Brains in Sync: Team Coordination and Interpersonal Prefrontal Neural Synchrony During Cooperative e-Gaming

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ABSTRACT

The underlying factors which account for team performance remain a topic of intense study. In successful teaming, information must be communicated quickly and efficiently, while solutions must draw upon the collective knowledge of the team through a process known as team cognition. Enhancing teamwork not only offers a means of boosting productivity, safety and satisfaction, but becomes necessary when high-pressure/high risk situations demand rapid and strategic responses. Increasingly, cooperation in esport gaming has become a representative model of dynamic fast-paced teamwork processes and more generally team cognition. Especially in tightly competitive team esports, the ability of a team to rapidly coordinate and engage in strategic decision-making can be turned into tremendous advantage and allow the team to outmaneuver opponents, even when other skill levels may be otherwise equal. Despite decades of research on the mechanisms of teamwork, it is only recently that non-invasive neuroimaging provided accessible approaches for the study of multiple individuals engaging in realistic teaming scenarios. In this paper, we survey factors underlying successful team performance and ways in which esport games offer a flexible context for studying these factors. Next, we introduce the proposed neurophysiological mechanisms involved in interpersonal interaction and collaboration as well as proposed approaches to measure interpersonal neural synchrony and its relevance to team cognition. Finally, we introduce a hyper-scanning protocol from an ongoing team cognition study and discuss prospective application of team-based neuroimaging approaches in real-world settings.

Keywords: Neuroergonomic, Functional near infrared spectroscopy (fNIRS), Electrodermal Activity (EDA), Hyperscanning, Interpersonal Synchrony, Teamwork, Collaboration

1.0 INTRODUCTION

While an individual person may possess a large degree of role flexibility and can complete a diverse array of tasks on their own, working together with others enables the completion of significantly more complex projects and the achievement of otherwise unachievable results. Teamwork is necessitated not only under situations of higher complexity, but is also critical in situations where information must be processed quickly, in parallel and responsively [1]. Such situations are often encountered in high-stress professions such as emergency medical services, first-responders, and military engagements[2]–[4]. Because the cost of failure in rapid strategic responses is often extremely high, the mechanisms of team performance are often placed under a microscope in order to tease apart the essential ingredients of successful collaboration. From this line of study, several key elements of team performance have been described including the impact of cognitive styles, personality, experience, trust, and leadership roles [5]–[7]. However, the majority of this research has focused on behavioural and qualitative evaluation and relatively little is known about how the brain facilitates successful collaboration in fast-paced and dynamic environments.

In recent years, advancements in neuroimaging modalities have enabled scientists to simultaneously monitor neurophysiological activity in individuals while they are engaged in cognitive tasks, a process known as "hyperscanning" [8]. This approach has leapfrogged social neuroscience forward and enabled brain-based approaches to the study of team function and cognition[9]. In parallel, team-based "electronic sports" or esports has from a relative fringe hobby into a multimillion-dollar industry with large prize-pools, audience followings, and even purpose-built arenas[10]. Due to the competitive nature of esports and its heavy reliance on effective communication and collaboration, researchers are granted a window into the mechanisms underlying well-practiced teaming recreated in these virtual environments[11]. In addition, the increasing popularity of esports in the public creates a highly varied range of skillsets amongst the general population allowing researchers to study how teams operate across differing experience levels, team composition, work environment, and other factors. Lastly, the relevance of esports as a model for teamwork has perhaps never been more relevant with the continued movement towards remote work driven in part due to economic changes, but greatly accelerated by the COVID19 pandemic[12], [13]. In this work, we introduce the key concepts introduced through the current neurobiological theories behind team cognition, how e-sports functions as a prototypical model of team cognition, approaches for quantifying neural synchrony, and eventual applications of these technologies in future neuroergonomic contexts.

