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TOPICAL REVIEW

# The Neuroscience of Team Dynamics: Exploring Neurophysiological Measures for Assessing Team Performance

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**ABSTRACT** Assessment of team performance has become increasingly important in recent years, prompting the exploration of innovative approaches to enhance our understanding of the underlying cognitive and neural processes involved. This review examines the application of neuroimaging techniques such as electroencephalography (EEG), functional near-infrared spectroscopy (fNIRS), and other brain imaging techniques in assessing team performance. It specifically emphasises the investigation of team aspects using neuroimaging techniques and their relationship to teamwork. By conducting a thorough analysis of the literature, the review highlights the unique capabilities, advantages, and limitations of brain imaging techniques. It also explores different research paradigms, including simulated tasks and real-world team interactions, to provide insights into the methodological landscape of studying team performance using neurophysiological measures. Moreover, the review underscores the significance of team aspects such as cooperation, workload, engagement, and decision-making, which have been investigated through neuroimaging techniques. By synthesising existing research, the review identifies associations between neurophysiological measures and specific indicators of team performance, shedding light on the underlying neural mechanisms that contribute to effective teamwork. Overall, this review highlights the value of neurophysiological measures in assessing team performance, emphasising the exploration of team aspects using neuroimaging techniques and identifying future research directions to advance our understanding of team dynamics and optimise performance in various domains.

**INDEX TERMS** Team performance, neurophysiological measures, brain imaging techniques, team aspects.

## I. INTRODUCTION

Effective team performance is a topic of significant interest to both researchers and organisations, given the crucial role of collaboration in critical environments such as sports, military operations, construction, and emergency services [1]. In these domains, the ability of a team to work together harmoniously, communicate effectively, and coordinate their efforts is essential for achieving goals and ensuring safety and success [2]. As a result, there is a growing need to explore innovative approaches that enhance our understanding of the underlying cognitive and neural processes involved in team performance [1], [2]. A team is defined as a cohesive unit of two or more individuals who work interdependently towards a common goal [3], [4]. Many organisations recognise the value of teams as the fundamental building blocks of their organisational structures. Teams offer the advantage of pooling diverse skills, knowledge, and perspectives, which are often necessary for tasks that require complex problem-solving, decision-making, and creativity [5]. Consequently, understanding team performance and identifying ways to improve collaboration and cooperation among team members

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have become crucial goals for organisations across various industries [3].

The evaluation of team performance and dynamics has traditionally relied on perception-based measurement tools, survey-based reporting, and observation-based reports [6]. However, these subjective methods are susceptible to biases and discrepancies [7]. As a result, there is a growing trend towards using objective assessments derived from physiological or behavioural data to evaluate team dynamics [1]. Objective assessments based on physiological or behavioural data offer several advantages. Firstly, they provide real-time information from multiple team members simultaneously, allowing for a more comprehensive understanding of team dynamics. Secondly, these objective measures are less influenced by biases that may be present in self-reports or observer reports. Finally, collecting physiological or behavioural data does not disrupt the natural emergence of team states and processes, ensuring that the assessment accurately reflects the team's dynamics [1], [2], [6]. By integrating objective assessments with traditional perception-based tools, researchers gain a more comprehensive and accurate understanding of team performance, communication, coordination, and other relevant aspects of team dynamics. Neurophysiological assessments, in particular, offer objective measures that provide insights into the physiological connections between team members. These measures can uncover cognitive load, emotional states, and coordination dynamics during team tasks [8]. Understanding these factors enables more effective analysis of team processes and performance. Neurophysiological assessments open up new avenues for studying team dynamics and designing interventions based on neuroscientific insights, ultimately improving team functioning and performance [9].

Numerous reviews have contributed to our understanding of team dynamics and functioning. For example, [2] conducted a comprehensive analysis of studies examining the relationships between autonomic physiological measures during interpersonal interactions. The review reveals consistent evidence of physiological linkage and synchronisation between individuals, highlighting the importance of considering interpersonal autonomic physiology in understanding social dynamics and human relationships [2]. In contrast, while [2] focused on group interaction in general, [1] study provides an overview of the literature specifically addressing team physiological dynamics. The authors provide an overview of the literature on team physiological dynamics [1]. They highlight the significance of understanding the physiological responses and interactions within teams for enhancing team performance and collaboration [1]. The review discusses the potential implications of team physiological dynamics in various fields, identifies methodological considerations and challenges, and suggests future research directions. A recent review conducted by [10] examines the use of wearable devices and sensors in measuring team coordination dynamics for the purpose of assessing team functioning and performance. The review highlights the significance of these technologies in capturing real-time data on team interactions, providing valuable insights into the dynamics of teamwork and potential avenues for improving overall team effectiveness [10].

Research on team dynamics and performance assessment has predominantly emphasised physiological measures, such as cardiac activity, electrodermal activity (EDA) [1], [2], [10], skin conductance synchronisation (SCS) [11], heart rate (HR) [12], electrocardiogram (ECG) [13], and eye-tracking [14], often sidelining the potential of neurophysiological measures. While these studies have enriched our understanding of team functioning, there's an evident research gap concerning the use of neuroimaging techniques like electroencephalography (EEG), functional near-infrared spectroscopy (fNIRS), and functional magnetic resonance imaging (fMRI) in team performance evaluation. These measures provide an in-depth look into the neural foundations of team interactions and decision-making [15], revealing cognitive and emotional dimensions of teamwork. They capture live brain activity, offering insights into intricate team tasks. Thus, this review will focus on non-invasive neuroimaging techniques used in team studies and seeks to bridge the research gap, spotlighting the relevance of neurophysiological metrics in team performance evaluation. It delves into the utilisation of EEG, fNIRS, and fMRI, examining teamwork aspects such as cooperation, workload, and engagement. Ultimately, this review aspires to enrich the discourse on team dynamics using neurophysiological approaches, adding depth to our comprehension of teamwork dynamics.

## II. NEUROIMAGING TECHNIQUES

Neuroimaging techniques encompass a range of techniques and tools used to assess and analyse the physiological aspects of brain function and activity [16]. Specifically, functional neuroimaging techniques provide insights into the neural processes underlying cognitive, emotional, and sensory functions, allowing researchers to investigate various aspects of brain functioning and its relationship to behaviour and performance [17]. Several types of these techniques such as EEG, fNIRS, and fMRI have been utilised to record brain activity from multiple participants. Each of these techniques has its pros and cons. For instance, fMRI provides a good spatial resolution but lacks temporal resolution and is very expensive to operate [17]. Additionally, fMRI studies may lack ecological validity due to the difficulty of the experiment setup and the constraint of being inside the scanner environment [18]. On the other hand, fNIRS and EEG demonstrate a better temporal resolution, capturing changes in brain activity with high temporal precision, but they lack spatial resolution compared to fMRI [19]. The EEG and fNIRS have been widely utilised over the last decades due to their lower cost and the availability of high-quality equipment, making them more accessible for research and practical applications. Moreover, both EEG and fNIRS are relatively easy to use and allow for portability, making them suitable for conducting experiments outside the laboratory setting [19].

### A. ELECTROENCEPHALOGRAPHY

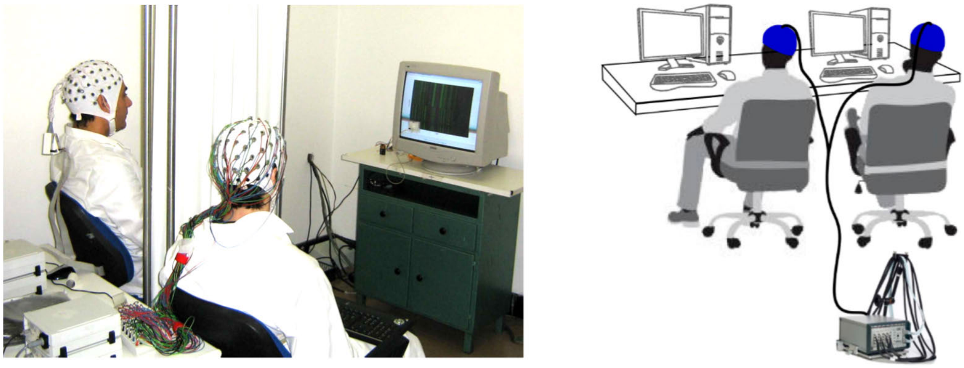
EEG records the brain's electrical activity via one or more scalp mounted electrodes [20]. Recent advancements in EEG technology have allowed for the development of neurophysiological metrics related to team processes, providing valuable insights into team dynamics and performance [7]. EEG offers higher temporal resolution and enables precise and varied brain analyses [20]. Moreover, EEG is a cost-effective option that allows for ecologically valid evaluations of team variables [7], [21]. Utilising EEG technology has demonstrated potential in contrasting brain activity patterns across teams, pinpointing configurations that might correlate with enhanced cohesion and possibly better team performance. Such patterns are framed within the concept of team neurodynamics. This approach offers immediate and unbiased perspectives into team cognition, paving the way for potential advancements in team enhancement and adaptive training methodologies [22]. While EEG studies have traditionally been conducted in controlled laboratory environments with standard paradigms [23], there is ongoing progress towards incorporating more naturalistic paradigms, such as playing musical instruments [24] and engaging in romantic kissing [25], [26].

