Multimodal, Musical Hyperscanning to Promote Empathy in HCI

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ABSTRACT

Understanding social interaction is an important step in efforts to create empathic design solutions. However, measuring empathy in multi-person interaction systems remains an open area of study. In this work we present hyperscanning, a recent technique for simultaneous brain imaging of multiple participants, as a tool to apply neuroscientific evidence to the understanding of empathy and social interaction. We review the implications of empathy in human-centric design, previous attempts to measure empathy and the importance, and the potential of hyperscanning for the understanding of social interaction. We propose music activities as organic and controllable social interaction environments, and suggest a new set of experiments aimed at better understanding empathy and social bounds in multiple interaction scenarios.

KEYWORDS

hyperscanning, empathy, music, interaction, design

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1 INTRODUCTION

Humans are social beings by nature. Over thousands of years we have developed behaviors that allow us to engage and cooperate amongst ourselves, as well as with our environment. Two key universal components of those social behaviors are music making [10] and empathy [8].

Music is undeniably an important part of human culture and society [10, 16]. We use music to non-verbally communicate our emotions to others [33], regulate our own emotions [45], and even convey aspects of our personalities [61]. Given the highly interpersonal and emotion-driven nature of human musical behaviors, it follows that music has close ties to empathy [35].

Empathy plays an important role in everyday social interaction [66] by facilitating prosocial behaviours and interpersonal understanding and cooperation with those around us [17, 23]. Understanding the underlying neural and cognitive mechanisms of empathy is an important step, not only towards creating a more empathic society [30], but also a more empathic, and immersive, digital world [65].

In this paper, we demonstrate the importance of hyperscanning research in understanding the neural mechanisms behind empathy, and how this novel technique can advance human-centered design (HCD) and human-computer interfaces (HCI). In Section 2, we present a review of empathy and its relation to HCD, affective computing, and embodied cognition. Section 3 introduces hyperscanning, its history, and recent work in this field. Section 4 gives an overview of how hyperscanning studies have been supporting a better understanding of empathy. Section 5 shows how musical activities can be used as models for social interaction. Lastly, we propose ways to use musical free improvisation as a naturalistic, multi-person research context for empathy hyperscanning studies.

2 EMPATHY

Over the years, there have been multiple attempts and perspectives on the definition of empathy. This term is attributed to the German word "*Einfühlung*", coined in the 19th and early 20th century in the fields of art and aesthetics. The term is defined as the act of projecting yourself into another person or environment, and could be translated as "feeling into" [19]. However, its origins can be traced back from the Ancient Greek *εμπάθεια* (empatheia) as the combination of ἐν (en, "in", "to go into") and πάθος (pathos, "feeling" or "suffering"), which can be understood as the human capacity to put yourself into the feeling of another.

The modern term "empathy" was then adopted from "*Einfühlung*" by English psychologist Edward B. Titchener in the early 20th century. Since then, it has been generally used to describe feelings and behaviors related to recognizing, perceiving, and sharing the feelings or emotional states of others [8]. Despite this fluctuating and rather abstract definition, empathy research has yielded promising results across many disciplines [58], including design, HCI, and neuroscience.

2.1 Empathy and Design

There are several ways to incorporate empathy in any design process. It can be a design principle, requiring the transformation of emotional feeling into a feature [38]. Designers can also use empathy to acquire insight into users' needs [22]. Over the last two decades, the principle of "empathic design" has gained significant attention. Empathic design is a user-centered design process that keeps users' context at its core [38, 39]. Leonard et al. established the importance of observing user behavior to create more empathic and meaningful products, rather than solely relying on marketing

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questionnaires [41]. Empathy-driven product designs have led to better experiences, and furthermore, higher user satisfaction and involvement.

With growing technological penetration, empathy-led design in computer interfaces is a growing area of research [72]. An early example is Hekkert et al.'s design of an experiential copier [28], featuring a movable arm that could self-adjust based on the user's orientation and visual cues to evoke empathy. *Ticket to Talk* [69] is a good example of empathy-driven, virtual networking interface design. It is a mobile application designed to let younger people interact with older people suffering from dementia. It curates photographs and videos of family members to be watched together remotely. In doing so, it also solves the issues of age gap that younger people feel while initiating conversations.

