State Dependency - Audiovisual interaction through brain states

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ABSTRACT

Artistic installations using brain-computer interfaces (BCI) to interact with media in general, and sound in specific, have become increasingly numerous in the last years. Brain or mental states are commonly used to drive musical score or sound generation as well as visuals. Closed loop setups can emerge here which are comparable to the propositions of neurofeedback (NFB).

The aim of our audiovisual installation *State Dependency*, driven by brain states and motor imagery, was to enable the participant to engage in unbound exploration of movement through sound and space unmediated by one's corpo-reality. With the aid of an adaptive feedback loop, perception is taken to the edge.

We deployed a BCI to collect motor imagery, visual and cognitive neural activity to calculate approximate entropy (a second order measure of neural signal activity) which was in turn used to interact with the surround *Immersive Lab* installation. The use of entropy measures on motor imagery and various sensory modalities generates a highly accessible, reactive and immediate experience transcending common limitations of the BCI technology.

State dependency goes beyond common practice of abstract routing between mental or brain with external audiovisual states. It provides new territory of unrestrained kinaesthetic and polymodal exploration in an immersive audiovisual environment.

1. INTRODUCTION

Interaction with sound and image without a direct physical action is possible with the aid of BCIs. With this technology, 'imagined' activity, so called *motor imagery* can be directly linked to sound and image and influence the perception of motion in space. Placed in an immerse audiovisual environment, such a technically mediated perceptual cycle can provide a clear experience of an intentional, but suppressed movement and its reality to the mind. This shows that human perception of agency and the emergence of reality is constructed by the brain and completed in a multimodal fashion, even if certain sensory elements are missing.

Media technology allows the simulation of a physical surrounding through a few well placed and carefully balanced sound and image elements. This functional and mostly modality-specific simulacrum of a naturally occurring phenomenon may induce the brain to enter into resonance with and to reinforce the perception of the most credible scenario through completion [1].

State Dependency aims at realising a NFB scenario through a research experiment with artistic techniques and scientific methods. In the feedback between the (preparatory) imagination of movement and the perception of motion, the blending of modalities becomes possible, in a way that goes beyond established functional combinations of sensory inputs.

The adaptive feedback configuration proposed is based on the premise that perception depends on both inner and outer states and is dependent on reactive behaviour. In this experimental approach, the reactive loop is modulated to extend the limits of normal perception and (re-)action cycles.

Concretely, we want to combine movement control via motor imagery [2] and audio-visual media in a spatial setup. Driven by entropy measures, these two layers can coalesce into a coherent multi-modal immersive experience that is rooted in kinaesthetic and visual perception.

The inner sense of position and movement in space of the participant gets projected or linked onto a physically present, enveloping audio-visual flow of particles. The resulting amalgamated experience points toward the concept of 'telekinesis'. Thus, the installation can be experienced as a participant-centric telekinetic steering of the energetic particle flow. Alternatively, it can be felt as a physical trans-location inside a stream, where the sense of position and centrality gets lost, even if momentarily.

The merging of the modes of position, agency, and movement sensing lead to a new experience and awareness of interaction with – projected – reality. This pre-reflective, sub-personal access to agency and a sense of position and orientation proposes a mode of experience that explores poly-modal kinaesthetically-driven awareness, hitherto an uncharted territory.

2. BACKGROUND

BCIs, mostly in the form of commercial ready-to-wear electroencephalography (EEG) devices, have become widely-used in (digital) art and music [3]. [1] In these installations, brain-derived EEG signals are measured on the head, amplified and sent to a recording or streaming device (e.g., computer or mobile device). The raw signal or processed derivatives are then used to control visual or acoustic features of the installation.

Given the plethora of recent and current works using BCI in the art and music context, we here focus on relevant works using real-time brain signals mapped to audio-visual outputs in a performative setting. The first report of BCI art is from 1965 where Lucier performed 'Music for Solo Performer' which can be considered the first brain-driven musical piece [4]. Pioneering visuals, Nina Sobell in her work 'Brain Wave Drawings' [5] overlayed a real-time video portrait of two persons with the EEG raw signal reflective of putatively synced brain states of the portrayed persons.

