Current needs and future directions of functional near-infrared spectroscopy (fNIRS) hyperscanning for social interaction research

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Abstract

Hyperscanning, the simultaneous recording of multiple brains during social interaction, is an emerging method in social neuroscience. Among available techniques, functional near-infrared spectroscopy (fNIRS) is particularly promising for studies outside laboratory environments. fNIRS hyperscanning presents opportunities and challenges in key domains including data processing, the quantification and interpretation of inter-brain synchrony, and increasing interest in multimodal approaches. To assess the field's current status and trajectory, we developed a questionnaire for fNIRS hyperscanning researchers, addressing both best practices ("what has been done") and future priorities ("what ought to be done"). Survey responses were compared with the empirical literature to identify unmet needs, align community perspectives, and chart a course for the field's progression. Findings showed (i) broad agreement on preprocessing workflows, (ii) widespread use of wavelet transform coherence to quantify inter-brain synchrony, and (iii) growing enthusiasm—and a rapidly expanding pool of datasets—for multimodal recording. Meanwhile, (iv) systematic training in fNIRS hyperscanning is largely absent from university curricula, (v) theoretical frameworks for interpreting neural synchrony remain underdeveloped, and (vi) methodological pipelines integrating multimodal behavioral and neural signals are still lacking. By linking survey insights with existing literature, we highlight solutions and propose concrete steps for advancing fNIRS hyperscanning research.

Keywords: functional near-infrared spectroscopy (fNIRS), hyperscanning, social interaction, neural synchrony, multimodal neuroscience

Word count: 6,420

Introduction

Scientists have been interested in what makes us the social creatures we are for more than a century (Triplett, 1898), but have often focused more on the individual than on multiple people interacting. In the early years, there was a persistent focus on dyads and groups (Asch, 1951; Milgram, 1963), but as personal computers and cognitive psychology became a central part of the landscape of social psychology in the 1980s, there was an overwhelming tendency to put people alone in cubicles and have them read vignettes about social interactions rather than personally participating in them. This trend reached its pinnacle in the early 2000s as social neuroscience began to take off with functional magnetic resonance imaging (fMRI). In fMRI studies, we isolate participants as much as possible by putting people in what often feels like a coffin, connected to the outside world by wearing headphones that are hard to hear due to scanner noise and video goggles showing a computer screen.

This focus on isolated elements of social stimuli inherently neglects the rich, dynamic, and multimodal nature of real-world interactions. Social signals do not occur in isolation—they unfold across multiple modalities, including speech, gesture, facial expressions, bodily synchrony, and neural activity (Wheatley et al., 2024). During interaction, individuals must continuously monitor and interpret subtle, moment-to-moment changes in one another's behavior—a pause, a shift in gaze, a modulation of tone—each reflecting underlying cognitive and affective states (Cheong et al., 2023; King-Casas et al., 2008). These signals operate at varying temporal scales, and their coordination gives rise to the fluid rhythm of social engagement (Thibault, 2020). While traditional paradigms have yielded valuable insights into social cognition by isolating specific inputs or processes, such approaches risk oversimplifying the mechanisms that support interpersonal understanding. In contrast, examining how neural activity aligns with behavioral and physiological signals across time offers a more ecologically valid framework for studying social cognition as it unfolds in naturalistic, embodied contexts (Clark, 1996; Di Paolo et al., 2018; Wohltjen & Wheatley, 2021; Cooney & Wheatley, 2025).

Emerging research increasingly emphasizes the need for experimental paradigms that more closely replicate naturalistic social environments, facilitating a deeper understanding of how the brain integrates multimodal information streams in real time (Alviar, Kello, & Dale, 2023; Dale et al., 2013). From a theoretical standpoint, multimodality is not just an added dimension—it represents a foundational challenge in understanding how the brain and body coordinate during social interaction. As Alviar et al. (2023) argue, effective interpersonal interaction emerges from finely tuned multimodal coordination, where signals across the verbal and nonverbal channels converge to support pragmatic meaning-making.

Reflecting this shift, over the past 15 years, social psychologists have progressively returned to studying direct interpersonal interactions, recognizing that genuine engagement is essential for accurately capturing the complexities of human social cognition. These real-world interactions lend themselves to multimodal analyses, which leverage modern analytical approaches and sophisticated computational models to integrate body movements, speech, and physiological data streams (Duran, Paxton, & Fusaroli, 2019; Pentland, 2010; Kim et al., 2012). Such approaches not only enrich the empirical scope of social neuroscience but also offer computational tractability for modeling complex interaction dynamics.

Multimodal integration has also been championed across disciplines—ranging from sociometric sensor research (Kim et al., 2012) to organizational behavior and communication studies (Pentland, 2010)—further underscoring its cross-cutting importance. Dale, Kello, and Schoenemann (2016) provide a comprehensive review illustrating how coordinated activity across different signals is central to understanding shared meaning and joint action. As the field evolves, it is increasingly clear that tools and theories capable of embracing this complexity are not optional but essential for scientific progress.

Functional near-infrared spectroscopy (fNIRS) emerges as an ideal method for investigating the multimodal dynamics of natural social interactions between multiple individuals. fNIRS captures a signal similar to the BOLD signal measured with fMRI. This signal can only be measured on the surface of the cortex and the spatial resolution is poorer than with fMRI (e.g., ~1 cm^2 vs. ~2 mm^2). However, these limitations are offset by the portability and mobility of fNIRS, along with its superior temporal resolution and its strong coverage of key networks implicated in social processes, such as the theory-of-mind and action-perception networks. Further, fNIRS offers excellent compatibility with multimodal research approaches as it can be combined with other measurement modalities including physiology, eyetracking, and encephalography (EEG), and can be integrated with virtual reality equipment as well. Thus, while fNIRS, like any method, has its limitations, its ability to be taken anywhere in the world (Burns et al., 2019; Dieffenbach et al., 2021) and used as people are freely interacting face-to-face makes fNIRS a game changing technology for social neuroscience.

In this review, we consider current and best practices for the use of fNIRS in social interaction research. We report on the methods that are most commonly used and share the results of a survey with researchers in this space about the state of methods for this work. Along the way, we will see a number of key insights. Specifically, we highlight (1) the growing interest in multimodal approaches and the urgent need to develop pipelines for integrating and unifying multimodal data, (2) the importance of revisiting the theoretical foundations underlying the alignment of biosignals recorded from interacting partners (referred to as 'interactional synchrony,' 'neural synchrony,' or 'intersubject synchrony'), and (3) the need to tackle challenges in interpreting results obtained through multimodal paradigms. These insights reflect the evolving landscape of social neuroscience and the increasing complexity of studying human interactions through diverse methodological lenses.

The Rise of Near-Infrared Spectroscopy

fNIRS was developed in 1977 (Jöbsis, 1977) and initially used to monitor cerebral oxygenation in preterm infants and adult cerebrovascular patients (Brazy et al., 1985). Over the years, its applications broadened to include research on individuals with psychiatric disorders (Okada et al., 1994). Although fNIRS has been around for nearly 50 years, it wasn't until 2011 that it began to be used to study interactions among people. Since then, it has been employed in various social contexts, including face-to-face conversations (Jiang et al., 2012), cooperative and competitive tasks (Cui et al., 2012), and educational environments, such as monitoring teacher-student dyads (Pan et al., 2020). More recently, its use has been extended to studying group dynamics, enabling the simultaneous measurement of brain activity in groups of three or more individuals engaged in collaborative or competitive tasks (Nozawa et al., 2016). Additionally, fNIRS has been invaluable in studying parent-child interactions, providing unique insights into bonding, emotional alignment, and developmental processes during naturalistic exchanges (see Figure 1 for an overview).