2.0 TEAM COGNITION AND PERFORMANCE

2.1 Shared mental models and team performance

A team can be considered to be as any social group of two or more individuals work together interdependently towards a common objective[14]. Whether a team functions to make decisions regarding long-term project goals, or must respond dynamically to a constantly changing environment, an effective team operates with a shared understanding between team members about the nature of the task, the present situation, and the goals/risks present[15]. The development of a "shared mental model" (SMM) is critical for team function and model consistency can be viewed as a prerequisite for successful team coordination[14], [16]. When team members operate with an optimized SMM, they are able to draw on shared knowledge and expertise to describe task-relevant information in a parsimonious manner, greatly enhancing both situational awareness and team adaptability. In addition, this shared cognitive model allows team members to readily anticipate others actions and the expected outcomes for these actions, facilitating an implicit communication which functions with the teams' needs in mind. Together, these shared mindsets allow for a seamless coordination which is often observed to as an embodiment an effective team[16].

While evidence has shown that accurate SMMs correlate positively with team performance and help drive successful teams[14], the process of developing a team with such characteristics may be challenging. Training team members to facilitate construction of an optimal models may require a significant investment of resources and can easily be rendered ineffective if training does not accurately reflect the task, or in situations where environmental conditions are unexpectedly changed [17]. Acquisition of experience in realistic or otherwise translatable settings is one requirement towards building effective models [18], [19]. In addition, the inclusion of dynamic or unexpected situations may encourage the development of more flexible mental models by discouraging rigidity and encouraging team members to constantly assess the reality of a situation and adapt actions towards the task goals[20], [21].

In addition to a fluid understanding of a particular task, SMMs must also take into account expectations regarding the actions of others, and specifically, their trust in the actions of others. Many of benefits that come from team cognition directly rely on the predictability of team members with respect to roles, actions, and intentions. Mutual trust amongst team members is necessary for successful collaboration to occur[15], [22]. Although the downsides to participating in untrustworthy or even openly hostile teams are self-evident[23], such situations also can apply even when simply working with new team members. This is readily seen in individual preferences to work together with friends over strangers, but also can describe a perceived relationship between stability of team members, group cohesion, and performance[24]. However, in many contexts, such as in healthcare systems or emergency situations, working together with a stable team is simply not practical and individuals may be freely substituted and are still expected to be able to rapidly coordinate as a team[25]. It is here, in the absence of familiarity that open communication, predictability, experience, and personality take a center stage to maintain effective team performance.

2.2 Roles of personality composition and leadership in successful teams

Similar to the way in which unexpected changes to an environment might perturb SMMs and substantially degrade performance, the addition of unfamiliar or unfavourable team members can have similar results. Studies investigating the impact personality dimensions on team performance have identified emotional stability and openness to experience as the most influential factors[26]. In particular, the positive combination of these two factors underlies the ability of a team to resolve task-related conflict productively in a manner which actually increases team performance when such conflicts are encountered[27]. This skillset is also necessary for adaptive SMMs to operate effectively as updating a cognitive model requires a process of reflective introspection which does not necessarily come easily or naturally to teams. In addition, such feedback requires an environment where individuals can feel psychologically safe enough to speak freely and propose ideas which otherwise may place them at greater interpersonal risk[23]. For this same reason, emotional instability and closed-mindedness amongst team members interact poorly to disrupt performance in the face of conflict[27].

Interpersonal communication and understanding are greatly aided by additional forms of communication beyond what might be literally stated such as body language and tone. These auxiliary affective channels help team members understand the internal states of other members in a rapid and intuitive manner which is not easily accomplished when communication only occurs over written text[28]. Affective communication is particularly helpful in establishing trust and report between team members, but this medium cannot be employed as effectively in virtual/remote teams[29]. The lack of face-to-face communication has become an increasingly common fixture in the modern work environment and this impairs the development of affective trust in the remote workplace[30], leaving individuals to place more weight on "cognitive" elements of trust including expectations about a members competence reliability and professionalism[29]. Because virtual teams also require inter-member trust in order to operate effectively, assembling virtual team members may require alternative strategies to aide in initial trust development including providing team members with additional information about other members which describe their personal interests and professional expertise[31].

