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Original Article

In-person, video conference, or audio conference? Examining individual and dyadic information processing as a function of communication system

Jingjing Han [1,2,3,*], Lucía Cores-Sarría [4], Han Zhou [5]

[1]School of Journalism, Fudan University, Shanghai, China
[2]Institute for Global Communications and Integrated Media, Fudan University, Shanghai, China
[3]Shanghai Key Laboratory of Data Science, Fudan University, Shanghai, China
[4]Digital Democracy Center, University of Southern Denmark, Odense, Denmark
[5]Department of Communication Arts, University of Wisconsin-Madison, Madison, WI, USA

*Corresponding author: Jingjing Han. E-mail: hanjing@alumni.iu.edu

Abstract

The wide use of virtual communication has raised a need to understand its effect on communication effectiveness and the ways its different forms influence users' information processing. To that end, this study proposes the Dynamical Interpersonal Communication Systems Model and posits that the amount of information directly perceived affects individual and dyadic information processing. This proposition is tested by examining how visual information influences physiological patterns, known to underlie information processing, during in-person, video, and audio-only conferences. Results indicate that while audio-only communication sustained emotional intensity better, visual-based communication required less initial cognitive effort. Visual information in combination with physical presence (in-person communication) resulted in consistently lower cognitive effort and stronger synchronization of positive emotions, compared to contexts involving visual but without embodied information (video communication). This study shows the importance of investigating interpersonal communication simultaneously across multiple systems and at the intra- and inter-personal levels.

Keywords: video conference, virtual communication, interpersonal synchrony, information processing, cognitive effort.

Virtual meetings have become a major communication tool worldwide for businesses, education, healthcare services, and political activities. Many companies now allow remote working for a significant amount of time, with some estimates indicating that as much as 30% of the workforce in the United States worked fully remotely in 2022 (Kessler, 2023). Tech companies are also racing to develop argument reality and virtual reality systems in hopes of providing a more immersive and thereby a more in-person-like meeting experience. While virtual meetings hold flexibility and cost advantages, the all-day long use of virtual meetings might not come without a cost, as it can negatively impact team collaboration and innovation (Brucks & Levav, 2022) and cause many physical and mental health problems (e.g., Zoom fatigue). More importantly, different virtual meeting formats vary in their social impacts. For example, they can significantly alter the perception of others, which is critical in contexts such as job interviews, elections, and judicial court systems (e.g., Wienrich et al., 2022). Some formats may lead to increased biases toward certain social and racial groups. Therefore, it is of great importance to understand how virtual meetings in various forms influence individual and interpersonal processes, and how these formats differ from one another and from the traditional face-to-face counterpart in terms of the above processes. To that end, this study aims to provide a systematic framework for understanding virtual and face-to-face communication and examines how three different communication channels (in-person, video conference, and audio conference) affect physiological patterns at the individual level as well as at the dyad level in terms of synchronized processes.

This article begins with a theoretical framework that is built to provide a better understanding of the dynamical processes involved in in-person and virtual communication. Along with that we propose our hypotheses, testing differences in the individual and interpersonal synchronized processes across various communication channels.

Theoretical aim and framework building

In recent years the communication field has seen a growing interest in developing a dynamic dyadic systems approach (Brinberg & Lydon-Staley, 2023; Holmstrom et al., 2023; Solomon et al., 2021, 2023). However, the research published to date primarily focuses on the context of face-to-face interaction and has paid far less attention to the dynamics in mediated contexts. This research combines the dynamic dyadic systems approach and the Dynamic Human-Centered Communication Systems Theory (DHCCST; Lang, 2014) and develops a general theoretical framework that captures face-to-face and mediated communication within one single model, enabling comparisons of various forms of interpersonal communication. The goal is to build a comprehensive framework for analyzing interpersonal communication across different communication channels and timescales. This holistic framework is particularly important in an era where a variety of media technologies are used for interpersonal communication, during which communication processes vary

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temporally (synchronous versus asynchronous) and dynamically at different timescales.

Toward the dynamical interpersonal communication systems model

Both the DHCSST and the dynamic dyadic systems approach were drawn from a nonlinear dynamical systems theory (NDST) perspective (Strogatz, 2000) and conceptualized interpersonal communication as a dynamical system. In this article, we propose a working model, the Dynamical Interpersonal Communication Systems Model, which defines interpersonal communication as a dynamical system consisting of at least two humans interacting with one another through one medium either in the same location or in different locations, and either in real time or asynchronously. Interpersonal communication as a dynamical system entails that (a) conversants influence one another, (b) processes involved in their interaction evolve over time, and (c) the surroundings continuously influence conversants and their processes. Another important characteristic of interpersonal communication being a dynamical system is that, within the system, there are subsystems including inter- and intrapersonal systems that run on different timescales and interact with one another over time. For instance, the interpersonal system runs at the between-individual level and is restricted by macro-level systems such as environmental and cultural systems, as well as affected by micro-level systems including the intrapersonal system and systems nested within it. On the other hand, the intrapersonal system runs at the individual level and is restricted by the interpersonal system and those above it, while it is also affected by microsystems including cognitive, emotional, motivational, and biological systems. This multi-timescale nature was found in the literature on bio-behavioral coupling in social interactions (e.g., Dumas et al., 2011), stressing the importance of not only understanding the natural laws running at each timescale but more importantly the interactions between these timescales (see Figure S1 in Supplementary Section 1). With that, this article will first define and categorize different interpersonal communication systems based on the DHCCST and approach a dynamical systems understanding of interpersonal communication by analyzing physiological processes occurring in two critical subsystems, that is, the inter- and intrapersonal systems.

Categorizing interpersonal communication systems

DHCCST proposes that all types of communication rely on at least one of three different encoding systems: evolved, representational, and symbolic. The *evolved encoding system* consists of directly perceivable actions or expressions of animals. Information in the human evolved natural environment, for example, body language and facial expression (light and air mediated), can be directly perceived by the visual and other perceptual systems. Drawings, pictures, moving images, and recorded sound are conceptualized as *manmade representational encoding systems* because they convey some directly perceivable information such as the shape of an object from pictures and laughter from recorded soundtrack but lack other types of perceptual information like smell and touch. Finally, *a symbolic encoding system* shares no perceptual information with the thing being encoded (e.g., language, Morse code), humans must learn the meaning through association instead of automatically drawing it from their perceptual experience of the world. With that, interpersonal communication systems can be categorized as a function of the encoding systems they rely on. An *evolved communication system* is a system in which two or more humans in the same physical space exclusively rely on evolved encoding systems to communicate with one another spontaneously. This system conveys the highest perceptual information of conversing partners, with communication occurring synchronously in both time and space.

