here**

We aimed to show that IPS constitutes a crucial element in human interaction and development, and that it creates a basis for the synchronization of minds and joint action. Numerous studies point to the close relation between behavioral and neurophysiological synchrony and their effects on individual and social outcomes. Causality between social outcomes and IPS evidently goes both ways. Yet, investigations into IPS as a dependent variable are scarce, and it might be particularly interesting to develop paradigms to explore social and individual factors that promote or hinder IPS in human interactions. We made a case for studying IPS as a dynamic, emergent process, encouraging precise definition and measurement, based on the concept of coupled oscillators. This implies the assessment of repetitive patterns in overt motion or covert neurophysiological processes. Although there are similarities between metronomes, fireflies, and
humans in this regard, our perspective notes key differences among these categories. Metronomes are not living creatures, whereas fireflies are – and though fireflies and humans are both living, humans possess the additional ability to attend to and perceive (rather than just sense) informational changes in the environment. These comparisons could be conceived as continuous, from purely mechanical (or “offline”) synchrony to a combination of physical and perceptual aspects (“online” synchrony). We see this continuum as useful in defining the type of synchrony upon which researchers focus. For example, physicists and psychologists likely have different aims when examining properties of synchronized behaviors and should conceptualize their version of synchrony accordingly.

We also see a particular challenge in distinguishing more clearly synchrony from other similar coordination behaviors such as mimicry or imitation. Some work (i.e., Hove & Risen, 2009; Noy et al., 2011) already shows that synchrony has stronger effects than mimicry, though more work is needed to disentangle the mechanisms leading to these effects. If mimicry and synchrony both involve shared representations of self and other, and they both impact social outcomes, in what ways are they different? Approaches to answer this question could strongly benefit from a combination of behavioral and neurophysiological methods looking at interpersonal synchrony in EEG patterns as well as distinctive activation patterns by means of brain imaging. Most importantly, the study of IPS in natural human interactions will have to overcome different methodological challenges, which include the multidimensional assessment of communication behavior, the identification of interrelated channels, quantification in terms of frequencies, amplitudes and phase shifts, and the establishment of robust interrelations between IPS and relevant social outcomes.

Last, not least, we see a major challenge for communication research in identifying periodic phenomena and their interpersonal entrainment within ongoing social interactions. Conversations,
discussions or negotiations are not steady processes. They are progressive, implying changes in topics and relational quality over time. Depending on these changes, one can expect dyads to repeatedly fall into sync and out of sync over the course of one interaction or at different stages of a relationship. Moreover, frequency of the entrained behaviors can change, and phase transitions between in-phase and anti-phase synchrony, or changes in the phase shift, can occur. For instance, in an early stage of relationships high levels of motor synchrony might be more important to facilitate bonding, promote trust, and foster self-disclosure. In later stages, IPS might be only necessary to overcome conflicts and readjust the relationship balance. In fact, we know very little about these temporal dynamics, and their study represents a particular theoretical and methodological challenge for future communication research.
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