Neuroscience and Biobehavioral Reviews 189 (2026) 106892

Contents lists available at ScienceDirect

Neuroscience and Biobehavioral Reviews

journal homepage: www.elsevier.com/locate/neubiorev

Social presence and its role in social interactions: Insights, challenges and a call for action

Ulrike M. Krämer [a,*], Pauline Petereit [b], Shir Genzer [c], Jannik Heimann [a], Anat Perry [c], Sarah Jessen [a]

[a] University of Luebeck, Institute of Medical Psychology, Center of Brain, Behavior and Metabolism, Luebeck, Germany
[b] University of Luebeck, Department of Neurology, Center of Brain, Behavior and Metabolism, Luebeck, Germany
[c] Psychology Department, Hebrew University of Jerusalem, Jerusalem, Israel

ARTICLE INFO

Keywords:
Social presence
Social cognition
Empathy
Mentalizing
Computer-mediated communication

ABSTRACT

Over the past decades, we have seen a fundamentally new form of social interaction become more and more common in our everyday lives: mediated social interactions, in which we do not speak to a person face-to-face, but the interaction takes place via a video call or some other form of technology. While most people would agree that a mediated interaction is somehow different from a face-to-face interaction, we currently lack a framework for conceptualizing what exactly is different. This is especially important when studying how mediated interactions shape our understanding of others' mental states and its neural basis. To address this gap, we propose a framework that conceptualizes the impact of social presence on social interactions and their neural underpinnings along a continuum of two key dimensions: sensory and temporal presence. Whereas sensory presence refers to the *amount* of sensory information available, temporal presence refers to the *immediacy or temporal delay* with which information is available. We argue that a systematic manipulation of both dimensions is essential for our understanding of the impact of social presence on social cognition and affect. Our conceptual framework will lay ground for integrating and advancing research on this topic in social neuroscience and beyond.

1. Introduction

In recent years, computer-mediated social interactions have become increasingly important. Nowadays, work meetings, even between colleagues in the same company, are often held via videoconferencing, medical and psychotherapeutic consultations are increasingly offered via online channels, and people talk to friends and family via videoconferencing in their daily lives. For instance, in mental health care in the USA, telemedicine use has increased considerably from less than 1% before the COVID−19 pandemic (Busch et al., 2021) to 19% fully remote treatment and 69% hybrid treatment in 2024 (American Psychological Association, 2024 Practitioner Pulse Survey). In other words, interacting with others who are not physically present with us in the same room has become a common experience in our everyday social activities. However, although most people would agree that mediated interactions are somehow different from direct social interactions, we lack a proper understanding of what is lost or gained by moving toward or away from direct social interactions and actual *social presence*. In particular, we do not know whether and how our understanding of the other, i.e., our access to the mental state of the interaction partner - what they think, feel and want - changes. What is the effect of social presence on social cognition, that is, the processes by which we understand other people's minds (Lieberman, 2007)?

However, we currently lack a conceptual framework that allows for a systematic investigation of what characterizes the difference between mediated and real-life interactions. In this article, we propose such a comprehensive framework that enables us to systematically investigate the role of social presence in social interactions. Our framework is based on other frameworks which were originally developed in research on computer-mediated communication and online education (Biocca et al., 2003; Oh et al., 2018; Short et al., 1976) and in research on online therapy (Grondin et al., 2019). Here, we extend and apply these previous frameworks to the case of current neuroscience research on social interactions. Thus, our framework will facilitate the development of new paradigms that allow us to differentiate the separate components that contribute to social presence in our understanding of others. It is

* Correspondence to: Institute of Medical Psychology, University of Luebeck, Ratzeburger Allee, Luebeck 16023538, Germany.
E-mail address: ulrike.kraemer@uni-luebeck.de (U.M. Krämer).

https://doi.org/10.1016/j.neubiorev.2026.106892
Received 31 March 2026; Received in revised form 23 June 2026; Accepted 26 July 2026
Available online 27 July 2026
0149-7634/© 2026 The Author(s). Published by Elsevier Ltd. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

important to note that the term "social presence" is also used in many other research contexts that are not discussed in this paper. For example, it refers to a *feeling* of social presence in virtual realities, a sense of a deceased person's presence in the context of grief, a sense of imagined others, and the audience effect on people's performance (Dabas et al., 2025; Hamilton and Lind, 2016; Nowacka et al., 2025). This paper focuses on social cognition in social interactions, specifically how the degree of another person's presence affects our thoughts and feelings about them.

We will begin by describing the framework of social presence and its core dimensions, namely sensory and temporal presence. For each dimension, we will discuss what is already known about the neural and behavioral effects of social presence and what is missing in the literature to date. We will then highlight implications for and from developmental research, a field that has the potential to provide fruitful additions to our understanding of social presence, both at the empirical level and in terms of experimental paradigms. Finally, we outline experimental approaches that can be used in the future to systematically manipulate social presence in order to gain an understanding of what exactly makes direct social interaction special.

2. Conceptual framework of social presence

Central to our conceptual framework for studying mediated social interactions and their effects on social cognition is the construct of social presence (Fig. 1). Traditionally, presence has often been understood as a binary feature of the situation: someone is either present or absent (Bond and Titus, 1983; Uziel, 2007). Here, we propose to conceptualize social presence as a continuum along which another is present in an interaction. Social presence is maximal in face-to-face communication and declines gradually, especially in computer-mediated interactions, depending on the temporal delay and the number of available communication channels (e.g., visual, auditory). Thus, in our framework, we understand social presence as a feature of the communication medium

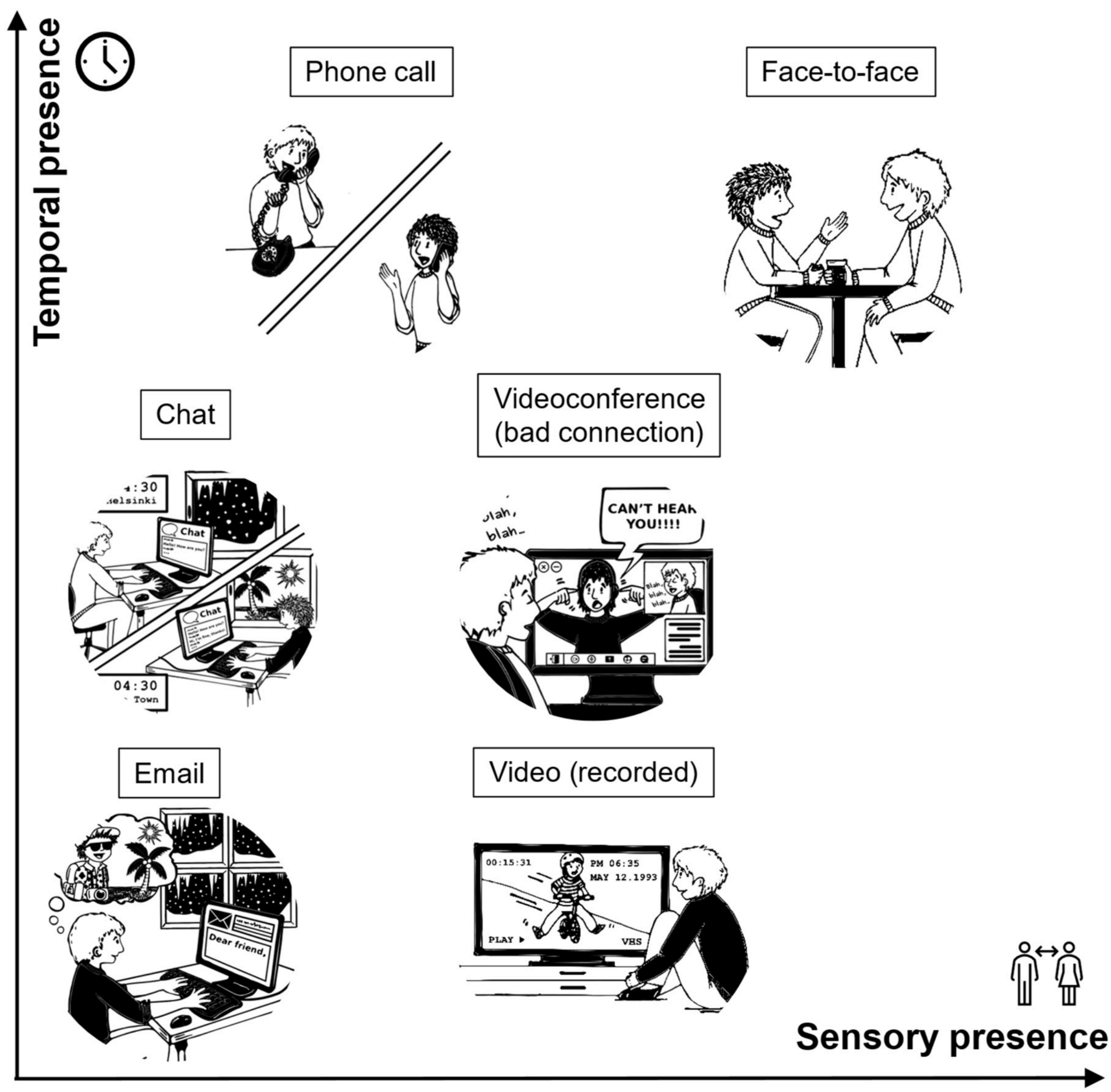

Fig. 1. Framework of social presence with its two dimensions of sensory presence and temporal presence. Social interactions can vary along the two dimensions of social presence; a high degree of both sensory and temporal presence is given in direct, face-to-face interactions (upper right corner). Sensory presence is reduced in a phone call, which still allows for high temporal presence. Video conferencing reduces the level of sensory presence relative to face-to-face encounters, but has higher sensory presence than phone calls. However, in case of connection problems, as alluded to here, it comes with lower temporal presence. Temporal presence is further reduced when chatting with another person, and when watching a previously recorded video of another person. Both sensory and temporal presence are lowest when responding to a previously written letter of another person (lower left corner). Drawings: Cecilia Puebla Antunes.

or the situation. We define it as the degree to which the other person is sensorily and temporally present, that is, the extent to which verbal and nonverbal cues about the other are available (sensory presence) and the immediacy or delay with which information about the other is transferred during social interactions (temporal presence; see Table 1 for terminology and definitions).

Sensory presence therefore refers to the sensory channels available in the interaction, whether one can hear, see, touch and smell the other, and to what degree one can perceive the other's facial expressions, gestures and bodily signals. It describes the richness of interpersonal cues, which can be more or less limited in computer-mediated communication. For instance, compared to a voice call, a videoconference provides more interaction channels, as one can see and hear the other. Still, it provides less information compared to a face-to-face meeting, during which one can see the whole body, including body posture and tension or gestures and also smell and at least potentially touch the other person.

Temporal presence in contrast refers to the immediacy or temporal delay within the communication, which entails the possibility to readily respond to the other and perceive the other's response to one's own actions. Two people in a direct conversation would be an example of high temporal presence, as information from one person to the other is transmitted instantly and with no delay. An individual watching a pre-recorded video of someone else implies low temporal presence due to the temporal delay between recording the person and presenting it to the other person. Text messaging would be a case of intermediate temporal presence as there will always be at least some temporal delay in the transmission of information from one person to the other, resulting in less fluency in turn-taking behavior.