Even in relatively small teams which possesses little formal hierarchy, the emergence and nature of leadership plays an important role in team cohesion and performance. The presence of strong team leadership has a positive impact on team performance whether that leadership originates from a single member or develops as a form of shared leadership. While in-person teams may rely more on institutional hierarchy, the influence of traditional hierarchical roles is often minimized in virtual contexts[32] and the development of a leadership structure may depend more readily on the personality of team members[33]. The presence of a single extraverted team member amongst more introverted members may more readily invite the emergence of a single-leader team model, whereas teams with a more homogenous personality composition may instead favor collective decision making in a shared leadership[26], [34]. Other desirable team-member qualities such as emotional stability and openness to experience also may similarly predict the emergence of a particular individual as the leader which differs from a shared decision-making structure. However, both models of leadership offer beneficial effects on performance and help mediate inter-individual conflict and foster the development of team trust[35]–[37]. The present transition towards the more regular inclusion of virtual teamwork as a facet of every-day work, places an increasing importance on understanding the differences between team collaboration in co-located teams and those who work remotely.

Although research into the nature of teamwork and team performance has spanned decades, the nature of teamwork represents an ever-evolving role in the modern world. In addition, the COVID-19 pandemic has accelerated trends towards remote/at-home work which requires increased importance of individuals engaging virtually where previously interactions were primarily in-person. Here, adoption of multiplayer video games offers a repeatable, flexible, and increasingly relevant model for virtual teamwork and cognition.

3.0 E-GAMING AS A MODEL OF COOPERATION

3.1 Multiplayer videogames and virtual teamwork

Fundamentally, any team must operate with a shared goal and aligned motivations of its members. Often times in the study of teamwork, apart from an observational study of real teams in practice, experimental assessment may often be contrived and artificial. Here videogames represent a controllable and dynamic team environment featuring naturalistic motivation to engage participants with the task [11]. The capability of multiplayer games to engage and promote teamwork is not only part of the natural draw towards gaming behaviors [38], but also is often explored as a team-building activity to enhance team cohesion with positive results which may translate to improved performance in future collaborative activities [39], [40].

Multiplayer video games offer substantial diversity as to the ways in which collaboration can occur. Gaming models of slower strategic decision making can occur in game with more turn-based encounters or in simulation environments, whereas faster paced team-based games such as first-person-shooters (FPS) such as (e.g. *Overwatch*) and multiplayer online battle arenas (MOBA) (e.g. *DOTA*, and *League of Legends*) may demand increased reactivity as a direct result of the dynamic nature of these games. In this respect, multiplayer games offer a highly engaging collaborative medium for the study of teamwork in virtual environments and to further the understanding of teamwork, team organization, cognition, and impact of other factors on team performance.

Multiplayer games also allow the ability to study diverse team structures and control for variables such as skill level, team composition, and communication structures. Most online games offer matchmaking services which attempt to pair similarly skilled individuals with one another. Although skill-matching alone might prevent lopsided game outcomes, it is often recognized as insufficient to ensure effective team performance[41]. While players are often willing to team up with strangers, interacting with strangers is significantly more socially demanding as individuals must navigate unknown cognitive and communication styles in order to work together effectively[42]. Perhaps unsurprisingly, people exhibit strong preferences towards playing with individuals with whom they have had prior social interactions[43] and it has been reported that team effectiveness is maximized when moderate connections exist between members[44].

The development of leadership structure operates similarly in multiplayer games as in virtual teams, where benefits are often especially seen under shared leadership[32]. Here, multiplayer game scenarios allow for not only laboratory models of teamwork to study emergent leadership structures[45], but also opportunities to train individuals to be effective leaders[46].

Regardless of the specific video game used, team members in video games often have incomplete information regarding the current situational status, the actions of their opponents, and even the actions/intentions of their teammates. Therefore communication between team members is not only critical for success[47], but also a considerable factor in qualitative perceptions of team effectiveness[11]. Although online videogames do not often allow individuals to interact in a face-to-face manner, audio communication through tools such as *Discord* or other in-game services allow individuals to communicate effectively in a hands-free fashion. Individuals in games may also make use of in-game text messaging and non-verbal game-specific cueing systems (eg: pinging a map location, or tagging an objective) in order to facilitate free communication and situational awareness amongst the team members. While in-game communication is certainly an important factor, efficient communication aided by well-developed SMMs can drastically enhance a team's coordination by reducing communication "overhead" and enable smooth implicit interactions and strategy[48]. In particularly effective teams, the role of implicit coordination can play a more important role than overt communication between team members[49].