Evidence suggests that individuals are not only able to successfully engage in empathic behaviors within these virtual environments, but that empathy is also an important component in this scenario. For example, it is possible for users to experience empathy towards other members in online communities [57], and audio or video web conferencing groups can be almost as effective as face-to-face communication in facilitating supportive interpersonal relationships [7]. Empathic design also plays a crucial role in designing virtual reality (VR) environments. An empathic approach helps users "ease" into the virtual environment, and has been shown to increase users' immersion and flow, supporting the need for a more active role of empathy in VR design [65].

Increasing demand for empathy-driven design has highlighted questions of how to measure or quantify empathy. Physiological signals measured from users provide an objective approach to this problem. For example, neural mechanisms underlying visuo-affective mappings have offered insight into how people relate to computer game characters [73]. Auditory heartbeats have also been used as an intervention to enhance empathy by regulating heartbeat of participants [71]. However, most of the neuroscience research on empathy and design has been limited to "user-system" scenarios. With increasing prevalence of multi-user interaction across various online platforms, expanding our current neuroscientific understanding of empathy can help inform future design practices.

2.2 Embodied Empathy

Recognizing emotional and affective states is a fundamental part of daily social interaction. Children naturally learn how to express and interpret emotions through gestures, speech nuances, and facial expressions. With advances in computer science and HCI have included the capability for a digital system to recognize affective states of a user. This launched the field of Affective Computing (see [55]), and led to the development of computational models capable of recognizing human affective states. While many of these systems are based on the same cues that we naturally learn how to interpret (facial expressions and speech nuances), recent efforts have focused on analyzing physiological signals, such as heart rate variability (HRV), electrodermal activity (EDA), and respiratory rate [32]. These signals originate from the Autonomous Nervous System (ANS), meaning they are triggered and controlled unconsciously and are tightly connected with both physical and mental experience of the subject [34].

However, following advances in machine learning and brain-computer interfacing, even more recent efforts have focused on affective computing based on neurological signals. Originating from Central Nervous System (CNS), these signals are the origin of the information sent to the ANS. Recent studies have shown accuracy levels higher than 95% through the use of EEG signals for emotion detection on subjects [59].

Affect is closely related to emotional and mental states, and the link between these entities to the physical body has been the focus of many philosophical discussions over the past centuries. Previous ideas regarded the mind and body as two separated entities (cartesian dualism) or understood mental and cognitive processes as pure mathematical operations (computationalism). It was only during the last decades of the 20th century that the new theory of embodied cognition, grounded over phenomenology and the recent advances of neuroscience, was established. Embodied cognition emphasizes the connection between mind and body, and the mutual influence of these two entities one over one another [68].

Stemming from embodied cognition, embodied emotion [53] addresses the reciprocal relationship between bodily expression of emotion and how we perceive and interpret emotional information. This concept has become an important framework within the HCI community for studying empathy and affective computing; it provides a unique understanding of one's physical experience within a given environment and establishes a theoretical basis for ongoing research [18].

3 HYPERSCANNING

3.1 Motivation

The past decade has seen researchers taking a special interest in cognitive neuroscience and embodied cognition to understand the neural correlates of human behaviors. This area of research has a major application in studying social interaction. Interdisciplinary domains such as information sciences and interactive design borrow concepts from cognitive neuroscience to explain the theory behind complex mental processes in a social setting such as decision making in a workplace [49] and internet usage [2], and use this knowledge to further enhance human machine interactions [9].

Many cognitive processes are influenced by environmental factors and other individuals. For instance, fundamental tasks such as verbal communication, learning, dancing, courting, and tool manipulation require multiple agents collaborating and coordinating their behaviors based on a common set of practices [27]. This coordination of behavior involves an exchange of information between a sender and receiver and is a result of inter-brain synchronization i.e a neural response coupling also referred to as brain-to-brain coupling. This phenomenon refers to a natural tendency to perceive and produce events that are synchronized with other people during an interaction. Inter-brain synchronization amongst people can be applied to almost all social situations and provides a neural basis to analyze the interpersonal synchronizations found in certain behavioral traits [14].