It is important to note that sensory and temporal presence do not always align between social interaction partners. For example, in a video conference, sensory presence becomes uneven or asymmetric when one participant turns off their camera while the other remains visible. Similarly, a one-way mirror demonstrates how sensory and temporal presence can diverge. While one person receives detailed social information about the other immediately, no information is transmitted in the other direction. However, in most situations, temporal presence is symmetrical between interacting partners. When two people sit face to face, all sensory signals from one person are transmitted just as quickly as the other person's signals. When texting, there is a temporal delay in the signal transmission in both directions. Writing letters results in an even larger temporal delay.

Table 1
Terminology and relevant concepts.

Concept	Description
Social Presence	a continuous measure of the environment indicating the degree to which the other is present, in terms of temporal and sensory presence
Temporal Presence	the immediacy of the available sensory information, i.e., how instantaneous information about the other is available
Sensory presence	the amount of sensory information available about a person, both within a modality (e.g., facial expressions, body movements, gestures) and across modalities (e.g., vision, audition, touch)
Synchrony	simultaneous action or occurrence of two events; in social neuroscience, physiological synchrony is often investigated as simultaneous occurrence of physiological events
Reciprocity	psychological construct reflecting the bi-directionality and contingency of the responses of persons in a social situation
Social Interaction	any exchange of information between two or more persons. In the present article, we focus on the understanding of another person's mental states, which predominantly includes mentalizing and experience sharing. More generally speaking, social interactions also encompass for instance interpersonal learning and action coordination.
Mentalizing	cognitive, explicit reasoning about another person's mental states
Experience sharing	affective, implicit access to another person's mental states
Social Cognition	the mental processes that are relevant for our understanding of others
Self-other-distinction	the ability to distinguish between our representations of our own mental states and those that relate to the mental states of others

As we will see below when discussing studies on the effects of social presence on social cognition, the two dimensions of sensory and temporal presence are often not clearly separated in experimental manipulations. For instance, when comparing a live, direct interaction with a pre-recorded video presentation, both temporal and sensory presence are reduced in the latter condition. However, the two dimensions *can* be independently manipulated, and we argue that doing so will help to pinpoint which factor of social presence is relevant for which social cognitive process.

Importantly, as both, sensory and temporal presence, are factors that can be objectively measured from the environment rather than psychological constructs, we do not have to rely on a necessarily subjective interpretation of the participant's behavior. This contrast becomes most obvious when considering the relationship between temporal presence, synchrony and reciprocity. High temporal presence, i.e., no time-lag in the transmission of signals from one person to another, is a prerequisite for behavioral or physiological synchrony between two people in a social exchange. Behavioral synchrony occurs when both people act at the same time, and physiological synchrony occurs when changes in their physiological states occur at the same time. Temporal presence is also necessary for direct reciprocity, or the immediate, temporally contingent response between individuals. As we will see below, high temporal presence often influences social interactions by facilitating direct and reciprocal exchanges (Gregory and Antolin, 2019; Kulke et al., 2024; Rubo et al., 2020). It should be noted that social exchanges between individuals can be reciprocal even with low temporal presence, for instance, when exchanging letters. However, only in high temporal presence can interacting partners respond directly and immediately to each other. Importantly, synchrony and reciprocity are constructs that describe the interaction and relationship between partners rather than being measures of the environment.

There are other nuances that *relate* to sensory and temporal presence that could be considered and could affect interactions. For example, knowing that you are video conferencing with someone who is next door as opposed to across the Atlantic could affect social communication even if the degree of sensory and temporal presence as defined above is the same (Liberman and Trope, 2014). Differences could be due to the known distance between you, as well as to time zone differences that could affect the interaction. In addition, the possibility for verbal communication can be considered orthogonal to both, temporal and sensory presence. Verbal information can be transmitted in text-based communication (which is low in sensory presence) as well as in audio or video messages (which can vary along both dimensions of social presence). Thus, although verbal communication is clearly relevant to social interactions and for our understanding of others, we consider it to be a factor independent of social presence and orthogonal to the dimensions of temporal and sensory presence. We will return to these two points – the epistemic state and the possibility of verbal content – in the outlook.

3. Differences to other theories of social presence

As pointed out above, our proposal of temporal and sensory presence as core dimensions of social presence is based on previous theoretical accounts. There are several similarities, as well as differences, between our social presence framework and these other theoretical accounts. The concept of social presence is widely used in research on computer-mediated communication, where it can be traced back to Short, Williams, and Christie's book on the social psychology of telecommunications (Short et al., 1976). Short and colleagues defined social presence as a (subjective or perceived) quality of the medium that reflects the "degree of salience of the other person in the interaction and the consequent salience of the interpersonal relationship". They hypothesized that the degree of social presence is central to how individuals perceive the interaction and the relationship with the other person (Short et al., 1976). Since then, various theoretical accounts and measures of social presence have been suggested (Biocca et al., 2003; Oh et al., 2018). For instance, the dimensions of sensory and temporal presence are also featured in the hyperpersonal model of computer-mediated communication, although with different terminology (Walther, 1996; Walther et al., 2015).

Importantly however, as Biocca and coauthors (2003) pointed out in their influential review of research on social presence, definitions do not agree on whether social presence refers to a feature of the medium or to a psychological state. For example, in research on virtual reality, social presence is understood as the subjective experience of being with another "real" person and of being able to access their mental states (Oh et al., 2018). Although the degree of social presence provided by the communication medium or environment and the feeling or subjective experience of social presence will be closely aligned, it is important to clearly distinguish between the two. Indeed, how one conceptualizes social presence has far-reaching implications for psychological research. If social presence is understood as a property of the medium, it is an independent variable that can be manipulated in an experimental setting. If, on the other hand, social presence is defined as a feature of subjective experience, it has to be understood as a dependent variable to be measured. Using the term social presence for both, independent, experimental variable and dependent variable will lead to circular reasoning. Moreover, the various questionnaire measures of social presence suggest little agreement on the defining features of the subjective experience of social presence (reviewed in Oh et al., 2018). In our framework, we consider social presence to be the former rather than the latter, that is, a feature of the medium or the situation rather than a psychological state.

The temporal and sensory dimensions of social presence partially overlap with the relevant factors of online communication that Grondin and others have recently introduced in their framework for empathy in computer-mediated interactions (Grondin et al., 2019). They understand a communication medium as a filter that affects the information conveyed in the interaction. In their view, the degree of filtering depends on four main features: (1) the richness of the communication medium, (2) the immediacy of the feedback and the synchrony of the communication, (3) the transmission quality and (4) the communication content. The first two features bear some resemblance to the sensory and temporal dimensions of social presence. However, Grondin et al.'s approach is more specifically concerned with empathic interactions in dyadic relationships between clients and therapists. With our account, we aim to complement these theories from research on computer-mediated communication by providing a framework that focuses on the effects of social presence on social cognition in social interactions and its neural underpinnings.

Interacting with others requires cognitive and affective processes that enable us to understand their thoughts and experiences. These mental processes involved in understanding other minds can be summarized with the term *social cognition* (Lieberman, 2007). In social neuroscience, two ways of accessing other minds are usually considered: the experience sharing or affective route and the mentalizing or cognitive route (also related to the term Theory of Mind). The neural networks involved in social cognition and these different routes have been reviewed and discussed in detail by other reviews (Abu-Akel and Shamay-Tsoory, 2011; Bernhardt and Singer, 2012; Frith and Frith, 2006; Keysers and Gazzola, 2006; Lieberman, 2007; Maliske et al., 2023). We will therefore directly move on and discuss in the next sections why and how social presence and its constituent dimensions of temporal and sensory presence influence social interactions and their neural underpinnings.

4. Temporal presence and social cognition

As explained above, the temporal dimension of social presence refers to the immediacy or time-lag within social interactions, which entails the possibility of readily perceiving and responding to each other's behavior. In a face-to-face meeting, temporal presence is at its highest because people can interact in "real time" with no time lag. However, depending on the communication medium, temporal presence is reduced. The transmission delay in today's videoconferencing systems is usually quite small, but still large enough to affect turn-taking in conversations or social interactions that require high temporal coordination, such as playing music together (Onderdijk et al., 2021; Tian et al., 2024). Temporal presence is further reduced in other communication media, such as online chats or instant messengers. It is lowest when the time delay becomes even longer, such as when one person communicates information in a video or text which is much later presented to another person, who in turn can only respond later (or, in the extreme, not all). Notably, the degree of temporal presence can differ between channels in some situations. For instance, when communicating with a foreigner via a simultaneous interpreter, visual and paraverbal cues are conveyed instantly, whereas semantic information is transmitted with a delay.

Instantaneous signal transmission between people is a key prerequisite for the smooth adjustments and temporal alignment that are often required in social coordination and communication, be it in synchronized behavior, fine-grained motor coordination or fast turn-taking in conversation. Indeed, synchrony, defined as the simultaneous occurrence of things or events, which is thereby only possible within social exchanges with high temporal presence, is considered a basic process in social interactions, forming the basis for social relationships. Research has long studied the effects of motor synchrony on liking, trust and prosocial behavior (Goldstein et al., 2020; Hove and Risen, 2009; Sebanz et al., 2006; Wiltermuth and Heath, 2009), recently also within online interactions (Biswas and Brass, 2024; Gvirts et al., 2023). For instance, movement synchrony between physician and patient was found to predict the patient's trust in the clinician (Goldstein et al., 2020). As mentioned above, a related factor and consequence of temporal presence is the opportunity or necessity for direct and reciprocal action, which implies the self-relevance of the other's behavior and the direct consequences of one's own actions for the other. Different theoretical accounts have emphasized the relevance of synchrony and reciprocity within social interactions for social cognition (De Jaegher et al., 2010; Gallotti et al., 2017; Schilbach et al., 2013). In their opinion article, De Jaegher and colleagues (2010) argued that social interactions, understood as "autonomous agents co-regulating their coupling" (hence reciprocity), must be studied to truly understand social cognition. According to their argument, critical aspects of social cognitive processes only become apparent in direct and, what they call, "engaged" interactions (De Jaegher et al., 2010). Similarly, Schilbach and colleagues (2013), in their influential paper advocating a "second-person neuroscience", called for the study of social cognition in real-time social exchanges rather than focusing on passive observers of social stimuli. Again, they argue that reciprocal relations and emotional engagement within social interactions are constitutive of social cognition. Gallotti and coauthors (Gallotti et al., 2017) postulate that alignment, as the dynamic and multilevel mechanisms involved when two or more individual agents exchange information, is the critical component for understanding the nature of social interactions and social cognition. These different accounts agree that the degree of reciprocity and alignment should decisively influence, if not establish, social cognition. A prerequisite for direct reciprocity and temporal alignment is temporal presence.