Representational communication systems are the ones with manmade media delivering information that is primarily representationally encoded. This includes contexts such as individuals watching videos, listening to radio, and having conversations via video or voice call or virtual reality platforms. In this study, video conference and audio conference represent two types of representational communication systems—the audio/video and audio-only systems—because they rely on evolved-like (i.e., representational) visual and auditory encoding. Visual information captured and reproduced by video messages is analogous to visual information in natural light because it preserves the changing structure in the optic array (Gibson, 1977). Although video-mediated visual information is automatically meaningful to our visual system, there are important differences with embodied visual perception. For example, the visual perspective in video is not determined by the position of the observer, as it would in real life, but by the position of the camera. Human vision is stereoscopic and dynamic (as characterized by a moving observer), while a web camera placed on top of a screen presents a narrower, singular, and static visual field (Gibson, 1966). As a result, video messages in video conferencing contain reduced three-dimensional information from what a moving observer perceives (Cores-Sarría, 2022; Gibson, 1966) and forces a perspective that is abnormally close and low in relation to the speaker's face due to the fixed position of the camera. Therefore, the visual information available to conversants in video conferencing is optically different from that in the evolved encoding system. Similarly, the auditory information in video and audio conferences is also a result of a filtered process from the sound in nature. Both audio/video and audio-only communication systems rely on auditory information that is primarily representationally encoded (paralinguistic cues like intonation and event-related information such as coughs or laughter) and can also be symbolically encoded such as language. However, the audio/video communication system delivers a higher level of perceptual information because it includes visual information that is directly perceivable, while audio-only communication does not. Overall, representational systems deliver a moderate level of perceptual information of conversing partners and therefore offer a limited set of the affordances available in in-person interaction.

Symbolic communication systems are those in which interactions between conversants are symbolically encoded. In this context, people share their thoughts and emotions with textual methods such as messaging, emailing, and posting, leaving symbolic information being the dominant information to one another. Therefore, this communication system has the minimum perceivable information available, reducing the affordances of the interaction even further.

It is worth noting that the spatial and temporal aspects vary across the three systems. The evolved communication system occurs within the same location whereas all other communication systems take place in at least two different locations, and with varying delays in receiving information. The table in Supplementary Section 1 summarizes the differences between the interpersonal communication systems from the DHCCST perspective. All these differences, namely the encoding method, the medium, and the spatial and temporal convergence inevitably bring about distinct and emergent patterns of information processing and communication behavior. Because of the varying degrees of directly perceivable information involved in the encoding systems, DHCCST argues that they have differential effects on our biological and motivational systems. For example, representational information activates the person's motivational systems before the viewer is consciously aware of it because it is directly perceivable. On the other hand, symbolic information requires that we decode symbols and generate meanings out of the meaningless shapes of words. As a result, our motivational systems are activated more slowly when we process symbolic information compared to representational information (Lang et al., 2015).

This brings to a general model tenet that because evolved, representation, and symbolic communication systems vary in the level of directly perceivable information, these systems entail differentiated information processing patterns at both individual and dyadic levels. Earlier research supports this argument. For example, at the individual level, these systems afford different information processing strategies such that videoconferencing facilitates more heuristic processing while in-person meeting participants adopt more systematic processing (Ferran & Watts, 2008). At the dyadic level, research studying the television co-viewing context where both human–media interaction and interpersonal interaction take place revealed varied synchronized patterns of information processing between co-viewers (Han, 2020). Notably, the types of interpersonal communication, including in-person, videoconferencing, audioconferencing, and messaging, significantly contribute to the differentiated synchronized process between individuals during the co-viewing task. To further understand how the linear change of perceptual information in those communication systems alters communication processes, this study was designed to test the impact of one type of perceptual information—visual information—on the two levels of information processing.

The interpersonal system nested within interpersonal communication system

The fundamental assumption of the model at the interpersonal level is that when individuals interact, they reciprocally influence each other's emotional and cognitive processes and states. It also implies that many interpersonal processes such as emotional contagion and synchrony share the same systematic structure that can be described with the characteristics of dynamical systems (Butler, 2011). Theories using the NDST perspective such as the Temporal Interpersonal Emotional Systems (TIES; Butler, 2011) have been developed for a systematic understanding of dynamical processes inherent to interpersonal emotion and cognition. For example, TIES synthesizes related but different emotional processes such as emotional contagion, synchrony, and entrainment into a coherent theory by revealing the dynamical system structure (or operational NDST principles) underlying these processes.

In this study, we focus on interpersonal, synchronized physiological processes, as a way for understanding the complex and dynamic processes that emerge from the interaction between individuals. Physiological synchrony in this study refers to the dynamic similarity of two-person's physiological signals and describes the extent to which two conversants' physiological processes are coupled in real time. Understanding dyads' synchronized physiological processes is critical because it is positively associated with a variety of core dimensions of human experience, including mutual understanding, the depth of information processing, task performance, team collaboration and collective intelligence, communication success, and social rapport (e.g., Bente & Novotny, 2020; Tomprou et al., 2021).

The core assumption of this proposed model, as stated earlier, is that the synchronized physiological processes between conversants have a perceptual basis. In other words, communication information (visual, verbal, and vocal) during interpersonal interactions automatically and dynamically affects one's physiological processes, producing synchronized physiological activity between individuals. One example is emotional contagion, which occurs when a person mimics someone else's facial and vocal expressions, postures, and movements (Hatfield et al., 1993). Those behaviors provide feedback information to one's own emotional feelings, transferring a specific emotional state from the body to the mind and synchronizing emotion between conversants (Weber & Quiring, 2017). Furthermore, directly perceivable information also plays a role in the synchronization of cognition, even if it may not be as determining as in emotion. Synchronized attentional processes have been found at the neurological, physiological, and behavioral levels (e.g., Nummenmaa et al., 2012; Richardson & Dale, 2005; Stuldreher et al., 2020). In particular, visual information of one another might be more likely to bring people's attention together as humans naturally tend to follow each other's eye gaze for shared understanding and enhanced communication effectiveness. Because joint attention is a key determinant of interpersonal synchrony, the presence of visual information will thus produce stronger physiological and behavioral synchrony than do other types of communication information (e.g., Richardson et al., 2007).

By and large, synchrony during interpersonal interaction can emerge from visual information (e.g., eye gaze, facial expression, gestures, and body movement), vocal information (e.g., speech tones, sighs, and shouts), verbal information (e.g., spoken language and words), or a combination of all the three. To test the model's tenet, a more specified proposition is that a communication system with more directly perceivable information could generate greater interpersonal physiological synchrony (Model Proposition 1).