The growing body of research on social cognition using fNIRS has led to comprehensive reviews (e.g., Carollo & Esposito, 2024; Liu et al. 2022) and meta-analyses (e.g., Lotter et al., 2023; Czeczumski et al., 2024; Zhao et al., 2024). These reviews have pursued several key objectives: (1) identifying regions within the so-called "social brain" that exhibit interpersonal neural coupling across diverse contexts of social exchange (Zhao et al., 2024); (2) evaluating the most effective methodological approaches for estimating coherence coefficients between two time series within dyads (Hakim et al., 2023; Wang et al., 2021; Nazneen et al., 2022; Burns, 2020); (3) analyzing the most common tasks designed to induce synchrony, both within specific participant groups – such as caregiver-child dyads (McDonald & Perdue, 2018; Minagawa et al., 2018; Liu et al., 2022; Russo & Senese, 2023), – and in particular contexts – such as spoken communication (Kelsen et al., 2022), classroom (Tan et al., 2023), and virtual environments (Barde et al., 2020), and (4) uncovering factors that enhance intersubject synchrony (e.g. Liu et al. 2022).

Empirical and review studies consistently highlight fNIRS as a valuable tool for studying social multimodal interactions, owing to its portability, motion tolerance, and superior spatial resolution compared to methods such as EEG. These social multimodal interactions could be examined while watching the same video stimuli (i.e. passive co-experience) or doing a task together (i.e. active interaction) (e.g. Bizzego et al., 2022). However, as a relatively young field—evidenced by a growing body of research over the past 15 years (Figure 2)—fNIRS hyperscanning still lacks standardized and validated protocols for data collection and analysis. This lack of uniformity limits cross-study replicability and comparability, posing a significant challenge to the field’s advancement.

Currently, many researchers rely on data analysis methods and research practices developed within their own labs, often tailored to specific study designs and informed by local best practices. While these approaches are valuable, they contribute to variability across studies, emphasizing the need for greater methodological alignment.

This paper aims to amplify the voices of the fNIRS research community by exploring their needs, expectations, methodologies, and suggestions. Through a targeted questionnaire, we sought to identify pathways for advancing the field, focusing on methodological improvements and standardizing best practices to enhance research in contexts with social multimodal interactions.

Specifically, we identified key domains prevalent in fNIRS literature for consideration: data processing (preprocessing methods, analysis of intersubject synchrony, visualisation tools) and multimodality. The questionnaire, designed for hyperscanning researchers using fNIRS, addressed these domains to explore current best practices (e.g., *What has been done*) along with existing needs and perspectives (e.g., *What ought to be done to advance the field*). Additionally, we compared the respondents' insights with findings from existing empirical publications.

Methods

Identifying Relevant Literature

Our literature search process started in March 2023, utilizing specific search terms ("(Neural synchrony) AND (interactions) AND (fNIRS)") to identify relevant papers from Web of Science and PubMed, yielding 48 and 44 articles respectively. A follow-up search in February 2024 with broader terms, including "(Neural synchrony OR "wavelet coherence" OR "intersubject correlation" OR "inter brain synchrony") AND (interaction OR hyperscanning) AND (fNIRS OR NIRS OR "near infrared spectroscopy")" resulted in 83 articles from the Web of Science alone. To ensure the inclusion of the latest studies, an additional search was performed in June 2024, retrieving 8 more articles published towards the end of 2023 and in 2024.

After eliminating duplicates from the searches, we narrowed the collection to 95 unique articles. Subsequent screening steps, aimed at aligning with our research theme, further reduced the pool to 83 articles. Specific reasons for exclusion included papers discussing EEG in the context of hyperscanning without referencing fNIRS, fNIRS studies examining only one person at a time rather than employing hyperscanning techniques, or focusing on the coupling between arterial blood pressure instead of neural synchrony.

Among these 83 articles, we identified 16 review papers that were discussing various aspects of fNIRS hyperscanning studies but not reporting on new data (details provided in the Introduction), 1 simulation study, and 1 methodological toolbox. The remaining 65 articles were empirical studies directly relevant to our review.

Survey for fNIRS Community and Literature Coding

We crafted questions that explore fNIRS researchers' experiences, perspectives, and future outlooks on key themes widely discussed in fNIRS literature: data processing (preprocessing methods, analysis of intersubject synchrony, visualisation tools) and multimodality. Questions about experiences focus on methodological practices–including software usage, analytic methods, data recording, and multimodal analysis–and personal experiences–such as their background, how they learned fNIRS analysis, and what they found challenging in their first hyperscanning fNIRS study. Questions about perspectives include: whether analysis methods used in passive (eg. video watching) vs. active social interaction should be different, and what they wish others reported in their methods section. Questions about future prospects include insights into unexplored potentials within the fNIRS domain that current research endeavors may have overlooked. The full survey can be found in Supplementary Materials.

From May to July 2024, we reached out to corresponding authors of the 65 empirical articles for survey. We issued both initial and 2 reminder emails, obtaining 42 responses. Only responses with a completion rate of 67% to 100% were considered, totaling 25 useful surveys.

From these, 17 respondents agreed to be acknowledged for their contributions, and their details are listed in our acknowledgments, however the data is reported on all 25 of the mostly completed surveys.

Following the completion of survey response collection, we compared reported results to findings from existing empirical publications. We report the results below.

RESULTS

The fNIRS Research Community

Backgrounds of fNIRS researchers. In survey questions using checkboxes that allowed multiple selections, the majority (64%) of fNIRS researchers reported a background in cognitive neuroscience, making it the most common field. Social psychology and general neuroscience were each selected by 40% of respondents, followed by developmental psychology and cognitive science at 28% each. Although less common, other notable backgrounds also included clinical psychology, educational psychology, cognitive/perceptual psychology, physics, engineering, computer science, and medicine.

Experience with Other Neuroimaging Techniques. The survey revealed that EEG is the most frequently used technique, in addition to fNIRS, among fNIRS researchers, with 76% reporting experience with it. This is followed by MRI (60%), transcranial direct current stimulation *(*tDCS) (32%), transcranial magnetic stimulation (TMS) (20%), and magnetoencephalography (MEG) (12%). Fewer researchers (4%) have worked with electrocorticography (ECOG), LFP, and single neuron recording. Notably, all fNIRS researchers who answered the survey have experience with at least one other neuroimaging technique.

Programming Languages Used. Matlab is the preferred programming language for 84% of fNIRS researchers, making it the most popular choice. R is used by 64% of the community, while Python is favored by 56%.

Learning fNIRS Analysis. Online resources are the primary method reported for learning fNIRS analysis, utilized by 52% of researchers. Additionally, 40% learn from colleagues within their labs, and 24% from faculty or colleagues within their departments. Organized courses or workshops have contributed to the education of 20% of researchers in this field. Remarkably, none of the fNIRS researchers reported learning this technique as part of a university curriculum. Instead, some have acquired skills by visiting labs that specialize in fNIRS, or by adapting fMRI methodologies.

Data Processing - What has been done

Analysis of the frequency of using various preprocessing tools revealed minor discrepancies between self-reported survey responses and the methodological descriptions documented in the reviewed literature. According to the survey data (see Figure 3), the most commonly used software tools for *data pre-processing* was Homer, with Homer 2 being dominant before 2019 and Homer 3 after. There was also frequent use of customized Matlab or Python scripts, followed by SPM-fNIRS, which ranked as the fifth most commonly used tools. However, findings from the published literature suggest that researchers most frequently employed customized Matlab scripts, with Homer and SPM-fNIRS ranking second and third, respectively.

When it comes to statistical analysis, the responses obtained from the survey and the literature review consistently indicate that researchers conducting fNIRS hyperscanning studies most frequently use Matlab, R, and Python, respectively (see Figure 4). Less frequently, they rely on stand-alone software designed for analyzing fNIRS signals through a graphical user interface.

When it comes to visualization tools, respondents most frequently reported using Matlab, xjView, NIRX fNIRS software, R, and Python. These responses were partially confirmed by a review of the literature, which indicates that published data is most often visualized using xjView, SPM fNIRS, Matlab, Python, and R.