Researchers have made significant progress in studying neurophysiological measures-based on EEG to investigate brain activity of two or more participants during team tasks. For instance, Stevens et al. [27] conducted a series of studies examining the neurodynamics of team members to identify patterns of neural organisation and synchronisation. In a study from 2009, they assessed the performance of five teams during a problem-solving task, analysing workload and engagement expressions across the team members [27]. Building on this work, in 2013, they expanded their model of neurodynamic synchronies (NS) to investigate a Submarine Piloting and Navigation (SPAN) task, monitoring the EEG of each team member in a six-person team. They observed periods of team reorganisation characterised by entropy fluctuations, which reflected team communication and external perturbations. Decreased entropy indicated increased organisation within the team [28]. Likens et al. [29] also explored team behaviours during a SPAN task using EEG synchrony as a measure, employing a dynamical system approach to capture nested team cognition and large-scale organisation. The results demonstrated that the multi-fractal analysis properties of EEG signals were related to the organisational behaviour of teams. These studies highlight the potential of EEG-based neurophysiological measures in understanding team dynamics and performance.

EEG hyperscanning, a technique that simultaneously measures brain activity from multiple individuals, has been explored in literature. For example, Astolfi et al. [30] and Toppi et al. [31] investigated the simultaneous connectivity of brains during cooperation using the partial directed coherence (PDC) method. In one study [30], the authors examined the neural activity between team members during a card game as an ecological task, revealing significant connectivity between cortical areas of the players' brains. Figure 1. (a) shows the simultaneous EEG recording of brain activities during a hyperscanning study [30]. In study [31], Toppi et al. investigated cooperative behaviours among six dyads of civil pilots during real-time flights. They found a statistical difference in graphs derived from PDC analysis of EEG signals between pilots in real-world flight environments compared to simulated scenarios. Another study [32] utilised EEG hyperscanning to enhance cooperation accuracy among teammates. The experiment involved five teams of two members performing the Multi-Attribute Task Battery (MATB) [33], and the results showed a significant influence of cooperative states on mental states using co-variance-based metrics. Specifically, average accuracies of 66.6%, 64.5%, and 65.3% were achieved for the theta, alpha, and low beta bands, respectively. Additionally, Cha and Lee [34] used quantified EEG signals to investigate changes in neural synchronisation during cooperative work in a picture puzzle game with six participants. They found increased neural synchronisation between teammates through bi-spectral analysis during periods of cooperative effort. However, the relationship between neural synchronisation and human error was not reported in their findings.

### B. FUNCTIONAL NEAR-INFRARED SPECTROSCOPY

fNIRS is a non-invasive neuroimaging technique that provides an indirect assessment of brain activation by measuring changes in the concentration of oxyhemoglobin (HbO) and deoxyhemoglobin (HbR) in the blood. It offers several advantages, including portability, ease of use (refer to Figure 1. (b) to see the experimental setup), and resistance to movement artifacts, making it suitable for studying brain activity in naturalistic environments [36]. The mobility of fNIRS allows researchers to investigate brain function in real-world settings, providing valuable insights into the neural correlates of various cognitive processes and social interactions. Hyperscanning has been successfully applied using fNIRS. Funane et al. [37] conducted a pioneering study using fNIRS hyperscanning, where they examined the relationship between task performance and inter-brain neural coherence during a pressing synchronisation task. Their findings demonstrated the feasibility of capturing and analysing neural activity from multiple participants using fNIRS. Since then, fNIRS hyperscanning has been employed in various paradigms to investigate brain activity and interpersonal dynamics. For example, Scholkmann et al. [36] reviewed the application of fNIRS hyperscanning in different experimental setups, highlighting its potential in studying social interactions, joint actions, and communication processes. Czeszumski et al. [17] further emphasised the advantages of fNIRS hyperscanning, including its suitability for studying naturalistic scenarios and its potential to capture real-time brain activity during social interactions.



(a) (b)

**FIGURE 1.** **Neuroimaging and hyperscanning setups. (a) Simultaneous EEG recording of brain activities [30]. (b) Experimental fNIRS setup demonstrated by participants [35].**

### *C. FUNCTIONAL MAGNETIC RESONANCE IMAGING*

In order to study the brain signals of two or more participants simultaneously, researchers have explored the use of remote fMRI setups due to the limitations of placing multiple participants inside a single fMRI scanner. Wang et al. [16] developed a method that involved storing data from two or more remote fMRI apparatus in a host client via an intranet. This approach allowed for concurrent data acquisition from multiple participants in separate fMRI scanners. Participants were able to interact with each other while functional MRI data were acquired simultaneously during their behavioural interactions. The study involved three pairs of participants competing against each other in a simple deception task, with the fMRI scanners arranged to work over the internet [18]. Hyperscanning with fMRI has showcased its strengths in accurately mapping the synchronicity across brain regions. This technique delivers superior structural precision and unrivaled imaging depth, however, the cost of setting up and maintaining multiple fMRI systems makes this approach inaccessible and impractical for many research settings [18]. Additionally, the ecological validity of fMRI studies conducted in controlled laboratory environments is relatively low compared to real-life situations [16]. Despite these limitations, fMRI hyperscanning remains a valuable tool for investigating the neural dynamics of social interactions. Ongoing advancements in technology and methodologies are aimed at addressing the challenges associated with cost, accessibility, and ecological validity, thereby expanding the application of fMRI hyperscanning in various research domains.

### *D. MAGNETOENCEPHALOGRAPHY*

Magnetoencephalography (MEG) is a neuroimaging technique that involves recording the changing magnetic field produced by cerebral activity in the human brain [38]. Compared to EEG, MEG provides superior capabilities in determining the regions and timing of underlying brain activities [39]. MEG offers valuable insights into sensory and higher-level processing, providing high-resolution and spatio-temporal dynamics of neuromagnetic activities during various behavioural and cognitive tasks [40]. It allows researchers to study the precise locations and temporal sequences of brain activations, shedding light on the neural mechanisms underlying cognitive processes. Combining MEG with other modalities further enhances its performance. For example, MEG can be combined with EEG, known as MEG-EEG, to benefit from the complementary advantages of both techniques [41]. The combination of MEG and magnetic resonance imaging (MRI), known as MEG-MRI, enables the integration of anatomical and functional information, offering a more comprehensive understanding of brain activity [40]. In the context of hyperscanning, Hirata et al. [42] developed an audio-visual system for MEG hyperscanning. They investigated brain-to-brain interactions using a dual MRI and eye-tracking system. The MEG hyperscanning system they developed allowed for real-time observation of each other's facial expressions. This approach is not only applicable to studying mother-child interactions but also holds potential for studying interactions between two participants in various paradigms, expanding the scope of MEG hyperscanning research.

## III. TEAM WORK ASPECTS

In the context of teamwork, various aspects play a crucial role in determining the effectiveness and efficiency of the team. In the following section, we will delve into some of these aspects and explore their connection to effective teamwork.

### *A. COOPERATION*

Cooperation plays a crucial role in a teamwork environment, involving collaborative behaviours among team members to achieve a shared objective [43]. Poor teamwork, characterised by a lack of communication and cooperation, is a leading cause of human errors. EEG has been utilised in several studies to investigate neural activity and cooperative behaviours within teams [30], [31], [34], [43], [44], [45], [46]. For example, Cha et al. [34] measured neural synchronisation between pairs of individuals using EEG hyperscanning during collaborative work. They discovered that neural synchronisation increased during collaboration, indicating enhanced communication and improved teamwork. Sciaraffa et al. [47] investigated cooperation between two team members performing the NASA MATB at varying difficulty levels. They found that inter-brain connections increased during cooperative tasks. Another study by Roy et al. [32] employed machine learning classification on connectivity features to estimate the level of cooperation between teammates, achieving an average accuracy of 66.6% for theta band signals. In addition to EEG, fNIRS neuroimaging techniques have demonstrated cooperation between individuals in various paradigm designs, including computer-based cooperation games [48], [49], [50], attentional tasks [51], cooperative button-press tasks [37], turn-taking games [52], [53], and realistic problem-solving scenarios [54]. Furthermore, fMRI neuroimaging techniques have been employed to examine neural activity in the brain during collaborative tasks [55]. Table 1 summarises the cooperation studies that assess team performance highlighting the team size, analysis methods and the experiment task. The "term" in the tables refers to the associated activity identified within the physiological processes of two or more individuals.

### B. WORKLOAD

The quantification of workload in teams is a complex task, influenced by various factors such as individual workload and overall team functioning [61]. The conceptualisation and measurement techniques of team workload have been extensively reviewed in study by [61]. In EEG research, Stevens et al. delved into a neurodynamics study, seeking to uncover the essence of teamwork in challenging problem-solving tasks [22]. Using EEG techniques, they evaluated the workload dynamics of three-member teams during a substance abuse simulation task, both independently and collectively, employing the B-Alert system for data collection [22]. Notably, the study demonstrated that the workload was higher when participants collaborated, as opposed to working individually [22]. Building upon this foundation, Stevens et al. adopted a parallel approach in a subsequent study [28]. The research aimed to understand how teams alter their cognitive patterns in response to task modifications, focusing specifically on submarine piloting and navigation teams. By integrating the neurophysiologic model, they successfully mapped out the neurophysiological shifts during team reorganisations, presenting a crucial tool for analysing the caliber of teamwork in intricate, real-world situations [28]. In addition, Borghetti et al. [62] developed a neuroergonomics model that utilised machine learning on EEG data to estimate a time-series numerical approximation of operators' workload. The model demonstrated no practical difference between cross-participant and within-participant data for change activity detection. They also applied a stochastic Monte Carlo re-sampling method to the model, generating synthetic training data with a small number of participants, which performed similarly to the trained model with real participants. Several other studies have utilised EEG and fNIRS neuroimaging techniques to examine the workload of teams (refer to table 2).