Prior research measures the neuronal activity of a single subject participating in an interactive task with other people through various neuroimaging techniques [56][63]. These experiments account for action-perception or stimulus-to-brain coupling, i.e., the brain's response to objects such as chemical, electromagnetic and mechanical elements as an individual entity in an interaction [27]. However, there is a need to record neurological signals of all participants in the interactive task simultaneously to truly capture the essence of social interactions via inter-brain synchronizations and behavioral synchronizations. This arrangement is facilitated by hyperscanning, a system that enables simultaneous monitoring of brain activities of multiple subjects during social interaction [50].

Hyperscanning aids in investigating the effect of a stimulus on multiple actors in an interactive environment. The configuration exists for many common neurological data collection modes such as Functional Magnetic Resonance Imaging (fMRI) [50], Electroencephalography (EEG) [5], and Magnetoencephalography (MEG) [29], and has recently been introduced for Functional Near Infrared Spectroscopy (fNIRS) [43, 52]. It also supports more ecological procedures despite retaining the laboratory context since it allows participants to remain engaged in the task due to a common environmental setting with real-time reciprocal responses amongst subjects.

3.2 History and Related Work

The first hyperscanning experiment, completed in 1965, observed extrasensory EEG in identical twins [13]. The aim of the experiment was to examine telepathy or transmission of brain information amongst isolated subject pairs. Although the results were unreliable, it laid the foundation for the hyperscanning concept. The first formal implementation of hyperscanning was by Montague et al.[50]. The experimental setup used hyperscanning for fMRI where the brain activities of two participants playing a competitive game of deception were recorded. This experiment was at the forefront of hyperscanning in a dyadic context for social interaction. Babiloni et al. came up with a novel experiment that simulated the hyperscanning setup for EEG and studied the interaction of participant dyads playing a cooperative card game [5].

Further iterations of the setup focus on studying brain signals of multiple participants by varying the interactive task. For instance, Lindenberger et al. conducted an EEG hyperscanning experiment involving musical interaction. It examined the presence of a pronounced effect on phase synchronization of intra- and inter-brain oscillations existing between a pair of guitarists under two playing conditions [42]. The results showed locations of coherence and synchronization between the two brains. Hyperscanning experiments have also seen applications in studying correlated neural coupling in socially interacting animals [36].

In the process of examining cognitive behaviors during social interaction, researchers have also explored emotion and empathy using hyperscanning. As an example of a study for non verbal interactions using EEG hyperscanning, Goldstein et al. recorded brain-to-brain coupling while one subject empathetically touches the other subject experiencing pain. The experiment also tested the involvement of inter-brain synchrony in pain alleviation [21].

3.3 Going Beyond the Dyadic Walls

The previous section discussed various hyperscanning experiments relevant to a dyadic context. However, social interactions in the real world are not restricted to two people. There is a necessity to break beyond the walls of dyadic interaction in hyperscanning since very little is known about the neural mechanisms supporting dynamic group interactions [60].

The dyadic interaction hyperscanning setup not only misrepresents the true nature of social interaction, but also provides incomplete information. It is limited to a correlational analysis of social situations and cannot prove causation [51]. A correlation between inter-brain synchrony and social behavior observed during a dyadic hyperscanning experiment could be coincidental and specific to that particular interaction. Exogenous manipulations of inter-brain synchronies must be present to observe causal effects on social interaction [54] and this can be achieved through hyperscanning for multiple participants.

Until recently, exploring inter-brain synchronization beyond two participants has been a difficult task. The high costs of the equipment needed for laboratory hyperscanning studies usually limits the number of simultaneous participants. Recently, with the advances on wearable technology and the emergence of commercial brain-computer interfaces (BCI), researchers have started to investigate inter-brain coupling on more than two participants at once.

In a recent study, Dikker et al. observed the relationship between classroom engagement and total interdependence, and the role of social dynamics in student learning by simultaneously monitoring the brain activity of 12 high school students in a classroom for a semester using wearable EEG equipment [12]. This was followed by another experiment that conducted EEG hyperscanning for 22 high school students over a period of 17 days that provided neural evidence of the impact of high school class start timings and class activity on adolescents' brain states. The paper suggested mid-morning to be the best time for learning [11].