3.2 Teamwork in competitive esports

In recent years, "electronic sports" or esports has developed from a relative fringe arcade hobby into a multimillion-dollar industry with large prize-pools, audience followings, and even purpose-built arenas [50]. E-athletes can be directly compared to professional athletes in other sports with respect to demands of the sport, requiring hours of dedicated practice a day, the employment of professional coaches, as well receiving financial compensation from a mixture of prize money and sponsorships[51]. Although it now possesses many of the traits associated with traditional sports, esports are still often overlooked as a sport and still fight for formal recognition in some contexts[52]. However, the rapid growth of the industry and wide-spread public interest, combined with the competitive, collaborative, and dynamic nature of esports offers researchers with a valuable platform to study effective teaming.

The professionalism demanded in esports encourages teams and team members to search for every potential advantage and attempt to optimize their team's performance. Both the practice and performance of e-sports can require strenuous demands on cognition, taxing both mental and physical endurance. These demands are easily reflected in peripheral physiological measures and can be observed after even single sessions of esport gameplay[53]. Cognitive skillsets which give esport teams advantages over their opponents may stem from observations that videogame players possess enhanced attention spans, are skilled at spatial reasoning, exhibit faster reaction times, and stronger decision-making skills[54]. There is however some debate as to whether competence in these cognitive domains produces better videogame players or whether videogames can act to enhance cognitive abilities through practice[55]. The fiercely competitive and demanding nature of esports requires teams to develop strategies to maintain mental endurance in the face of cognitively demanding gameplay, interventions which can include mental training in translatable skills alongside physical fitness routines[56]. In addition to optimizing individual performance, the workings of team membership in esports are also of interest to the research community. Esports teams may consist of long-term members who regularly interact in person, remote acquaintances who have never met, or even complete strangers[57].

In professional esports, the intense cognitive demands under the stress and time-pressures of a competitive environment require teammates to work together and coordinate efficiently. In these situations, effective communication and collaboration enables team members to specialize and delegate in a manner which complement each other's strengths and optimizes information sharing. Together, team members can take advantage of collective experience and respond more effectively to immediate responses and strategic decision-making in dynamic environments. These dynamic environments serve as more than models of gameplay, but also can help us better understand teamwork under reactive conditions in both virtual teamwork settings and similar reactive demands present in physical teamwork and coordination required in situations which require rapid response and coordination.

4.0 THE SOCIAL BRAIN AND INTERPERSONAL SYNCHRONY

4.1 Societal and Brain Architecture

Human society would not be possible without the continuous products of successful collaboration. It has been proposed via the "social-brain hypothesis" that our brains have evolved specifically to enhance social function [58]. The social-brain hypothesis predicts that a species' mean social network size is related to the relative proportion of the neocortical region to the remainder of the brain. While brain sizes may vary amongst primates, humans possess a significantly larger neocortex and thought that this supports the complex computations required to engage with relatively large social circles. Even amongst humans, inter-individual differences in prefrontal cortex morphology as well as white-matter tract size has been shown to relate to in-person social network sizes[59], [60] and similarly regions of the mirror neuron system have been shown to correlate with the size of an individual's online social networks [61].

Our neural architecture may also produce emergent effects which operate as fundamental rules of social organization, defining how we act with respect to one another and even place practical limits of organization scalability and team structure. One such observation may reflect the our maximum capacity to interact with others, through observations of large organizational groups tend to be most successful and stable when the network does not exceed approximately 150-200 individuals [62], [63]. In more practical terms, understanding the ways in which the social brain operates may help describe naturalistic organization of social networks such as the "rule of three" [63]. This heuristic serves as a practical description of both inter-personal relations as well a model for general scaling of subgroups under hierarchical organization such as those typically observed in modern military organization. Although personal social relationships and military command structure differ significantly in their rules and functions, this fundamental cognitive grouping is distinctively similar and may represent a natural balance between the ability of individuals to scale group sizes and effectively attend various elements of their community. As such, these findings have both practical, scientific, and organizational implications for design and teaming.