### C. ENGAGEMENT

In their study, Xu et al. [15] employed fNIRS to investigate team engagement in a simulated crisis event management (CEM) task. The task scenarios varied in difficulty level, and the participants had different levels of expertise. The results indicated that scenario difficulty influenced the cooperation between team members, with higher levels of engagement observed in more challenging scenarios, reflecting the need for closer cooperation. The team-level fNIRS measures proved to be sensitive indicators of team engagement, showing increased neural synchrony during team cooperative work compared to individual work. Using fNIRS, Zhang et al. [65] examined interpersonal brain synchronisation between counselors and clients during naturalistic psychological counseling. The findings revealed that neural synchrony in the right temporal parietal junction (r-TPJ) area increased as the engagement in the conversation between counselors and clients increased, highlighting the role of neural synchrony in interpersonal interactions. Stevens and colleagues [28] applied the neurophysiologic model of SPAN teams to measure engagement between teammates in response to task changes. They analysed the engagement levels of individual team members and the entire team during their interactions. The study demonstrated that engagement during the scenario was dynamic, exhibiting fluctuations different from speech frequencies. Engagement between teammates can be evaluated through various activities such as shared attention [66], shared communicative history [67], verbal communication/speech [68], and hand movements/nonverbal interactions with turn-taking [69] (refer to Table 3).

### D. COGNITION

Team cognition refers to the collective mental processes that occur when team members interact with each other, enabling them to predict each other's actions, attitudes, and thoughts without explicit communication [73]. The ability to maintain effectiveness and achieve shared goals in teams, especially in the face of unexpected crises and evolving situations, relies on essential cognitive skills. Methods for tracking these skills have been discussed in the literature [73]. The communication reorganisation model suggests that experienced teams exhibit effective and timely reorganisation in response to perturbations, while inexperienced teams may show delayed reorganisation that does not occur simultaneously with the

**TABLE 1. Cooperation studies assessing team performance.**

| Modality | Team Size | Analysis Method | Task | Finding | Term |
|---|---|---|---|---|---|
| EEG | 3 | Bispectral analysis | Picture puzzle | When teammates communicate smoothly and collaborate effectively, there's an observable increase in neural synchronisation between their EEGs [34]. | Synchrony |
| EEG | 2 | PDC | Prisoner's Dilemma game / a card game | The findings reveal significant activity in the prefrontal and anterior cortex, predominantly in the theta and alpha frequency bands [30]. | Connectivity |
| fNIRS | 2 | Pearson correlations | Solving problem task realistic presented problem (RPP) | The findings indicate that when less creative pairs collaborated on a creative task, they often cooperated to improve their overall creative performance [54]. | Synchrony |
| fNIRS | 2 | Pearson correlations | Alternative uses task (AUT) / Object characteristic task (OCT) | The fNIRS findings revealed heightened inter-brain synchrony (IBS) in the right dorsolateral prefrontal cortex (r-DLPFC) and right temporoparietal junction (r-TPJ) exclusively for dyads participating in cooperative activities during the AUT task performance [56]. | Synchrony |
| fNIRS | 2 | WTC | Joint-drawing task and control task | The study reveals that basketball teams completed the joint-drawing task more quickly and exhibited a higher degree of cooperation compared to teams comprised of college students [57]. | Synchrony |
| EEG | 2 | PDC | Simulated flight | Intra-subject connectivity can be used to gauge the level of cooperation among civil pilots during various stages of a simulated flight [31]. | Connectivity |
| EEG | 2 | Linear discriminant analysis (LDA) | NASA MATB-II | The developed pipeline facilitates the estimation of cooperative states through covariance matrices. It achieves average accuracies of 66.6% in the theta band, 64.5% in the alpha band, and 65.3% in the low beta band [32]. | Connectivity |
| EEG | 2 | Pearson Correlation | Pong game | The findings indicate an increased inter-brain synchrony (IBS) between participants when cooperating. Notably, the IBS further was significantly enhanced when participants were physically apart [46]. | Synchrony |
| fMRI | 2 | Correlation analysis | Testing emotional attunement and mutuality (TEAM) | The study found a correlation between the activation of the anterior insula in adolescents and the anxiety levels of their parents [58]. | Connectivity |
| fNIRS | 2 | Wavelet coherence | Computer-based cooperation game | The study found that when participants of opposite genders collaborated, there was a notable increase in task-related coherence within the frontal brain region [48]. | Coherence |
| fNIRS | 2 | Pearson correlation | Turn-taking game | When interacting with a cooperative partner, the builder's activation in the right IFG is increased [52]. | Synchrony |
| fNIRS | 2 | Linear regression | Turn-taking game | During both cooperation and competition scenarios, an increased synchrony value was observed in the right pSTS, attributed to the requirements of joint attention and intention comprehension [53]. | Synchrony |
| fNIRS | 4 | WTC | Cooperative word chain game | The findings indicate increased frontopolar interpersonal neural synchronisation (INS) during team member communication compared to periods of silent contemplation [59]. | Synchrony |
| fNIRS | 2 | WTC | Ultimatum game | The result showed increased INS in rTPJ during the face-to-face interactions associated with shared intentionality between subjects [60]. | Synchrony |
| fNIRS | 2 | WTC | Computer-based cooperation game | The research offers insights into gender differences in neural and behavioral markers. Specifically, for same-sex pairs, there was a positive correlation between task-related inter-brain coherence and performance in cooperative tasks [50]. | Coherence |
| fMRI | 3 | GLM analysis | Collaborative task (verbal drawing) | GLM analysis revealed enhanced activation in brain regions associated with the theory-of-mind when participants collaborated [55]. | Synchrony |

**TABLE 2. Workload studies assessing team performance.**

| Modality | Team Size | Analysis Method | Task | Finding | Term |
|---|---|---|---|---|---|
| EEG | 2 | shrinkage linear discriminant analysis (sLDA) | NASA MATB-II | The research assessed the mental workload and cooperation between pairs using EEG spectral features and a classification method. The binary classifier in this study achieved a 60% accuracy rate [63]. | Connectivity |
| fNIRS | 2 | WTC | Crisis event management (CEM) | The findings from the WTC indicate that active teamwork was associated with higher levels of both HbO and HbR [15]. | Synchrony |
| EEG | 2 | PDC | NASA MATB | The study revealed that task difficulty influenced the average local properties of a brain network. Specifically, as the workload increased, there was a decrease in clustering values, particularly over the central and parietal brain regions [47]. | Connectivity |
| EEG | 2 | Neurophysiological patterns | Map Task (MT) | The study identified nine task disruptions that significantly influenced the team's neurodynamic reactions [64]. | Synchrony |
| EEG | 3 | Neurophysiological patterns | Submarine Piloting and Navigation (SPAN) | The research indicates that EEG-measured neurophysiological patterns could provide insights into team behavioral interactions over both short milliseconds duration and longer time frames [22]. | Synchrony |

perturbation [73]. In a study by Gorman and colleagues [74], the relationship between EEG-measured brainwaves and team communication was examined across varying training and experience scenarios. Their results suggested that as team members became more experienced, shifts in cognitive behavioural constraints, like communication methods, correlated with alterations in neural patterns. To assess cognitive strategies and inter-brain responses in dyads, Balconi et al. [51] employed fNIRS neuroimaging techniques during an attentional task. They observed a consistent decrease in shared activity for the dyads, particularly in the post-response condition. Feng et al. [75] utilised fNIRS to investigate the cognitive and neural mechanisms underlying the effect of synchronisation on prosociality. Their findings demonstrated that behavioural synchronisation increased self-other overlaps, leading to enhanced brain-to-brain synchrony [75]. These studies and the studies in table 4 highlight the use of neuroimaging techniques, such as EEG and fNIRS, to examine team cognition and inter-brain dynamics during various tasks and interactions.

### *E. DECISION MAKING*

Team members engage in decision-making processes during tasks, and the ease of teamwork can vary depending on the individuals involved. Neuroimaging studies have explored how team dynamics impact decision-making. For instance, Szymanski et al. [83] measured EEG activity of teams performing a visual search task individually and as a team. They observed higher inter-brain phase synchrony when participants jointly attended to the task, leading to more efficient and faster decision-making compared to individual performance. In addition, Zhang et al. [84] investigated the influence of individual personality on inter-brain synchrony during decision-making using fNIRS. Their study focused on pairs engaged in a decision-making game and found higher inter-brain synchrony in the right dorsolateral prefrontal cortex (DLPFC) for group decision-making compared to individual decision-making. Other studies utilising fMRI techniques have also examined inter-brain synchronisation in decision-making contexts, including tasks such as simple estimation, trust games, and the Ultimatum Game [85], [86], [87], [88], [89]. Table 5 further summarises the decision-making studies that assess team performance.