Following advances in technology, especially regarding portability of systems, BCI art became more common in the early years of the third millenium. In a recent work by Dmitry Morozov named 'eeg_deer', the brain activity of the user was used to generate music and visuals in real-time with no further actions by the user [6]. In Novellos performance titled "Fragmentation" [7], on the other hand, the user performed with dance while the BCI and the linked audio-visual streams served as an extension. Combining live video footage with brain activity of users, Ursula Damm manipulated the degree of abstraction of video streams in 'Chromatographic Orchestra' [8].

Further adding aspects of immersion and interaction, current works also apply virtual reality (VR) technology. In 'The Hidden Rooms' [9] and the 'Errant Eye' [10] virtual (visual but not acoustic) reality is explored driven by brain states. Lastly, 'Conductar' [11] combines virtual and augmented reality with a BCI in a mobile setting. The setup depends on the GPS location and produces an artificial world on the screen of a smartphone alongside sounds driven by EEG and movement data.

The stability and quality, but also the reliability and validity of these measured frequency band power values are partly questionable. This is especially true when they are used in interactive closed loop setups like many of the existing BCI art installations. This is partly explained by the equipment employed, especially low-grade consumer devices with dry electrodes, but also by the situation (movement and other artefacts) and inappropriate use. In neuroscientific literature, consensus has arisen that the signal quality but also related claims of access and control over mental states are lacking any solid evidence and theoretical background [12].

Our goal was to set up an immersive 3D environment where accessible states can be explored using BCI technology in a functioning interdependent manner.

[1] `https://bci-art.tumblr.com/`

3. BRAINSTATES

In the last section, we introduced the current state of use of BCI systems in art. Concretely, we also shortly discussed technical details and limitations of BCI signal acquisition, processing and mapping, and also looked at fundamental claims of the relation between neural activity and subjective mental states. Because we identified several shortcomings or even questionable claims, the central motivation of the work at hand was to implement a working BCI installation which builds on verified aspects of current mobile neural technology.

First, motion control via motor imagery is an established concept which is used effectively for lateral bodily movements (e.g., left motor cortex μ-rhythm de-activation to control the right arm) [13]. Usually, with electrodes placed over positions of the motor cortex, μ-rhythm de-activation is then measured during motor imagery and compared to idle baseline activity of the same electrode. This procedure can be both time-consuming and unreliable, as the contrast between active and passive activation patterns can be too weak or disturbed by artefacts or general signal quality. The resulting baseline or calibration period can be considered as detrimental for any spontaneous setup and immersion into an art installation. In recent times, attempts have been made to optimise the measurement of this motor activity by applying machine learning (ML) on the features of motor imagery with a respective optimisation of the former differential approach [14].

Yet, the latter approach is in need of individualised baseline measurements and respective investment of computing power and time to train the ML algorithms. Therefore, we planned to use an entropy-based, second order information-theoretical analysis of ongoing neural activity to enable us to overcome the baselining as well as calibration phase and immediately start to derive motor imagery data from the activity at the electrode. This becomes possible because the μ-rhythm is highly responsive and, more importantly, regular so that the entropy algorithm identifies the rhythm as highly ordered and thus non-entropic. The detection properties of the entropy algorithm come in handy for movement control and have already been similarly implemented in state of the art BCI applications [15]. Details about our implementation can be found in the next sections (4).

Second, while motor imagery is able to control movement or directional parameters of the audiovisual flow, we were interested in aesthetic mappings of the sensory input domain, namely the visual system. We considered the implementation of this sensory neural input as feasible for a mapping beyond movement control, as the visual cortex is a large, accessible site with high activity. With the mapping of entropy measures derived from visual cortex activity, we envision a closed-loop NFB between visual effects projected and the response of the visual system. Naturally, this feedback loop is not directly controllable by the participant but rather relies on the unsupervised reactive neural activity (reflective of visual processing) in the individual's visual cortex.