4.2. Networks and architecture supporting the social brain

The social brain does not exist in one particular region of the brain, but instead is thought to consist of multiple interconnected systems which ultimately are responsible for managing social interaction. These regions include the prefrontal cortex (PFC) and its subdivisions including the dorsolateral (dlPFC), ventromedial (vmPFC) and ventrolateral PFC (vlPFC). In particular, the dlPFC and vmPFC have been implicated in self-referential processing including the personal importance an individual places on their specific actions and goals[64]–[66]. These regions are densely interconnected with other regions of the PFC as well as with the posterior partial cortex (PPC), superior temporal sulcus (STS), and other cortical regions [67].

While self-evaluation may be responsible for goal-setting within the context of an individual's actions, in order to understand and anticipate others we may rely on systems such as the mirror neuron system, including lateral regions of the PFC such as the inferior frontal gyrus (IFG), as well as the PPC, STS, and the anterior cingulate cortex (ACC)[68], [69]. Considerable overlap exists between systems which regulate an individual's assessment of their current state and goals and those responsible for relating such goals to the external social environment. However, it has been proposed that at least for the PFC, parts of this balance between self-referential mentalizing and situational assessment may be roughly organized in a medial to lateral manner[65], [70] and this theory has been supported by functional differences between the medial and lateral dorsal PFC in both task activation and functional connectivity[71].

The ability to interpret the actions and intentions of others and mentalize an internal representation of your goals, situation and form intentions, must ultimately also interact with attentional and affective networks which serve to guide information processing in the brain. Goal-relevant information is selectively processed and filtered in order to assist in social processing and the identification and interpretation of emotionally salient information also plays important roles in complex social interactions[72]. These emotional evaluations are encoded into expected social outcomes in regions such as the amygdala and ACC and can further signal subcortical regions in order to bias attention to selective emotional stimuli[73]. These regions coordinate with two attentional networks, the dorsal attention network responsible for intentional (top-down) control of attention[74] and the ventral attention network [75], responsible for automatically drawing attention to important/novel stimuli.

Between these three major systems, the brain is able to receive and interpret stimuli from other individuals, model the intention and sentiment of other's actions and state, and finally integrate this information with an internal model of the self in order to make value-based judgements. Together these systems operate to give an individual all relevant information available in order to make social decisions effectively and support task-relevant executive decision-making processes necessitated in teamwork.

4.3. Rise of Neuroergonomics: Monitoring Multi-Brain Activity Non-invasively

Until very recently, these social processes which mediate social interaction have primarily been studied using well-controlled laboratory settings in which one individual performs a cognitive task cleverly designed to isolate a particular cognitive function in a manner which while often compelling from a scientific perspective, does not resemble typical human interactions at all. In addition, although specific cortical regions have been implicated in internal and receptive social processes by such studies, it would be incorrect to presume that these regions encapsulate the entirety of socio-affective processing[76]. Furthermore, our understanding of these environments has been limited due to technological barriers on neuroimaging technologies and typically limited research to one brain at a time.

With the advent of portable and wearable neuroimaging methods like electroencephalography (EEG), functional near-infrared spectroscopy (fNIRS), and neurostimulation approaches like transcranial direct-current stimulation (tDCS), significant progress has been made in recording and altering brain activity without restricting body movements and without limiting research to laboratory environments[77]. Traditional approaches had imposed limitations for experimental protocols, data collection settings and task conditions at the expense of ecological validity. Neuroergonomics integrates advancements of neuroscience and neuroengineering, to provide the flexibility to assess body and brain function in naturalistic work settings bringing neuroscience into everyday life[78]. Particularly with the minimally intrusive new generation of wearable neuroimaging systems, multiple individuals that in close proximity (e.g. in the same room, next to each other, performing joint attention and collaborative or competitive tasks) could be monitored[8], [79], [80].