Several authors have provided recommendations on tools for preprocessing, analysis, and visualization of fNIRS synchrony data. These recommendations are detailed in the Supplementary Materials for further reference.

Data Processing - What ought to be done

While the Society for fNIRS standardized the data format and recommended best practices for preprocessing (Tucker at al., 2023; Yücel at al., 2017), survey respondents indicated that further efforts are needed to better standardize paradigms for data collection in both passive and active tasks, as well as to harmonize the diverse analyses that can be performed. Researchers are also interested in details regarding data collection and preprocessing including: global mean removal, recommendations for localizers (analogous to those commonly employed in fMRI) to verify the quality of the signal, descriptions for how the regions of interest are identified, as well as a clear characterization of how to replicate the caps setup.

Many researchers expressed desire for practical guidelines, workflow, and framework for inter-brain synchrony analysis, including templates and demo code for analysis. An example resource site is https://pvrticka.com/fnirs-hyperscanning-an-introduction/, which contains guidelines on how to analyze fNIRS hyperscanning data, sample data, and freely available Matlab and R code. Additionally, as indicated by another survey respondent, fostering greater clarity around these methodological aspects is crucial for "distinguishing between causality and correlation".

Neural Synchrony - What has been done

Here, we consider the different ways that researchers are examining neural synchrony, both in terms of self-report and what is in the literature. Neural synchrony (or intersubject synchrony), in the context of hyperscanning, refers to the alignment between neural signals between two or more people as they interact (Czeszumski et al., 2020). Roughly speaking, it refers to correlated fluctuations over time between brain regions in two or more people.

Analysis of survey responses (Figure 4) and literature review (Figure 5) indicates that Wavelet Transform is by far the most commonly employed method for synchrony quantification. This finding was consistently reflected across the survey, our literature review, and a recent published review (Hakim et al., 2023). However, a slight divergence emerged regarding the second most frequently used methods. Survey respondents identified Granger Causality as the second most prevalent technique, although this was not yet corroborated by the literature. In contrast, the literature review highlighted Pearson Correlation as the second most widely reported method, with regression as the third most common method followed.

An interesting aspect of the survey explored the analytical approaches employed for passive tasks (e.g. video watching) in comparison to active tasks (e.g. live social interactions). The responses revealed a notable divergence in preferred methodologies depending on task type (Figure 4). For passive tasks, such as video watching, the majority of respondents indicated that Pearson Correlation is the most appropriate method for synchrony analysis (32% selection). In contrast, for active tasks involving direct interaction between participants, a more diverse set of analytical approaches emerged as preferred. The three most commonly cited methods for analyzing active tasks were Wavelet Transform (40% selection), Granger Causality (32% selection), and Cross Correlation (including sliding windows) (28% selection). Only 16% selected Person Correlation for active interaction.

Neural Synchrony - What ought to be done

In terms of content areas, researchers have identified several domains where hyperscanning would be fruitful, but have been underutilized to date. These include: professional sports, peer interactions among children, performance at school, and physically distant interactions. Additionally, the combination of fNIRS hyperscanning with neuromodulation techniques—such as multi-brain stimulation or transcranial magnetic stimulation (TMS)—applied to a single brain.

Researchers have also emphasized the need for clearer theoretical frameworks in studies of neural synchrony—a construct that remains both central and ambiguously interpreted within social neuroscience. While neural synchrony is typically defined as the temporal alignment of neural activity across individuals, its psychological and functional significance varies across contexts and remains insufficiently understood (Schilbach & Redcay, 2025). As respondents noted, *"the lack of an appropriate explanation for decreased inter-brain synchronization during specific tasks needs to be further explored in future research"* and *"we need more specific language and precise theories"*, underscoring the pressing need for conceptual clarity and interpretive consensus.

Reflecting growing concern over this ambiguity, Burns et al. (2025) recently proposed a set of conceptual distinctions aimed at clarifying overlapping terms in the literature. They differentiate neural synchrony (i.e., consistent co-occurrence of the same neural state across individuals) from related constructs such as meta-stable synchrony (fluctuating synchrony strength over time), recurrence (reappearance of the same state at different times), and complementarity (coordinated pairing of different states). Notably, this framework was developed in response to the proliferation of empirical studies that have used diverse methods to operationalize inter-brain synchrony.

However, most existing studies still fall short of explicitly addressing whether inter-brain synchrony reflects shared attention, joint action, empathy, or other forms of coordination—or whether, in some cases, it might be epiphenomenal. The few studies that have begun to explore these distinctions have largely focused on children (see review by Roche et al., 2025), underscoring the need for analogous research in adults to better understand what neural synchrony may signal in more mature social interactions.

Although this was not a commonly expressed concern, we believe the following point raised by one respondent is particularly noteworthy, as it highlights a critical issue regarding methodological diversity in inter-brain synchrony research. The respondent stated: "*As an early-career researcher utilizing fNIRS technology, I believe there is an urgent need to delineate the distinctions between the various methods employed to calculate inter-brain synchronization. Despite my efforts to apply different techniques for assessing inter-brain connectivity, the underlying principles and potential discrepancies between these methods remain unclear. I am also concerned that the choice of method could influence the comparability and interpretation of findings across existing studies.*"

This perspective underscores a broader challenge: although theoretical efforts like Burns et al. (2025) offer much-needed conceptual clarity, the field still lacks standardized methodological practices that map clearly onto these distinctions. The use of diverse analytic techniques—such as wavelet coherence, cross-correlation, or Pearson correlation—often proceeds without explicit justification or alignment with theoretical constructs. This lack of integration not only complicates cross-study comparisons but also raises concerns about the interpretability and reproducibility of findings. For early-career researchers especially, the absence of consensus guidelines can create barriers to both rigorous analysis and theoretical contribution. Bridging this gap between conceptual clarity and methodological consistency remains a critical priority for advancing inter-brain neuroscience.

Multimodality - What have been done

We also inquired whether researchers incorporate multimodal data collection in their studies, such as combining fNIRS with complementary modalities including video recordings, audio capture, or physiological measurements, and how they used the collected data. From survey responses, we found that fNIRS researchers embrace multimodality–88% of survey respondents indicated that they recorded multimodal data concurrently with fNIRS. The most popular multimodal data recording (Figure 6, top) is video recording (90.9%), followed by audio recording (72.7%), heart rate (50%), eyetracking (36.4%), and Galvanic skin response (GSR) (22.7%).

Although multimodal data are increasingly collected in fNIRS research, they are still relatively infrequently analyzed together. As shown in the published literature (Figure 6, bottom), such integration remains less common than might be expected given the prevalence of multimodal designs reported in the survey. While all these response modalities reflect different aspects of a single underlying biological system, they are rarely modeled together within a unified analytical framework.

From both survey of researchers and the literature review on multimodal recording (Figure 6), we can see that video is the most common recording method employed concurrently with fNIRS. For the 'Other' category, authors provided specific examples of additional variables recorded that were not listed as options in our survey. These included reaction time, electromyography for muscle activity, motion data, blood pressure, and self-report questionnaires.

Next, we asked how authors used the data obtained from the multimodal recordings (Figure 7). More frequently, this data is used as predictors for outcomes of interest, sometimes for preprocessing, and less frequently for exploratory purposes. One of the most common usages is to code features from video recording and use that information as a predictor for neural signals or survey responses. The ‘Other’ additional recordings indicated above were used for a wide range of purposes, including measurement of arousal (Galvanic Skin Response), assessment of neural oscillations related to live social tasks (EEG), and validation of signals (heart rate).

Multimodality - What ought to be done

Despite growing enthusiasm within the fNIRS scholarly community for methodological advancements that enable the simultaneous recording of neural, behavioral, linguistic, and physiological signals, the field of multimodal integration remains underdeveloped. While recent work in social neuroscience has begun to advocate more strongly for multimodal and multilevel approaches—such as examining child–caregiver bonding through simultaneous fNIRS, behavioral, and conversational data streams (Bonnaire, Dumas, & Cassell, 2024)—the actual integration of these signals in analysis remains rare.