## IV. NEURAL-SYNCHRONY MEASURES

Analysing and quantifying hyperscanning data, which captures neural activity during team interactions, presents a complex and challenging task as it necessitates evaluation

**TABLE 3.** Engagement studies assessing team performance.

| Modality | Team Size | Analysis Method | Task | Finding | Term |
|---|---|---|---|---|---|
| EEG | 4 | Time-frequency analysis (coherence) | Problem-solving tasks | The results show that inter-brain synchrony might be informative in understanding team dynamics and predicting successful teams [45]. | Synchrony |
| EEG | 3 | Neurophysiological patterns | Problem-solving | The resulting patterns differed for the five teams reflected the teams' efficiency [27]. | Synchrony |
| fNIRS | 2 | WTC | Psychological counseling | The study discovered that as counselors and clients deepened their engagement in the conversation, there was an increase in neural synchrony in the rTPJ area [65]. | Synchrony |
| EEG | 11 | Neurophysiological patterns | SPAN | The results showed the neurophysiologic synchronises (NS) data streams that measure using entropy decreased when the team was stressed [70]. | Synchrony |
| EEG | 6 | Neurophysiological patterns | SPAN | Reduced neurophysiological synchronised entropy was linked to episodes of less effective team performance [28]. | Synchrony |
| EEG | 6 | Neurophysiological patterns | SPAN | The periods of intensity or stress are associated with decreases in NS entropy, which will increase the organisation [71]. | Synchrony |
| EEG | 2 / 5 | Neurophysiological patterns | Map task / SPAN task | The research indicates that by mapping entropy and mutual information of neurodynamic symbols from teams, it's possible to identify organisational patterns across brains [72]. | Synchrony |
| EEG | 2 | PLV | Live interaction | They discovered that interactional synchrony states are associated with the development of an inter-brain synchronisation network in the alpha-mu band, focused on the right centroparietal areas [69]. | Synchrony |
| fMRI | 2 | Correlation analysis | Mutual gaze task / Joint attention task | During tasks involving mutual gaze and joint attention, a positive correlation was observed between neural synchronisation and higher eye-blink synchrony [66]. | Synchrony |
| fMRI | 2 | GLM analysis | Simple deception task | This study introduced the term "hyperscanning," which involves allowing individuals to interact in a controlled environment while simultaneously scanning their brains [18]. | Linkage |
| fMRI | 2 | Correlation analysis | Live verbal interaction | The time course of neural activity in regions related to speech production exhibited coupling with the auditory cortex of the interlocutor [68]. | Coupling |
| fMRI | 2 | Coherence analysis | Communicative task | Interpersonal cerebral coherence was not observed when communicators used stereotyped signals; instead, it only occurred within dyads who shared a communicative history [67]. | Coherence |

at both the individual and team levels. In the following section, we will discuss neural-synchrony that have been widely observed in the literature and utilised to quantify the responses of teams.

**TABLE 4. Cognition studies assessing team performance.**

| Modality | Team Size | Analysis Method | Task | Finding | Term |
|---|---|---|---|---|---|
| EEG | 3 / 5-6 | Neurophysio-logical patterns | Healthcare / SPAN task | A reduction in entropy could potentially be linked to moments of stress or uncertainty [76]. | Synchrony |
| EEG | 2 / 5-6 / 3 | Neurophysio-logical patterns | Map task/ SPAN task/ Healthcare | Teams that exhibit greater variability, indicated by higher entropy levels, tend to perform better. This finding, consistent across the neurodynamics of various teams, suggests that team neurodynamics could play a crucial role in advancing theoretical insights into physiological synchronisations associated with teamwork [77]. | Synchrony |
| EEG | 2 | Neurophysio-logical patterns | Map task/ SPAN task/ Healthcare | The majority of team information comprises the summation of each individual's neurodynamic data, while the remainder is distributed among team members. On average, this shared information constitutes approximately 15% of the individual information, with occasional variations ranging from 1% to 80% [78]. | Synchrony |
| fNIRS | 2 | WTC | Creativity task of designing | The findings indicated that cooperation was linked to the production of a more efficient product, and the overall creativity of the team correlated with the creativity of their final product [79]. | Synchrony |
| EEG | 6 | Cross-correlation | SPAN task | The peak cross-correlations indicate that alterations in the training segment of communication precede changes in neural patterns in more experienced teams [74]. | Linkage |
| EEG | 3-5 / 6 | Recurrence analysis (determinism) | Medical task / SPAN task | The results indicate that more experienced teams demonstrated timely and effective responses, whereas less experienced teams tended to exhibit ineffective responses [73]. | Communication reorganisation |
| EEG | 2 | Cross-correlations | Non-combatant evacuation operation (NEO) / Minecraft | The study discovered that the nature of the task influenced how teams organised their communication but had unpredictable effects on the team's neural synchronisation when averaged throughout the task session [80]. | Synchrony |
| EEG | 6 | Multifractal analysis | SPAN task | The findings indicate that neural data streams have the potential to identify both novel and routine events, revealing nested patterns of team activity [29]. | Synchrony |
| EEG | 2 | PDC with graph-theory approach | Joint action task | The results demonstrated that all the investigated indexes were capable of modulating their values based on the level of interaction between subjects [81]. | Connectivity |
| fNIRS | 2 | WTC | Key-pressing computer game task | Behavioral synchronisation enhanced self–other overlaps, which resulted in the higher brain-to-brain synchronisation [75]. | Synchrony |
| fNIRS | 2 | Correlation analyses | Modified attention task | The correlations between response times (RTs) and inter-brain connectivity suggest that efficient performance may be guaranteed by the connections between the two players [82]. | Connectivity |
| fNIRS | 2 | Correlation analysis | Attentional task | The fNIRS measures revealed a reduction in inter-brain synchrony among the pairs in the post-feedback condition. Additionally, a right-lateralised effect was observed, indicating the representation of negative emotions in response to unsuccessful interactions [51]. | Synchrony |

**TABLE 5.** Decision-making studies assessing team performance.

| Modality | Team Size | Analysis Method | Task | Finding | Term |
|---|---|---|---|---|---|
| EEG | 2 | Coherence(PLI and IPC) | Visual search task | When teams collaboratively focused on a visual search task, PLI and IPC values were higher compared to when team members addressed the same task on their own [83]. | Synchrony |
| fNIRS | 2 | Pearson correlation | Prisoner's dilemma game | The research indicated a higher inter-brain synchrony in the right DLPFC while engaging in group decision-making [84]. | Synchrony |
| fMRI | 2 | Linear regression analyses | Trust game | Linear regressions analyses identified significant predictors of change in trust for trustees and investors [86]. | Connectivity |
| fMRI | 2 | GLM analysis | Trust game | The average brain-to-brain correlations within groups notably deviated from the mean values of the population distribution. This shift suggested that pairs were synchronising based on their blood oxygenation level-dependent (BOLD) amplitude decision patterns when taking initial actions in consecutive rounds of trust games [87]. | Synchrony |
| fMRI | 2 | GLM analysis | Ultimatum game | Results showed that brain signals are strongly correlated with interacting players who reciprocate one another [89]. | Neural alignment |
| fMRI | 2 | GLM analysis | Ultimatum game | The results indicated that mediation is associated with increased activity in the brain's reward circuitry region [88]. | Coupling |

### A. NEUROPHYSIOLOGICAL PATTERNS OF TEAMS

Neurophysiologic patterns have emerged as a valuable tool for understanding team collaboration during complex tasks, thanks to the pioneering work of Stevens and his colleagues [22], [27]. Their research has focused on developing a neurodynamic model that captures the intricate interplay of neural activity within team members. By aggregating the second-by-second vectors from each team member, they constructed a comprehensive representation of the team's neurophysiologic dynamics. To analyse and interpret these complex patterns, an artificial neural network (ANN) was employed. The ANN classified the vectors and generated a symbolic state space comprising a number of symbols (see Figure 2). Each symbol represents a unique combination of EEG engagement across team members, providing a concise representation of the team's cognitive states [28]. This approach enabled researchers to identify distinct neurophysiologic synchrony (NS) patterns associated with individual team members, shedding light on the intricate neural mechanisms underlying team collaboration [64], [72], [76], [78]. To quantify and analyse these patterns further, Shannon's entropy was employed. By using sliding windows of an appropriate length, researchers were able to assess the team's cognitive states and measure the complexity and information content of the neurophysiologic measures. This allowed for a deeper understanding of the dynamic cognitive processes that unfold within teams during complex tasks [70], [71]. The use of neurophysiologic measures in team research has proven instrumental in unraveling the intricacies of team collaboration. By capturing and quantifying the neural dynamics at both the individual and team levels, researchers can gain valuable insights into the cognitive processes that drive team performance and effectiveness. These measures not only provide objective indicators of team dynamics but also contribute to the development of neuroergonomics, which aims to optimise human-machine systems by integrating neurophysiological data into system design and evaluation [78]. The exploration of neurophysiologic patterns in team contexts opens up new avenues for understanding and enhancing team performance in various domains.

### B. COUPLING ANALYSIS

In the field of neuroscience, coupling metrics have been utilised to investigate the inter-connection between two or more brains. These metrics serve as valuable tools for quantifying and understanding the extent of coordination and synchronisation among neural activities across individuals.