So what do we know from empirical studies that have experimentally manipulated temporal presence about its effects on social cognitive processes? How was temporal presence manipulated in these studies, and what were the results in terms of neural measures of social cognition? Several studies have investigated the role of temporal presence by focusing on the behavioral and neural responses to eye gaze as an important interpersonal communication signal (Bohannon et al., 2013; Hamilton, 2016; Risko et al., 2016). These studies have mostly compared the presentation of real-life stimuli with pre-recorded, usually video stimuli. Note that the comparison of real-life stimuli and videos or pictures pertains not only to the level of temporal presence, but also, to a lesser extent, to sensory presence (see below). The results of these studies suggest that enhanced neural responses to direct vs. averted gaze occurred only under real-life conditions, but not when video stimuli were presented (Hietanen et al., 2008; Pönkänen, Alhoniemi, et al., 2011; Pönkänen, Peltola, et al., 2011). These effects have been found for the face-sensitive N170 event-related potential (ERP) component (Pönkänen, Alhoniemi, et al., 2011), for frontal EEG asymmetry (Hietanen et al., 2008), a putative marker of approach-avoidance tendencies, and for autonomic arousal (Pönkänen, Peltola, et al., 2011). Eye-to-eye contact in real time was also associated with higher cross-brain coherence and increased activity over temporoparietal areas relative to direct eye gaze in a pre-recorded video (Noah et al., 2020). Another study compared three situations, namely a real-life interaction, an interaction via a webcam, and watching a pre-recorded video (Hietanen et al., 2020). Both real-life (face-to-face) interaction and webcam interaction can be considered conditions of high temporal presence, differing mainly in sensory presence. The authors found that the skin conductance response to the direct vs. averted gaze of others differed only in real-life and webcam interaction, but not in pre-recorded videos. This suggests that temporal presence, which led to high self-relevance of direct gaze, was the critical factor for increased autonomic arousal (Chen et al., 2024; Hietanen et al., 2020; Myllyneva and Hietanen, 2015). In an intricate fMRI study, Cavallo and colleagues (2015) compared direct with averted gaze in a set-up allowing for face-to-face interaction of the participant within the MRI with a person sitting in the scanner room. They found that direct compared to averted gaze as well as compared to a picture of direct gaze (low temporal as well as sensory presence) activated a number of brain regions including the inferior frontal cortex, premotor cortex, ACC and AI. The mPFC was activated when the participant reciprocated the gaze behavior, i.e., during mutual gaze (Cavallo et al., 2015).

Other studies have examined how one's own gaze behavior is modulated by temporal presence. For example, Rubo et al. (2020) used eye-tracking data from people in the lab or walking around "in the field" to show that interindividual differences in social anxiety affected the tendency to look at close others only in the field, but not in pre-recorded videos. Another study by Gregory and Antolin (2019) went further by comparing three conditions: a pre-recorded video, a live, but one-way webcam stream with no opportunity for direct responses and a two-way live webcam stream. Only when temporal presence was high for both interaction partners, meaning that signals were transmitted immediately in both directions allowing for direct interaction, was gaze behavior different, such that people looked less at people's faces. Similar results were reported by Kulke et al. (2024) for both adults and 4-month-old infants (see below for the developmental perspective). Taken together, these studies of gaze behavior and gaze processing suggest that temporal presence affects social attention and arousal in social situations.

Temporal presence also appears to have effects beyond attentional and perceptual processes. In a recent study using motor-evoked potentials as physiological read-outs, Prinsen and Alaerts (2019) showed that motor resonance to the other's hand movements was enhanced during direct gaze only in live interactions, but not when video stimuli were presented. Motor cortex activation to observed actions has also been found to be stronger in real-life versus pre-recorded video settings (Järveläinen et al., 2001; Shimada and Hiraki, 2006). This is particularly interesting because motor cortex activation in response to observed actions suggests co-representation of others' actions and intentions, which is considered a crucial prerequisite for more complex forms of empathy (Decety and Jackson, 2004). Therefore, changes in this activity may have consequences for our ability to feel with others who are not directly present. This is consistent with a behavioral study by Diana et al. (2023), who examined mimicry and trust behavior in three conditions that varied temporal and sensory presence: watching a pre-recorded video, an online video call, and a face-to-face interaction. Both mimicry and trust behavior were reduced in the pre-recorded video condition, but did not differ between video calls and face-to-face interactions. In an fMRI study, performing simple cooperative games live as compared to in response to a pre-recorded video led to increased activity in mentalizing regions as well as in the striatum and amygdala (Redcay et al., 2010). Notably, similar findings were obtained in a study with macaque monkeys. In a turn-taking choice task with other macaque partner either live or with a pre-recorded monkey, the condition of high temporal presence was associated with higher single neuron activity in the superior temporal sulcus (Ninomiya et al., 2021). Interestingly, in a behavioral study, Morgan and colleagues (2022) found that a live social situation compared to pre-recorded videos resulted in an increase in an implicit measure of mentalizing (eye-gaze behavior), even though individuals did not directly interact in the social situation.

In a hyperscanning EEG study measuring mother-adolescent dyads in two conditions, face-to-face interaction and texting communication from different rooms, Schwartz and colleagues observed increased fronto-temporal interbrain-coupling during the face-to-face interaction relative to texting. Moreover, the degree of increased interbrain coupling was correlated with behavioral, but not affective synchrony (Schwartz et al., 2024). In a similar study using fNIRS, Sacristan and colleagues observed increased dorsomedial PFC activity in text-based communication compared to face-to-face interactions (Sacristan et al., 2023). However, as texting differs from face-to-face interaction in terms of both temporal and sensory presence, it is difficult to attribute these effects to one dimension or the other. Interestingly, we found in a recent study that temporal presence did not affect behavioral and neurophysiological indices of pain empathy, including physiological coupling (Heimann et al., 2025), although the neural responses to the other's pain were delayed when observed in a pre-recorded video as compared to a live, video-mediated interaction.

In summary, the role of temporal presence has been studied mostly, but not exclusively, with respect to gaze behavior. This research suggests that high temporal presence leads to altered social attention, increased social perceptual processes and heightened arousal, but also affects both mentalizing and experience-sharing processes (Fig. 2), although results are limited and not fully consistent. Very few studies have investigated the neural basis of these effects. Moreover, the common comparison of face-to-face interactions and pre-recorded videos complicates the task of determining which aspect of social presence drives these effects, as the two conditions vary along both dimensions.

5. Sensory presence and social cognition

Sensory presence refers to the richness of interpersonal cues provided by the type of information channels available. Again, face-to-face meetings provide the highest sensory richness to experience the other person. Video calls may already reduce some of the more subtle visual and auditory information and do not provide olfactory or haptic information, whereas phone calls further reduce the information to only auditory signals. Text messages are at the lowest extreme of sensory presence, providing no direct sensory information about the other person, but only indirect, verbal information. Notably, sensory presence can be reduced even in situations when two people are in the same room, such as when they are sitting back-to-back or when something blocks visual or auditory contact. Moreover, depending on the communication medium, certain information within a sensory channel might be reduced. For instance, we often do not see the other's hand gestures or posture when videoconferencing, which might also influence our understanding or experience of the other.

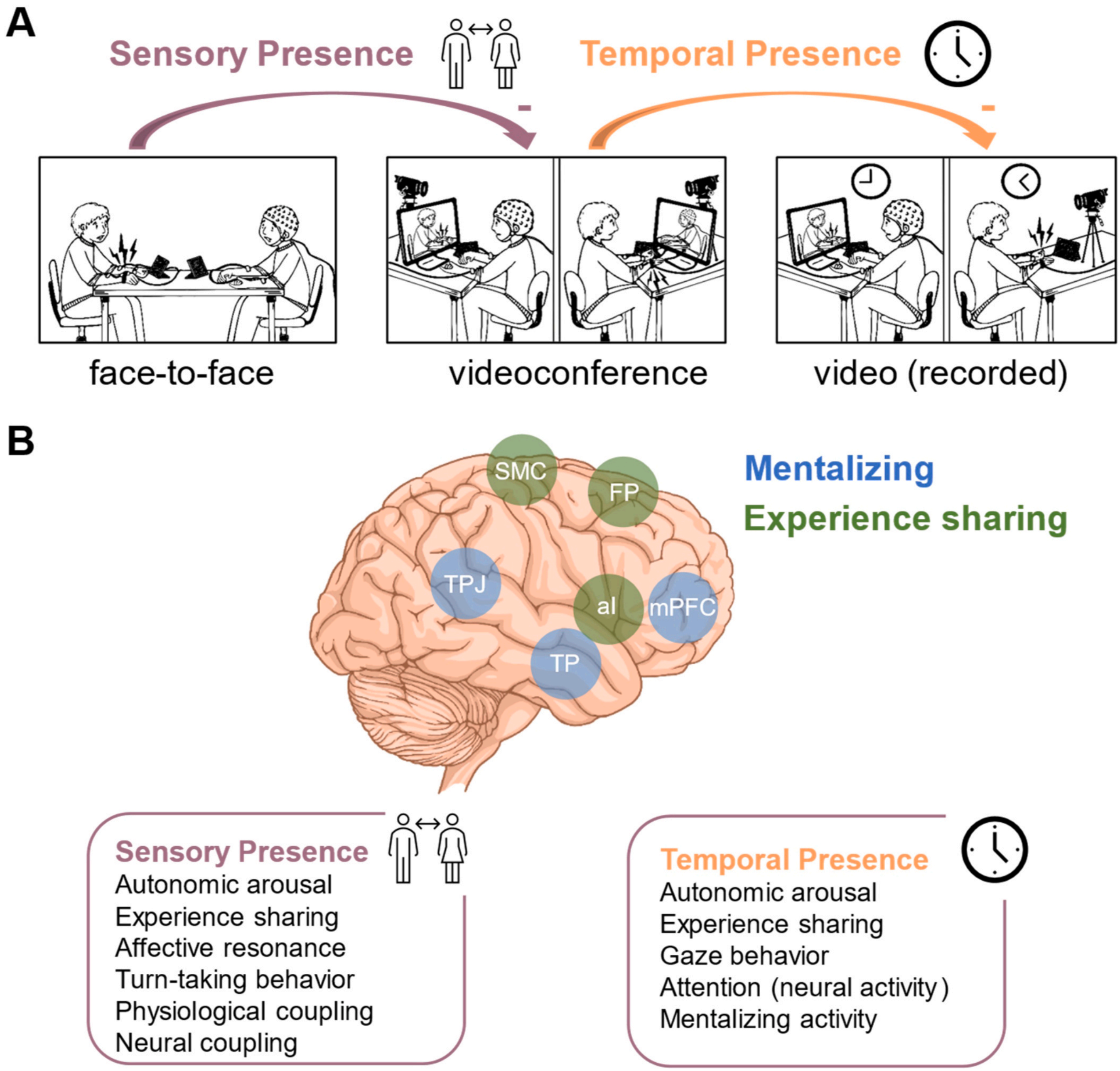

Fig. 2. Experimental work on social presence. A Examples of experimental manipulations which reduce sensory (from face-to-face to videoconference) and temporal presence (from videoconference to pre-recorded video) in an empathy for pain task. Note that many studies compare face-to-face interactions and pre-recorded videos, changing both the degree of sensory and temporal presence. B Depiction of the two core neural networks of social cognition, mentalizing and experience sharing networks, and summary of empirical findings on the effects of social presence on these networks and beyond. Manipulations of sensory presence led to increased autonomic arousal, increased affective resonance and turn-taking behavior and to altered physiological coupling, neural coupling and experience sharing. A higher degree of temporal presence was associated with altered gaze behavior and arousal, increased experience sharing and mentalizing activity and neural markers of attention. Abbr.: SMC supplementary motor cortex, FP frontoparietal areas, aI anterior Insula, mPFC medial prefrontal cortex, TP temporal pole, TPJ temporoparietal areas. Drawings: Cecilia Puebla Antunes.