FNIRS is a wearable and mobile neuroimaging modality that has emerged over the last decade as a new technique to measure brain activity non-invasively [81]. FNIRS uses near infrared light to monitor changes in oxygenated and deoxygenated hemoglobin at the outer cortex of the brain [82]. By employing wearable light sources and detectors, photons are emitted over the scalp that pass by layers of tissue and detectors then collect the fraction of them that return. Because most tissue is transparent to light between 700-900 nm and because absorption is minimal within this optical window, fNIRS systems use multiple wavelengths within this near infrared range. fNIRS is able measure optical density fluctuations caused by metabolic changes in neural activity through a mechanism called neurovascular coupling [83] and can measure the hemodynamic response in a similar fashion to functional magnetic resonance imaging (fMRI)[84]. However, in contrast to fMRI, fNIRS sensors are wearable, portable, low-cost and possess a higher temporal resolution. fNIRS allows subjects to be seated at a computer or in natural postures while monitoring cortical regions such as the prefrontal cortex or motor cortex in a way that is compatible to research surrounding cognitive and motor tasks[79].

Neuroergonomics also includes tight integration of body physiology into the context, and hence wearable biosensors assessing complementary signals are of great interest. To this end, particularly Electrodermal Activity (EDA) a portable, non-invasive and wearable sensor that measures skin electrical properties to track correlates of autonomic nervous system (ANS) activity[85]. Although EDA utilization is sparse compared to some other biomedical signals in ambulatory settings, it can be a potentially helpful adjunct tool in neuroergonomics studies and mobile brain and body research. EDA mainly assesses changes of electrical properties of the skin caused from sweat gland activity, and is generally considered as an indicator of physiological arousal[86], [87]. Similarly, accessible measures of systemic measures such as heart rate and heart rate variability (HRV) can be acquired using electrodes or optical heart rate monitoring (OHRM) devices. While increased heart rate might typically represent increased physiological arousal, HRV has been correlated with the ability to maintain attentional control[88] as well as more cognitive function in a more non-specific fashion[89]. Together, integration of peripheral measures can help place neural activity in context with body function and provide adjacent biomarkers of participant state.

4.4. Quantifying interpersonal interaction through neural synchrony

The prospect of capturing otherwise hidden information from interacting individuals is particularly exciting to the neuroscientific community but the study of naturalistic social interaction also represents one of the most challenging issues in the field[90]. These challenges arise in part due to the exceedingly subtle interactions which make up social behaviours as well as the invited variability and complexity that comes from naturalistic interactions[79] and two interacting complex systems. Hyperscanning was first introduced as an approach in 2002 by Montague et al[91] where two individuals in separate fMRI machines engaged in a simple social guessing game. Since then with the introduction of more affordable EEG and fNIRS systems, hyperscanning has exploded into a field of its own with researchers investigating everything from basic motor synchronization[92], to the classroom[93] and even in musical concerts[94].

A variety of approaches have been employed to assess cognitive synchrony across multiple individuals. One such approach employed by Hasson et al, has been the use of phase-locked stimuli and to analyse the effective correlations between all participants[95]. Similarly, this approach has been used to study interactions between speaker and listener pairs to assess the way in which information associated with language is received by the listener[96]. Neural synchrony approaches assume that pairs of subjects, or dyads, may contain similar neural activities which may be spatially separated or lagged in time. These measures such as phase-locking value (PLV), phase lag index (PLI), phase coherence provide measures of brain-to-brain coupling [97].

Although strict estimation of phasic relations in signals is mathematically simple, neural signals are practically never accurately represented between participants in an exact scaled translation of the original signal. One approach which attempts to preserve more complex relationships between signals has been the use of the wavelet transform coherence (WTC). Originally developed by Grinsted et al, as an approach for geological research[98], the WTC has become a standard tool for assessing inter-brain connectivity in a wide variety of tasks and domains offering particular advantages over more-rigid cross-frequency approaches with a stronger capacity to break down subtle time-frequency features.

Quantifying neural synchrony during team cognition represents an important candidate biomarker of team performance. Individuals who interact well together are able to synchronize neural oscillations more effectively in joint attention tasks[99] and oscillatory activity is thought to help integrate self-other information during joint-action paradigms[100]. Similarly, familiarity and social relationships may mediate interactions through similar neural synchronies[101]. Here it can be expected that the study of naturalistic teaming through hyperscanning approaches can assist in the development of new ways to construct, organize, train, and manage effective teams.