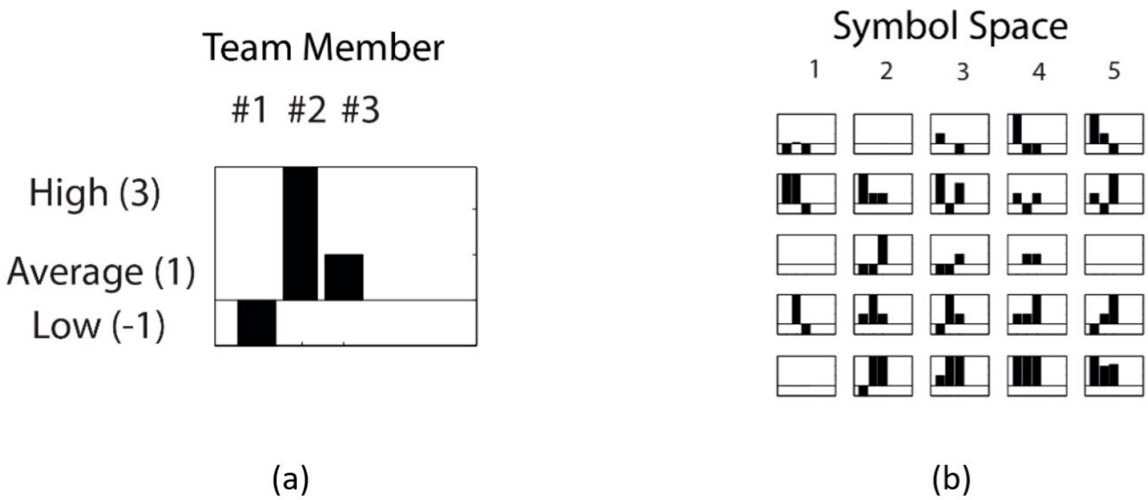



**FIGURE 2.** Neurodynamic symbols and symbol space. (a) Sample neurodynamic symbol (NS) showing the power levels of 3-team members, and (b) The 21-symbol state space that was used for creating the neurodynamic symbol data streams [76].

A range of measures has been employed to explore inter-brain connectivity, revealing intriguing insights into the dynamics of brain-to-brain interactions.

### 1) WAVELET COHERENCE

Wavelet coherence is a powerful method that has gained popularity in the field of neurophysiology for studying the connectivity and synchronisation between neural signals from different brains. Originally developed for analysing geophysical time-series data, wavelet transform coherence (WTC) has been successfully adapted for use in neuroscience research. In recent years, several studies have utilised WTC to investigate the inter-brain coherence and connectivity during various experimental paradigms. For instance, Czeszumski et al. [17] and Cui et al. [49] have employed WTC in their investigations. These studies highlight the versatility and applicability of WTC across different research contexts. One notable application of WTC is its usage in team-level analyses. Xu et al. [15] employed WTC to examine neural synchrony among pairs of participants in an experimental scenario. By analysing the levels of HbR and HbO, they were able to assess the degree of coherence between the brain activities of team members. Moreover, WTC has also been employed in studying dyadic interactions during various tasks. Studies have used WTC to investigate brain activity in dyads engaged in computer-based cooperation games, Jenga games, and creativity tasks involving designing [49], [52], [79]. The utilisation of WTC in neurophysiological research has significantly advanced our understanding of how multiple brains interact and synchronise during different activities. By quantifying the coherence between neural signals, WTC provides a valuable tool for exploring the dynamics of inter-brain communication and coordination. Its application in team-level analyses and dyadic interactions has yielded valuable insights into the complex nature of social and cognitive processes.

### 2) PHASE SYNCHRONISATION ANALYSIS

The analysis of inter-brain coupling and synchronisation has been facilitated by the implementation of measures such as Inter-brain phase coherence (IPC), phase synchronisation Index (PSI), and phase locking value (PLV). The IPC and PSI measures are derived from time-frequency matrices, capturing the phase differences and stability across time within a time-series [90]. The IPC specifically quantifies the phase difference at different frequencies, while PSI reflects the phase invariance or stability over time. Szymanski et al. utilised these phase measures to investigate joint attention during a visual search task, shedding light on the neural dynamics underlying cooperative attention [83]. The PLV, on the other hand, assesses the degree of phase synchronisation between two signals within a time window. A PLV value of 0 indicates complete unsynchronisation, while a value of 1 signifies perfect phase locking and synchronisation at a specific frequency [91]. Researchers have employed PLV to study brain synchrony during cooperative decision-making tasks [91], as well as during live interactions involving hand movements [69]. Inter-brain connectivity patterns, as revealed by PLV analysis, are shown in Figure 3. (a). These patterns demonstrate inter-subject neural synchronisations during interactive synchrony. The figure illustrates statistically significant coupling using PLV among all subjects, with electrodes of the model and the imitator. This comparison is made between spontaneous imitation trials involving behavioral synchrony episodes and those without such synchrony. On the left side of the figure, participants act as models, while on the right, they serve as imitators. The Alpha-Mu band cluster is discerned in the right centro-parietal areas, the Beta band cluster is positioned between the central and right parieto-occipital areas, while the Gamma band cluster is identified between the centro-parietal and parieto-occipital regions [69].

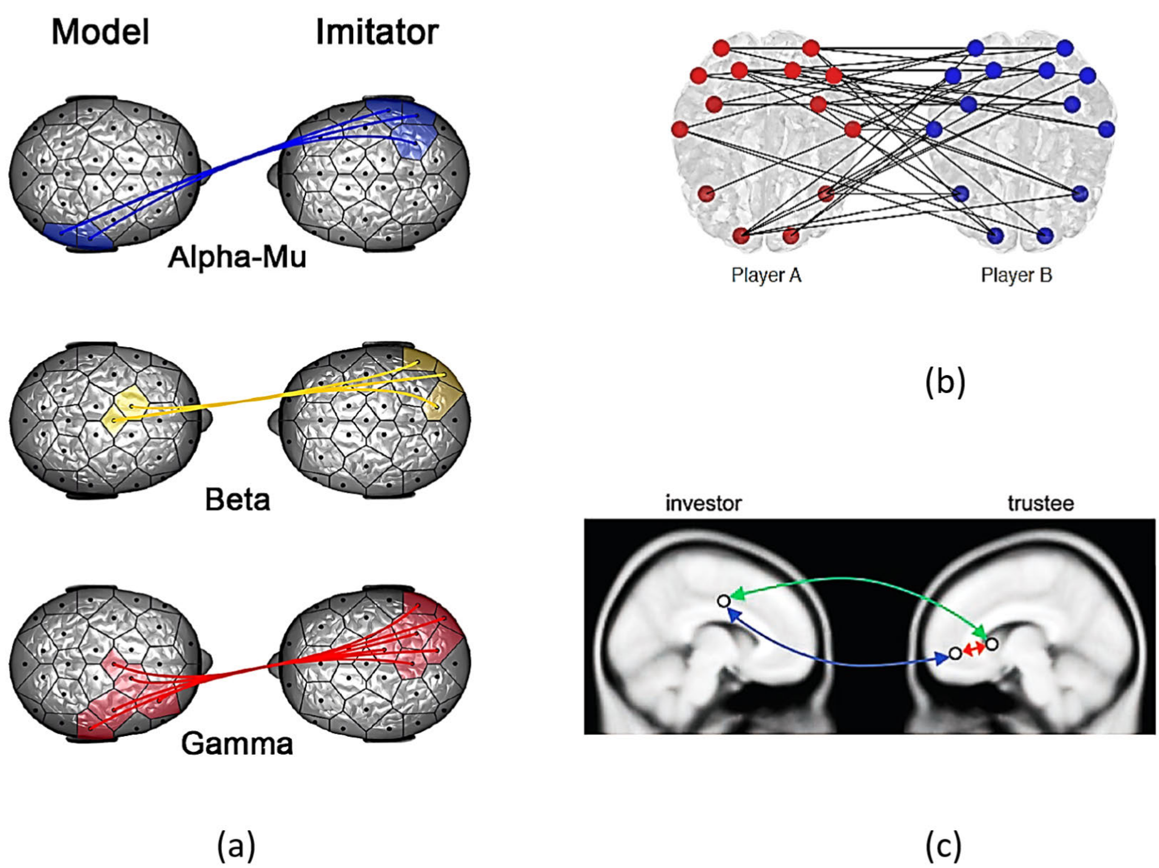



**FIGURE 3.** Inter-brain connectivity patterns revealed using different coupling measures: (a) PLV where clusters in the Alpha-Mu band are observed between the right centro-parietal regions and the Beta band cluster is prominent between the central and right parieto-occipital regions, while the Gamma band cluster spans between the centroparietal and parieto-occipital regions [69], (b) Correlation analysis, the EEG electrodes of player A and player B are shown on the brain schematics by red and blue dots, respectively [46], and (c) Regression analyses between different hemodynamic signals [86].