Lastly, in an attempt to additionally experiment with cognitive states, we incorporated an electrode on the forehead measuring frontal, potentially cognition- and memory-related, activity. Again, by using entropy instead of frequency band power, we aimed at covering a more global state of cognition, which contrasts ordered putatively goal-oriented active cognition with more entropic idle states of thinking. We furthermore opted to use this remaining electrode of the current BCI system to both test for mental control option and to be able to access a 'control' electrode signal (e.g., muscle noise artefacts from frowning). This signal could then be used to test the entropy algorithm's vulnerability to noise or general responsiveness.

The implementation of entropy measures for motor imagery and NFB features in *State Dependency* can be considered a novel territory of artistic and scientific exploration.

4. DEPENDENCIES

4.1 Technical Implementation

The hardware and software setup of *State Dependency* provides the technical means for establishing a feedback loop between a participant's audio-visual perception and mental activity and the generation and spatialisation of audio-visual media (see figure 1).

The setup consists of a wearable EEG BCI, a computer for acquiring and analysing EEG data, and a second computer for generating real-time audio-visual content. The BCI is based on the *OpenBCI Ganglion* [2] board to which multiple wet electrodes are connected. Two of these electrodes provide reference and ground signals and are attached to the Lobule and Scapha of the right ear (see figure 2). The other four electrodes are embedded into an elastic headband and mounted at the back, forehead, and crest of the head. These sensors measure neural activity in the visual cortex, pre-frontal area, and left and right primary motor cortex. The interface, which is worn around the neck, sends the sensory signals via Bluetooth to a computer. The setup of the BCI with the current wet electrodes takes about 10 minutes before the user can properly interact with the system. This computer runs the *OpenBCI GUI* application which conditions the sensor data. Conditioning involves removal of signal values around 50 Hz by a notch filter to eliminate interference from AC current. For the motor imagery data, frequencies below 8 Hz and above 14 Hz were filtered out with a band pass filter to better access the μ rhythm. The visual and prefrontal data was filtered with a wider band pass filter between 5 Hz and 50 Hz to capture a wider range of frequencies typically produced by the areas underlying the respective electrodes. With this filtering strategy measuring artefacts, that would appear due to facial and bodily movement (i.e. below 5 Hz and above 50 Hz) as well as unwanted neural activity in different frequency bands, are suppressed. The conditioned sensor signals are subsequently sent via the Open Sound Control [OSC] protocol to an additional application that conducts feature extraction.

This application has been custom designed in the *OpenFrameworks* C++ programming environment and implements the *Approximate Entropy* [AE] method according to the mathematical description provided by Sabeti et al. [16] (see figure 3). *Approximate Entropy* is a statistic measure for the predictability of new values in a time series based on the history of previous values [17]. For our purpose of controlling through neural activity the generation of video and audio in real-time, this entropy measure proved to be more responsive than other entropy measures such as *Shannon Entropy* or *Spectral Entropy*. Optimal performance of the AE algorithm was achieved by setting the size of the sample window to 512, the embedding dimension to 2, and the threshold to 1.0. Latency and responsivity are issues to be considered in this optimisation process, which was mostly performed by manual approximation resulting in the final values above. Taking into account all elements of the feedback system from measuring the activity on the scalp to the audiovisual presentation in the IL, the resulting latency is estimated at about 350-500 ms. This includes time for data transfer, parsing, processing, and feedback (e.g. visual delay of the beamers of about 100 ms). Considering aspects of volition and cortical initialisation the latency value is slightly increased. Overall, we estimate the latency not to be larger than 1 second for all the processes described above. Certainly, the system will be further optimised to decrease latency and increase responsivity for better immersive experiences.

4.2 Experimental Setting

An essential part of the experimental setting for this project is it's application in an immerse media space called the *Immersive Lab* [3]. The installation was developed by two of the authors as a platform for artistic creation and research. It combines panoramic video and surround audio with touch-based interaction across its entire projection surface [18, 19]. The installation's video projection screens are arranged into a circular setup with a diameter of about 4 meters. It is furthermore equipped with 16 loudspeakers, arranged in two rings of eight loudspeaker placed above and below the screens and complemented by two subwoofers.