The intrapersonal system nested within the interpersonal communication system

As mentioned, the model proposes that the characteristics of perceptual information within interpersonal communication systems impact physiological processes not only at the interpersonal level but also at the individual level. DHSSCT posits that the more evolved characteristics a system has, the more rapid and automatic human responses are. Previous research supports this proposition across a range of research focusing on various proposed mechanisms. For example, most laughter occurs in social settings compared to when one is alone.

The main reason is that social contexts afford emotional contagion and behavioral mimicry, thus resulting in greater use of facial expressions (Provine, 1996). Moreover, social facilitation theory argues that the presence of another human by itself increases one's physiological arousal, for instance by increasing their engagement in the task, or by experiencing fear of being evaluated (Hwang & Won, 2021). Likewise, AI research found that a robot presented with a more embodied form (a human-like agent versus an animated image) can lead to a stronger effect of social facilitation (Hertz & Wiese, 2017). All these suggest two important points for this study: first, a more embodied context with more directly perceivable information, especially those with physical presence, should lead to higher levels of physiological arousal and facial expression activities than a less embodied context such as an audio conference. Second, interpersonal emotional processes via traditionally known pathways such as emotional contagion and behavioral mimicry can more easily occur when more perceptual information is available, leading to greater use of facial expressions for these communication systems. Thus, the second model proposition is that a communication system with more directly perceivable information could lead to higher levels of individual physiological activities in relation to emotion (Model Proposition 2).

On the other hand, the impact of communication systems on individuals' cognitive processes may be more complex and less predictable than their impact on emotional processes. According to DHCCST, representational communication systems might, to some extent, require similar levels of energy to evolved communication for cognitive processing because they afford evolved-like information. However, the coronavirus disease 2019 (COVID-19) pandemic made researchers realize how exhausting videoconferencing can be, prompting the creation and popularization of the term "Zoom fatigue." Recent research theorized a few factors that might cause videoconferencing exhaustion, including restricted physical movement, constant self-focused attention and self-evaluation ("mirror anxiety"), and the use of continuous direct eye gaze at extremely close distances with other human faces (Bailenson, 2021). It is worth noting that the latter two factors are associated with visual information processing. The Model we proposed here also emphasizes the critical distinctions in visual perspective between videoconferencing and in-person meetings, as discussed earlier. Mental fatigue from the all-day long use of videoconferencing may be largely due to the increased cognitive effort of having to process unnatural visual cues, and if this is true, we should see a lower level of cognitive effort during in-person as opposed to video communication. Furthermore, audio conferencing might also lower cognitive effort because it does not provide "unnatural" visual information. On the other hand, conversants in audio conferencing may try to make up for the lack of visual information by altering their vocal behavior by increasing their volume, exaggerating their vocal intensity, and changing turn-taking frequencies to best convey and transmit their emotion and thoughts. This behavioral adaptation might require a significant number of cognitive resources, resulting in a high level of cognitive effort for people in audio-only communication. In this regard, we focus on cognitive effort as one aspect of cognitive processing for investigation in this study. Based on the discussions above, we propose the following research question: will a communication system with more directly perceivable information be less cognitively, emotionally, and/or perceptually challenging (known as *psychological challenges*, Porges, 2023), leading to lower levels of cognitive effort? (Model Proposition 3).

Relationships between physiological processes and cognition/emotion

Because physiological measures offer a continuous measure of psychological processes, they have been widely used to understand interpersonal processes in interactions as varied as parent–infant, patient–therapist, teacher–student, romantic partners, and teammates (Palumbo et al., 2017), as well as individuals' intrapersonal cognitive and emotional processes during media use (Potter & Bolls, 2012). Among various physiological measures, electrodermal activity (EDA) and respiratory sinus arrhythmia (RSA) are major measures of the sympathetic and parasympathetic nervous systems. Skin conductance as a measure of EDA has been interpreted as an indicator of emotional arousal, with a higher level of skin conductance activity indicating a more intense emotional response. Interpersonal synchrony in skin conductance indicates similar evolving patterns of emotional arousal during communication. RSA refers to a high-frequency band (0.12–0.40 Hz, Porges, 1985) of heart rate variability, which can be calculated from an electrocardiogram (ECG). While RSA has been used to indicate various types of psychological processes such as changes in mental effort, cognitive load, emotional regulation, and other psychological processes (Beauchaine, 2001; Porges, 1995), it in essence reflects the body's response to environmental challenges by modulating the vagal break that controls the metabolic resources required by the body and the environment. In short, RSA changes whenever there are psychological challenges that require the body to regulate. In the context of this study, lower RSA is interpreted as indicating more cognitive effort for regulating cognitive, emotional, and sensory challenges occurring during communication (Ravaja, 2004). Interpersonal synchrony in RSA thus suggests a coupling in cognitive effort between conversants.

Another widely used physiological measure in communication research is facial EMG (fEMG), which records electrical activity in muscle areas responsible for emotional expressions. Three muscle areas are commonly used to indicate changes in emotional valence: corrugator supercilii (frowning muscle), orbicularis oculi (OO; located beneath the lower eyelid), and zygomaticus muscle (smiling muscle in the cheek area). More corrugator activity suggests an increase in negative emotion, and more OO and zygomatic activities indicate an increase in positive emotion. Because OO is much less affected by speech physiology than the zygomaticus muscle, this study uses corrugator and OO activities as measures for individuals' emotional states. Using fEMG for understanding emotional states and their synchronized patterns during dyadic conversation is not uncommon (e.g., Hess & Bourgeois, 2010; Riehle et al., 2017). In particular, Cacioppo et al. (1988) validated the corrugator's ability in predicting emotion in an interview task that involved talking. They found that increased corrugator activity was associated with higher reported negative emotion and lower reported positive emotion.

Research hypotheses and questions

The model propositions predict that a communication system with more directly perceivable information would generate greater interpersonal physiological synchronization at the interpersonal level and physiological activation meaning greater emotion and less cognitive effort at the individual level. To test the model propositions, this research uses in-person, video-, and audioconferencing as the operationalization of the evolved, audio/video and audio-only communication systems, and compares them by examining several physiological signals at both the individual and dyadic levels. To disentangle the role of visual information, the tests will be organized into two sets of analyses. First, we compare in-person and video conferences with audio conferences as the comparison between visual and non-visual-based systems. Second, within visual-based communication, we compare in-person conferences to video conferences, which, as we have already noted, rely on different types of visual information (i.e., embodied versus mediated visual information). Below are specific hypotheses and questions we developed from the model propositions. Hypotheses for synchronized processes are denoted by the letter S and those for individual processes are marked with the letter I.