Although many studies include both neural and behavioral components, these are often analyzed in separate sections rather than through a unified analytical framework. To our knowledge, only one study to date (Bonnaire, Dumas, & Cassell, 2024) has implemented an integrated approach to modeling interactions across modalities in a theoretically coherent way.

As a result, there remains limited empirical evidence to establish best practices, and little guidance on how to meaningfully link different modalities in models of social interaction.

One survey respondent captured both the excitement and the challenge ahead: "*In addition to the emerging field of imaging brains during live and ecologically valid conditions, we also have the new advantage of acquiring many simultaneous streams of behavioral data such as eye-tracking, EEG, facial classifications, verbal output, etc. Applications of these variables as covariates and linear regressors open opportunities for exploring new neural correlates in the domain of live interactions.*"

This quote reflects a broader sentiment: the tools are available, and the interest is high—but much remains to be done to translate this potential into actionable research pipelines. Moving forward, the field would benefit from developing shared protocols, benchmark datasets, and computational models capable of handling the complexity of multimodal data in naturalistic interaction.

CALL TO ACTION

Although fNIRS has been around for nearly half a century, it has only been used to study social interaction for a small slice of that time. As such, it is still early days with methodological norms in flux, varying from lab to lab and within the same lab over time. While fMRI methods have achieved significant standardization over the past decade, that is still absent in the domain of fNIRS social interaction research. We undertook this review informed by community survey responses in order to try to assess what scientists are doing in this space as well as what they think the field ought to do, to identify field-wide challenges, and to begin a conversation about best practices in this literature so that we can achieve greater agreement and standardization about fNIRS research practices going forward. To this end, we examined both the published literature on fNIRS social interaction research and surveyed the authors of those papers.

Our findings emphasize the interdisciplinary nature of fNIRS, evident both in the diverse academic backgrounds of fNIRS researchers—from social psychology to engineering—and the methodologies employed. The survey shows that nearly all fNIRS researchers have experience with other neuroimaging techniques suggesting that their prior experience might influence their approach to data interpretation and choice of analysis methods.

Furthermore, the proficiency in programming, especially Matlab, among most community members highlights the importance of these skills for success in this field. However, the absence of formal university training in fNIRS underscores a significant educational shortfall. Researchers predominantly resort to online resources and peer learning to acquire their skills. Addressing this educational gap with structured curricula and standardized training protocols could lead to greater innovation, enhance accessibility, and significantly bolster the growth and development of the field.

Neural Data Processing and Synchrony Analysis

Our review suggests a clear—though not yet complete—consensus on pre-processing pipelines and statistical frameworks for hyperscanning. Wavelet-Transform Coherence (WTC) is by far the most frequently deployed metric for inter-subject neural synchrony, echoing the recommendations of earlier methodological overviews.

The survey responses, however, expose a broader theoretical bottleneck: the challenge of translating synchrony indices into psychologically meaningful constructs. Currently, researchers often rely on a single metric—frequently without articulating why that particular method was chosen or how it aligns with theoretical assumptions (Burns et al., 2025). This heterogeneity hinders comparability across studies and limits the interpretability of findings. Building on the recommendations of Burns et al. (2025), we advocate for a more theory-driven approach to selecting synchrony measures, alongside systematic multi-metric reporting. Specifically, we urge future researchers to:

1. **Provide a concise, theory-informed rationale** for each selected synchrony metric, explicitly linking it to the psychological construct under investigation.
2. **Make pre-processed data publicly available** upon publication to facilitate systematic comparisons across complementary metrics—such as WTC, Pearson's correlation, phase-locking value, cross-correlation, and others—enabling future meta-analyses and more cumulative progress in the field.

Additionally, future research should explore the potential benefits—and possible limitations—of increased synchrony. Specifically, it remains unclear whether greater synchrony consistently translates into improved social outcomes (e.g., prosocial behavior, interpersonal understanding) or enhanced cognitive and performance-related measures, or whether there are contexts in which heightened synchrony may be neutral or even detrimental. For instance, increased neural synchrony has been associated with stronger interpersonal attunement, supporting positive developmental outcomes in parent–child interactions (Nguyen et al., 2021; Reindl et al., 2018), and facilitating performance in cooperative tasks. A recent paper by Miao et al. (2025) offered a case study using qualitative methods to examine moments of increased synchrony during dyadic bonding conversations, finding that approximately 80% of 10-second episodes marked by increased neural synchrony corresponded with high verbal and nonverbal engagement. While these findings offer promising validation of theoretical models, they are preliminary and call for more extensive, follow-up investigations to generalize across contexts and populations. Conversely, in tasks that require independent reasoning or creative problem-solving, excessive synchrony may have drawbacks—such as dampening divergent thinking or reducing individual task efficiency (Mayseless et al., 2019). A more nuanced understanding of when and for whom synchrony is beneficial will be essential for advancing theory and guiding applied interventions.

Multimodality

A growing consensus—emerging from both interaction science and the fNIRS research community, including responses from our survey—underscores a central insight: to understand the mechanisms that support human social interaction, we must adopt a multimodal approach. This means attending not only to neural signals, but also to dynamic shifts in facial expressions, body posture, gestures, speech, and how these behavioral markers relate to underlying neurocognitive processes. A multimodal perspective is not just a methodological enhancement; it is foundational for capturing the layered, interactive nature of real-world social encounters.

To advance social neuroscience meaningfully, we call for a renewed focus on multimodal data integration—both conceptually and analytically. Studying how neural activity aligns with and responds to behavioral signals across time is essential for developing mechanistic theories of social connection. Without such integration, we risk missing the very essence of what makes social interaction dynamic, responsive, and richly human.

Multimodal approaches offer powerful tools for social neuroscience, enabling researchers to explore how different manifestations of synchrony—neural, behavioral, and physiological—interact during real-time social exchanges. These methods help address pressing questions such as: What is the temporal relationship between brain-to-brain synchrony and synchrony in body movements, facial expressions, or vocal rhythms? Can fluctuations in one domain predict or influence alignment in another? By combining neural data with detailed behavioral signals, researchers can begin to uncover causal links between internal brain states and the observable social behaviors of interacting individuals.

This approach is particularly valuable for understanding complex social capacities, such as theory of mind, empathy, and perspective taking—abilities that allow individuals to share others' emotional states and attribute beliefs, intentions, and feelings to them. These processes do not unfold in isolation, but within dynamic, interactive contexts where multiple channels of information (i.e. speech, nonverbal behaviors, and neural fluctuations) are continuously exchanged and coordinated. Measuring neural synchrony between individuals, especially when paired with multimodal data, can reveal when and how interpersonal understanding occurs. For instance, increased brain-to-brain synchrony during emotionally charged or cognitively demanding moments may reflect successful perspective-taking or affective resonance. Importantly, such alignment is not just a marker of momentary understanding—it can have meaningful downstream consequences. Stronger interpersonal neural synchrony has been associated with enhanced rapport, increased feelings of social bonding (Kinreich et al., 2021), and even long-term outcomes such as friendship (Parkinson, Kleinbaum, & Wheatley, 2018) and greater marital satisfaction (Li et al., 2022). Emerging evidence also suggests that these mechanisms may play a role in fostering cooperation, reducing social polarization, and promoting mutual understanding across diverse contexts. Tracking how alignment across verbal and nonverbal cues relates to neural coupling offers a richer, more ecologically valid view of the mechanisms that support empathy and mentalizing in everyday interactions.

Importantly, researchers are beginning to characterize the behavioral signatures that correspond with "shared reality" or high intersubjective alignment. Preliminary evidence (e.g., Miao et al., 2025) suggests that rises in right temporal-parietal junction (TPJ) synchrony often co-occur with observable behaviors such as mutual nodding, verbal agreement, or repetition/paraphrasing of a partner's speech. These findings raise exciting possibilities: could these behavioral events serve as windows into underlying mental alignment? And can we use such moments to develop richer, more predictive models of social bonding and collective problem-solving?