The capability of the installation to fully immerse participants plays a crucial role in establishing a feedback loop between EEG controlled media generation and movement perception (see figure 4). The EEG entropy measures control the creation of audio-visual media presented in a surround format to the participant in real-time.

4.3 Media

4.3.1 Audio

The auditory side of the media aims at providing a flow of sound elements that envelop the listener. The continuous flow of sound particles reinforces an immersed, almost hypnotic state. Changes in brain states modulate sound elements, in their balance, their spatial distribution, and their timbre. In our setup, the sound parameters are

[2] `http://docs.openbci.com/Hardware/07-Ganglion`

[3] `http://immersivelab.zhdk.ch`

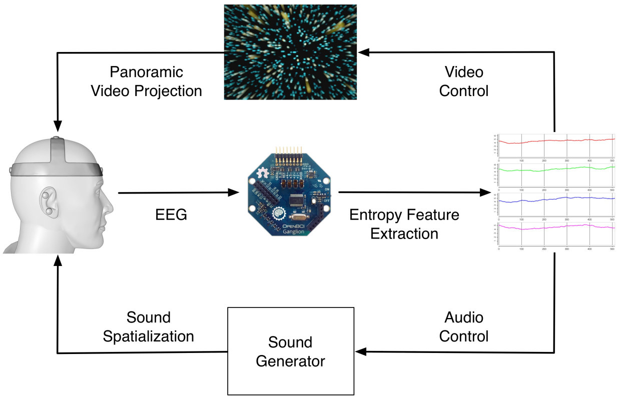

Figure 1. Schematic depiction of NFB loop. The sequence of EEG data acquisition and processing is shown in the middle section. From left to right: electrodes mounted to the participant's head, four channel EEG interface, approximate entropy-based analysis. The top and bottom sections depict the visual and acoustic feedback channels, respectively. From right to left: EEG-based control of media generation, panoramic media projection

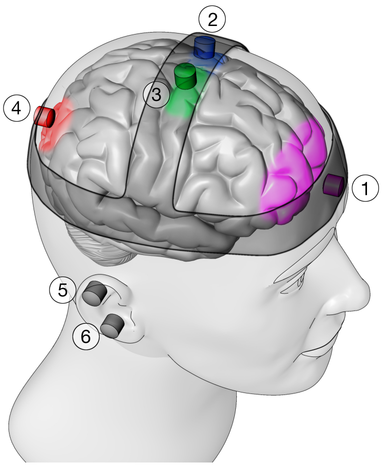

Figure 2. Schematic depiction of electrode placement. Six wet electrodes are mounted to the participant's head. Four electrodes are attached to an elastic headband and located above the following brain regions: 1. prefrontal area, 2. left primary motor cortex, 3. right primary motor cortex, 4. visual cortex. Two additional electrodes serve as reference and ground and our mounted with tape to the ear's 5. lobule and 6. scapha, respectively.

tightly linked to the flowing particles' behaviour and reinforce their physicality: A constant flow of sonic particles is streaming past the listener, always synchronised with the visual elements. Two continuously fluctuating instrumental voices provide a second, musical layer.

The sound particles are generated via granular synthesis of filtered noise. A bandpass filter is applied to the noise sources and serves two functions: The filter produces an individual pitch for each particle. The frequency of the filter is swept downwards as each particle moves past the listener, creating a Doppler effect. The particles are spatialised around the listener using Ambisonic processing [20], which provides a clear localisation of the sounds in the actual space of the installation.

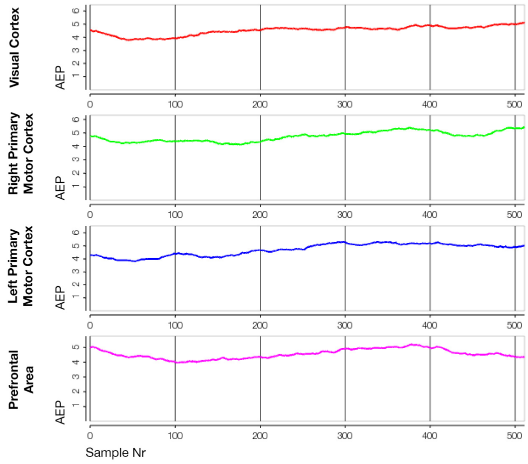

Figure 3. Approximate entropy feature analysis. Shown are entropy values as time series for all four electrodes.