Another recent study by Liu at al. used fNIRS to investigate inter-brain synchrony across nine participants on a drumming task. This research proposes a new modeling method for multibrain network based on Graph Theory to measure interpersonal neuronal synchronization (INS), and could effectively demonstrate higher INS during the cooperative task of willfully synchronize the drumming beat of the group [44].

4 HYPERSCANNING FOR EMPATHY

Researchers have begun exploring how hyperscanning may be applied to study meaningful, naturalistic multi-person social interactions. Indeed, the measure of individuals' inter-brain synchrony (or inter-brain coherence) has been linked to various elements of interaction, such as personal significance [24], and empathic response [4, 37]. Kinoshita et al. used EEG hyperscanning to show greater inter-brain band power correlations between participants who engaged in affective sharing through observation of the other's facial expression [37].

Other empathy hyperscanning studies have employed paradigms including nonhuman participants, suggesting ways for empathy to be studied not only within human-human situations, but also human-computer interactions. Using a Dictator Game/Third Party Punishment paradigm, Astolfi et al. studied empathic responses of a third-party, human "observer" witnessing interactions between a human "receiver" and a human or computer "dictator" [4].

Past hyperscanning studies on social interaction showed that two neural systems play a major role on inter-brain connections, the mirror neuron system (MNS) and the mentalizing system (MS). MNS is commonly associated with imitation and observation of others' actions, and the MS activation is usually observed during attempts to understand emotions and intentions of others' based on observations. MNS and MS are considered two of the most important neural systems for social interaction, cooperation and empathy [46].

While many hyperscanning studies to date have utilized similar cross-brain analysis techniques (e.g. "coherence" [62] or "density" [4] calculations) in an attempt to quantify elements of empathy, we believe non-dyadic, multi-modal experimental paradigms will be crucial in characterizing underlying neural mechanisms of empathy in naturalistic social situations. As suggested in [26], modeling participants' brain, body, and behavioral data using a cross-brain Generalized Linear Model (xGLM) could more accurately capture the complex, and often asymmetric, nature of everyday interactions. Furthermore, the advancement of synchronous data acquisition systems is making it less necessary to confine these studies to a dyadic context [11, 12, 40], enabling us to move toward studying large-scale group interaction. We propose that music and the context of group performance is a prime experimental context for this.

5 MUSIC AS SOCIAL INTERACTION

Music is onserved as a medium of social interaction across species. 40% of socially monogamous bird families practice "duetting" for mating [25]. Gibbons that share synchronized rhythm generally spend more time doing the same activities and occupy the same spatial proximity [20]. Across human history, it is a common cultural practice for people to get together to chant or sing in synchrony [47]. Synchronized tapping with others have been found to increase expectations of cooperation [70]. Evidence suggests that music has been an integral facilitator of social bonds among variety of different species, including humans [15]. as defined, is a feeling of understanding one's emotion from their perspective.

A peculiar and unique differentiating feature between musical activities and other shared social behaviour is the presence of shared rhythm. The ability to predict a rhythm is responsible for rhythmic synchrony in multiple people, as measured by inter-brain synchronization (IBS) [6][48]. High inter-brain synchrony between a group of people has proven to be a contributor in group creative tasks [46] and collaborative decision-making [31][60]. Given that music can induce IBS, hyperscanning can further help in understanding musical attributes responsible for IBS. This information can then be used in designing co-working environments (physical and virtual) to enhance co-creativity and work experience. It can also be used to create environments for more empathic experiments. Patterns of neural couplings have been successfully identified and observed in leader-follower dynamics during a guitar duet [64]. Product features inspired by leader-follower dynamics can be designed by understanding parameters like duration, complexity, context of the follower, etc of the melodies that contributed to the neural couplings. Music has been used to objectively measure emotional state using EEG in virtual reality environments [67].

5.1 Experiment proposals

Acquadro et al. uses the example of an opera presentation as an ecological activity for social interaction where three different levels of interaction can be observed: *observation condition*, *turn-based interaction* and *continuous interaction* [1].

Observation condition is the case of an audience which passively watches the presentation, receiving audio-visual stimuli from the musicians and actors. *Turn-based* interaction is the case of actors on stage that take turns speaking and singing while sharing the stage, and *continuous interaction* is the case of the orchestra that continuously accompanies the piece with many musicians performing together in synchrony. These scenarios mimic many typical social interactions. One important factor of natural social interaction is the fact that, in their daily lives, people do not usually use enacted action or lines. Natural actions are spontaneous, and emerge at will. Any rehearsed actions do not reflect the naturalness of a spontaneous and improvised action.