### C. REGRESSION AND CORRELATIONS

The examination of cross-level team effects has provided valuable insights into the relationship between neurophysiology and communication data. Cross-correlations (CC) have been widely employed to investigate the associations between neurophysiological measures, such as neurodynamics entropy, and communication variables, including content and flow [74], [80]. These studies have revealed how changes in neurophysiological patterns align with variations in team communication dynamics. Additionally, CC has been utilised to measure the correlation between physiological signals among team members, highlighting the inter-brain synchrony within a team [51], [74]. Sinha and colleagues used the Pearson CC to analyse inter-brain synchrony (IBS), probing its alterations across varied experimental scenarios [46]. As depicted in Figure 3. (b), the inter-brain synchrony, as captured through EEG hyperscanning, showcases brain diagrams with EEG electrodes for player A and player B marked in red and blue dots, respectively. The links between the electrodes of both players represent the functional synchrony of the underlying cortical areas beneath the electrodes. Furthermore, Pearson CC has been employed to analyse the inter-brain correlation coefficient in dyadic settings, shedding light on the interpersonal neural synchrony within pairs of individuals [52], [53], [54], [56], [84]. In the analysis of time series data, measures such as autocorrelation and synchronisation coefficient have been derived from correlation analyses. Autocorrelation captures the temporal dependencies within a single time series, while SE assesses the degree of synchronisation between multiple time series [58], [92]. These measures offer valuable insights into the patterns and dynamics of neural activity and synchronisation over time. Regression-based models have also been employed to assess linear and nonlinear synchronisations within groups. Guastello and Gregson demonstrated the use of multiple linear regression to quantify overall synchronisations among group members [93]. This approach allows for the examination of how individual neurophysiological patterns contribute to the collective synchronisation within a team. Regression analysis has also been utilised to measure synchronisations between two members, providing insights into the interplay and coordination of neural activity within collaborative settings [86]. As depicted in Figure 3. (c), areas showcasing a correlation are highlighted, particularly concerning the "intention to trust" signal in the trustee's caudate. This signal exhibited correlations both intra-brain and inter-brain with regions primarily activated during essential behavioral events within each game round. Specifically, the investor's middle cingulate cortex (MCC) demonstrated significant activation during the investor's decision-making process. In contrast, the anterior cingulate cortex (ACC) of the trustee became notably active when the investor's decision was disclosed [86].

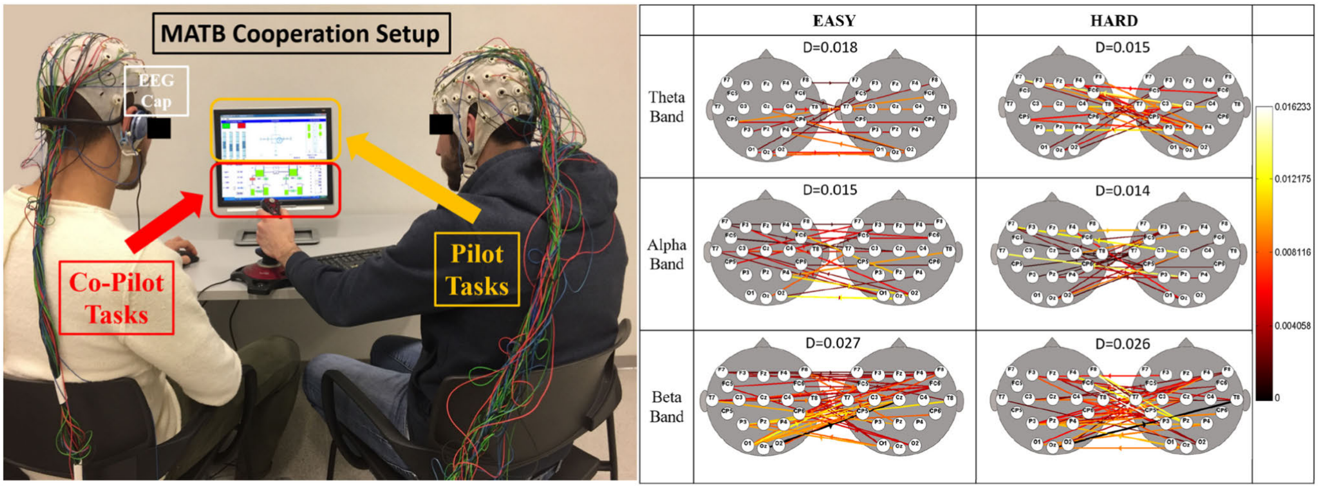
### D. PARTIAL DIRECTED COHERENCE

Partial Directed Coherence (PDC) was introduced by Baccala et al. as a frequency-domain approach that characterises the relationships between multivariate time series data based on Granger causality and autoregressive modeling [94]. This method has been widely utilised in the study of connectivity among multiple brains. Sciaraffa and his research team conducted a study employing PDC analysis to investigate the connectivity between multiple brains during a NASA MATB task (refer to Figure 4. (a)) under different experimental conditions [47]. They selected five pairs of participants and recorded EEG signals from 20 electrodes placed on each pair at various locations (C3, Cz, C4, CP5, CP6, F3, F4, F7, Fz, F8, FC5, FC6, O1, O2, Oz, T7, T8, P3, Pz, P4). The generalised PDC values were computed in three frequency bands (theta, alpha, and beta) to examine the connectivity patterns between the pairs of participants refer to Figure 4. (b) that show connectivity maps comparing both conditions during the three frequency bands. Furthermore, PDC has been used to derive various measures that provide insights into the connectivity linkages between brain signals. Density and global efficiency are among the measures that quantify the overall connectivity strength and efficiency between pairs of signals [31]. The application of PDC analysis enables researchers to investigate the directed interactions and connectivity patterns between multiple brains.

## V. NEUROIMAGING MULTIMODAL FUSION APPROACH

Traditionally, researchers have focused on utilising a single model to investigate interpersonal physiology. However, due to the complexity of team dynamics, relying solely on one measure may limit the comprehensive understanding of the various perspectives involved. Recognising this limitation, recent studies have highlighted the importance of incorporating multimodal measurements to capture a more holistic view of team neurophysiological/physiological dynamics [1]. There are several advantages to evaluating multimodal measurements in team studies. Firstly, it allows researchers to assess the relative sensitivity and specificity of different models in capturing the intricacies of team interactions. By considering multiple measures simultaneously, researchers can gain insights into the unique contributions and limitations of each modality, thus improving the overall predictive power of their analyses. Additionally, employing a multimodal approach aligns with the robustness principle in understanding human responses and actions, as these processes inherently involve multi-interactions between psychological and physiological factors. The advancement of technology, such as EEG and fNIRS, has enabled the non-intrusive collection of multimodal measurements in team settings [95]. These modalities allow researchers to simultaneously capture multiple aspects of team members' physiological responses and brain activity. However, despite these technological advancements, explaining the variability observed across time within team members remains a significant challenge for neuroscience researchers. The dynamic nature of team interactions and the multitude of factors influencing individual and collective physiological responses require innovative approaches and sophisticated analyses to unravel the complexities involved [1]. The collection of multimodal data has become more accessible through technological advancements, and further advancements in data analysis techniques are needed to fully unravel the intricate dynamics of team physiology over time. This interdisciplinary approach holds great potential for uncovering the mechanisms underlying effective teamwork and has implications for various domains such as organisational psychology, sports science, and human-computer interaction.

The integration of multimodal neuroimaging techniques, such as EEG, fNIRS, and fMRI, offers significant advantages in understanding brain dynamics during team interactions [16]. While the fusion of multiple neuroimaging modalities has received less attention in research, a few studies have explored the combination of EEG and fNIRS, demonstrating promising results. For instance, Lin et al. [96] investigated the fusion of EEG and fNIRS modalities in the context of deception detection. Their model exhibited superior sensitivity in distinguishing between guilty and innocent groups, achieving a classification accuracy of 94%. By integrating EEG and fNIRS data, the study was able to capture complementary neural information and provide a more comprehensive understanding of inter-brain impacts during team interactions. Although EEG is a cost-effective and user-friendly neuroimaging modality that allows for the measurement of brain activation, its spatial resolution is limited. On the other hand, fMRI offers high spatial resolution but lacks the temporal resolution of EEG. To overcome these limitations, the combination of EEG and fMRI through simultaneous hyperscanning has been utilised. Hyperscanning EEG-fMRI allows for the acquisition of data with both high temporal resolution (from EEG) and high spatial resolution (from fMRI), enabling researchers to investigate human brain function in a more detailed and comprehensive manner [97]. The use of multimodal neuroimaging techniques holds great promise in elucidating the complex neural dynamics underlying team interactions. By integrating EEG, fNIRS, and fMRI, researchers can capitalise on the strengths of each




(a) (b)

**FIGURE 4.** An example study of MATB task and connectivity maps. (a) Participants share MATB tasks, The Pilot (right) tracks and manages emergency lights, while the Co-Pilot (left) handles fuel management and auditory monitoring. (b) Connectivity Maps comparing Easy (left) and Hard (right) conditions with the baseline in Theta, Alpha, and Beta. Patterns are displayed on a 2-D scalp model. Only significant connections are shown (paired t-test, $p < 0.05$). Arrow color and size indicate averaged strength within the experimental group. "D" represents inter-brain density [47].

modality, obtaining both fine-grained temporal information and detailed spatial mapping of brain activity.

## VI. NEUROIMAGING AND BEHAVIOURAL-BASED APPROACH

The neuroimaging and behavioural-based approach is an interdisciplinary framework that integrates insights from neuroscience and psychology to explore the intricate relationship between the brain and behaviour. By recognising the importance of studying both domains in conjunction, this approach offers a comprehensive understanding of how the mind functions. In the context of team dynamics, this approach has been employed to investigate real-time tasks involving pairs of individuals, allowing for dynamic analysis of their performance [98]. Researchers, such as Tognoli and colleagues, have developed neurobehavioural models that combine neural and behavioural measures. These models aim to uncover the relationship between naturally occurring behavioural factors and neural events, shedding light on the ideal temporal distribution of brain activity for optimal task performance. By examining both neural and behavioural performance simultaneously, researchers gain a valuable means of investigating the intricate neural mechanisms that underpin human behaviour [99]. Brain imaging techniques, including EEG, fMRI, and fNIRS, play a pivotal role in the brain and behavioural-based approach. These neuroimaging modalities enable researchers to monitor brain activity during specific behaviours, providing insights into the specific neural networks that support these behaviours. By examining brain function alongside behaviour, researchers can gain a comprehensive understanding of how the mind operates [99]. One of the advantages of this approach is its recognition of the complexity of the brain. It acknowledges that various factors, such as the environment and individual experiences, can influence behaviour. By considering both brain function and behaviour, researchers can explore the intricate interplay between neural processes and observable actions. Table 6 summarises the multimodal studies that assess team performance.