To move the field forward, we must develop more robust methodological pipelines for integrating diverse, multimodal data streams. This is not just a technical challenge—it is essential for capturing the full complexity of real-world social interaction. Encouragingly, several promising tools have begun to emerge, such as PyFeat for facial expression recognition (Cheong et al., 2023), the Deep Neural Network for integrating neural and facial data (Miao et al., 2024), and the DIMS Dashboard for visualizing dynamic multimodal signals (Miao et al., 2025). Several workshops have also aimed to advance these conversations, including the Computational SAN Preconference 2024 (https://compsan.org/Preconference_2024.html), the Dynamic Interactions and Methodologies Symposium (DIMS) held at UCLA (http://gracemiao.com/dims/), and the education activities organized as a part of an EU-funded SYNCCIN project focused on caregiver–child interactions (https://synccin.uw.edu.pl/en/).

As the field evolves, we envision multimodality becoming not just a technical strategy but a guiding theoretical lens. To understand how relationships form, how conflict unfolds, and how humans bond over time, researchers must develop standardized pipelines and pursue integrative questions that bridge brain, behavior, and lived experience. We call on the field to embrace the complexity of multimodal data as essential for capturing the full richness of real-world social interaction.

CONCLUSION

FNIRS, and hyperscanning in particular, represents a young and rapidly evolving area of research. While the field has made significant strides in social cognition, the literature on naturalistic social interaction remains relatively limited (Fig. 2). With this paper, we aimed to gather collective insights from the hyperscanning fNIRS scholarly community to inform the next steps forward.

Our survey revealed emerging areas of consensus—particularly around data processing pipelines and the widespread use of neural synchrony as an analytic approach. However, important theoretical and methodological questions remain unresolved. For example, the interpretation of neural synchrony across different contexts—such as how to understand negative synchrony, or how to reconcile differing values produced by eg. Pearson correlation versus wavelet transform coherence—continues to be a source of ambiguity. While theoretical integration is still nascent, promising frameworks are beginning to emerge (e.g., Burns et al., 2025).

A second major theme that surfaced is the growing interest in multimodality. While the use of concurrent multimodal recordings is becoming increasingly common—88% of hyperscanning fNIRS researchers in our survey reported collecting additional data streams such as audiovisual recordings, eye tracking, heart rate, or skin conductance—published studies have yet to fully reflect this trend. In most cases, neural and behavioral results are reported in separate sections, without integrated analysis. As the field matures, we strongly advocate for greater methodological diversity and deeper theoretical integration. While new multimodal tools and workshops are emerging (e.g., Cheong et al., 2023; Miao et al., 2024; Miao et al., 2025), many questions remain open—highlighting the importance of continued innovation and collaboration.

Overall, we are at a pivotal moment in social neuroscience—one where we have the tools and momentum to investigate not only brain function, but the lived experience of human connection. Hyperscanning fNIRS research has the potential to shed light on how people bond, coordinate, and reduce feelings of loneliness through real-time social interaction. As a community, we are well-positioned to shape a future in which neural data is meaningfully integrated with behavior and context, offering deeper insights into what it means to connect.

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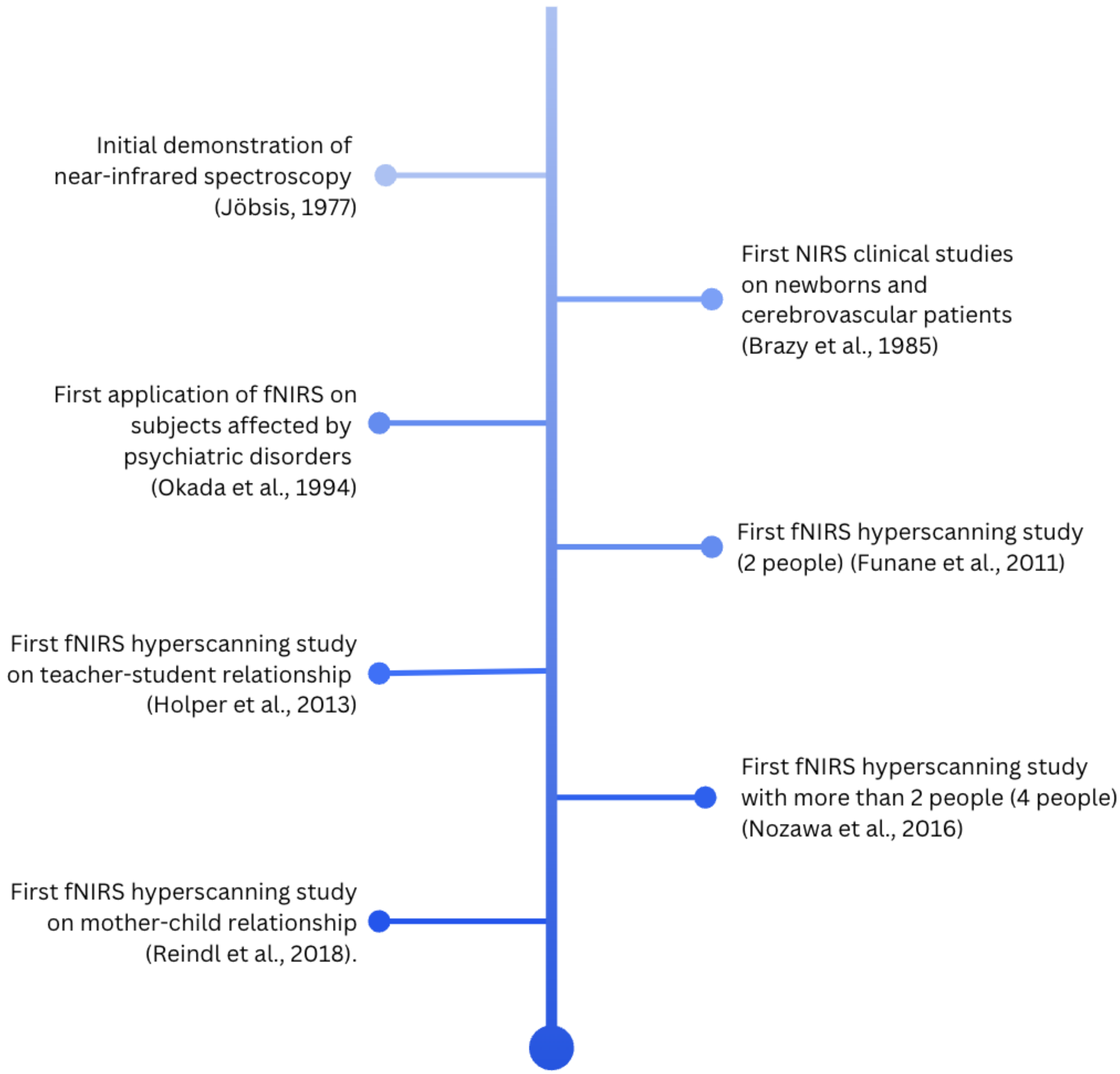