For synchronized physiological activities per Model Proposition 1:

> **S-H1:** In-person and video conferences (visual-based communication), compared to audio conferences (nonvisual-based communication), will lead to stronger synchrony in *OO activity* (**S-H1a**), in *corrugator activity* (**S-H1b**), in *skin conductance activity* (**S-H1c**), and in RSA (**S-H1d**).
> **S-H2:** In-person, compared to video conference, will lead to stronger interpersonal synchrony in *OO activity* (**S-H2a**), in *corrugator activity* (**S-H2b**), in *skin conductance activity* (**S-H2c**), and in *RSA* (**S-H2d**).

For individuals' physiological activities in relation to emotion, per Model Proposition 2:

> **I-H1:** In-person and video conferences (visual-based communication), compared to audio conference (non-visual-based communication), will lead to more *OO activity* (**I-H1a**), more *corrugator activity* (**I-H1b**), and more *skin conductance activity* (**I-H1c**).
> **I-H2:** In-person, compared to video conference, will lead to more *OO activity* (**I-H2a**), more *corrugator activity* (**I-H2b**), and more *skin conductance activity* (**I-H2c**).

For individuals' physiological activities in relation to cognition, per Model Proposition 3:

> **I-RQ1:** Will audio conference (nonvisual-based communication) lead to lower or greater cognitive effort (RSA) than in-person and video conference (visual-based communication)?
> **I-H2d:** Video compared to in-person conference will lead to greater cognitive effort, indicated by a lower level of RSA.

Method

Design and data

This study is a secondary data analysis from a research project that examines interpersonal synchrony during television co-viewing (Han, 2020, IRB protocol # 1611311746) where participants watched television programs with their partners either together in the same room or in a separate room. Participants had known each other at least for 3 months and were randomly assigned to four communication conditions (in-person, audio/video, audio-only, and text-based communication) so that they could talk with each other using their assigned communication channel while watching the television programs simultaneously. Upon signing the consent form and finishing skin preparation for physiological data collection (Supplementary Section 2), participants were asked to keep silent for 2 min (the silence phase), followed by an unstructured conversation using the assigned communication channel for another 2 min (the talking phase). Participants were instructed to engage in a casual conversation as they normally would and were given the freedom to discuss any topic of their choosing (see Supplementary Section 3 for lab setting). After the two baseline sessions, they were then instructed to complete the main task. ECG, EDA, and fEMG were recorded during the entire protocol. The data were collected in 2018 prior to the COVID-19 pandemic, at a time when participants had less experience with video/audio conferencing than they likely would do now.

The talking phase data from the evolved, audio/video, and audio-only communication were used for this study based on the hypotheses. Focusing on these three types of communication enabled us to test how visual information from nonverbal behavior influences information processing. Therefore, the text-based communication condition, which heavily relies on symbolic encoding, was not included in this study.

Participants

A total of 150 undergraduates (75 dyads, 69 females, average age = 20.35, $SD = 2.42$) participated in the in-person (28 dyads), video (24 dyads), and audio (23 dyads) conferences. Most participants identified themselves as being White ($n = 100$). Supplementary Sections 3 and 4 reported detailed demographic information, the final sample sizes used for analyses, and information about missing data.

Physiological variables

RSA, skin conductance, and corrugator and OO activities were measured to indicate cognitive effort, emotional arousal, and negative and positive facial expressions, respectively.

Covariate variables

Data assessing dyadic relationships and individual differences were also collected during the experiment and used in this study as covariate variables (see details in Supplementary Section 5). Specifically, two friendship variables, *psychological closeness* and *relational satisfaction*, were measured with two scales, respectively. The Big Five personality traits were also measured. Agreeableness, which was found to account for interpersonal synchrony in this study, is the tendency to cooperate with others. People high in agreeableness are more likely to adjust their behavior to meet others' needs and thus are more likely to exhibit prosocial behaviors.

To reflect the dyads' combination of their traits and friendship perception, we divided individuals into Low and High groups using the sample medians for each variable when assessing friendship and the Big Five personality. We then created a three-level variable for each dyad based on individuals' Low/High status: Low–Low, Low–High, and High–

High. This results in seven group variables for dyadic analysis, including two for friendship and five for personalities.

Communication behaviors

To evaluate dyads' behavior during their conversation, two trained research assistants coded three types of behavior for each individual: talking behavior, looking at the basketball image on television, and looking at partner for the in-person communication or looking at the camera or laptop for the video- and audio-conferencing conditions. These behaviors were coded second-by-second with 1 (*Yes*) or 0 (*No*), creating three individual-based time series for behavioral variables. For the dyadic level of analysis, we summed the amount of time individuals spent on each behavior and then averaged the duration scores within each dyad, creating one single value for each behavioral measure to match the single synchrony value per dyad at each time lag, which is the dependent variable in the MLM model.

Data pre-processing

Physiological data were pre-processed with varying frequencies, including 5 Hz RSA, 1 Hz EDA, and 10 Hz fEMG (Supplementary Section 2). For the individual-level analysis, all data were averaged to 1 Hz to match with the behavioral data frequency, and change scores were calculated by subtracting each data point from the baseline value (an averaged value from the two-minute silence phase). For the dyadic-level analysis, the pre-processed data were used to preserve the dynamics within the data when calculating interpersonal synchrony using cross-recurrence analysis. This results in one data point per time lag for each dyad for each physiological measure, which was later used as the output for modeling.

Data analysis

Individual-level analysis

Multilevel modeling with planned contrasts was used for the individual-level analysis. Models for fEMG and RSA had a nested random effect structure with individuals nested within dyads. The MLM for skin conductance did not include the nested structure due to convergence issues, and as a result, only individuals were included as the random effect. For each model, we first tested whether the covariates had significant effects on the physiological variable and then removed nonsignificant predictors from the model for simplicity. For all final models, the physiological variable was the dependent variable, explained by an interaction term between time and communication system, and with talking behavior as a control variable because talking alters breathing frequency, speech, and other physiologies. Hypotheses comparing visual- to nonvisual-based communication were tested with **planned contrast 1 (PC1)**, and hypotheses comparing in-person to video conference were tested with **planned contrast 2 (PC2)**.

The MLM for RSA had tonic resting RSA as an additional covariate. Prior research showed that people with higher tonic RSA are better at self-regulation, and therefore tend to have more RSA suppression in challenging tasks (Beauchaine, 2015). Tonic RSA was calculated from the silent phase by averaging RSA values across the silent 2 min.

