An Auditory Interface for Realtime Brainwave Similarity in Dyads

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ABSTRACT

We present a case-study in the development of a"hyperscanning" auditory interface that transforms realtime brainwave-similarity between interacting dyads into music. Our instrument extends reality in face-to-face communication with a musical stream reflecting an invisible socio-neurophysiological signal. This instrument contributes to the historical context of brain-computer interfaces (BCIs) applied to art and music, but is unique because it is *contingent* on the correlation between the brainwaves of the dyad, and because it conveys this information using entirely auditory feedback. We designed the instrument to be i) easy to understand, ii) relatable and iii) pleasant for members of the general public in an exhibition context. We present how this context and user group led to our choice of EEG hardware, inter-brain similarity metric, and our auditory mapping strategy. We discuss our experience following four public exhibitions, as well as future improvements to the instrument design and user experience.

CCS CONCEPTS

• **Human-centered computing → Mixed / augmented reality**; **Sound-based input / output**; Auditory feedback; Activity centered design.

KEYWORDS

augmented reality, sonification, sound interaction design, brain-computer interfaces, social, neuroscience, sound art, audio

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1 INTRODUCTION

There is a long history of musicians and artists transforming neurophysiological (brain/body) signals into realtime audio and multimedia [9, 12]. Neurophysiological information is an attractive data source because these signals are difficult to control and reflect a person's authentic psychological cognitive or affective state. Such "biomusic" systems might also be applied to therapies and interventions, where auditory feedback from realtime autonomic processes can be used as a means of communication, control and behavioral modification [3]. Recent developments in social and affective neuroscience have uncovered ways that brains become similar (e.g. "synchronized") during cooperative and interpersonal interactions [1, 4, 6]. New interpersonal therapies and interventions might apply auditory neurofeedback to convey this brainwave similarity during realtime social interactions, but to date, only a few systems have begun to explore this prospect (i.e [5]).

Within this context, we introduce a case-study in the development of a realtime auditory neurofeedback instrument based upon brainwave similarity in dyads. Our system was designed for an exhibition setting where many sets of dyads would use the system in a relatively short amount of time. These use context and constraints informed the design of our instrument, which we describe in terms of our choices for hardware, signal analysis and auditory mapping strategies. We synthesize results from a series of four public exhibitions over a period of 15-months, including the feedback we received and the challenges we faced. We conclude by discussing our approaches to improvements on our system and future work.

2 BACKGROUND

Our work has developed in the context of Brain-Computer Interfaces (BCIs) [17] applied to new digital music instruments [8] (i.e. BCMIs [7]) and artistic expression more generally [9, 10]. BCIs developed over the 20th century to enable a more direct line of communication from the brain, and hold promise as a means to enhance and extend human abilities [17]. This work has produced several protocols for "active" or "direct" control, which can in principle be applied to the output of any computer interface (e.g. wheelchair, music-player, word-processor). However, at the present time, there are many difficulties in acquiring reliable control signals non-invasively, adding information transfer constraints. As an alternative, "passive" interfaces use brain-body signals in an indirect manner, not requiring conscious attention or intention on behalf of the user. These information dynamics nevertheless reflect internal systems, allowing computer systems to become responsive to user's mental state. Because our instrument was passive, we were able to invite members of the public to use our system without prior training.

2.1 Hyperscanning & Socio-Affective Neuroscience

The design of the instrument was also inspired by social and affective neuroscience [11], particularly empathy [14] and the paradigm

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of "hyperscanning" [1]. Empathy is the capacity to understand and share in the feelings of another person, an essential component of social psychology [2]. Hyperscanning is an approach to quantifying the correlations between EEG signals from systems of two or more people engaged in a synchronous, and usually shared activity. A consistent finding in this literature is that cooperation, synchronization and intimacy are associated with higher-levels of inter-brain synchronization [1, 4, 6].

Although face-to-face social interactions occur in a synchronous manner, the results garnered from these scientific studies are generated offline after extensive post-processing and statistical analysis. In creating our instrument, we wondered what would happen to human interaction if reality was extended to include social feedback that was not usually observable, such as similarities in inter-brain neurophysiological signals. Like the application of sonification for process-monitoring [16], we chose non-speech auditory feedback ("music") to convey this information so as not to interfere with visual and verbal communication.