Figure 1. Summary timeline of first fNIRS articles in different settings

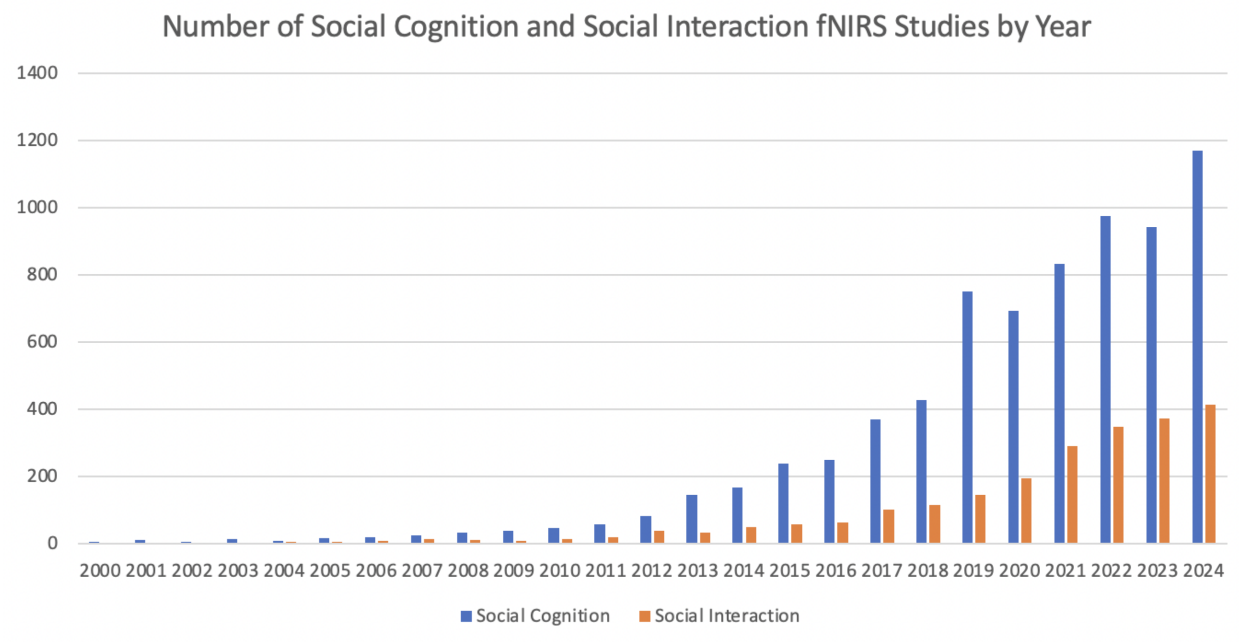
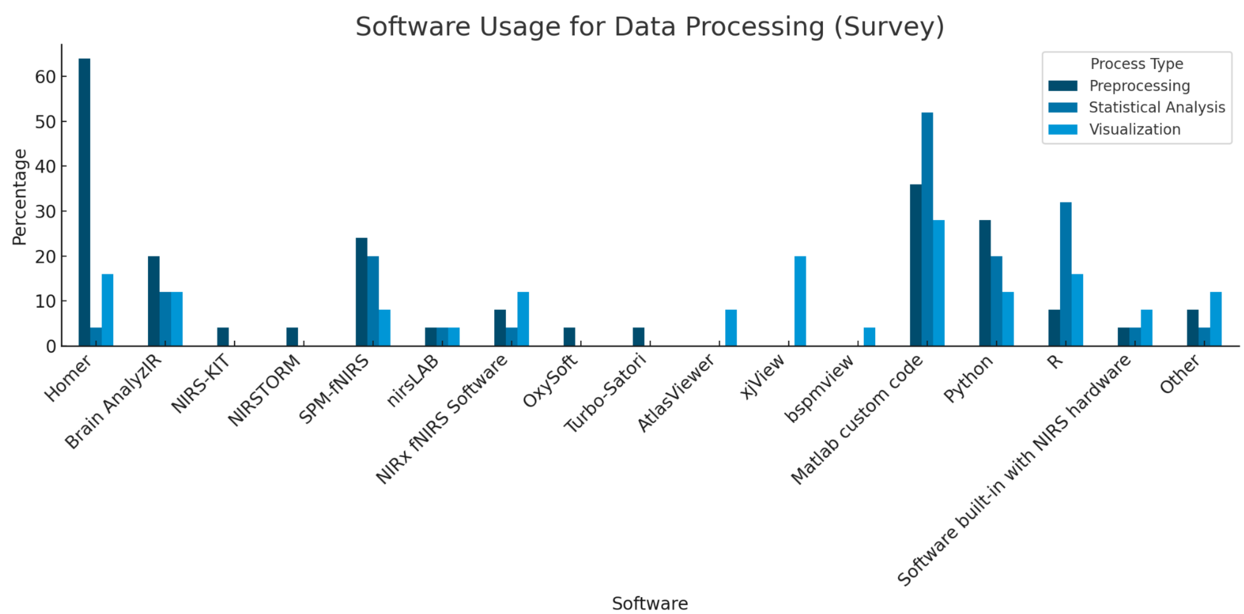


Figure 2. Increased publications over time on fNIRS studies of social cognition (*blue*) and social interaction (*orange*) indicated by relevant searches in Google Scholar.

Search terms for social cognition (*blue*): (fNIRS) AND (“social neuroscience” OR “social cognition” OR “social psychology”)

Search terms for social interaction (*orange*): (“Neural synchrony” OR "wavelet coherence" OR "intersubject correlation" OR "inter brain synchrony") AND (interaction OR hyperscanning) AND (fNIRS OR NIRS OR "near infrared spectroscopy").



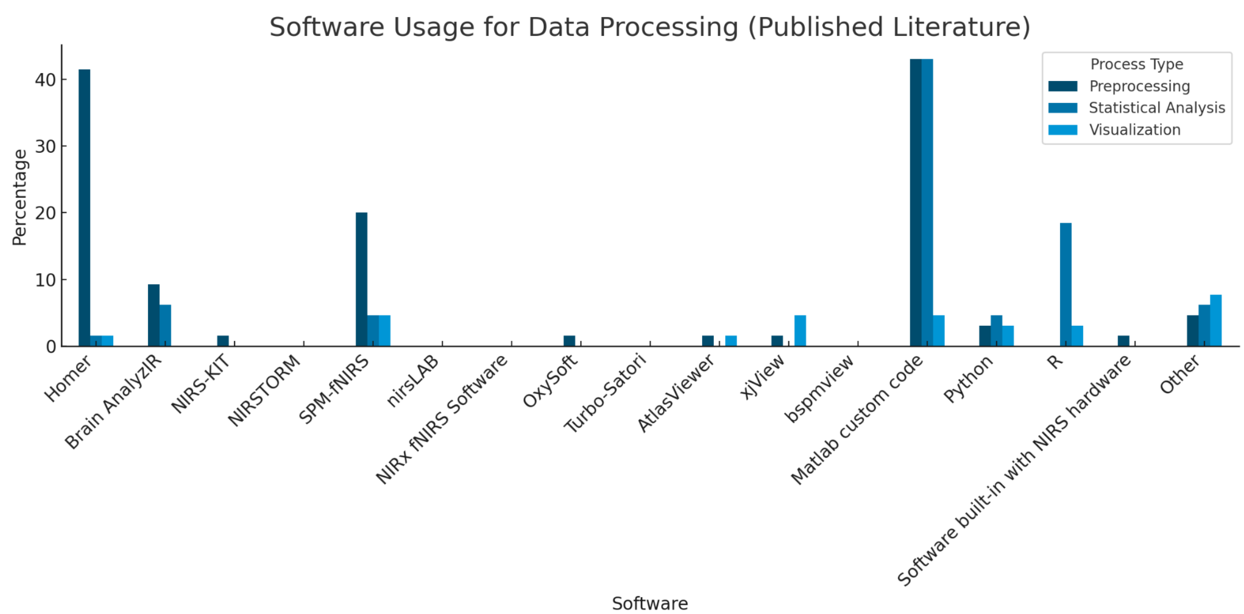


Figure 3. Software usage for data processing (preprocessing, statistical analysis, and visualization) from survey (top) and published literature (bottom).

Note: Responses for Homer2 and Homer3 were combined and represented as a single category, "Homer."