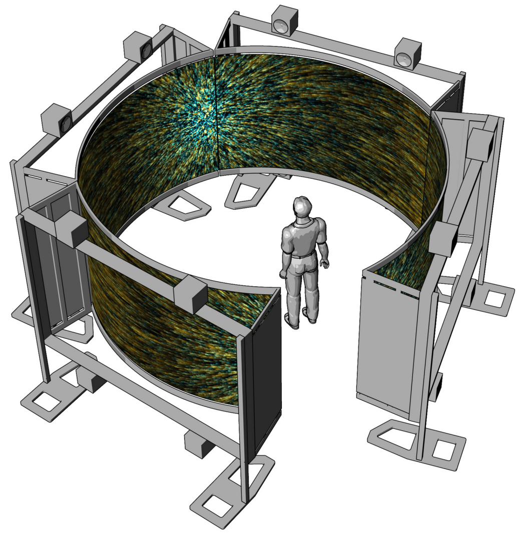

Figure 4. Schema of the installation setup. Two rings of speakers produce spatialised sound in azimuth and elevation. A panoramic screen presents an enveloping image.

The musical sounds originate from double bass recordings of continuous bowing. One consists of bow hair noise near the bridge of the instrument and the other stems from extended techniques providing multiple harmonics. The sound's pitches get altered through changes in playback speed, to provide a slightly alien harmonic timbre. The balance between these two sound layers is controlled by the difference in AE between left and right motor cortex.

The density of the sonic field duplicates the effect of the visual, where paying attention to a single event becomes difficult, i.e., the auditory stream segregation fails [21]. This increases the sensation of immersion and contributes to the perception of egocentric self-motion.

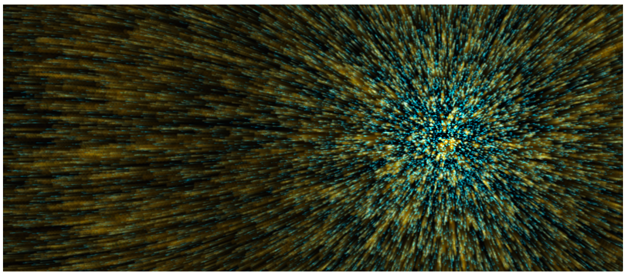

Figure 5. Screen capture of visual feedback. The image shows a section of the graphical rendering of a particle field which is four times as wide as shown here.

4.3.2 Video

The imagery evokes the sensation of being in an infinite space, densely populated by a stream of visual particles in the viewer. The particles of identical appearance exhibit a uniform global movement (see figure 5). This creates a perception that lies at the limit of a participant's capability for visual stream segregation. Depending on the density and visual representation of the particles' motions, the participant's attention is either drawn towards the individual visual elements or instead evokes an illusion of egocentric imbalance and translocation. By relating EEG measurements of neural activity to changes in the particles' motion and appearance, the balance between egocentric and allocentric movement perception is altered.

The visual flow is created by drawing 500'000 particles as textured billboards whose size, colour, and transparency vary with distance. The motion of the particles is visually accentuated by superimposing the most recent image with previously drawn images. This causes a motion blur effect whose strength depends on the amount of transparency applied to the previous images.

The particles move through an euclidean space that is delimited by a spherical boundary whose origin coincides with the center of the installation. When particles exit this boundary, their positions are wrapped around to slightly randomised positions on the opposing side of the boundary surface.

In order to create a panoramic projection for the circular screen, the image goes through two stages of optical and geometrical correction. A cube map captures the space and gets transformed into a panoramic image by an equirectangular projection shader. The shader's output is mapped onto four *Bezier* surfaces which compensate for the curvature of the projection screens.