Several recent studies in social neuroscience have begun to disentangle the contribution of different facets of sensory presence to social interactions and their neural and physiological correlates. More specifically, social neuroscience work has shown that people respond to sensory cues from others by sharing the other's physical perspective, their affective state or their action intentions. Based on this, one might expect that high sensory presence facilitates understanding others by providing more cues about the other's state.

Several studies have examined how the availability of interpersonal cues affects physiological coupling, i.e., the association between physiological signals (e.g., heart rate, skin conductance) of two or more individuals (Jarvela et al., 2016). For example, studies have shown that reducing the amount of information available during a task by setting up a physical shield between participants in the same room reduces cardiovascular and electrodermal coupling (Behrens et al., 2020; Murata et al., 2020). Crucially, in both of these studies, participants were engaged in the same task and perceived the same task-relevant stimuli in both conditions, demonstrating that visual cues about the other's state are important for physiological coupling and not only being engaged in the same task. This was also found for interpersonal neural synchrony, measured with EEG, in a recent study by Koul et al., (2023). When pairs of participants were able to see each other, they not only showed more synchronized behavior (body movement, eye contact, smiling), but also higher neural synchrony. Goldstein et al., (2018) demonstrated the importance of touch for neural coupling during a pain empathy task. When holding hands, romantic couples showed higher neural coupling in the alpha/mu band during the administration of pain to one of the partners, and the amount of coupling was found to correlate with empathic accuracy. Together, these studies suggest that even when participants are in the same room, access to richer sensory information about the interaction partner – reflecting higher sensory presence – can enhance physiological and neural coupling and promote more accurate empathic responses.

Whereas these studies manipulated the sensory input available about the other person when both interaction partners were in the same room, others have examined the influence of sensory presence in mediated interactions. In simple eye-contact tasks, high degrees of sensory presence (face-to-face encounters) were associated with higher interbrain coupling between (temporo)parietal areas, increased theta activity, higher arousal and higher visual dwell time on the face compared to online encounters (Sato and Sato, 2025; Zhao et al., 2023). In one of our own studies, we examined the effect of sensory presence on empathy for pain by comparing direct, face-to-face interactions with indirect, webcam-transmitted interactions (Petereit et al., 2023). When observing another person in pain via webcam, participants showed reduced physiological coupling (SCR) with that person and reduced neural responses (theta power) to the other's pain compared to the same interaction while being in the same room. However, the neural differences were relatively small, and no behavioral effects of the reduced sensory presence were observed. Other studies have used more naturalistic and story-based paradigms like the empathic accuracy paradigm, in which participants watch videos of people telling emotional stories from their lives and are asked to rate their own or the other's affective experience (Ickes et al., 1990). Using this approach, Hall and Schmid Mast (2007) investigated sources of accuracy by presenting video-based interactions in different cue modalities (full video, audio, transcript, or silent video) and with different instructions (infer thoughts and feelings, infer thoughts, or infer feelings). Verbal information contributed the most to accuracy, followed by vocal nonverbal cues. Visual nonverbal cues contributed the least, although still at levels above zero. When asked to infer feelings, perceivers appeared to shift their attention to visual nonverbal cues and away from verbal cues, and the opposite occurred when they were asked to infer thoughts. Consistent with these findings, we and colleagues have shown that the auditory, mostly linguistic, information is most important for empathic accuracy, but that people were still better than chance when they had to rely on visual information alone (Jospe et al., 2020). Interestingly, the reduced sensory presence when seeing but not hearing the other person led to increased physiological (heart rate) synchrony, suggesting enhanced affective resonance (for similar results with EEG, see (Genzer et al., 2022)). In an even more realistic design (live interactions via the Zoom platform), one of our labs showed that seeing each other is less important for empathic accuracy than hearing each other, but crucial for enhancing experience sharing, for feeling together, listened to and empathized with (Genzer et al., 2025). Note that auditory information in these studies was confounded with semantic information. It would be interesting in future studies to disentangle the relative contribution of semantic and paraverbal, auditory information by presenting stories in a foreign language, which the listeners do not understand.

These results are thus consistent with the above-mentioned effects of sensory presence on empathy for pain, particularly impacting affective resonance rather than empathic accuracy. Others have examined conversational behavior and tested whether and how it changes in computer-mediated interactions compared to face-to-face meetings (Balters et al., 2023; Hu et al., 2025; Schwartz et al., 2022). For example, Balters et al. (2023) reported that conversational turn-taking in dyads engaged in different tasks (problem solving, socio-emotional tasks) was reduced when participants interacted via videoconferencing compared to face-to-face. Furthermore, reduced turn-taking behavior was associated with reduced interbrain coherence between right frontopolar regions, measured with fNIRS. As videoconferences also come with at least subtle temporal delays, a reduction in temporal presence might have played a role here as well. These results are consistent with an EEG study by Schwartz et al. (2022), who asked mothers and their adolescent children to communicate in person or via videoconference. Again, direct interaction led to increased indices of interbrain coupling that were associated with communication behavior (gaze synchrony, empathic social engagement) only during the direct interaction, but not during videoconferencing.

In summary, sensory presence has been studied primarily for its effects on empathy and communication. Studies have mostly compared face-to-face interactions with videoconferencing and have shown effects on both neural measures of interbrain coupling and single-brain measures of empathy. There is by now converging evidence for a reduction of interbrain coupling with reduced sensory presence, although the behavioral implications of this reduction are less clear. In particular, conversational behavior, empathic accuracy and task performance in these studies did not generally change from direct to indirect interactions, as long as the auditory stream was present, suggesting a relative flexibility of human social cognition to adapt to the reduction in interpersonal cues available in videoconferencing for accurately inferring the emotional states of others. Sensory presence may be more important for "feeling with" the other as well as for other aspects of the affective experience (e.g., feeling together, being "in sync"). Generally, it is still unclear what specific aspects and what interindividual factors drive effects of sensory presence - is it the available sensory cues (eye gaze), olfactory signals, the potential for touch or other sensory signals?

Although a higher degree of sensory presence and thus more interpersonal cues is likely to be beneficial in most cases, there may be conditions under which a higher degree of sensory presence is detrimental to a person's understanding of others. First, these interpersonal cues must be integrated which becomes more challenging as more information is available. Therefore, in cases where this integration is impeded, sensory presence may actually impair understanding of others. This is likely to be the case in Autism Spectrum Disorder, where individuals have difficulty integrating social cues in social interactions (Ashwin et al., 2015; Krach et al., 2015; Schilbach, 2016; Schilbach et al., 2013). Thus, individuals with Autism Spectrum Disorder may actually benefit from reduced levels of sensory presence. Second, more sensory cues about the other's state might also challenge the ability to discriminate between self-generated and other-generated responses. As explained above, interpersonal cues about the other's perspective, intentions or affective states automatically activate one's own mental and neural representations of those affective states, intentions and perspectives. Therefore, when interacting with others, we need mechanisms that distinguish between mental representations of our own state and the other's state. This ability is often referred to as self-other distinction, and it is thought to be impaired in several psychiatric conditions such as Borderline Personality Disorder, Autism Spectrum Disorder or Schizophrenia (De Meulemeester et al., 2021; Eddy, 2018; Goregliad Fjaellingsdal et al., 2025; Lamm et al., 2016; Pronizius et al., 2024). A situation with a high level of sensory presence with its abundance of social cues might therefore be detrimental for people with difficulties in self-other distinction. However, these are open questions that remain to be investigated.

6. Role of social presence in development

One area that has the potential to provide important insights for a better understanding of social presence is developmental research. First, while adults have been socialized – to varying degrees – with both real and mediated interactions, and thus have certain knowledge and expectations about how they work and how they differ, young children are just beginning to learn the rules of social interactions as well as the function and attributes of mediated interactions. In addition, a number of higher cognitive as well as lower-level perceptual skills do not mature until childhood. For example, even in middle childhood (6–11 years old), children are less sensitive to audiovisual temporal asynchrony than adults (Hillock-Dunn and Wallace, 2012; Kaganovich, 2016), which could have implications for temporal presence constraints in social interactions. Thus, considering children and developmental patterns may help us tease apart effects that arise from our experience with mediated communication from those that are inherent to such interactions. Second, from an experimental point of view, the manipulation of sensory and temporal presence has long been a topic of investigation in developmental psychology, especially when it comes to language acquisition. Hence, considering paradigms from developmental research may be informative for adult paradigms as well.

As described for adults in the previous sections, a common comparison also in developmental research has been that between real-life interactions (i.e., high sensory and temporal presence) and videotaped recordings (i.e., low sensory and temporal presence). In particular with respect to language acquisition, infants and young children in the first two years of life learn less from video recordings than from instructions given by a real-life person (Kuhl et al., 2003), a phenomenon termed the "video deficit" (Anderson and Pempek, 2005). Also in other domains, such as object retrieval (Kirkorian et al., 2015), action imitation (Barr et al., 2007), or identity recognition (Myers et al., 2017), children perform better after seeing a real person compared to a recording (see Strouse and Samson, 2021, for a recent overview). This effect is observed not only at the behavioral level, but also at the neural level. Infants show stronger mu suppression, an EEG signal thought to be related to simulation of motor acts, or "mirroring" of the other (Pineda, 2005), during live observations compared to video recordings (Ruysschaert et al., 2013), and a greater difference in activation in motor area between observing actions and simple object motion (Shimada and Hiraki, 2006). Both findings are comparable to the adult results discussed above, suggesting a co-representation of others' actions already early in development. Interestingly, the video deficit appears to be strongest in the second year of life, with both infants and older children showing a weaker deficit (Barr and Nichols Linebarger, 2016).

A number of explanations have been proposed for this video deficit. For example, a 2D image contains less perceptual information compared to a 3D image, referred to as "perceptual impoverishment" (Barr et al., 2007; Kirkorian et al., 2015), which may make encoding and decoding more difficult for young children. In addition, infants need to learn that 2D screen representations are a symbolic representation of 3D real-world entities with different properties that are still informative about the real world (Troseth, 2010). These properties include physical properties such as depth, but also more abstract properties such as anchoring in space and time. Finally, and most relevant to the social aspect, is the lack of interactivity, which results in the absence of contingent responding and reciprocity. Since contingent responding is fundamental for social learning from an early age (Csibra, 2010), its absence unsurprisingly hinders socio-cognitive performance. Thus, temporal presence appears to play a key role even early in development.