2.2 Contingent Multi-Agent Artistic BCIs

An exciting trend in the world of BCMIs and Artistic BCIs has been work with *multi-agent* BCIs [13]. If a single-agent BCI is like a musical soloist, multi-agent BCIs span the gamut from duos, trios to quartets and entire orchestras. These have grown steadily more common since their first explorations in the 1970s [12]. An important point of differentiation stems from whether the system operates essentially as a group of single-agent BCIs, or if the system is dependent upon EEG features arising from the simultaneous and synchronous EEG recordings of multiple-agents. Because our realtime EEG similarity measurement requires signals from two networked EEG systems, our instrument example of a *contingent*, multi-agent BCMI.

Our work also draws direct inspiration from a similar, recent work called *Measuring the Magic of Mutual Gaze*, a re-staging of Marina Abramović's *The Artist is Present* as a public art installation/neuroscience experiment [5]. In that work, a dyad engages in sustained face-to-face eye-contact while a visualization of the similarities between their brainwaves[1] is projected behind them for an audience. Subsequent iterations of this approach resulted in an immersive and motorized audio-visual interface called the *Mutual Wave Machine*.[2] The instrument was applied over several years at different venues in a naturalistic, crowd-sourced neuroscience experiment [4]. Compared to this work, we explore the possibilities of real-time *auditory* neurofeedback. Although lacking the visual and material sophistication of this multi-modal interactive museum installation, the relative simplicity of our interface might be ideal for more practical, intimate settings.

3 INSTRUMENT DESCRIPTION

Within this context, we created a contingent, multi-brain BCI that transformed realtime similarities in the brain-waves of interacting dyads into ambient music. Figure 1 displays the basic concept. In our mapping strategy, increases in brainwave similarity controlled the volume of an ambient music stream. When the signals from two brains were similar with each other, the dyad would "hear music." When they were dissimilar, they would "hear silence." In this section, we describe the principles and objectives that guided our choices in hardware, signal processing and mapping strategy.

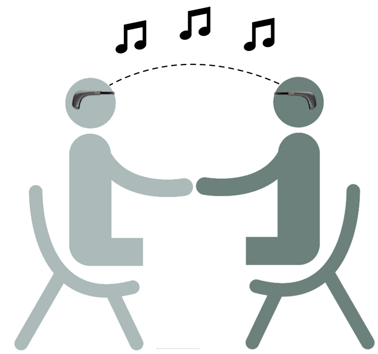

Figure 1: The basic use context of our auditory instrument. Two people (a "dyad") engage with each other in face-to-face communication while networked Muse EEG headsets transform transient inter-brain similarity into music.

3.1 Hardware

One of the challenging requirements for our study was achieving a quality EEG signal in a relatively short amount of time. The time constraint arose out of our desire for the system to be used in succession by groups of interested dyads in an installation or exhibition setting. Traditional "wet" cappings of EEG systems for scientific experiments and medical monitoring can require 15-30 minutes or preparation and an additional 15 minutes for clean-up. New "dry" systems require less preparation and clean-up time, but can also be less reliable in terms of signal quality.

In addition to these primary constraints, we also wanted our system to be portable, wireless and inexpensive, so that the system would be mobile, simple to set-up, and financially accessible. These constraints ultimately led us to the Muse EEG headset.[3] This simple, dry EEG headset calculates voltage fluctuations over four channels positioned over the forehead and behind the ears (AF7, AF8, TP9, TP10). Using these headsets, we could typically achieve the required signal quality in less than five minutes on members of the general public. They furthermore operated on battery charges and sent information wirelessly.

3.2 Signal Acquisition & Analysis

To acquire the EEG data from the headset, we made use of the Muse Direct application, built specifically for the MUSE EEG headsets. After connecting to the Muse headsets over Bluetooth, we used built-in functions of the software to lower impedance values, identify useable signal, perform basic EEG cleaning, analyze spectral power in frequency bands, and send information to Supercollider over Open Sound Control (OSC).