Several parameters of the particle visualisation are controlled by EEG signals acquired from the participant (see figure 6). The difference in the AE levels of the EEG signals acquired from the right and left primary motor cortex controls the direction and amount of lateral movement of the particles. The AE level of the primary visual cortex controls the amount of motion blur in the visual image. The AE level of the prefrontal area controls the distance threshold of the particle's transparency and thereby alters the visual density of the particle system.

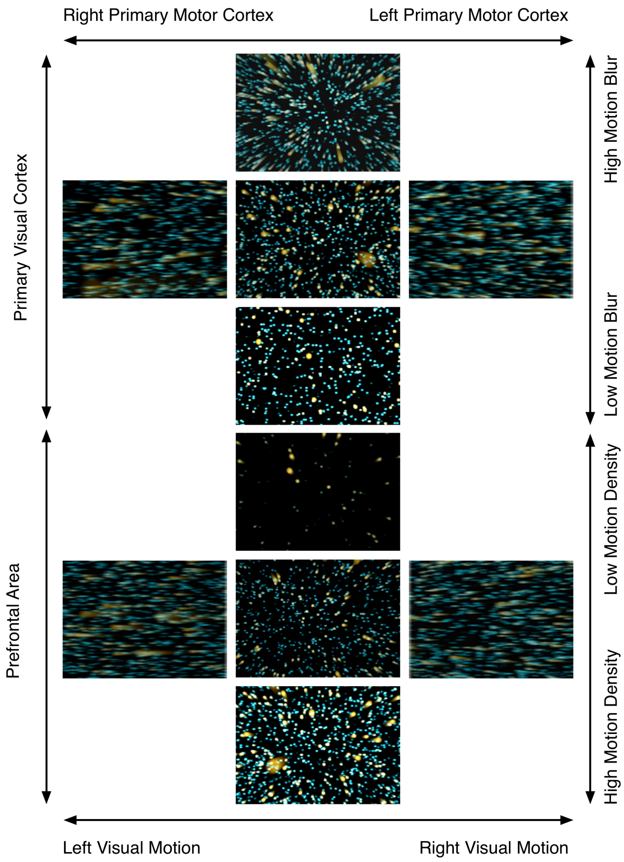

Figure 6. Overview of mapping between EEG features and visual control parameters. Approximate entropy analysis values of all four electrodes are mapped to visual control parameters as follows. The neural activity difference between the right and left primary visual cortex controls the horizontal direction of the particle's movements. Neural activity in the primary visual cortex is proportional to the amount of motion blur in the visual output. Neural activity in the prefrontal area is inversely proportional to the distance-based transparency increase of the particles.

5. EXHIBITION

Some visual impressions of a NFB interaction situation within the *Immersive Lab* are provided in figures 7 and 8. A video recording of this interaction situation is available online.[4] Notably, the installation has merely been tested by a single user which renders the following statements and claims anecdotal in nature at this point in time. It is though envisioned to continue with the installation and make it accessible to general public by working on all technical aspects of the BCI, data processing, mapping and audiovisual feedback.

During the setup, calibration and first experimental phases of *State Dependency*, the chosen NFB setting could demonstrate its potential in creating an immersive, volitional movement control and (mental) state dependent experience. The specific combination of state of the art technology with a consistent, intuitively-accessible installation enables immediate entrance to polymodal movement, drift

[4] http://immersivelab.zhdk.ch/?page_id=4485

and flow through audiovisual space without intermediate physical borders. The motor imagery setup is responsive and the interaction with it can be quickly integrated in one's own mental movement perception, while the separate visual NFB loop allows the participant to de-focus and even lose track of the granularity of the audiovisual output. The visual blurriness nicely emphasises this visual and possibly related attentional de-focus. Regarding cognitive control, we did not expect much intentional control options through mental imagery or cognition, which also became obvious when actually interacting with the setup. This comes as no surprise given the complexity of human cognition and related neural correlates - yet may be an interesting avenue for further iterations of this installation and BCIs in general.