Dyadic-level analysis

Cross-recurrence quantification analysis (CRQA) was applied to assess interpersonal synchrony. CRQA is a method used to analyze the temporal structure of two time series and identify patterns of synchrony between them. It is commonly used to study the coordination of behavioral and physiological signals during social interactions. Recurrence rate (%REC) is the measure of synchrony calculated from CRQA. A higher %REC at lag0, which conceptually corresponds to zero-lag correlation, suggests stronger concurrent synchrony; and a higher %REC at a specific lag indicates that one's response is more synchronized with another's with that specific time delay indicating a leader-follower structure in the interaction (Coco & Dale, 2014).

With %REC as the dependent variable for each physiological measure, multilevel modeling with planned contrasts was then used to test the hypotheses. Previous research suggests that interpersonal synchrony can vary as a function of time lag and studying time-lagged synchrony can provide insight into the extent to which one person may influence their conversing partner (Armstrong-Carter et al., 2021). If interpersonal synchrony varies as a function of communication system, this shows that different communication systems have varying abilities in terms of the lag of sending and receiving information, and/or varying extents to which they afford a leader-follower structure in conversations. We expect that physiological synchrony may be affected by an interaction between time lag and the communication system. For example, concurrent synchrony may be the strongest for in-person communication. Mediated communication systems, on the other hand, may have a delay in terms of sending and receiving information, resulting in weaker concurrent synchrony and stronger time-lagged synchrony than in-person communication. With this regard, CRQA calculated recurrence rates at each lag of up to 5 s. Han et al. (2022) introduced CRQA and provided an example of interpersonal synchrony calculation using the data from the aforementioned project. Parameter settings for this study's data were reported in Supplementary Section 6.

As with the individual-level analysis, for each physiological signal, we first tested if covariate variables had significant effects on the recurrence rate, and removed the nonsignificant predictors for model simplicity. The final models contain dyads' recurrence rate as the dependent variable, an interaction term between lag and communication system, and a second interaction term between the communication system and the variables that produced significant effects in the base model (i.e., agreeableness group for RSA synchrony and closeness group for corrugator synchrony), with dyad ID treated as the random effect grouping variable. Supplementary Sections 7 and 8 include reports of communication system effect on covariates (as manipulation check) and post power and sensitivity analyses, and the OSF link for R codes and data.

Results

The results are presented in two sections based on the two sets of hypotheses, tested with the following planned contrasts: (a) visual- versus nonvisual-based communication (PC1) and (b) in-person versus video conference (PC2). Within each section, results are organized by each measure, with the dyadic level reported first followed by the individual level. All hypotheses were tested with multilevel models. Post hoc probing of significant interactions was done with simple slope tests and linear trend analysis. Specifically, nine equally spaced time or time lag points were selected for simple slope testing, including the beginning and end points and seven points in between. Only significant findings are reported in the text, the complete results can be found in Supplementary Section 9.

Visual- versus non-visual-based communication (PC1)

We predicted that in-person and video conferences, compared to audio conferences, would lead to stronger interpersonal synchrony in OO (S-H1a), corrugator (S-H1b), skin conductance (S-H1c), and RSA (S-H1d) at the dyadic level; and more OO (I-H1a), corrugator (I-H1b), and skin conductance activity (I-H1c) at the individual level. For RSA at the individual level, I-RQ1 asked whether RSA would be higher or lower for in-person and video conferences.

OO

Dyadic level

There was a main effect of time lag but not of PC1. S-H1a was not supported.

Individual level

OO results at the individual level revealed significant main effects of time and talking behavior. Specifically, OO activation decreased over time and increased when participants spoke, regardless of communication system. There were no significant effects associated with PC1. I-H1a was not supported.

Corrugator

Dyadic level

There were significant main effects of time lag and friendship closeness on corrugator activation, qualified by two interaction effects of PC1 with time lag and with friendship closeness. Simple slope testing revealed no significant differences between the communication systems tested by PC1 at specific lags. Rather, the statistical significance of the interaction effect was driven by differences in the effect of lag on each communication condition, that is, the slope. While both visual and nonvisual-based communication produced less synchrony the longer the lag, this decrease was less pronounced for visual-based communication, suggesting that visual information in interpersonal communication might help maintain synchrony across longer lags ($\beta = .002$, $p = .05$, see Figure 1b).

Simple slope testing of the PC1 by friendship closeness interaction revealed that when both individuals perceived their closeness as Low (the Low–Low group), visual-based communication produced significantly lower corrugator synchrony than nonvisual-based communication ($\beta = -.23$, $p = .005 < .01$). In contrast, when only one individual perceived their closeness as Low (the Low–High group), visual-based communication produced significantly higher corrugator synchrony than nonvisual based ($\beta = .25$, $p = .013 < .05$, see Figure 1e). No significant difference was found for the High–High group ($p > .05$). Therefore, S-H1b was supported by the Low–High closeness group only.

Individual level

There were significant main effects of talking behavior and PC1. Importantly, corrugator activity overall and over time was below baseline, meaning that participants were in a more positive state than baseline. A higher corrugator value in this case indicates less corrugator relaxation and not necessarily negative emotions. The lack of emotional negativity was verified with textual analysis of their speech content and by closely watching their conversation recordings (Supplementary Section 10). Participants exhibited more corrugator activation (or less reduced from baseline) during talking compared to listening, and during visual- compared to nonvisual-based communication (see Figure 2b). I-H1b was supported.

Skin conductance

Dyadic level

There was a main effect of lag. Dyads had significantly higher SC synchrony at longer lags, suggesting that in each dyad, there was a tendency for one individual to lead the other's emotional arousal regardless of the communication system. There were no significant effects associated with PC1. S-H1c was not supported.

Individual level

There were significant main effects of talking behavior and time, qualified by an interaction effect of PC1 by time. Skin conductance was higher when participants were talking as opposed to listening. For the significant PC1 by time interaction, simple slope testing showed that visual-based communication elicited lower skin conductance activity than nonvisual-based toward the end of the communicative session ($\beta = -.39$, $p = .045$ for time at 106th second and $\beta = -.41$, $p = .032$ for the endpoint, i.e., 120th second), but not in the beginning. Figure 2c shows that all participants exhibited a decreasing skin conductance activity over time, but the audio conference condition had a slower rate of decrease than visual-based communication, resulting in a significantly higher level of skin conductance toward the end of the conversation. I–H1c was contradicted.