Scientific hyperscanning studies typically apply sophisticated time-domain algorithms to quantify the similarity and causality

[1]Demo Online: https://youtu.be/Ut9oPo8sLJw
[2]More Information: http://www.suzannedikker.net/mutualwavemachine
[3]More Information: https://choosemuse.com/

across multiple EEG sensor positions offline [1]. However the Muse Direct application does not offer those functions by default. Instead, information is available in "Raw Data" form, or as spectral power over the typical EEG frequency bands (i.e. Delta, Theta, Alpha, Beta & Gamma). Following other approaches to realtime hyperscanning instruments (e.g. [5]), we decided to create our similarity metric from the spectral power in EEG Alpha frequency band. We viewed this as a simple and robust approach, that could be directly linked to the level of attention [3]. The two headsets were connected over a local Wi-Fi network to a laptop running SuperCollider. Supercollider received the global Alpha power of each individual headset, calculated the similarity metric, and applied this similarity to the sonification mapping.

3.3 Auditory UX Design

We designed our Auditory UX (AUX) for dyads engaged in a simultaneous and primary face-to-face interpersonal interaction. As such, participants needed to understand the meaning of changes in an ambient "always-on" sound. We leveraged a subset of the BUZZ: Auditory Interface User Experience Scale [15] as design objectives. Specifically, we wanted the auditory interface to be:

(1) Easy to Understand
(2) Relatable
(3) Pleasant

By making the sounds easy to understand, we hoped to help new users quickly grasp what our sounds were conveying, and also to limit the amount of auditory attention required to make sense of these changes. By making the sounds relatable, we hoped to match user's sonic expectations for the underlying data concept. Finally, we wanted the sound to be pleasant, so that it would not become annoying in the context of a more primary spoken interaction, or bothersome over sustained periods of time. Like background music in films, its purpose was to enhance and extend the existing visual and verbal context.

To meet these AUX design objectives, we explored multiple data to sound mappings. For the purpose of being easy to understand, we decided to use a simple one-to-one mapping strategy, so that only one aspect of the sound would change with the underlying data. Although there are multiple possibilities for the acoustic cue (e.g. harmony, pitch, tempo, volume, timbre), we ultimately decided on volume. We reasoned that a silence/music continuum might make a relatable mapping for brain-similarity. For example, with a volume mapping, we could explain to users: "When your brainwaves are similar, you will hear music."

Another advantage of this mapping strategy was that it gave us great freedom for the choice of underlying soundscape/musical texture, which we used to help meet our AUX design goals. Specifically, we designed the sound to be pleasant and help reinforce the idea of "brainwaves" (i.e. relatability). To choose the sound, we composed six sounds that we felt were relatable to brainwaves and would be pleasant over long periods of time. We then held informal interviews with a set of four adult, english-speaking, technologically-minded listeners unfamiliar with the project. After giving them ample time to play through each of the sounds, we asked them which sound sounded the most "like brainwaves" and why. From their responses, we found that sounds that included a small amount of low-frequency amplitude modulation best mapped the cognitive model of brainwaves, and we selected their top choice for the timbre of the continually looping musical clip.

Figure 2: A set of two dyads using our system during face-to-face interaction. Because of the auditory feedback, participants can hear their inter-brain similarity as they engage with each other.

4 RESULTS

4.1 Exhibitions

With the hardware, analysis and mapping strategies in place, we sought out opportunities for members of the public to use and experience our system. We had two primary goals for these exhibitions: i) to bring awareness to the unique possibilities of realtime auditory hyperscanning neurofeedback and ii) to acquire critical feedback regarding our system so as to learn and improve our design.

To meet these goals, we submitted the work to several public exhibitions, workshops and demonstrations over the course of 15 months (see Table 1). These venues often combined audiences with varying disciplinary and socio-economic backgrounds, but were all hosted by groups that were primarily academic in nature.