An important novel insight generated by this installation was the the observed mechanism of a kinaesthetic sense strongly influenced by the visual motion. This mechanism can enforce the perceived movement immensely and therefore acts as a cross-modal ‘ interaction between visual, auditory and kinetic modalities. It can thus be very difficult to neutralise or change directions, when exposed to the visual motion with ever increasing speed (i.e., to move in the opposite direction than the visual and kinaesthetic modalities are implying). This challenge in the actual movement control has to be learned to keep a balance and flexibility in the movement interaction with the setup.

All in all, this novel immersive closed loop setup has shown to be successful in enabling the participant to freely interact with an audiovisual surrounding blended with his motor imagery, sensory and mental states. With time, the participant can reach a state of dependency with the linked system, which extends his self-concept and agency beyond the usual physical and mental boundaries.

Figure 7. Exhibition situation in the Immersive Lab. A participant controls audio-visual media through a NFB loop

6. DISCUSSION

6.1 Perception

In the immersive, interactive situation of this installation, the participant is able to explore kinaesthetic and proprioceptive modalities in their pure form: No intermediate motor system is required to alter movement and in consequence its perception. In practice, the participant therefore merely imagines (rotary) movements on a basic, preconscious or intuitive level, while at the other end of the feedback loop the media-counterpart of this imagination is manifested. It is surprising, how intuitively this motor imagery can be learned and applied. However, this impression emerged during the testing of the installation by a single user. The setup has to be validated with other users to further back these experiences. Certainly, the responsiveness of the system contributes critically to this effect and thus also further increases immersion. [5]

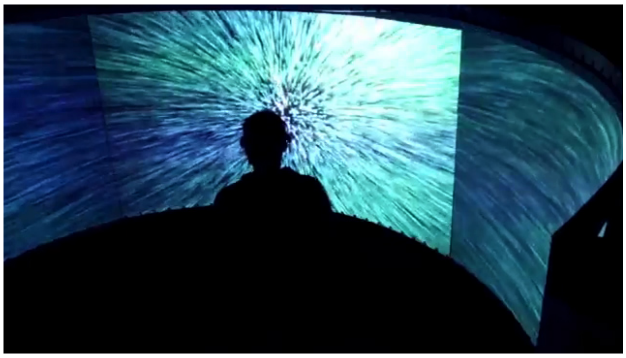

Figure 8. Overview of the exhibition situation in the Immersive Lab. A participant controls audio-visual media through a NFB loop

A fundamental question that becomes apparent in this setting is about the contradiction inherent to presenting simulated content in a physical media installation. From an ‘enactive’ point of view [22], the participant is put into a state of suspension, in order to eliminate the disparity between physical space and simulated perception. From a phenomenological point of view [23], however, this setting makes sense: the presented stimuli reach a level of consistency, and are convincing enough for the perception to fill in the missing pieces. The suspension of disbelief on the one hand, and the physical embeddedness in the immersive setup on the other, allows the participant to reach the edge of coherent perception and experience the breakdown and error-correction of movement control and spatial movement perception.

The goal is to take perception to the edge, with the aid of an adaptive feedback loop. This loop involves the participant's intention, through the motor imagery of motion, and affects the perception of stability in space, which is both a kineasthetic and a proprioceptive perception. There is a contradiction between the visual and auditory flow and the physiological stability in place in the centre of the installation. The inner perceptual achievement of suspension allows for a sense of effortless movement through space. The real-time nature of the adaptive loop contributes to the sensation of agency. Perceiving that one is 'the author of change in the environment' is usually physiologically linked through the coherence between the efferent and afferent sensory streams tied to an action [24]. In this configuration, providing agency is achieved by circumventing direct action and directly taking the cortical arousal state to

[5] For a short video documentation see: `https://tube.switch.ch/videos/e815b5e7`

modify the media stimuli presented to vision and audition.

Critical for the success of this effect is a responsive mapping and relaying of the felt inner states to the external audiovisual stream. Not only should the setup be reactive in the split-second temporal resolution, but also cover a meaningful range, which can be thoroughly explored. Only then does the setup become an extension or dissolvent of the participant's corporeal boundaries.