Accordingly, studies that directly compared videoconferencing scenarios in which children actively interact with a person on a screen to passive screen viewing have shown several advantages for the interactive condition. Young children demonstrate better learning performance and person recognition (Myers et al., 2017), higher rates of imitation (Nielsen et al., 2008), and improved word learning (Roseberry et al., 2014). Infants also look less at prerecorded videos than at live videos or live interactions (Hains and Muir, 1996; Stormark and Braarud, 2004). However, other research has produced less clear-cut results. For example, Troseth et al. (2018) systematically examined the role of contingent responding (i.e., responding to the child's behavior by smiling, pausing when the child is distracted etc.) and sensory presence on word learning in toddlers. They found that while children successfully learned in the contingent live condition, they failed to do so in both the contingent (similar to a videoconference) and noncontingent video conditions, indicating that sensory presence was the relevant factor for learning. Finally, a recent meta-analysis found that children between 0 and 6 years were worse at learning from videos compared to face-to-face interactions, irrespective of whether the videos were prerecorded or a live videoconference scenario (Strouse and Samson, 2021).

While most studies in infants focus on some form of learning (e.g., language learning but also learning about the location of objects in a room), less is known about the influence of social presence on infants' affective responses. At least one study directly compared 6–12-month-olds' affective responses to their mother playing peekaboo in a live interaction, a contingent video condition, and a non-contingent video condition, and found no difference in infants' behavioral displays of affect (smiling, looking at the camera) and physiological responses (heart rate, respiration rate, skin conductance) (McClure et al., 2020).

Thus, studies in young children suggest that even early in development, manipulation of sensory and temporal presence has subtle influences similar to those described above for adults, but that even young children can already adapt to mediated interactions. The socio-cognitive system thus appears to be flexible enough from an early age to accommodate situations of impoverished social presence. This raises the question to what degree children who grow up with an increasing exposure to mediated social interactions in virtual settings, as may be the case in the near future, might become even more proficient in compensating reduced physical and/or temporal presence. Perhaps, future generations who have been socialized in virtual interactions from early on might show a smaller response to a reduction in social presence than adults currently do (Venter, 2017). Notably, however, most relevant studies in development have focused on some aspect of cognitive processing, such as language acquisition or spatial cognition. Expanding this research to include social cognition related to understanding others would therefore be important for a better understanding of the underlying developmental trajectories.

7. Methodological challenges in studying social presence effects

First and foremost, to understand how social presence affects social interactions, we need a framework that allows us to make predictions regarding under what conditions and at what point in processing we expect changes in social cognition to occur, and which brain networks we expect to be involved. Without such a framework, even a direct contrast between conditions of high and low social presence will only allow the conclusion that high social presence allows for better understanding or leads to differences in neural activation, but will not provide insights into the underlying mechanisms. The present manuscript provides such a framework.

As discussed at the beginning of this article, the key to understanding the contribution of sensory and temporal presence to social understanding is the ability to systematically manipulate these factors. While traditional social neuroscience relies on a highly reduced operationalization of social presence, typically presenting photographs or audio recordings, in recent years, second person neuroscience has begun to develop paradigms characterized by a higher degree of social presence. These include the use of videos, either live or recorded, as well as actual social interactions (Dikker et al., 2020; Dumas et al., 2020; Kelsen et al., 2020; Meshulam et al., 2021; Reinero et al., 2020). The implementation of such paradigms is challenging, as today's neuroscience methods (fMRI, EEG but also fNRIS) have a number of constraints such as susceptibility to motion artifacts or very specific positioning of the subject in the MRI scanner. However, the challenge raised in the present article is not the lack or difficulty of naturalistic paradigms per se, but rather the lack of paradigms that systematically manipulate facets of social presence in the field of interactive social neuroscience.

From a practical standpoint, the challenge here is to develop paradigms that manipulate one aspect of social presence while holding everything else constant. One useful starting point for addressing this challenge is the approach used in many of the above studies (visualized in Fig. 2A). These studies contrasted a live interaction, a video-mediated interaction, and a pre-recorded video (Diana et al., 2023; Gregory and Antolin, 2019; Heimann et al., 2025; Hietanen et al., 2020; Morgan et al., 2022; Petereit et al., 2023; Prinsen and Alaerts, 2019), thus having a condition of high temporal and sensory presence (live interaction), high temporal but medium sensory presence (video-mediated interaction) and low temporal and medium sensory presence (pre-recorded video). We also applied this approach in our research on the effects of social presence on pain empathy. In two studies, we manipulated sensory presence by comparing direct, face-to-face interactions with video-mediated interactions (Petereit et al., 2023), and we manipulated temporal presence by comparing live, video-mediated interactions with pre-recorded videos (Heimann et al., 2025). In other studies, we reduced sensory presence by limiting the sensory channels through which participants could interact (e.g., providing only an audio channel, not a video channel) (Genzer et al., 2025), while keeping temporal presence constant. Alternatively, one could manipulate temporal presence by gradually increasing the temporal delay in a video-based interaction, while keeping the sensory information the same.

However, a realistic interaction with high temporal presence, whether live or video mediated, is by its very nature a setting that is difficult to control. Even with detailed instructions, we cannot know in advance exactly how participants will behave in a live interaction. In contrast, we know exactly what will happen in a pre-recorded video. To account for this discrepancy, most studies use video recordings of a previous live interaction as a subsequent prerecorded video stimulus (Diana et al., 2023; Morgan et al., 2022; Prinsen and Alaerts, 2019). However, this implies that the live interaction is always the reference point from which the prerecorded condition is derived (rather than a balanced comparison between the two). Furthermore, since no two live interactions are identical, the body of stimulus material is potentially very heterogeneous, raising the challenge of how to extract general patterns, and the need for a larger number of participants to find significant effects. A related challenge is the fact that social interactions per se must be operationalized in a meaningful way that (a) allows for a brain-behavior link, (b) captures the essence of social interaction, and (c) translates across different manipulations of social presence.

Another issue, which we touched upon before is the symmetry or asymmetry of temporal and sensory presence in social interactions. Although this aspect could be very relevant for social cognitive processes, only a few studies have directly manipulated it, and more research is needed. Most studies, our own work included (Heimann et al., 2025), which presented pre-recorded videos as condition of low temporal presence, do not control whether the participants and the people in the videos will have the opportunity to interact later on. In other words, the relationship between the people involved in the social interaction is often not specified.

Finally, there are certain limitations to what we can currently, or even in principle, distinguish in the study of social presence. First, while visual and auditory signals can be quite reliably conveyed in a mediated form, such as a video or a phone call, this is not the case for other relevant sensory modalities such as touch. Also, social odors, which can in principle be conveyed in a mediated way (and are, in fact, evolutionary the most important modality for conveying information without the presence of the interaction partner) (Lledo-Ferrer et al., 2011; Lubke and Pause, 2015), are rarely included in systematic studies of social presence. Even the visual modality that is typically studied is often only transported to a certain extent, namely in a 2D way. While recent VR approaches allow for the presentation and manipulation of 3D information (Thurley, 2022), this typically comes at the expense of naturalness of the presentation, with avatars - at least today - often being a rather poor representation of a real person. In practice, these subtle nuances of sensory presence are difficult to manipulate systematically, which often leads researchers to contrast conditions that are conceptually very far apart (e.g., a live interaction and a pre-recorded video, which differ in terms of temporal presence as well as multiple aspects of sensory presence such as the presence of 3D information, touch, and odor).

On a more fundamental level, while sensory presence can be manipulated quite easily while maintaining high temporal presence (e.g., in a phone call), the reverse is not true. It is difficult to reduce temporal presence while maintaining high sensory presence, because some sensory information cannot be transmitted in a mediated way. When a person is able to touch and be touched by another person, they necessarily have a high temporal presence. However, despite these limitations, it is generally possible to manipulate the two dimensions independently. We therefore believe that with a theoretical framework, along with ongoing advances in communication platforms (e.g., in virtual or augmented reality), experimental psychologists and neuroscientists are well equipped to begin systematically investigating these questions, in order to better understand how sensory and temporal presence affect social interactions.

8. Outlook – How to better understand social presence in the future

While several lines of research have begun to explore the role of social presence in social interactions and its neural underpinnings, a conceptual framework has been lacking. We are convinced that the current framework will help to synthesize the empirical evidence, allow for a more systematic and comprehensive understanding of previous work, help to identify critical limitations, and provide insight into future directions. For example, we have found that social presence is often manipulated in ways that confound temporal and sensory presence, making it impossible to draw conclusions about the specific factors driving observed effects. Thus, our framework can help inform the design of future experiments that systematically and independently vary the degree of sensory and temporal presence across different cognitive and affective domains.

In addition, a common conceptual framework for social presence will help to bring together currently disparate lines of research. For example, while the effect of social presence in early language learning has been studied quite systematically, we know little about its effect on social interactions in early development and its neural underpinnings. To investigate whether the influence of social presence in adults is the product of lifelong learning or a deeper, inherent component of social interactions, a better understanding of its effects in infancy would be highly informative. At the same time, developmental research may provide valuable paradigms for adult research, as the systematic manipulation of contingency and interaction medium (closely related to our concepts of temporal and sensory presence) is commonplace in research on early language learning (Troseth et al., 2018).

Future paradigms should go a step further by incorporating both finer-grained and more far-reaching manipulations. Current studies that manipulate social presence most often include conditions of natural interactions and screen-based interactions (manipulating sensory presence), sometimes in addition or as an alternative to a pre-recorded video of an interaction (manipulating temporal presence). A more fine-grained manipulation of sensory presence might systematically compare text, audio and video, odor or touch. Manipulations of temporal presence might consist of a systematic manipulation of temporal delays (similar to a progressively worse connection in a video call), addressing questions such as how much delay is tolerated, and are the effects of reduced temporal presence on cognition gradual or sudden?

At the same time, modern technologies such as virtual or augmented reality allow for a new and more systematic investigation of social presence that is not possible with traditional methods (Oh et al., 2018). For example, what is the qualitative difference in terms of social presence when meeting a person in virtual reality compared to a video call? Both scenarios include visual and auditory information, but virtual reality lacks many visual and auditory details. It also lacks olfactory or tactile information, despite sharing a high level of temporal presence with the other scenario. Virtual reality technology allows for the precise manipulation of the different sensory channels and temporal delays in communication and the interaction partner's behavior. This allows us to clarify which features contribute to the perceived difference between virtual reality and a video calls, as well as differences in social cognitive processes (Hasler et al., 2021; McCall, 2017; Seinfeld et al., 2018).

While the framework of sensory and temporal presence proposed in this article provides an important starting point for a systematic study of social presence, social presence may include certain components not captured by the framework. As alluded to in the introduction, one aspect not addressed is the epistemic state of a person; how does my knowledge of whether I am interacting with a person (as opposed to a screen recording, a virtual avatar or an AI) affect social presence? Work of Rice and Redcay suggest that the epistemic state is indeed highly relevant: When participants believed that stories were being told over a real-time audio feed, they showed increased activity in mentalizing regions compared to when they believed to be listening to a pre-recorded story, although in fact the stories were always pre-recorded (Rice and Redcay, 2016). Moreover, while the current framework focuses on social interactions between people, these important questions should be considered when extending the framework to incorporate human-machine interactions. In particular, as large language models (LLMs) are increasingly used for social-emotional support and mimic expressions of interpersonal emotional responses such as empathy, compassion, and caring (Rubin et al., 2024; Sharma, Lin, et al., 2023; Sharma et al., 2023), the question arises as to whether the same concepts of social presence also apply to social interactions with AI.