## VII. DISCUSSION AND FUTURE RECOMMENDATIONS

### A. SPATIAL-FREQUENCY ANALYSIS IN TEAM DYNAMICS

Various hyperscanning studies have delved into spatial-frequency relationships, discovering associations between specific brain areas and frequency bands. For instance, Lindenberger et al. [24] demonstrated that when coordinating actions for music creation, there are inter-brain connections within the theta frequency band, notably pinpointed to the prefrontal cortex regions. Similarly, Dumas et al. [69] found that states of synchronised interaction correlate with the development of an inter-brain synchronisation network in the alpha-mu (7-12 Hz) frequency band, primarily in the right centroparietal scalp areas. During face-to-face communication, neural synchronisation occurs where brain activities of interacting individuals align, reflecting mutual engagement and a shared understanding. Key brain regions involved include inferior frontal cortex (IFC) [106]. Such synchronisation, observable via tools like fNIRS or EEG, may be stronger during effective, smooth communication and weaker during misunderstandings or conflicts. The result from [106] indicated that the left IFC might be involved in such an action-perception system. Authors in [107] also

**TABLE 6. Multimodal studies assessing team performance.**

| Measures | Aspects | Team Size | Analysis Method | Task | Finding | Term |
|---|---|---|---|---|---|---|
| EEG / EOG | Workload | 2 | Cross-fuzzy entropy (CFEn) | Cooperative task | Significant coupling was observed for both Theta and cross-fuzzy entropy (CFEn) and Fz coupling that indexed by CFEn was sensitive to task load transitions and showed a minimal response lag [100]. | Coupling |
| EEG / Galvanic skin response (GSR) | Cognition | 4 | Correlations, multiple linear regression | Vigilance dual task | Distributions of synchronisation coefficient are not affected by team size up to 16 members [92]. | Synchrony |
| EEG / Eye gaze/ HRV | Engagement | 3 | Event-related potentials(ERPs) | Viewed pictures | Positive emotions can be induced relatively and can be measured using a combination of central and autonomic measures [101]. | NA |
| EEG / HR / SCR | Cooperation | 2 | Analysis of Variance (ANOVA) | Attentional task | The results showed a significantly increased activity in the right DLPFC area of the brain during a negatively reinforced joint action [43]. | Synchrony |
| fMRI / Eye gaze | Engagement | 2 | Correlation analysis | Joint attention tasks | Paired subjects showed more prominent correlations than non-paired subjects in the right inferior frontal region [102]. | Synchrony |
| EEG / facial electromyography (fEMG) | Cooperation | 2 | Coherence / Correlation | Turn-based game | The findings showed higher linkage within dyads when they focus on each others' actions [103]. | Linkage |
| EEG / ECG | Engagement /Workload | 2 | Correlation | Vigilance Task | The results showed a significant correlation increased with experience in psychophysiological metrics [104]. | Synchrony |
| EEG / ECG / GSR / Respiration | Cognition | 2 | Machine learning classifiers | Flight simulation task | The results showed better accuracy performance using multimodal data [105]. | NA |

explored spatial-frequency decomposition and looked at the effect of the brain areas and different frequency bands. The study discovered distinct patterns of functional connectivity in cortical areas related to the decision-making process of cooperation or defection [107]. These patterns result in different hyper-brain networks based on game outcomes. Notably, when both participants chose defection (DD), there was a significant reduction in connectivity between the regions of interest in their brains across all analysed frequency bands. Conversely, tit-for-tat (TT) and mutual cooperation (CC) trials exhibited more tightly connected and intermingled hyper-brain networks. The primary regions driving this observed decrease in inter-connectivity, especially evident in the Beta and Gamma frequency bands (13-40 Hz), were located mainly in the prefrontal cortex, including Brodmann areas 10 and anterior cingulate cortex (ACC). These areas displayed task-specific decision representations even before decisions were visually presented [107]. The findings align with other studies which link beta oscillations to brain-to-brain synchrony that is influenced by interpersonal factors, such as affective personality traits, especially during face-to-face interactions in real-world scenarios [108].

Aforementioned studies are all related to social interactions. Only a very limited number of researchers studying team dynamics have explored neural synchronisation in time-frequency domain. For instance, an EEG study by [45] utilised six scalp mounted electrodes to evaluate inter-brain synchrony, focusing only on identical electrode pairs. Whole brain synchrony was calculated in their study measuring the average pairwise coherence across the team. They abstained from interpreting results based on electrode locations. To the best of the authors' knowledge, no research has yet explored spatial-frequency analysis in this context. Hyperscanning studies incorporating both spatial and frequency features of synchronising neural signals can introduce new dimensions to the assessment of team performance and underscores the potential of temporal-spatial-frequency analysis in understanding team dynamics and states. For example, EEG suffers from long subject preparation times for multiple team members, which can limit the use of such technology in hyperscanning studies. However, via research focusing on spatial-frequency domain, there's a potential to utilise only a selected number of electrodes for EEG acquisition, correlated to the team state under investigation.

### B. INTERPERSONAL NEURAL SYNCHRONY BENEFITS

Interpersonal neural synchrony (INS) is a fascinating phenomenon that occurs when the neural activity of two or more individuals becomes synchronised during a shared task or social interaction. It reflects the coordination and alignment of neural processes between individuals, highlighting the interconnected nature of our brains [109]. Studies have demonstrated that INS plays a crucial role in team performance, yielding several benefits for collaborative endeavors. One significant advantage is improved coordination among team members. When neural activity synchronises, individuals can effectively align their actions, timing, and responses, leading to smoother and more efficient coordination within the team [110]. This enhanced coordination can be observed in various team activities, such as music performances, sports, or even complex problem-solving tasks [110]. Furthermore, INS contributes to enhanced communication between team members. Synchronised neural activity allows for the exchange of information at a subconscious level, facilitating the sharing of intentions, emotions, and even nonverbal cues. This unspoken communication can enhance mutual understanding, empathy, and rapport among team members, fostering a sense of cohesion and collaboration [110]. Another advantage of INS is its potential impact on trust within teams. Synchronised neural activity is believed to be associated with a sense of shared understanding and common ground. When individuals' brains exhibit similar patterns of neural activity, it can create a sense of familiarity, trust, and social bonding. This shared neural synchronisation may promote cooperative behaviours and strengthen interpersonal relationships within the team [110]. The mechanisms underlying INS are linked to the process of predictive coding, which is fundamental to how our brains make sense of the world. Predictive coding suggests that our brains are constantly generating predictions about sensory inputs and updating these predictions based on incoming sensory information. During shared tasks, individuals' brains utilise predictive coding to anticipate and interpret their partner's behaviour. Through INS, individuals can integrate sensory inputs from their partners, enhancing the accuracy and efficiency of their predictive models. This integration of information leads to more accurate perceptions of the external world and better decision-making processes within the team [111].

### C. LARGER TEAMS AND COMPREHENSIVE TEAM-LEVEL ANALYSIS

The study of dyads has crucially augmented our understanding of human dynamics. However, despite the invaluable insights obtained from dyadic studies, the escalating need for enhanced collaboration and cooperation in today's world highlights the urgent need to shift the focus towards the study of larger teams, consisting of three or more members [112]. The exploration of team dynamics ushers in a unique set of challenges, largely attributed to the multifaceted and intricate interactions among team members, which are inherently more complex than dyadic interactions [112], [113]. While dyadic interactions lay the groundwork for comprehending specific facets of team dynamics, they fall short in encapsulating the extensive complexities inherent in larger teams. Certain team phenomena may either not emerge or function differently within dyadic setups compared to larger team configurations [114]. This shift underscores the critical necessity to discern the differences between dyads and teams to develop models adept at analysing larger team data effectively and overcoming the constraints of dyadic research [115]. One such constraint is the potential decrease in interpersonal synchrony as team size augments, leading to more intricate coordination of physiological and behavioral responses, which can adversely impact team performance [116]. Diving deeper into team dynamics necessitates a dual focus on individual and collective behavioral aspects within a team setting. It involves unraveling the complex social processes such as leadership dynamics, role allocation, and group cohesion, which profoundly influence team performance and outcomes [117]. Various methodologies, including brain neuroimaging and experimental designs, are utilised to compile extensive data on team behavior, communication patterns, decision-making processes, and performance outcomes [112]. Team-level analysis proves to be a more robust and comprehensive tool, enabling the detailed exploration of behavioral coordination, communication, and information sharing within the team [118]. This enhanced approach aids in identifying shared patterns, establishing communication networks, and understanding individual roles in achieving collective goals. It allows for the examination of complex phenomena resulting from the interaction of multiple team members, ensuring a more expansive and detailed view of team dynamics and their impact on team performance and cooperation [119]. Surpassing the boundaries of dyadic analysis, this holistic approach highlights the crucial role of team-level analysis in discovering vital insights essential for improving team performance, coordination, and ensuring efficient teamwork dynamics. Future research can focus on developing analysis methods to study team dynamics at the team-level, moving beyond the commonly used cross-dyadic approach discussed in section 3. Employing methods such as recurrence analysis can offer a wider perspective on team dynamics, providing essential information about the interdependencies, interactions, and coordination among team members [119].