6.2 Implementation

On the hardware and setup level, the applying of the EEG BCI system remains critical for a reliable and valid data flow from the brain to the subsequent devices. Dry electrodes have not been able to convince any EEG expert in respect to signal quality. Impedances below 10 kΩ at the electrode are not considered feasible for any EEG application, especially not for real time signals. In the case of dry electrodes, impedances can be as high as >100 kΩ and therefore the measured signal is highly unreliable [12]. Notably, signal quality or vulnerability to external noise sources increases proportionally with the impedance. Wet electrodes, on the other hand, require a more tedious and time-consuming mounting, which certainly limits their use in artistic contexts, especially in public installations or performances.

Even with an implementation of second order computations on the signal like entropy measures, which are less susceptible to bad signals, stable and reliable signals are key for a proper setup. This is particularly true when it comes to scales and ranges of mapped parameters, which have to be carefully optimised to allow for a satisfying immersion, as it is aimed at in the case of our installation. Of special note, we can not generalise our settings to a broader audience at this point because our installation has been set up and calibrated for a single individual. Beyond electrode montage difficulties, impedances and individuality issues, further artefacts can be present in the signal. Most prominently, and inevitable in an unconstrained media installation, are movement artefacts. There are also issues with the wireless data transmission streaming (mostly Bluetooth) given the spatial extent and interference present in many installation venues.

Taken together, these technical aspects still pose some limitations on the endeavour of using BCIs as live data for art installations.

7. OUTLOOK

It is conceivable that changing the currently fixed relationship between mental states and media content to an evolving one could increase immersiveness and alleviate the habituation and saturation process taking place in any artificial scenario. On the other hand, a quick succession of changes might prove to be counterproductive. After all, achieving through an adaptive loop an inner state of agency and telekinesis relies on a carefully calibrated configuration of techniques and connections. Another interesting modification of the setup could involve the generation of more naturalistic audiovisual content as part of the adaptive feedback loop.

On the technical side, the basic setup would profit from a faster and easier montage of the electrode headband. Additionally, exact positioning, especially in the case of the motor cortex electrodes, and individual differences are critical for optimised data quality. The responsiveness of the EEG entropy feature extraction could also be improved to better handle the participant's willingness to change movement directionality. Such optimisation could not only be performed on the parameters inherent to the AE calculation but also be implemented as an additional layer of signal analysis (e.g., rate of change of AE difference).

Given the relative stability of the BCI headset construction and measures of artefact and noise control in the EEG signal processing pipeline, it is conceivable that the participant can also make use of the touch features of the *Immersive Lab*. This could add an interesting optional layer of possibly further explorable amalgamation of the fed back states and modalities.

Thinking ahead, the chosen approach possesses great application potential in the context of VR. Being able to control through imagined rather than physical locomotion ones own movement through a virtual environment constitutes a fundamentally different approach to currently existing navigation and locomotion interfaces for VR. Traditional locomotion interfaces place the user of a VR system into a constraining physical exertion device such as a omni-directional treadmill or sliding surface within which he or she is barely able to execute natural locomotion behaviours, BCI-based interfaces dont require such a setup since they abolish the need for actual physical locomotion but instead tap into the brains innate capability to supplant actual motor activity with imagined motor activity. The preliminary results that have been described in this paper indicate that a BCI-based interface in combination with highly correlated and spatialised audiovisual feedback can successfully supplement physical and vestibular self-motion cues and thereby offer a level of movement control and awareness that is likely more natural and intuitive than is the case for traditional mechanical locomotion interfaces.

Finally, given the current state of the project and its evaluation, the installation would profit from experiences from different users. Ideally, technical functionality should be tested with different age groups and their respective technological backgrounds to investigate individual differences and generalisability of the system. A survey on both the control aspects but also on the subjective, immersive experience is envisioned to better evaluate the installation. Lastly, given the slow visual movements and absence of flickering or flashes, health issues (e.g. epilepsy or nausea) are very unlikely. General reported side effects of NFB are unsystematic and only reported in very rare cases with non-critical symptoms. On the other hand, the situation in the installation and the relying on NFB principles, may additionally qualify *State Dependency* as a relaxing or meditative experience.

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