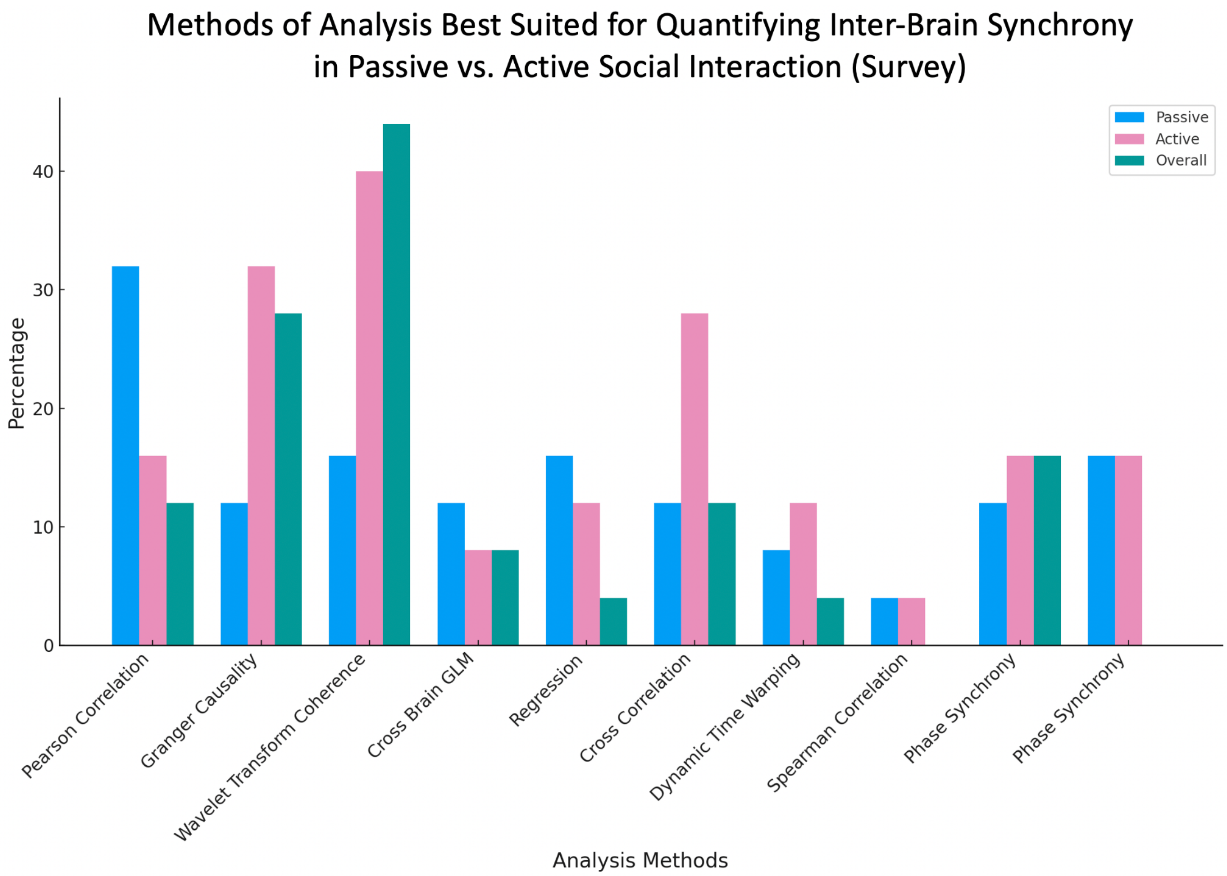


Figure 4. Methods of Analysis Best Suited for Quantifying Inter-Brain Synchrony in Passive vs. Active Social Interaction Indicated by Survey Results. Respondents were first asked: *Should different analysis methods be used on passive (eg. watching the same video, listening to the same sound) versus active (eg. interacting, having a conversation, playing a game) social interactions?* Those who answered yes (52% of respondents) selected the methods of analysis indicated in x-axis for passive (colored in blue) and active (colored in pink) social interaction separately. Those who answered no (48% of respondents) answered the methods of analysis question one time to reflect their overall opinion (colored in green).

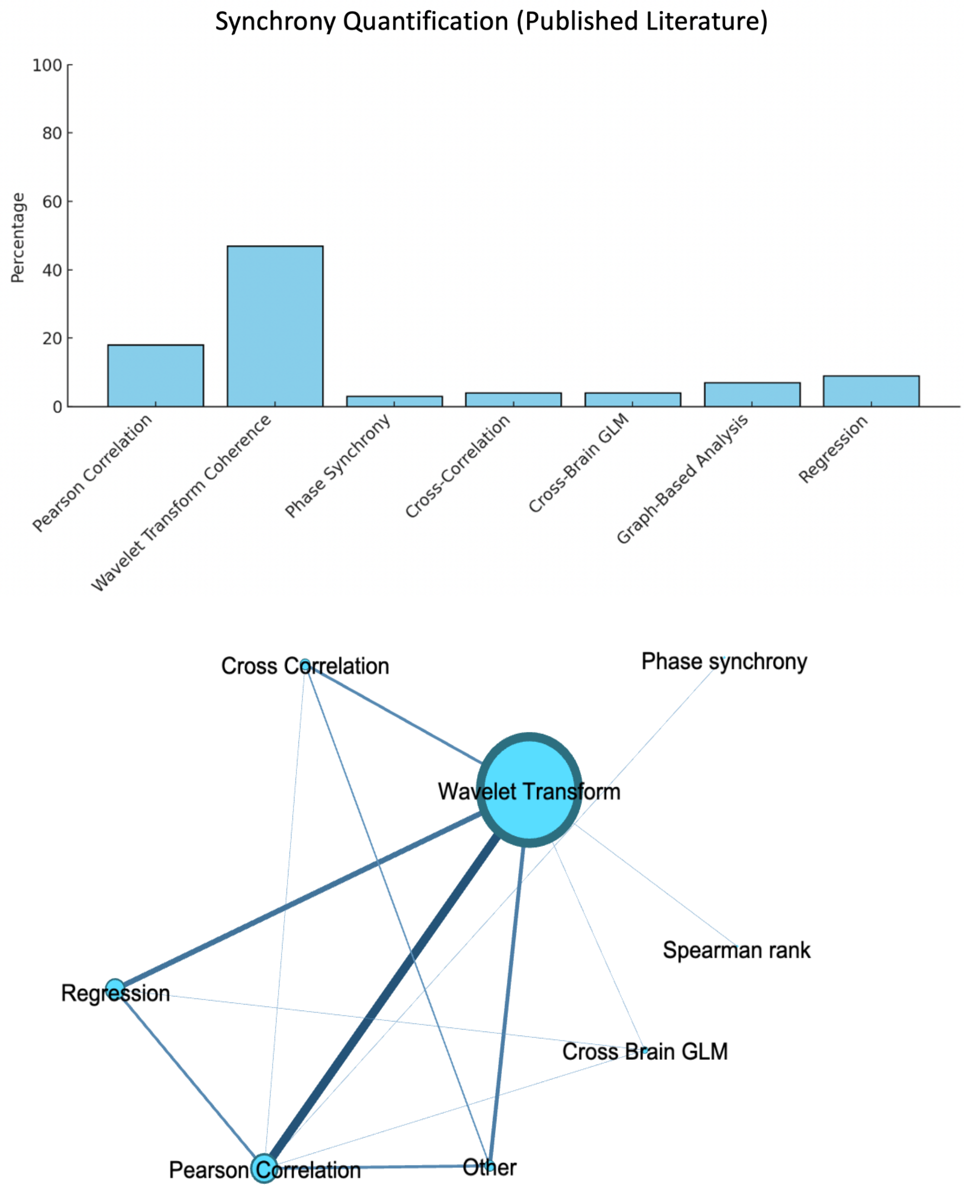


Figure 5. Methods of Analysis Used for Quantifying Inter-Brain Synchrony in Social Interaction Literature. *Top*: Summary bar graph reflecting the percentage of articles (out of 65 empirical articles) that use each method. *Bottom*: Network plot for the concurrent usage of existing methods for quantifying neural synchrony. The size of the circle reflects the frequency of usage for every method, and the width of the line reflects the frequency of concurrent usage for two methods.