The basic set-ups for these performances included two Muse headsets, two mobile phones running Muse Direct, a laptop running SuperCollider and an external loudspeaker. Altogether, this made the instrument lightweight and quite portable. We adopted the use of a speaker as opposed to headphones because we wanted observers to hear when there was alpha similarity during the interaction. Figure 2 shows two examples of dyads using our system.

4.2 Feedback & Challenges

Often in these public demonstrations, lines of people would accumulate to use the instrument, even in cases where there were many additional demonstrations available. The lines arose in part because the process of initializing the instrument and learning would take time for each new dyad. However, we also believe that these lines speak to the public's appetite for BCIs applied to artistic and musical endeavours, and an interest in social neuroscience and hyperscanning in particular. The instrument also faired well in academic audiences, winning "Best Poster Award" at the Congress of the International Neuropsychoanalysis Society in 2019.

We faced many technical challenges in these mobile public exhibitions, especially battery supply and signal quality. Even with a full charge, the headsets could typically not be used for more than 1.5 hours without needing to be re-charged. Including set-up time, this meant that we would need to take a break to re-charge

Date	Context	Event	Venue
November 2018	Workshop	Nat. Women's Studies Association (NWSA) Conf.	Hilton Hotel, Atlanta, GA
December 2018	Exhibition	Neuroscience & Art Exhibition	GSU Ballroom, Atlanta, GA
July 2019	Demonstration	Int. Neuropsychoanalysis Soc. Ann. Conf.	Université Libre de Bruxelles (ULB), Brussels, BE
March 2020	Fair	The Music, Art, and Technology Fair	Cadell Flex Space, Georgia Tech, Atlanta, GA

Table 1: A list of the public performances with the instrument to date.

the headsets during a typical exhibition. We also faced practical issues of signal quality. Although we wished to transfer the headsets as quickly as possible between participants, in practice it would take several minutes to reach a useable signal quality. To clean the headset between participants, we disinfected the headsets using isopropyl alcohol. However, we suspect that this method might have actually made getting good signal quality more difficult as naturally occuring sweat might increase conductivity of the sensors.

5 DISCUSSION & FUTURE WORK

5.1 Similarity Metric

Scientific hyperscanning studies (e.g. [1]) have used much more complex mathematical operations to construct their inter-brain similarity and coherence metrics than the approach we described in Section 3.2. It would be interesting to apply one of these metrics in the current context, as it could be revealing of even stronger relationships between the interacting brainwaves. However, we feel that these algorithms would best be used in more controlled (e.g. lab) environments, where there would be adequate time to guarantee EEG signal quality, and for which greater attention could be given to resulting music. In our case, the difficulties achieving quality EEG signal in short amounts of time combined with the often loud environments associated with demonstrations and installations made it all the more essential to operate on a simple and robust data and sound signals. We therefore position these more complex algorithms for future lab studies.

5.2 Alternative Mappings

As discussed in Section 3.3, we chose loudness to reflect the change in brainwave similarity between the dyads, enabling us to explain the mapping to members of the public by saying, "When your brainwaves are similar, you will hear music." However, this mapping strategy also produced problems as both "brainwave dis-similarity" and "poor signal quality" (i.e. no data) produced silence. In future work, we would like to explore additional or alternative acoustic cues and mapping strategies, for example consonance/dissonance, major/minor, timbre and tempo. Having designed our interface to meet three design objectives in terms of the Buzz Scale [15], we plan to use that scale to benchmark our current mapping and compare new designs. These studies will use videos and "pseudo-signals" to assist with experimental control and reproducibility.

5.3 Therapies & Interventions

While members of the public used the system, it was common to observe positive changes in behavior such as laughing and smiling when the music would start to play (i.e. signaling brainwave similarity). As shown in previous research, EEG neurofeedback is associated with positive health and well-being outcomes in individuals through cognitive remediation [3]. In the future, our instrument could be used to study the effects of EEG neurofeedback on the interpersonal interactions of dyads. For example, a controlled study might find that participants report higher-levels of closeness or understanding (i.e. empathy [2]) when they hear the music. If so, this might be related to prior research showing feelings of closeness correlate with brainwave-similarity [1, 4]. Alternatively, the music itself might actively change their social and affective cognition.

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