RSA

Dyadic level

There were significant main effects of time lag, agreeableness group, and PC1, qualified by significant interaction effects of PC1 by agreeableness. Simple slope tests for the PC1 by agreeableness interaction showed that dyads where both participants were high in agreeableness exhibited significantly greater RSA synchrony when they used nonvisual-based communication compared to those using visual-based communication ($\beta = -.13$, $p = .008$, see Figure 1f). There were no differences for the dyads with other combinations of agreeableness. S-H1d was contradicted.

Individual level

There were main effects of tonic RSA, talking behavior, and time, with the latter qualified by interaction effects of time by PC1. Consistent with the literature, participants with higher tonic or baseline RSA exhibited lower RSA during the conversation. RSA was lower while talking, indicative of more cognitive effort compared to listening. Simple slope test for the time by PC1 interaction showed a significant difference between visual- versus nonvisual-based communication at the beginning of the talking session, but not toward the end. In other words, visual-based communication led to significantly higher RSA, indicative of lower cognitive effort, than the nonvisual-based communication when dyads began their conversation. This effect lasted for about 40 s ($p = .049$ for time at 40th second) but as time went on, this effect disappeared (see Figure 2d).

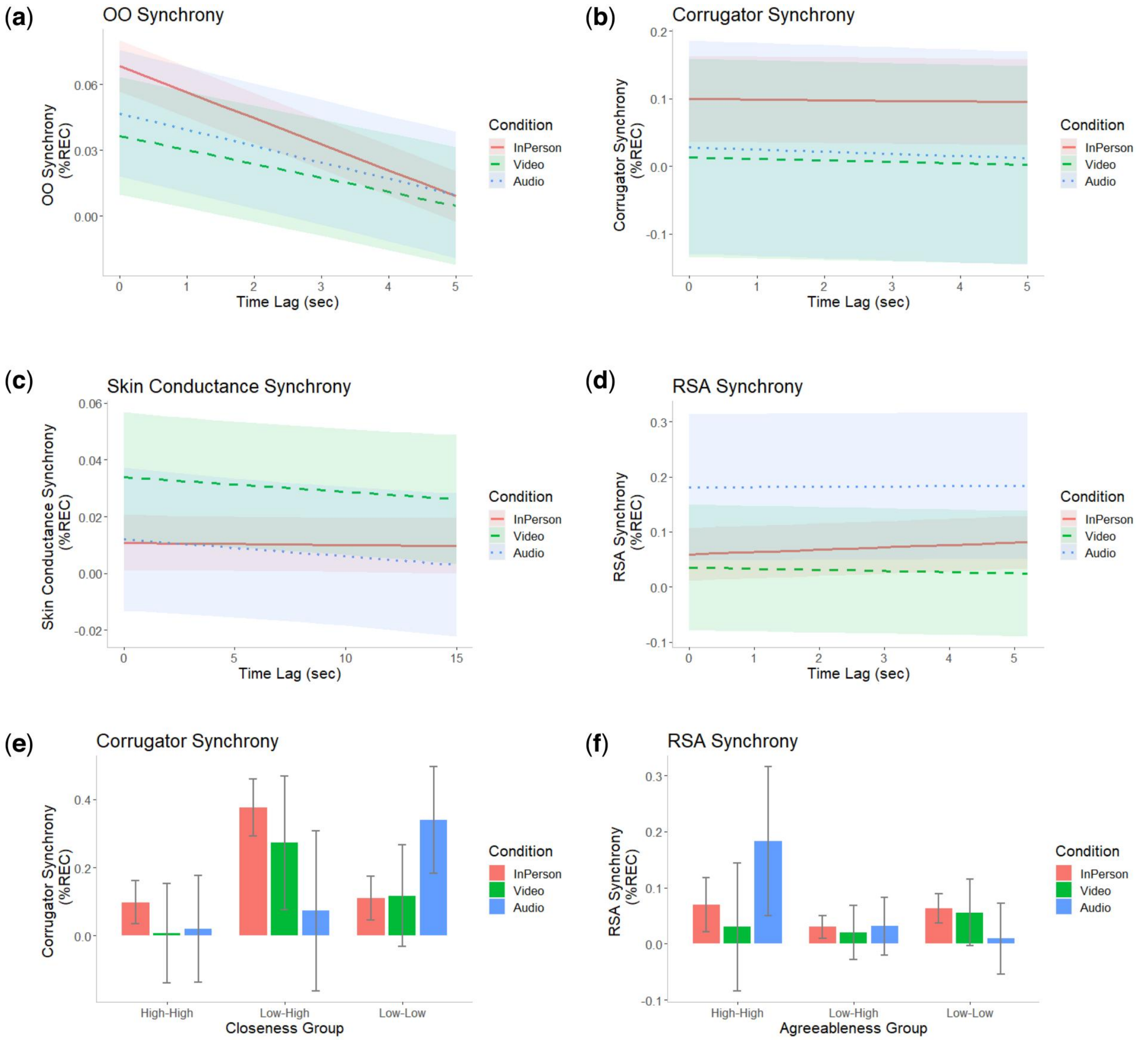

Figure 1. (a)–(f) Estimated interpersonal synchrony patterns by communication systems (dyadic level).

Note. Time lags for the calculation of lags for OO, CORR and RSA were set to 5 seconds. For SC, lags up to 5 seconds were originally calculated and tested with the model. Due to its non-significant results and the fact that skin conductance is a slow responding signal, we increased its time lags to 15 seconds for further examination, but again no significant results were found for the planned contrasts. The graphs represent estimated values from the MLM model across participants within each group. Error bars represent 95% Confidence Intervals (CI) of the estimated mean values.

In-person versus video conference (PC2)

We predicted that in-person, compared to video conference, would lead to stronger interpersonal synchrony in OO (S-H2a), corrugator (S-H2b), skin conductance (S-H2c), and RSA (S-H2d) at the dyadic level; and more OO (I-H2a), corrugator (I-H2b), skin conductance activity (I-H2c), and greater RSA (I-H2d) at the individual level. As planned contrasts PC1 and PC2 were tested together, and the main effects were the same as reported above. Below we reported the results specific to PC2.

OO

Dyadic level

Simple slopes test for the interaction effect between lag and PC2 revealed significantly higher OO synchrony for in-person communication than for video conference at both lag0 ($\beta = .03$, $p = .026$) and the lag of 0.5 s ($\beta = .03$, $p = .044$), but not for longer lags (see Figure 1a). S-H2a was partially supported.

Individual level

No significant findings were associated with PC2. I-H2a was not supported.

Corrugator and skin conductance

There were no significant effects associated with PC2 at both dyadic and individual levels, for either corrugator or skin conductance activity, suggesting that both types of visual-based communication had similar effects on those measures. H2b and H2c were not supported.