Another facet only briefly discussed above is the role of verbal and semantic content in social interactions. As mentioned above, verbal information can be transmitted via different sensory channels and across different time-scales. In our framework, we consider verbal communication therefore an independent factor for our understanding of others, which is orthogonal to the dimensions of social presence. However, it remains an open question for future research whether the factor of verbal information interacts with the effects of sensory or temporal presence. For instance, verbal information in a direct conversation could have different effects compared to the same written information in text messages, which go beyond the effects that can be attributed to other aspects of sensory presence (non-verbal and paraverbal information) or temporal presence (reciprocity, relevance).

In our article, we have only briefly touched on clinical aspects of social presence research, or, more generally speaking on interindividual variability in the experience of social presence. However, understanding the effects of social presence on social interactions is clinically relevant in (at least) two ways. First, as online psychotherapy becomes more common, we need to understand how reduced social presence affects empathic understanding and communication, trust and, more generally, the therapeutic alliance in online settings. This question has been discussed in detail by Grondin et al. (2019). Second, psychiatric disorders may be characterized by dysfunction in the very cognitive and affective skills that depend on high social presence. People with Autism Spectrum Disorder might be particularly sensitive to variations in both temporal and sensory presence, and might even benefit from *reduced* social presence. Individuals with difficulties in self-other distinction, for example because of a Borderline Personality Disorder, may also show specific impairments in social interactions with high levels of social presence. Thus, only social neuroscience studies that place participants in situations of varying social presence will allow us to fully delineate these critical functional differences.

A better understanding of the influence of social presence on our understanding of others is not only of academic interest, but also has strong implications for the unprecedented digitalization we are currently experiencing. To what extent can mediated interactions, such as a video call between a toddler and her grandparents, or a virtual appointment with a psychotherapist, in principle substitute for live, face-to-face interaction? Is this simply a matter of improving technology to avoid bad connections? Or is there a more fundamental component to live interactions that cannot be captured technologically in the foreseeable future? Theoretical and empirical work on computer-mediated communication has provided much insight into social information processing in digital environments, particularly with regard to online education and communication in work contexts (Biocca et al., 2003; Oh et al., 2018; Walther, 1996; Walther et al., 2015). With our framework, which is more tailored to neuroscience research on social cognition, we extend this research with a neurobiological perspective. Answering these questions is critical to informing digitization policies in all areas where social interactions require more than the exchange of objective information. This includes the medical sector, where the personal allegiance between healthcare providers and patients is highly relevant to the outcome, but also any company that increasingly relies on virtual meetings must ask whether and to what extent social cohesion among employees is affected when information exchange is largely shifted to virtual environments.

9. Conclusion

Social presence, or the lack thereof, is a key parameter in our understanding of others. To better understand its role also on a neurobiological level, we believe it is crucial to systematically manipulate the factors that contribute to social presence. Here, we present a framework for achieving this that incorporates two key features of social presence: temporal and sensory presence. Only by better understanding the distinct contributions of these features to social cognition can we fully grasp the core elements that define social presence. This research will form the basis for deriving a neurobiological model of social presence and its role in social interactions.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used "deepL" in order to edit the content for clarity, grammatical accuracy and comprehensibility. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Funding

The authors are supported by the German Science Foundation (DFG; grant numbers KR3691/12–1 and JE781/3–1).

Declaration of Competing Interest

The authors declare no conflict of interest.

Acknowledgements

We thank Cecilia Puebla Antunes for providing drawings used in this manuscript.

References

Abu-Akel, A., Shamay-Tsoory, S., 2011. Neuroanatomical and neurochemical bases of theory of mind. Neuropsychologia 49 (11), 2971–2984. https://doi.org/10.1016/j.neuropsychologia.2011.07.012.

Anderson, D.R., Pempek, T.A., 2005. Television and very young children. Am. Behav. Sci. 48 (5), 505–522. https://doi.org/10.1177/0002764204271506.