5.0 EXPERIMENTAL APPROACH

5.1 Overview

In this ongoing study we attempt to investigate the neural underpinnings of successful teaming, how teamwork is mediated by cognitive ability, and the nature of task environment on teaming. To do this we have developed a two-person hyperscanning study during which both members of the team are monitored continuously using functional Near-Infrared Spectroscopy (fNIRS) and peripheral physiological measures such as electrodermal activity (EDA) and optical heart rate monitoring (OHRM). The cooperative gaming task involves performance of a PC-based competitive first-person shooter, Overwatch, developed by Blizzard-Activision.

The central focus of this study is to identify robust neural and physiological correlates of team performance and behavior during cooperative gameplay. This relationship will be explored using neural measures of prefrontal cortical activity collected from fNIRS as well as peripheral physiological measures of autonomic nervous system activity as measured by EDA, and systemic measures of heart rate variability (HRV), alongside subjective measures of perceived teamwork quality and task behavioral outcomes. Because the nature of teamwork is highly dependent on environmental context and team make-up, these quantitative and qualitative measures will be evaluated in teams matched for similar task-specific skill levels and occupational background (civilian vs veteran). Participants will also be profiled using a cognitive baseline task-battery in order to assess the relationship between in-game skill and specific dimensions of cognitive performance, as well as to relate these profiles to qualitative and quantitative team outcomes.

5.2 Experimental Protocol

Recruited participants will be consented prior to participation, following the IRB approved by the Drexel Institutional Review Board, and subsequently surveyed according to their gaming backgrounds and skill with Overwatch, as well as their occupational background (civilian and veteran populations). Participants will be matched with other individuals of similar skill levels and both individuals will participate in the experiment during a single session consisting of three phases described below. Experimental outline is presented in Fig.1-1.

5.2.1 Cognitive Battery and Individual Play

An individual's performance in eGaming is expected to be related to other measures of cognitive ability. In particular, first-person shooter (FPS) games such as Overwatch are commonly observed to demand fast processing speeds, the ability to engage in frequent task-switching, visual search, and conflict inhibition. In this experimental phase, participants will be evaluated according to a psychometric test battery aimed at providing a cognitive baseline relevant to game performance. This battery will consist of four cognitive tasks targeting different cognitive domains. The Stroop Task [102] will be employed as a measure of conflict inhibition. The Symbol-Digit Substitution Test (SDST) will be used to evaluate speed of processing[103]. The Psychomotor Vigilance Test (PVT) [104] will be adapted as a measure of reaction time. Lastly, the Dual-Search task [105] will be presented as a measure of task-switching ability and visual search ability.

Following performance of the cognitive battery, participants will engage single-player performance of the games Escort mode against in-game AI opponents. In this mode, attacking players are asked to escort a "payload" along a set of predefined checkpoints. Players on the defending team are tasked with preventing the attacking team from advancing the payload until the time runs out. In this experiment, the in-game setup will feature multiple abbreviated games consisting of 2.5-minute rounds in which the player will either attack or defend the objective. In addition, the difficulty of the task will be randomly alternated between Easy and Hard AI characters. Following each block, participants will be asked to complete a brief survey related to their performance in the prior round.

5.2.2 Cooperative Teamplay – Condition A

Participants will be paired together into dyads to play cooperatively against a pair of AI-controlled opponents. Dyads will be divided into one of two randomly assigned groups. In the first group, participants will remain in separate rooms from each other during the gaming task. Whereas members of the second experimental group will be first introduced to each other in person and then seated across from each other in the same room on separate computers to engage in the task. Selection of experimental groups will be counter-balanced across dyads in order to account for any order effect. Participants will then complete 8 rounds of the specified gaming task. Following each round, participants will complete brief surveys about their individual performance and their perception of their team performance.

5.2.3 Cooperative Teamplay – Condition B

Following, completion of the gaming task, participants will be placed into the opposite experiment condition and the gaming task will be repeated. Participants who had in the previous experimental phase played together in the same room will be moved to separate rooms and participants who were playing together remotely will be subsequently introduced and then seated in the same room to complete the remainder of the gaming task. Participants will then complete an additional 8 rounds of the gaming task with a separate randomized order, completing performance surveys between each round.