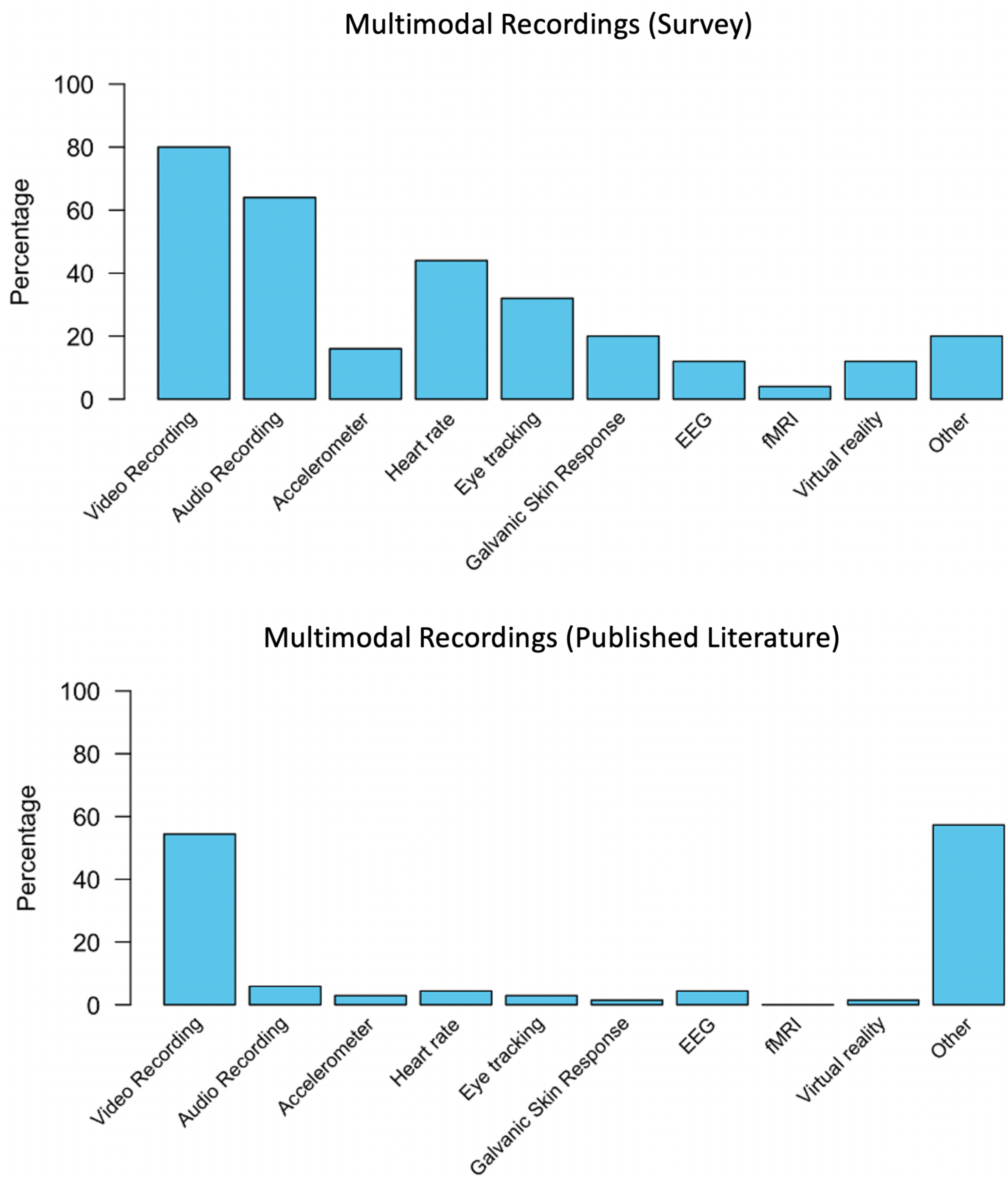


Figure 6. Types of multimodal recordings used in data collection from survey (top) and literature (bottom)

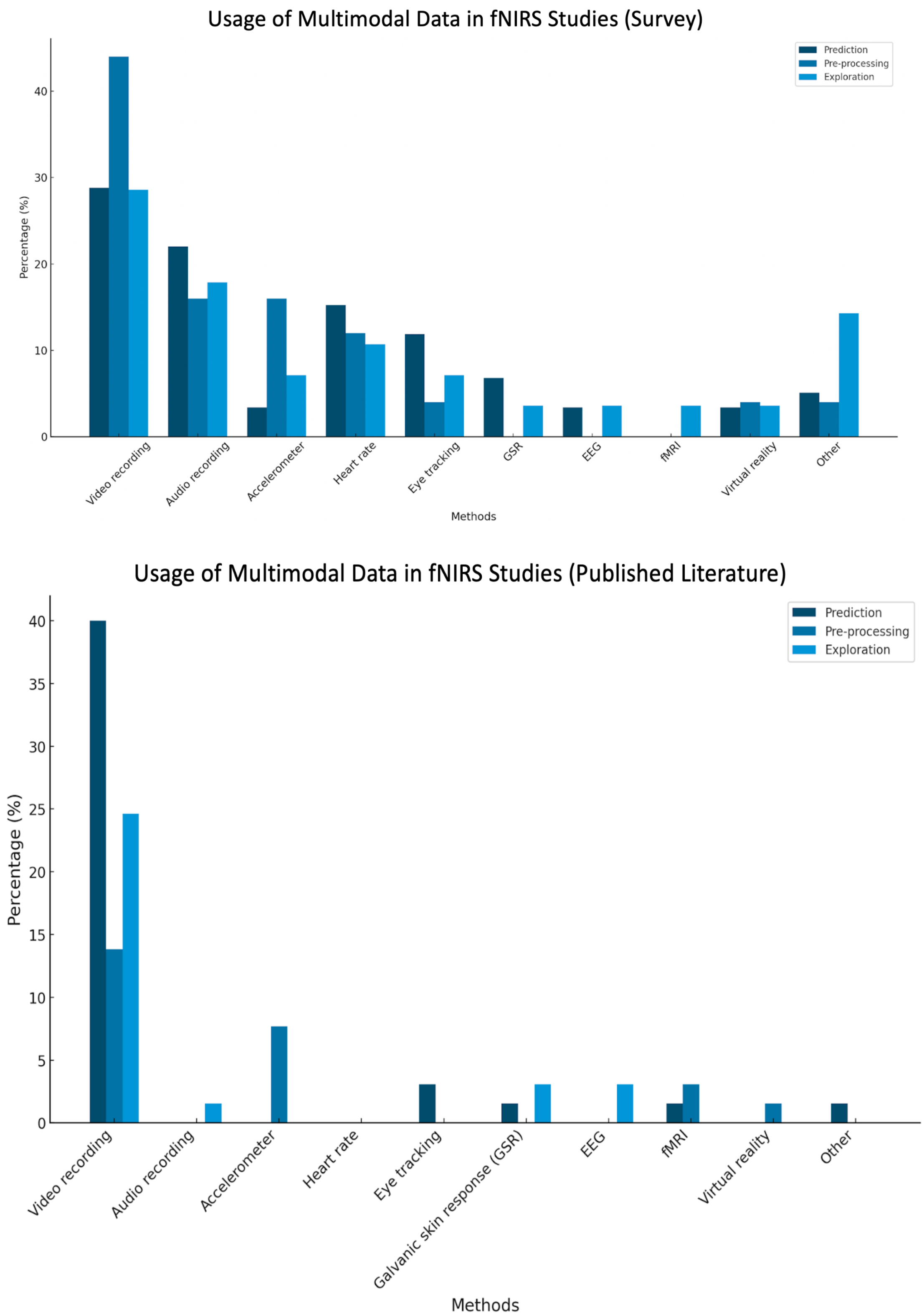


Figure 7. Usage of Multimodal Data in fNIRS Studies for prediction, pre-processing, and exploration from Survey (top) and Literature (bottom)