RSA

Dyadic level

There was a significant interaction effect of PC2 by time lag. Simple slope testing revealed no significant differences

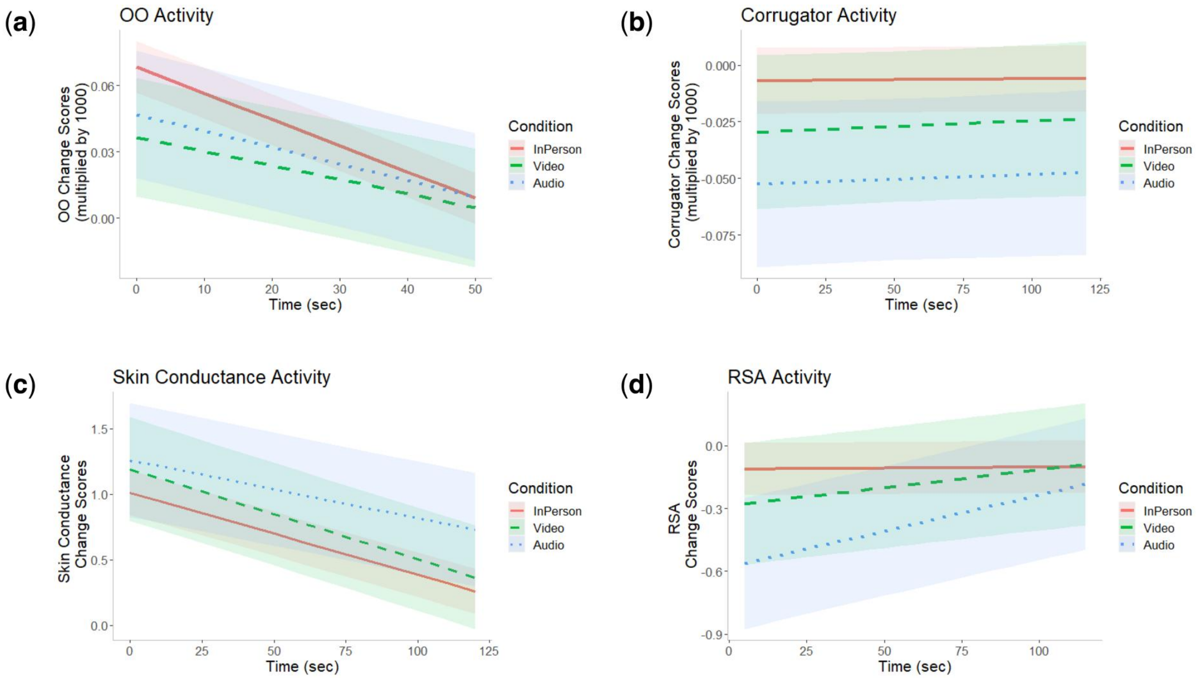

Figure 2. (a)–(d) Estimated physiological activities by communication systems (individual level).

Note. The graphs represent estimated values from the MLM model across participants within each group. Error bars represent 95% Confidence Intervals (CI) of the estimated mean values.

between the two communication systems at the time lags picked for analysis. Instead, the interaction was driven by a difference in slopes such that in-person communication had stronger RSA synchrony at longer lags ($\beta = .0008$, $p < .001$), whereas RSA synchrony decreased for video conference with longer lags ($\beta = -.0004$, $p < .001$). S-H2d was not supported.

Individual level

There was a PC2 by time significant interaction. Simple slope testing revealed no significant differences between in-person and video conference conditions at selected time points. Instead, the interaction was driven by the positive effect of time for participants in the video conference condition, who exhibited increased RSA over time, suggesting a period of adaptation to the medium. Conversely, for participants in the in-person condition, RSA remained consistently high without any effect from time. Hence the results did not support I-H2d, but the communication system did affect RSA, in a manner different from the original hypothesis.

Discussion

The study aims to develop the Dynamical Interpersonal Communication Systems Model that provides a dynamical systems framework for understanding in-person and virtual communication. The study tested the model's proposition by specifically testing the visual information role in the dyadic and individual levels of information processing. The findings revealed that communication systems varying in the level of visual information (and also embodiment) nonlinearly alter physiological processes in interpersonal communication at multiple timescales. More specifically, results showed that while video communication offers visual information that helps reduce initial cognitive load, it does not match the effectiveness of in-person interactions in maintaining low cognitive effort over time and high emotional concurrent synchronization. Audio-only communication, on the other hand, helps maintain participants' excitement but is more cognitively demanding due to the lack of visual information. A table of summarized results can be found in Supplementary Section 9.

From cues-filtered-out perspective to dynamical systems perspective

The study lays conceptual and empirical foundations for advancing the Model from two perspectives. First, it shows that communication processes through different communication channels are qualitatively different, emphasizing the importance of examining communication from a system perspective. Current theories in the related area, such as social presence theory (Short et al., 1976) and media richness theory (Daft & Lengel, 1986), categorize media from a cues-filtered-out perspective (Culnan & Markus, 1987) where the decrease of communication cues in interpersonal communication linearly reduces social connectedness, interpersonal relationship, and communication effectiveness. This suggests a linear relationship between communication cues and their outcomes. Nonetheless, this study showed that the linear decrease of communication cues does not necessarily lead to linear decreasing patterns of communication processes, implicating that the differences in communication are best explained by the system as a whole instead of by treating information quantitatively. Specifically, the study found that participants strategically used their facial expressions and mobilized their bodies by engaging their sympathetic nervous system (reflected by skin conductance) to optimize communication depending on whether visual information of their partner is available. This supports the theoretical argument that humans are adaptive to their communication environment and are able to rely on a limited set of affordances to achieve their communication goals (Lang, 2014; Walther, 1992). As a result, communication behaviors are altered in a nonlinear manner.

Second, the study shows that processes at the intra- and inter-personal levels are not directly dependent on each other. Knowing one process does not necessarily lead to understanding the other, highlighting the importance of examining the two levels for a better understanding of interpersonal communication. The conceptualization and analytical procedures involved in this study provide an empirical demonstration for studying interpersonal communication as a dynamic system. The findings highlight the Model's potential for better understanding interpersonal communication, which might address key shortcomings of the linear and static "cues-filtered-out" approach.