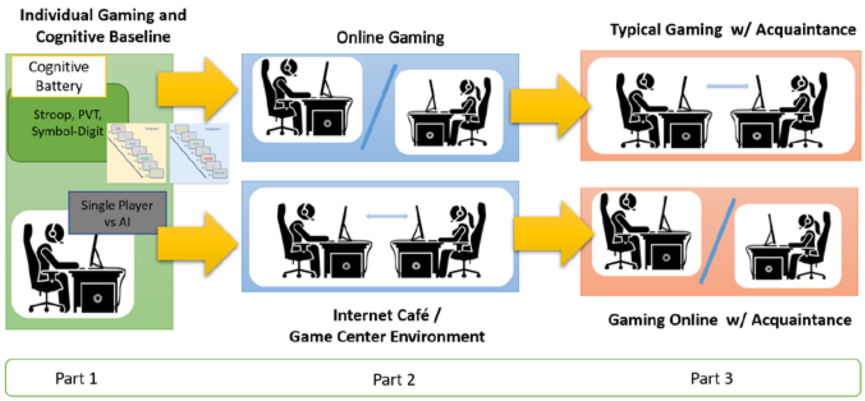

Figure 1-1: Experimental Outline.

5.3 Expected findings and approach

This paper describes an experimental protocol that aims to evaluate neural under-pinning of team performance and factors contributing to successful teamwork. We have designed a new multi-person experimental gaming platform to study co-operation with single-player and multi-player scenarios. Particularly, we will evaluate the impact of cyber or physical presence which is becoming more prominent with the COVID-19 global pandemic. We expect to see significant interpersonal synchrony between individuals when there's successful cooperation versus individual play. Moreover, we will be able to investigate factors contributing the increase or decrease of this link between individuals and understand the between being in close proximity, verbal communication and gaming behavioral performance. We expect to utilize this experimental protocol with cognitive task battery and e-game scenarios in multiple hyperscanning studies in the near future.

6.0 CONCLUSIONS AND NEXT STEPS

The underlying factors that account for high-performing teams remain a topic of intense study. In a successful team, information is communicated quickly and efficiently, while solutions can draw on the collective knowledge of the team members[1]. Improving teamwork is widely viewed as a reliable way to boost productivity, ensure optimal safety, and boost the satisfaction of all team members. However, effective team performance is demanded when the cost of failure is extremely high as often occurs in high-pressure situations such as medical, civil, and military rapid response teams[2], [4], [106]. A similar sensitivity to team-performance is observed in tightly competitive environments, such as professional e-sports gaming, where winner-take-all tournament models shrink the margin of error between success and failure[53], [107]. Here, the ability of a team to rapidly coordinate and engage in strategic decision can be turned into a tremendous advantage, allowing a team to outmaneuver their opponents, even when individual team-member skills may be otherwise comparable[56].

Although decades of research have been devoted to the study of team performance, it is only recently that applied neuroimaging techniques have been leveraged in this pursuit. Advances in portable, non-invasive and wearable neuroimaging techniques such as functional near-infrared spectroscopy (fNIRS) have allowed researchers to study multiple interacting brains under naturalistic situations with the goal of understanding and ultimately enhancing collaboration and work[77], [108]. This emerging field, known as neuroergonomics, has helped shed light on social neural interactions and the brain-to-brain dynamics which enable communication [96]and collaboration[79], [109].

In this paper, we examine motivation for brain-to-brain studies and present a study design to investigate neural mechanisms underlying successful team performance and its relationship to individual cognitive ability under different operating environments (remote vs in-person). To do this, we have developed a two-person cooperative hyperscanning paradigm during which participants' cortical activity was monitored using fNIRS along with peripheral measures using electrodermal activity (EDA). Team and individual performance were monitored as participants engaged with a competitive team-based first-person shooter videogame (Overwatch) and alternated between in-person and remote cooperative play. Dyads were matched for skill-level and occupational background (civilian and veteran populations). Measures of interbrain neural synchrony are explored as predictors of subjective team cohesion and observed performance during cooperative e-gaming scenarios. These findings provide a framework for evaluating naturalistic team cognition with the aim of understanding and enhancing team dynamics.

This work falls under the under the scope of the HMF panel with specific focus on characteristics which are central in team personnel selection and training. Translation of this framework into applied situations can enable team-based monitoring platforms and potentially interoperate with other neuroimaging-based measures of individual cognitive workload.

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