Ashwin, C., Hietanen, J.K., Baron-Cohen, S., 2015. Atypical integration of social cues for orienting to gaze direction in adults with autism. Mol. Autism 6 (1), 5. https://doi.org/10.1186/2040-2392-6-5.
Balters, S., Miller, J.G., Li, R., Hawthorne, G., Reiss, A.L., 2023. Virtual (Zoom) Interactions Alter Conversational Behavior and Interbrain Coherence. J. Neurosci. 43 (14), 2568–2578. https://doi.org/10.1523/jneurosci.1401-22.2023.
Barr, R., Muentener, P., Garcia, A., 2007. Age-related changes in deferred imitation from television by 6- to 18-month-olds. Dev. Sci. 10 (6), 910–921. https://doi.org/10.1111/j.1467-7687.2007.00641.x.
Barr, R., Nichols Linebarger, D., 2016. *Media Exposure During Infancy and Early Childhood* (R. Barr & D. Nichols Linebarger, Eds.). Springer.
Behrens, F., Snijdewint, J.A., Moulder, R.G., Prochazkova, E., Sjak-Shie, E.E., Boker, S. M., Kret, M.E., 2020. Physiological synchrony is associated with cooperative success in real-life interactions. Sci. Rep. 10 (1), 19609. https://doi.org/10.1038/s41598-020-76539-8.
Bernhardt, B.C., Singer, T., 2012. The neural basis of empathy. Annu. Rev. Neurosci. 35, 1–23. https://doi.org/10.1146/annurev-neuro-062111-150536.
Biocca, F., Harms, C., Burgoon, J.K., 2003. Toward a more robust theory and measure of social presence: review and suggested criteria. Presence. Teleoperators Virtual Environ. 12 (5), 456–480. https://doi.org/10.1162/105474603322761270.
Biswas, M., Brass, M., 2024. Syncing online: a methodological investigation into movement synchrony, proxemics, and self-other blurring in virtual spaces. PLoS. One 19 (10), e0308843. https://doi.org/10.1371/journal.pone.0308843.
Bohannon, L.S., Herbert, A.M., Pelz, J.B., Rantanen, E.M., 2013. Eye contact and video-mediated communication: a review. Displays 34 (2), 177–185. https://doi.org/10.1016/j.displa.2012.10.009.
Bond, C.F., Titus, L.J., 1983. Social facilitation: A meta-analysis of 241 studies. American Psychological Association. https://doi.org/10.1037/0033-2909.94.2.265.
Busch, A.B., Sugarman, D.E., Horvitz, L.E., Greenfield, S.F., 2021. Telemedicine for treating mental health and substance use disorders: reflections since the pandemic. Neuropsychopharmacology 46 (6), 1068–1070. https://doi.org/10.1038/s41386-021-00960-4.
Cavallo, A., Lungu, O., Becchio, C., Ansuini, C., Rustichini, A., Fadiga, L., 2015. When gaze opens the channel for communication: integrative role of IFG and MPFC. Neuroimage 119, 63–69. https://doi.org/10.1016/j.neuroimage.2015.06.025.
Chen, T., Helminen, T.M., Linnunsalo, S., Hietanen, J.K., 2024. Autonomic and facial electromyographic responses to watching eyes. Iperception 15 (1), 20416695231226059. https://doi.org/10.1177/20416695231226059.
Csibra, G., 2010. Recognizing communicative intentions in infancy. Mind Lang. 25 (2), 141–168. https://doi.org/10.1111/j.1468-0017.2009.01384.x.
Dabas, A., Bruckner, R., Schultz, H., Bergmann, F., Benoit, R.G., 2025. Learning from imagined experiences via an endogenous prediction error. Nat. Commun. 16 (1), 10845. https://doi.org/10.1038/s41467-025-66396-2.
De Jaegher, H., Di Paolo, E., Gallagher, S., 2010. Can social interaction constitute social cognition? Trends Cogn. Sci. 14 (10), 441–447. https://doi.org/10.1016/j.tics.2010.06.009.
De Meulemeester, C., Lowyck, B., Luyten, P., 2021. The role of impairments in self-other distinction in borderline personality disorder: a narrative review of recent evidence. Neurosci. Biobehav. Rev. 127, 242–254. https://doi.org/10.1016/j.neubiorev.2021.04.022.
Decety, J., Jackson, P.L., 2004. The functional architecture of human empathy. Behav. Cogn. Neurosci. Rev. 3 (2), 71–100. https://doi.org/10.1177/1534582304267187.
Diana, F., Juarez-Mora, O.E., Boekel, W., Hortensius, R., Kret, M.E., 2023. How video calls affect mimicry and trust during interactions. Philos. Trans. R. Soc. Lond. B Biol. Sci. 378 (1875), 20210484. https://doi.org/10.1098/rstb.2021.0484.
Dikker, S., Michalareas, G., Oostrik, M., Serafimaki, A., Kahraman, H.M., Struiksma, M. E., Poeppel, D., 2020. Crowdsourcing neuroscience: inter-brain coupling during face-to-face interactions outside the laboratory. Neuroimage, 117436. https://doi.org/10.1016/j.neuroimage.2020.117436.
Dumas, G., Moreau, Q., Tognoli, E., Kelso, J.A.S., 2020. The human dynamic clamp reveals the fronto-parietal network linking real-time social coordination and cognition. Cereb. Cortex 30 (5), 3271–3285. https://doi.org/10.1093/cercor/bhz308.
Eddy, C.M., 2018. Social cognition and self-other distinctions in neuropsychiatry: Insights from schizophrenia and Tourette syndrome. Prog. Neuropsychopharmacol. Biol. Psychiatry 82, 69–85. https://doi.org/10.1016/j.pnpbp.2017.11.026.
Frith, C.D., Frith, U., 2006. The neural basis of mentalizing. Neuron 50 (4), 531–534. https://doi.org/10.1016/j.neuron.2006.05.001.
Gallotti, M., Fairhurst, M.T., Frith, C.D., 2017. Alignment in social interactions. Conscious. Cogn. 48, 253–261. https://doi.org/10.1016/j.concog.2016.12.002.
Genzer, S., Ong, D.C., Zaki, J., Perry, A., 2022. Mu rhythm suppression over sensorimotor regions is associated with greater empathic accuracy. Soc. Cogn. Affect. Neurosci. https://doi.org/10.1093/scan/nsac011.
Genzer, S., Rum, Y., Krämer, U.M., Perry, A., 2025. Seeing to Connect: How Visual and Auditory Channels Shape Empathic Interactions. psyArXiv Prepr. https://doi.org/10.31234/osf.io/4j8w3_v2.
Goldstein, P., Losin, E.A.R., Anderson, S.R., Schelkun, V.R., Wager, T.D., 2020. Clinician-patient movement synchrony mediates social group effects on interpersonal trust and perceived pain. J. Pain. 21 (11-12), 1160–1174. https://doi.org/10.1016/j.jpain.2020.03.001.
Goldstein, P., Weissman-Fogel, I., Dumas, G., Shamay-Tsoory, S.G., 2018. Brain-to-brain coupling during handholding is associated with pain reduction. Proc. Natl. Acad. Sci. USA 115 (11), E2528–E2537. https://doi.org/10.1073/pnas.1703643115.
Goregliad Fjaellingsdal, T., Dohr, K., Zschoche, G., Kramer, U.M., 2025. Advancing the measurement of affective self-other distinction: a novel paradigm to measure intra- and inter-individual differences in emotional biases. Acta Psychol. 261, 105840. https://doi.org/10.1016/j.actpsy.2025.105840.
Gregory, N.J., Antolin, J.V., 2019. Does social presence or the potential for interaction reduce social gaze in online social scenarios? Introducing the "live lab" paradigm. Q J. Exp. Psychol. 72 (4), 779–791. https://doi.org/10.1177/1747021818772812.
Grondin, F., Lomanowska, A.M., Jackson, P.L., 2019. Empathy in computer-mediated interactions: a conceptual framework for research and clinical practice. –17 Clinical Psychol. Sci. Practice 26 (4), 17. https://doi.org/10.1111/cpsp.12298.
Gvirts, H., Ehrenfeld, L., Sharma, M., Mizrahi, M., 2023. Virtual social interactions during the COVID-19 pandemic: the effect of interpersonal motor synchrony on social interactions in the virtual space. Sci. Rep. 13 (1), 10481. https://doi.org/10.1038/s41598-023-37218-6.
Hains, S.M.J., Muir, D.W., 1996. Infant sensitivity to adult eye direction. Child. Dev. 67 (5), 1940–1951. https://doi.org/10.2307/1131602.
Hall, J.A., Schmid Mast, M., 2007. Sources of accuracy in the empathic accuracy paradigm. Emotion 7 (2), 438–446. https://doi.org/10.1037/1528-3542.7.2.438.
Hamilton, A.F. d C., 2016. Gazing at me: the importance of social meaning in understanding direct-gaze cues. Philos. Trans. R. Soc. B Biol. Sci. 371 (1686), 20150080. https://doi.org/10.1098/rstb.2015.0080.
Hamilton, A.F.C., Lind, F., 2016. Audience effects: what can they tell us about social neuroscience, theory of mind and autism? Cult. Brain 4 (2), 159–177. https://doi.org/10.1007/s40167-016-0044-5.
Hasler, B.S., H. Landau, D., Hasson, Y., Schori-Eyal, N., Giron, J., Levy, J., Halperin, E., Friedman, D., 2021. Virtual reality-based conflict resolution: the impact of immersive 360° video on changing view points and moral judgment in the context of violent intergroup conflict. New. Media Soc. 23 (8), 2255–2278. https://doi.org/10.1177/1461444821993133.
Heimann, J., Petereit, P., Perry, A., & Krämer, U.M. (2025). Temporal presence does not affect behavioral and neurophysiological indices of pain empathy. bioRxiv, 2025.2007.2007.663421. https://doi.org/10.1101/2025.07.07.663421.
Hietanen, J.K., Leppanen, J.M., Peltola, M.J., Linna-Aho, K., Ruuhiala, H.J., 2008. Seeing direct and averted gaze activates the approach-avoidance motivational brain systems. Neuropsychologia 46 (9), 2423–2430. https://doi.org/10.1016/j.neuropsychologia.2008.02.029.
Hietanen, J.O., Peltola, M.J., Hietanen, J.K., 2020. Psychophysiological responses to eye contact in a live interaction and in video call. Psychophysiology 57 (6), e13587. https://doi.org/10.1111/psyp.13587.
Hillock-Dunn, A., Wallace, M.T., 2012. Developmental changes in the multisensory temporal binding window persist into adolescence. Dev. Sci. 15 (5), 688–696. https://doi.org/10.1111/j.1467-7687.2012.01171.x.
Hove, M.J., Risen, J.L., 2009. It's all in the timing: interpersonal synchrony increases affiliation. Social. Cogn. 27 (6), 949–961. https://doi.org/10.1521/soco.2009.27.6.949.
Hu, S., Zhang, P., Fang, Y., Gong, X., Fu, L., Ma, E., Zhou, D., Lv, Z., Valdes-Sosa, P.A., 2025. Dyadic neural synchronization: differences between offline and computer-assisted online verbal interaction. Hum. Brain Mapp. 46 (18), e70436. https://doi.org/10.1002/hbm.70436.
Ickes, W., Stinson, L., Bissonnette, V., Garcia, S., 1990. Naturalistic social cognition: Empathic accuracy in mixed-sex dyads [Peer Reviewed] (pp.). J. Personal. Social. Psychol. 59 (4). https://doi.org/10.1037/0022-3514.59.4.730.
Jarvela, S., Katsyri, J., Ravaja, N., Chanel, G., Henttonen, P., 2016. Intragroup emotions: physiological linkage and social presence. Front. Psychol. 7, 105. https://doi.org/10.3389/fpsyg.2016.00105.
Järveläinen, J., Schürmann, M., Avikainen, S., Hari, R., 2001. Stronger reactivity of the human primary motor cortex during observation of live rather than video motor acts. Neuroreport 12 (16), 3493–3495.
Jospe, K., Genzer, S., Klein Selle, N., Ong, D., Zaki, J., Perry, A., 2020. The contribution of linguistic and visual cues to physiological synchrony and empathic accuracy. Cortex 132, 296–308. https://doi.org/10.1016/j.cortex.2020.09.001.
Kaganovich, N., 2016. Development of sensitivity to audiovisual temporal asynchrony during midchildhood. Dev. Psychol. 52 (2), 232–241. https://doi.org/10.1037/dev0000073.
Kelsen, B.A., Sumich, A., Kasabov, N., Liang, S.H.Y., Wang, G.Y., 2020. What has social neuroscience learned from hyperscanning studies of spoken communication? A systematic review. Neurosci. Biobehav. Rev. https://doi.org/10.1016/j.neubiorev.2020.09.008.
Keysers, C., Gazzola, V., 2006. Towards a unifying neural theory of social cognition. Prog. Brain Res. 156, 379–401. https://doi.org/10.1016/S0079-6123(06)56021-2.
Kirkorian, H.L., Lavigne, H.J., Hanson, K.G., Troseth, G.L., Demers, L.B., Anderson, D.R., 2015. Video Deficit in Toddlers' Object Retrieval: What Eye Movements Reveal About Online Cognition. Infancy 21 (1), 37–64. https://doi.org/10.1111/infa.12102.
Koul, A., Ahmar, D., Iannetti, G.D., Novembre, G., 2023. Spontaneous dyadic behaviour predicts the emergence of interpersonal neural synchrony. Neuroimage, 120233. https://doi.org/10.1016/j.neuroimage.2023.120233.
Krach, S., Kamp-Becker, I., Einhaeuser, W., Sommer, J., Fraessle, S., Jansen, A., Rademacher, L., Muller-Pinzler, L., Gazzola, V., Paulus, F.M., 2015. Evidence from pupillometry and fMRI indicates reduced neural response during vicarious social pain but not physical pain in autism. Hum. Brain Mapp. 36 (11), 4730–4744. https://doi.org/10.1002/hbm.22949.
Kuhl, P.K., Tsao, F.M., Liu, H.M., 2003. Foreign-language experience in infancy: effects of short-term exposure and social interaction on phonetic learning. Proc. Natl. Acad. Sci. USA 100 (15), 9096–9101. https://doi.org/10.1073/pnas.1532872100.
Kulke, L., Ertugrul, S., Reyentanz, E., Thomas, V., 2024. Uncomfortable staring? Gaze to other people in social situations is inhibited in both infants and adults. Dev. Sci. 27 (3), e13468. https://doi.org/10.1111/desc.13468.

Lamm, C., Bukowski, H., Silani, G., 2016. From shared to distinct self-other representations in empathy: evidence from neurotypical function and socio-cognitive disorders. Philos. Trans. R. Soc. Lond. B Biol. Sci. 371 (1686), 20150083. https://doi.org/10.1098/rstb.2015.0083.

Liberman, N., Trope, Y., 2014. Traversing psychological distance. Trends Cogn. Sci. 18 (7), 364–369. https://doi.org/10.1016/j.tics.2014.03.001.

Lieberman, M.D., 2007. Social cognitive neuroscience: a review of core processes. Annu. Rev. Psychol. 58, 259–289. https://doi.org/10.1146/annurev.psych.58.110405.085654.

Lledo-Ferrer, Y., Pelaez, F., Heymann, E.W., 2011. The equivocal relationship between territoriality and scent marking in wild saddleback Tamarins (Saguinus fuscicollis). Int. J. Primatol. 32 (4), 974–991. https://doi.org/10.1007/s10764-011-9516-9.

Lubke, K.T., Pause, B.M., 2015. Always follow your nose: the functional significance of social chemosignals in human reproduction and survival. Horm. Behav. 68, 134–144. https://doi.org/10.1016/j.yhbeh.2014.10.001.

Maliske, L.Z., Schurz, M., Kanske, P., 2023. Interactions within the social brain: Co-activation and connectivity among networks enabling empathy and Theory of Mind. Neurosci. Biobehav. Rev. 147, 105080. https://doi.org/10.1016/j.neubiorev.2023.105080.

McCall, C., 2017. Mapping social interactions: the science of proxemics. Curr. Top. Behav. Neurosci. 30, 295–308. https://doi.org/10.1007/7854_2015_431.

McClure, E., Chentsova-Dutton, Y., Holochwost, S., Parrott, W.G., Barr, R., 2020. Infant emotional engagement in face-to-face and video chat interactions with their mothers. Enfance N° 3 (3), 353–374. https://doi.org/10.3917/enf2.203.0353.

Meshulam, M., Hasenfratz, L., Hillman, H., Liu, Y.F., Nguyen, M., Norman, K.A., Hasson, U., 2021. Neural alignment predicts learning outcomes in students taking an introduction to computer science course. Nat. Commun. 12 (1), 1922. https://doi.org/10.1038/s41467-021-22202-3.

Morgan, E.J., Carroll, D.J., Chow, C.K.C., Freeth, M., 2022. The effect of social presence on mentalizing behavior. Cogn. Sci. 46 (4), e13126. https://doi.org/10.1111/cogs.13126.

Murata, A., Nishida, H., Watanabe, K., Kameda, T., 2020. Convergence of physiological responses to pain during face-to-face interaction. Sci. Rep. 10 (1), 450. https://doi.org/10.1038/s41598-019-57375-x.

Myers, L.J., LeWitt, R.B., Gallo, R.E., Maselli, N.M., 2017. Baby FaceTime: can toddlers learn from online video chat? Dev. Sci. 20 (4). https://doi.org/10.1111/desc.12430.

Myllyneva, A., Hietanen, J.K., 2015. The dual nature of eye contact: to see and to be seen. Soc. Cogn. Affect. Neurosci. 11 (7), 1089–1095. https://doi.org/10.1093/scan/nsv075.

Nielsen, M., Simcock, G., Jenkins, L., 2008. The effect of social engagement on 24-month-olds' imitation from live and televised models. Dev. Sci. 11 (5), 722–731. https://doi.org/10.1111/j.1467-7687.2008.00722.x.