Emotion dynamics in interpersonal communication

This study challenges previous research's understanding about OO synchronization in communication contexts. Previous literature found that OO can be more synchronized than corrugator in in-person communication and postulated this to be rooted in humans' proclivity to manifest their affiliative tendencies, leveraging smiles as an efficacious means for such manifestation (the affiliative hypothesis, Hess & Bourgeois, 2010, Riehle et al., 2017). Hence the affiliative hypothesis assumes that smiling must be visible and detectable by others to effectively signal their affiliative tendency. However, our findings challenge this tenet. The affiliative hypothesis would predict that people smile less and that there is less smiling synchrony in audio-only communication, as their partner cannot see their facial expressions. However, we found no difference in smiling behavior between visual and nonvisual communication at either the individual level or in terms of interpersonal synchrony.

It is worth noting that the affiliative hypothesis has primarily been explored within face-to-face contexts and solely at the individual level, thus limiting the depth of its validation. This study demonstrates the importance of investigating interpersonal communication from multiple communication systems and timescales. Limiting ourselves to one context and one timescale may constrain our ability to understand the fundamental laws of interpersonal communication. Specifically, by examining OO activities across the individual and dyadic levels, this study suggests that emotional conveyance might not be solely reliant on facial expressions but could encompass other channels such as auditory ones. Facial expressions in audio-only communication could potentially function as a self-referential activity so that, to prepare one's own positive emotion, activating your facial muscles might support vocal expressions to transmit positive emotion to others. Thus, visual information may not be the primary determinant for individuals' OO activity as no differences were found between visual and non-visual communication and between in-person and video communication. However, synchronizing OO is a different story. On the one hand, the presence/absence of visual input did not differ in OO synchrony as evidenced by the lack of difference between visual and nonvisual communication. However, OO synchrony was higher for in-person communication where visual information was rich and embodied, compared to video communication where visual information was poorer.

The corrugator activity in this study's conversational context turned out to be an indicator of positive emotion because it was consistently below the baseline throughout the conversation and across all groups and thus shows patterns of deactivation rather than activation (Potter & Bolls, 2012). Nevertheless, its deactivation patterns across conditions were different from those with OO, indicating that although both muscle activities signified positive emotional experiences, the underlying mechanisms modulating these two facial muscle types appeared distinct. For example, both the individual and synchronized processes in corrugator activity were significantly affected by the presence or absence of visual information, whereas OO remained unaffected in that comparison. Further investigation is needed to understand their roles in positive emotions.

Results also showed that audio-only communication led to more physiological arousal compared to visual-based communication. This is contrary to our prediction and to some extent reveals problems with the application of the social facilitation theory, which posits that the mere presence of another individual leads to higher physiological arousal. Our findings suggest a potential explanation for the increased arousal in the nonpartner-presence condition (audio-only communication). Unlike video-based communication that affords less energetic means (such as smiling) for emotional information delivery, the increased arousal in the audio-only condition might result from the need for increasing speaking volume and/or modulating voice to better transmit emotion, as voice was the only channel for information delivery in this context (Arnold et al., 2014; Laukka et al., 2005). This suggests that the high physiological arousal in audio-only communication might be a combination result of participants' own emotions and the physiological effort involved in expressing these emotions vocally. Interestingly, in some cases, this physiological effect on the voice can, in turn, impact the speaker's own emotions (Goupil et al., 2021). Future research could add self-report measures of one's emotion to see if the emotional feeling is also more aroused in audio-only compared to visual-based communication. Overall, the high arousal state in audio-only communication suggests that the need for effective communication has a stronger impact on physiological arousal than the mere physical presence of another in in-person contexts. The complexity of interpersonal communication, again, underscores the importance of conceptualizing communication as a dynamical system because merely one or two variables are insufficient to explain and predict system behavior.

Cognitive dynamics in interpersonal communication

Results from RSA showed that communication with visual information required less cognitive effort at the beginning of the conversation, but this difference disappeared as the conversation progressed. This suggests that communication without visual information might create uncertainty at the beginning of the conversation, but as the uncertainty subsides and people adapt to the environment, cognitive effort becomes comparable to communication with visual information. This effect may be more pronounced and last longer with larger group sizes, as there is more uncertainty involved with more participants in the case of audio conferences.

On the other hand, the dyadic-level analysis revealed a finding contradictory to our hypothesis, such that nonvisual-based communication resulted in more, instead of less, synchronized RSA, but this was the case only for dyads who were both high in agreeableness. Notably, the increased synchronization was observed not only at zero lag but across multiple time lags. Given that the audio-only group exhibited a greater reduction of corrugator activity from baseline than visual-based communication, the greater RSA synchrony observed in audio-only communication should not have been due to a negative experience. Together with the individual analysis, it implies that participants who are both willing to accommodate and collaborate with each other (i.e., high agreeableness), when engaged in audio-only interactions, made significant effort to ensure effective communication (as evidenced by higher RSA in the beginning and higher arousal toward the end), resulting in a more synchronized psychological process.

Participants in a video compared to in-person conferences exhibited an increase in RSA (suggesting a decrease of cognitive effort) over time and a decrease in RSA synchrony across time lags. A post-hoc inspection of gaze behavior suggested that video conference participants looked at their partner more frequently at the beginning of the conversation but this frequency decreased over time, whereas the in-person group consistently looked at their partner throughout (Supplementary Section 7). This gaze behavior may explain the decreased cognitive effort over time for video communication participants. This finding also supports the argument that "Zoom fatigue" may be caused by unnatural gaze behavior during video conferencing (Bailenson, 2021). Once the gaze is moved away from the screen, no more cognitive effort is needed for videoconferencing, but this also breaks the link necessary for synchronization.

Limitations and conclusions

The study has some limitations. First, the context analyzed here is short, casual, and unstructured conversations. Results may differ in more complex, task-oriented scenarios with larger group sizes and longer meeting durations. Second, as a secondary data analysis, this study lacks outcome variables that could provide more information about the effectiveness of individual and dyadic levels of information processing. Future research could address these limitations by studying information processing at the group level and assessing various communicative outcomes such as communication success and creativity, and how these outcome variables are associated with the two levels of processes in different communication contexts.

Despite these limitations, the study found distinct patterns across the three communication systems, although the Model's specific propositions remain to be refined. Nevertheless, this study emphasizes the importance of conceptualizing and analyzing these different types of communication as dynamical systems. The dynamic systems perspective adopted in this study, which also combines linear and nonlinear analysis to investigate changes in information processing (Brinberg & Lydon-Staley, 2023), offers a novel approach to understanding how communication channels shape communication processes and behavior. We hope that this conceptual and analytical framework will be adopted by future researchers, contributing to a better understanding of the dynamic processes involved in human communication.

Supplementary material

Supplementary material is available online at *Journal of Communication* online.

Data availability

Data used for this study are available on the OSF page: https://osf.io/7kaxs/.

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