Aiming to better understand social interaction on an even more ecological scenario, we propose a set of experiments using musical free improvisation based on the three levels of interaction proposed by Acquadro at al. Free improvisation is a improvised musical style in which what is played is not prearranged and does not follow formal rules. This free structure allows for spontaneous interactions, leading to musical dialogues not necessarily committed to the agreement, but always toward a common goal through the music [3]. These experiments serve to map the most natural social interaction forms while maintaining a controllable and replicable environment.

Our first experiment proposal (Figure 1, top left) takes into account the observation condition, where we intent to analyze inter-brain coherence among participants listening to a same auditory stimuli. The goal of this experiment is to observe the similarities of how subjects receives passively auditory information. This first experiment can give insights on the collective reception of information, an important issue for empathetic design at scale.

The second experiment ((Figure 1, top right) intend to investigate the connection between two active agents (musicians) performing simultaneously, accounting for both turn-based and continuous interaction. This dyadic paradigm has been one of the most investigated forms of social interaction so far, but, to the date, all musical experiments performed in this paradigm were based on written and/or rehearsed music. We believe that by making use of the organic interaction of free improvisation, these new results might give better insights on the understanding of natural social interactions. From the HCI perspective, this experiment might give new insights on the bounds created during the interaction of two active agents, an important element for empathetic relationship.

A third experiment (Figure 1, bottom left) also takes into account the observation condition, but in a situation where the active agent (musician) performs in real time for the passive agent (listener). Going beyond the dyadic scenario, this experiment could be performed for multiple listeners, where inter-brain coherence is measured both among musicians to listeners as listeners to listeners. This experiment can be seem as a combination of experiments one and two, by contributing to a better understanding of empathy from the perspectives of both the active agent, as a content creator, and the passive agents, as content consumers. The link and the feedback created by the passive interaction of the passive agents on the content creator might provide important insights on empathetic interaction for the HCI community.

The fourth experiment (Figure 1, bottom right) is based on the continuous interaction among multiple active agents, where we could investigate the effects of collective intentionality in a joint action through a hyperscanning study. A recent study performed a similar experiment with nine participants in a drumming circle, providing interesting results. We intend to further investigate this experiment with different scenarios. Collective intentionality plays an important role on social networks and social bounds. Through this experiment we intend to contribute to the neuroscientific understanding of this dynamic human interaction with multiple active agents.

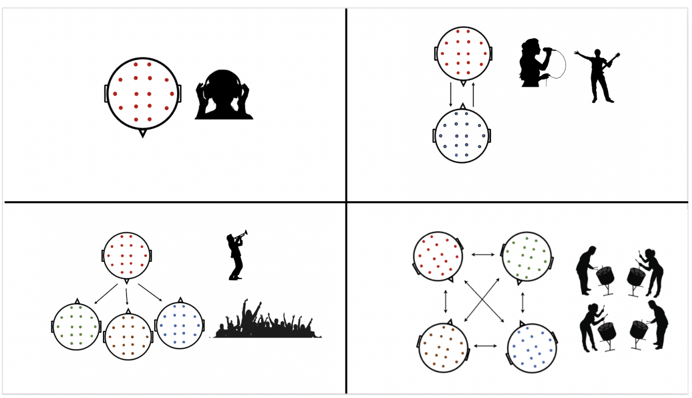

Figure 1: Pictorial representation of the proposed experiments

6 CONCLUSION

Music and empathy are both among core human social behaviors promoting communication and understanding. In this paper, we have reviewed some of the ways in which empathy-centered design practices have been implemented, and discuss how promising developments in neuroscience and hyperscanning technologies may be helpful in forwarding empathic design. We believe that a greater understanding of the neural mechanisms behind human empathy in a variety of naturalistic social scenarios (e.g. dyadic, multi-person, human-computer) is a crucial first step. To this end, we propose a series of music hyperscanning paradigms spanning solo, dyadic, one-to-many, and many-to-many style interactions, which may offer a controlled yet naturalistic experimental context under which to study human empathy.

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