Ninomiya, T., Noritake, A., Isoda, M., 2021. Live agent preference and social action monitoring in the macaque mid-superior temporal sulcus region. Proc. Natl. Acad. Sci. USA 118 (44). https://doi.org/10.1073/pnas.2109653118.

Noah, J.A., Zhang, X., Dravida, S., Ono, Y., Naples, A., McPartland, J.C., Hirsch, J., 2020. Real-Time Eye-to-Eye Contact Is Associated With Cross-Brain Neural Coupling in Angular Gyrus. Front. Hum. Neurosci. 14, 19. https://doi.org/10.3389/fnhum.2020.00019.

Nowacka, A., Shapiro, A., Douglas, K., Corballis, P.M., 2025. When perception meets grief: how the brain reconstructs person networks in response to absence. Soc. Cogn. Affect. Neurosci. 20 (1). https://doi.org/10.1093/scan/nsaf117.

Oh, C.S., Bailenson, J.N., Welch, G.F., 2018. A systematic review of social presence: definition, antecedents, and implications. Front. Robot. AI 5, 114. https://doi.org/10.3389/frobt.2018.00114.

Onderdijk, K.E., Acar, F., Van Dyck, E., 2021. Impact of lockdown measures on joint music making: playing online and physically together. Front. Psychol. 12, 642713. https://doi.org/10.3389/fpsyg.2021.642713.

Petereit, P., Weiblen, R., Perry, A., Kramer, U.M., 2023. Effects of social presence on behavioral, neural, and physiological aspects of empathy for pain. Cereb. Cortex 33 (18), 9954–9970. https://doi.org/10.1093/cercor/bhad257.

Pineda, J.A., 2005. The functional significance of mu rhythms: translating "seeing" and "hearing" into "doing". Brain Res. Brain Res. Rev. 50 (1), 57–68. https://doi.org/10.1016/j.brainresrev.2005.04.005.

Pönkänen, L.M., Alhoniemi, A., Leppanen, J.M., Hietanen, J.K., 2011. Does it make a difference if I have an eye contact with you or with your picture? An ERP study. Soc. Cogn. Affect. Neurosci. 6 (4), 486–494. https://doi.org/10.1093/scan/nsq068.

Pönkänen, L.M., Peltola, M.J., Hietanen, J.K., 2011. The observer observed: frontal EEG asymmetry and autonomic responses differentiate between another person's direct and averted gaze when the face is seen live. Int. J. Psychophysiol. 82 (2), 180–187. https://doi.org/10.1016/j.ijpsycho.2011.08.006.

Prinsen, J., Alaerts, K., 2019. Eye contact enhances interpersonal motor resonance: comparing video stimuli to a live two-person action context. Soc. Cogn. Affect. Neurosci. 14 (9), 967–976. https://doi.org/10.1093/scan/nsz064.

Pronizius, E., Bukowski, H., Lamm, C., 2024. Comparing self-other distinction across motor, cognitive and affective domains. R. Soc. Open. Sci. 11 (10), 240662. https://doi.org/10.1098/rsos.240662.

Redcay, E., Dodell-Feder, D., Pearrow, M.J., Maavros, P.L., Kleiner, M., Gabrieli, J.D., Saxe, R., 2010. Live face-to-face interaction during fMRI: a new tool for social cognitive neuroscience. Neuroimage 50 (4), 1639–1647. https://doi.org/10.1016/j.neuroimage.2010.01.052.

Reinero, D.A., Dikker, S., Van Bavel, J.J., 2020. Inter-brain synchrony in teams predicts collective performance. Soc. Cogn. Affect. Neurosci. https://doi.org/10.1093/scan/nsaa135.

Rice, K., Redcay, E., 2016. Interaction matters: a perceived social partner alters the neural processing of human speech. Neuroimage 129, 480–488. https://doi.org/10.1016/j.neuroimage.2015.11.041.

Risko, E.F., Richardson, D.C., Kingstone, A., 2016. Breaking the fourth wall of cognitive science:real-world social attention and the dual function of gaze. Curr. Dir. Psychol. Sci. 25 (1), 70–74. https://doi.org/10.1177/0963721415617806.

Roseberry, S., Hirsh-Pasek, K., Golinkoff, R.M., 2014. Skype me! Socially contingent interactions help toddlers learn language. Child. Dev. 85 (3), 956–970. https://doi.org/10.1111/cdev.12166.

Rubin, M., Li, J.Z., Zimmerman, F., Ong, D.C., Goldenberg, A., Perry, A., 2024. The Value of perceiving a human response: comparing perceived human versus AI-Generated Empathy. osf Prepr. https://doi.org/10.31219/osf.io/ng97s.

Rubo, M., Huestegge, L., Gamer, M., 2020. Social anxiety modulates visual exploration in real life - but not in the laboratory. Br. J. Psychol. 111 (2), 233–245. https://doi.org/10.1111/bjop.12396.

Ruysschaert, L., Warreyn, P., Wiersema, J.R., Metin, B., Roeyers, H., 2013. Neural mirroring during the observation of live and video actions in infants. Clin. Neurophysiol. 124 (9), 1765–1770. https://doi.org/10.1016/j.clinph.2013.04.007.

Sacristan, R., Royle, S., Galpin, A., 2023. Texting and the brain: the time-course of social brain activation in face-to-face versus text-based computer-mediated-communication. Cyber J. Psychosoc. Res. Cyber 17 (4). https://doi.org/10.5817/cp2023-4-3.

Sato, R., Sato, H., 2025. Synchronization of brain activity associated with eye contact: comparison of face-to-face and online communication. Sci. Rep. 15 (1), 608. https://doi.org/10.1038/s41598-024-84602-x.

Schilbach, L., 2016. Towards a second-person neuropsychiatry. Philos. Trans. R. Soc. Lond. B Biol. Sci. 371 (1686), 20150081. https://doi.org/10.1098/rstb.2015.0081.

Schilbach, L., Timmermans, B., Reddy, V., Costall, A., Bente, G., Schlicht, T., Vogeley, K., 2013. Toward a second-person neuroscience. Behav. Brain Sci. 36 (4), 393–414. https://doi.org/10.1017/S0140525X12000660.

Schwartz, L., Levy, J., Endevelt-Shapira, Y., Djalovski, A., Hayut, O., Dumas, G., Feldman, R., 2022. Technologically-assisted communication attenuates inter-brain synchrony. Neuroimage 264, 119677. https://doi.org/10.1016/j.neuroimage.2022.119677.

Schwartz, L., Levy, J., Hayut, O., Netzer, O., Endevelt-Shapira, Y., Feldman, R., 2024. Generation WhatsApp: inter-brain synchrony during face-to-face and texting communication. Sci. Rep. 14 (1), 2672. https://doi.org/10.1038/s41598-024-52587-2.

Sebanz, N., Bekkering, H., Knoblich, G., 2006. Joint action: bodies and minds moving together. Trends Cogn. Sci. 10 (2), 70–76. https://doi.org/10.1016/j.tics.2005.12.009.

Seinfeld, S., Arroyo-Palacios, J., Iruretagoyena, G., Hortensius, R., Zapata, L.E., Borland, D., de Gelder, B., Slater, M., Sanchez-Vives, M.V., 2018. Offenders become the victim in virtual reality: impact of changing perspective in domestic violence. Sci. Rep. 8 (1), 2692. https://doi.org/10.1038/s41598-018-19987-7.

Sharma, A., Lin, I.W., Miner, A.S., Atkins, D.C., Althoff, T., 2023. Human–AI collaboration enables more empathic conversations in text-based peer-to-peer mental health support. Nat. Mach. Intell. 5 (1), 46–57. https://doi.org/10.1038/s42256-022-00593-2.

Sharma, A., Rushton, K., Lin, I., Wadden, D., Lucas, K., Miner, A., Nguyen, T., & Althoff, T. (2023, July). Cognitive Reframing of Negative Thoughts through Human-Language Model Interaction. In A. Rogers, J. Boyd-Graber, & N. Okazaki, Proceedings of the 61st Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers) Toronto, Canada.

Shimada, S., Hiraki, K., 2006. Infant's brain responses to live and televised action. Neuroimage 32 (2), 930–939. https://doi.org/10.1016/j.neuroimage.2006.03.044.

Short, J., Williams, E., Christie, B., 1976. The social psychology of telecommunications. John Wiley & Sons, Ltd.

Stormark, K.M., Braarud, H.C., 2004. Infants' sensitivity to social contingency: a "double video" study of face-to-face communication between 2- and 4-month-olds and their mothers. Infant. Behav. Dev. 27 (2), 195–203. https://doi.org/10.1016/j.infbeh.2003.09.004.

Strouse, G.A., Samson, J.E., 2021. Learning From Video: A Meta-Analysis of the Video Deficit in Children Ages 0–6 Years. Child. Dev. 92 (1), e20–e38. https://doi.org/10.1111/cdev.13429.

Thurley, K., 2022. Naturalistic neuroscience and virtual reality. Front. Syst. Neurosci. 16, 896251. https://doi.org/10.3389/fnsys.2022.896251.

Tian, Y., Liu, S., Wang, J., 2024. A Corpus Study on the Difference of Turn-Taking in Online Audio, Online Video, and Face-to-Face Conversation. Lang. Speech 67 (3), 593–616. https://doi.org/10.1177/00238309231176768.

Troseth, G.L., 2010. Is it life or is it Memorex? Video as a representation of reality. Dev. Rev. 30 (2), 155–175. https://doi.org/10.1016/j.dr.2010.03.007.

Troseth, G.L., Strouse, G.A., Verdine, B.N., Saylor, M.M., 2018. Let's Chat: On-Screen Social Responsiveness Is Not Sufficient to Support Toddlers' Word Learning From Video. Front. Psychol. 9, 2195. https://doi.org/10.3389/fpsyg.2018.02195.

Uziel, L., 2007. Individual differences in the social facilitation effect: A review and meta-analysis. J. Res. Personal. 41 (3), 579–601. https://doi.org/10.1016/j.jrp.2006.06.008.

Venter, E., 2017. Bridging the communication gap between Generation Y and the Baby Boomer generation. Int. J. Adolesc. Youth 22 (4), 497–507. https://doi.org/10.1080/02673843.2016.1267022.

Walther, J.B., 1996. Computer-Mediated Communication:Impersonal, Interpersonal, and Hyperpersonal Interaction. Commun. Res. 23 (1), 3–43. https://doi.org/10.1177/009365096023001001.

Walther, J.B., Van Der Heide, B., Ramirez Jr., A., Burgoon, J.K., & Peña, J. (2015). Interpersonal and Hyperpersonal Dimensions of Computer-Mediated

Communication. In *The Handbook of the Psychology of Communication Technology* (pp. 1–22). https://doi.org/10.1002/9781118426456.ch1.

Wiltermuth, S.S., Heath, C., 2009. Synchrony and cooperation. Psychol. Sci. 20 (1), 1–5. https://doi.org/10.1111/j.1467-9280.2008.02253.x.

Zhao, N., Zhang, X., Noah, J.A., Tiede, M., Hirsch, J., 2023. Separable processes for live "in-person" and live "zoom-like" faces. Imaging Neurosci. 1. https://doi.org/10.1162/imag_a_00027.