### D. EMOTIONS IN TEAM STUDIES

In recent years, there has been an increasing recognition of the significance of emotions in the context of teams. Emotions can have a profound impact on team dynamics, influencing various aspects of team processes and outcomes. The study of emotions in teams has provided valuable insights into how emotions shape team functioning and performance [120], [121]. One key finding in this area of research is the concept of emotional contagion within teams. Emotional contagion refers to the phenomenon in which emotions are transmitted between individuals, leading to shared emotional experiences within the team. When team members are exposed to the emotions of their colleagues, they can "catch" those emotions and experience similar affective states. This affective convergence can significantly influence team processes, such as communication, decision-making, and conflict resolution [122]. For instance, positive emotions can enhance cooperation and collaboration among team members, while negative emotions may hinder effective teamwork and lead to interpersonal conflicts [120]. Additionally, research has explored the role of emotional intelligence in team performance. Emotional intelligence encompasses the ability to perceive, understand, and regulate one's own emotions and the emotions of others. Studies have found a positive relationship between emotional intelligence and team performance. Teams composed of members with higher levels of emotional intelligence demonstrate better interpersonal skills, conflict management, and the ability to maintain a positive team climate [123]. Emotional intelligence plays a vital role in fostering effective communication, empathy, and emotional regulation within teams, contributing to their overall success. Understanding the impact of emotions on team functioning and performance is crucial for promoting effective teamwork and collaboration. By acknowledging the role of emotions and their contagious nature within teams, organisations can develop strategies to manage emotions and create a positive emotional climate that supports team productivity and well-being. Future research in this field can delve deeper into exploring the specific mechanisms through which emotions influence team processes and outcomes. Moreover, investigating how emotional intelligence can be developed and nurtured within teams can provide practical insights for training and interventions aimed at enhancing team functioning and performance.

### E. COORDINATION DYNAMICS IN TEAMS

Coordination dynamics within teams encompass the intricate patterns of communication and interaction that enable team members to collaborate harmoniously towards a shared objective. It involves not only the synchronisation of physical movements but also the coordination of cognitive and emotional states among team members [98]. Research has underscored the significance of successful coordination in teams, emphasising the need for adaptability to environmental changes and task requirements, as well as the behaviours exhibited by other team members [124]. Effective coordination necessitates clear communication channels and the development of shared mental models, enabling team members to anticipate each other's actions and respond appropriately [73]. Within various domains, team coordination stands as a critical component of achieving optimal team performance. Recent studies have employed neurophysiological measures to evaluate the coordination dynamics among team members. By assessing synchronised physiological responses, such as brain activity, researchers have gained insights into the underlying mechanisms that facilitate successful team coordination [98]. For instance, investigations have explored the degree to which team members exhibit interpersonal synchrony in physiological responses while engaging in joint tasks [125]. These findings have shed light on the significance of interpersonal synchrony and effective communication in fostering cohesive teamwork. Understanding coordination dynamics in teams holds paramount importance in the development of effective teamwork training programs and the enhancement of team performance across diverse settings, including sports teams, military units, and business organisations. Gaining deeper insights into the factors that facilitate coordination, such as interpersonal synchrony and shared mental models, interventions can be designed to improve team coordination and overall effectiveness. Moreover, advancements in technology and data analysis techniques have opened up new avenues for studying coordination dynamics. For instance, wearable devices and sensor networks can capture real-time data on team members' physiological states and movement patterns, enabling a more comprehensive assessment of coordination dynamics. Additionally, computational models and simulations can help identify optimal coordination strategies and provide training scenarios to enhance team coordination skills. Further research in this field can explore the influence of contextual factors, such as team size, task complexity, and individual differences, on coordination dynamics.

### F. HUMAN-AI TEAMING

Human-AI teaming is an emerging and critical field that focuses on the collaboration and coordination between humans and artificial intelligence (AI) systems to achieve a common goal. As AI systems become increasingly prevalent across diverse industries, it has become imperative to explore how these systems can effectively integrate and work alongside humans in complex tasks [126]. Recent research has explored the application of neuroimaging techniques, such as fMRI and EEG, to gain deeper insights into the underlying brain activity associated with human-AI teaming [127]. These neuroimaging techniques aid in uncovering how humans process and assimilate information provided by AI systems, as well as how the collaboration between humans and AI impacts brain activity and cognitive function. The study of trust using neural measures is a relatively new and exploratory field, particularly in the context of Trust in Automation (TiA) [128]. Neuroimaging methods, including EEG, have been employed to capture neural activity related to trust. While these methods differ in their technical approaches, their common objective is to identify and measure brain activity that is relevant to TiA. These neural measures provide valuable insights into specific brain regions and networks that are associated with trust, serving as proxies for studying TiA. For instance, EEG signals have been utilised to detect instances of surprise and deviations from expectations while monitoring imperfect automation or algorithms [129]. Furthermore, EEG can distinguish between human-like agents, contributing to our understanding of human-AI interaction. On the other hand, fMRI has demonstrated its ability to differentiate brain regions and networks involved in observing errors with machines, compliance with automation, and distinctions between trust in human-human and human-machine interactions. Additionally, fNIRS has been applied to characterise suspicion and trust for review see [128]. Although the use of neural measures to study TiA is not yet widespread, mainly due to its exploratory nature and the requirement for specialised hardware and training, these methods enable the real-time collection of high-quality data that captures trust attitudes and cognitive states associated with trusting behaviours [128]. Experiments utilising these neuroimaging techniques have been successfully conducted in interactive tasks commonly found in human factors research, minimising disruptions to ongoing tasks. As these measurement techniques are further refined, validated, and made more accessible to non-neuroscientists, we can anticipate their increasing utilisation and prevalence in the study of trust within the context of human-AI teaming. This advancement holds the potential to enhance our understanding of the dynamics between humans and AI systems, leading to improved collaboration and performance in various domains.

### G. IMPROVING TASK PERFORMANCE

Understanding the neural dynamics that underlie effective collaboration can have significant implications for optimising teamwork and enhancing overall team performance. In this light, researchers in the field of group neuroscience and team dynamics have made strides to explore the relationship between inter-brain synchrony and collective performance, as demonstrated in the study by Reinero et al. [45]. In this study, they merged these fields to investigate how the synchrony of brain activity among team members relates to the team's performance. The authors employed an EEG-hyperscanning setup to measure the brain activity of individuals within teams while engaging in problem-solving tasks. The findings of the study unveiled a compelling association between higher levels of inter-brain synchrony and improved collective performance among teams. This suggests that the coordination and synchronisation of brain activity among team members play a crucial role in determining the team's overall task performance. The results underscore the potential of neuroscience measures, specifically inter-brain synchrony, as a means to assess and predict team performance. These findings contribute to the growing body of knowledge that links neural processes to team dynamics and performance. This research opens up new avenues for investigating the neural basis of teamwork and offers promising possibilities for developing interventions and training programs that enhance team performance. However, it is important to note that further research is needed to explore the underlying mechanisms and specific factors that influence inter-brain synchrony and its relationship to team performance. Factors such as team cohesion, communication patterns, and task characteristics may influence the level and patterns of neural synchrony within teams. Investigating these factors will provide a more comprehensive understanding of the intricate interplay between neural processes, team dynamics, and performance outcomes. Future studies in this domain will undoubtedly shed more light on the neural mechanisms underlying successful teamwork, enabling the development of targeted interventions and strategies to optimise team performance across various domains.

## VIII. CONCLUSION

In conclusion, neurophysiological measures have provided valuable insights into team performance dynamics. This review specifically focuses on the use of hyperscanning, a neurophysiological method enabling simultaneous measurement of brain activity in team settings. The reviewed studies highlight the growing trend of utilising hyperscanning techniques to investigate team dynamics, primarily employing EEG and fNIRS due to their cost-effectiveness, equipment quality, and real-time applicability. While research on physiological measurements in team settings has been explored to some extent, this review addresses a gap in the literature by specifically examining neurophysiological signals and brain-to-brain synchrony in teams. Although the use of neurophysiological measures for assessing team performance is still in its early stages, their potential benefits are evident. Real-time collection and analysis of neurophysiological data offer opportunities for optimising teamwork, developing targeted interventions, and enhancing team performance in various domains. However, further research is needed to deepen our understanding of the underlying mechanisms and factors that influence team dynamics. The validation and refinement of neurophysiological measures, along with increased accessibility for non-neuroscientists, are crucial for their broader adoption and application in studying team performance. As the field advances, exploring neurophysiological measures presents a promising avenue for advancing our understanding of the neuroscience behind team dynamics. This multidisciplinary approach has the potential to revolutionise teamwork training, collaboration, and overall team effectiveness, ultimately leading to improved performance outcomes across diverse domains.

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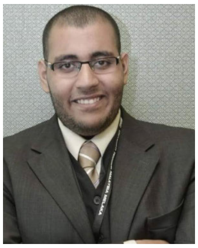

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