Passive Brain-Computer Interfacing in the Museum of Stillness

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Abstract
We describe a live demonstration we performed at the Museum of Stillness, consisting of a closed-loop passive brain-computer interface focusing on a state of relaxation. This state was measured while participants were contemplating a painting in the Museum of Stillness, Berlin. Participants were provided with auditory feedback in the form of the sound of wind blowing with varying amplitude. An audience in a separate room was given a view of the participant by camera and an artistic visualisation of that participant's state involving the same painting. A high offline classification accuracy was reached using only 10 dry electrodes and a calibration phase that lasted only 200 seconds.

Author Keywords
Passive brain-computer interface; neuroadaptive technology; art; live demonstration

Introduction
A brain-computer interface (BCI) allows an output channel to be established between a human brain and a computer "that is neither neuromuscular nor hormonal" [6], as opposed to all natural, unaided forms of human output (e.g. speech, movement, object manipulation), which rely on muscular activity. As such, BCI-based systems have long been seen primarily as solutions for people with impaired muscle function: a BCI could provide a means of com-

munication to those with no other option left. Instead of using their muscles for communication, these people could generate specific patterns of brain activity. The computer monitors their brain activity, recognises these specific patterns, and translates them into commands.

The technology that is used to establish such brain-computer communication channels, however, does not rule out other applications. In particular, *passive* brain-computer interfaces have been proposed to monitor brain activity that naturally occurs during human-computer interaction in order to provide an additional source of input to the computer [8, 3]. For example, when a person experiences high levels of workload, this is automatically reflected in their brain activity. A computer that has access to this brain activity may thus be able to detect this person's mental state, and adapt accordingly, for example by increasing automation [4]. Importantly, this human-computer interaction takes place *implicitly* [7]: the human does not explicitly instruct the computer; it acts autonomously based on an analysis of the human's brain activity.

Such *neuroadaptive technology* [9, 5] can have a number of benefits. It can relieve their users of the need for (some) explicit communication, and provide automated adaptation to the user's current mental state.

Here we describe a simple closed-loop passive BCI-based live demonstration that we implemented for the *Museum der Stille* (Museum of Stillness) in Berlin. Visitors of the museum were invited to have their brain activity monitored while they were attempting to relax, while they themselves and an audience in another room were provided with auditory and visual feedback, respectively, reflecting the participant's state of relaxation as they contemplated a specific work of art.

Note that this was not a scientific experiment. Data collection was limited as it was conducted in a public setting, and the set-up was designed primarily for its demonstrative value.

The Museum of Stillness

"(...) art has something to do with the achievement of stillness in the midst of chaos." — Saul Bellow

The Museum of Stillness[1] was founded in 1994 by Russian painter Nikolai Makarov, with the goal of providing the public of a large metropolis with a secular space for contemplation. Often, such spaces are only found in the context of religious functions. Aside from a small exhibition, the Museum of Stillness therefore contains one Room of Stillness which has been specifically designed for the purpose of contemplation. A large-format painting by Makarov, intended to "radiate a meditative aura", forms the centrepiece of the room.

The *Long Night of Museums*[2] is an annual event that was first held in Berlin in 1997. One day each summer, the city's museums remain open for longer than usual and organise special events. For this occasion, Team PhyPA and the Museum of Stillness collaborated in an attempt to demonstrate the visitors' ability to disengage whilst in the Room of Stillness.

Methods

The event was advertised as part of the Long Night of Museums. Six visitors of the event at the museum volunteered to be participants after the procedure had been explained to them.

[1] museum-der-stille.de

[2] lange-nacht-der-museen.de

Set-Up
One member of our team was with the audience at all times, explaining the process and answering questions, while two experimenters remained with the participants.

A small side room (Figure 1) to the Room of Stillness was used for preparation. Participants were seated in front of a computer screen. With their permission, a headband was placed around their heads, with which we would measure their electroencephalogram (EEG). This headband was custom-made by Brain Products GmbH (Gilching, Germany) and contained 10 actiCAP Xpress dry electrodes: two on the forehead, one each temporally, and six covering parietal/occipital sites. Ground and reference electrodes were placed on the forehead as well. The Brain Products MOVE system was used to wirelessly connect the electrodes to the computer, allowing the participants to walk from the side room to the main room, and sit freely when there.

Figure 1: The side room used for preparation and calibration.

After the electrodes were placed, a calibration phase was started.

Offline: Calibration
The calibration phase lasted only 200 seconds, gathering 100 seconds of data per class, in alternating trials of 10 seconds each. During ten seconds of one class, 'relaxation', a crosshair was displayed on the screen and participants were instructed to focus their thoughts inwardly on small details of a specific memory, chosen by themselves before recording began. During the second class, 'engagement', participants were shown randomly-coloured, randomly-sized rectangles appearing and disappearing on the screen at a rate of 60 Hz. They had the (impossible) task to attempt to count how many pink rectangles they saw.

Thus, the calibration paradigm elicited examples of brain activity during visual and cognitive load, as well as during inward contemplation. Using BCILAB [2], we used common spatial patterns [1] to extract features in the 6-15 Hz frequency band, in one-second time windows to distinguish 'relaxation' from 'engagement'. The classifier was trained using regularised linear discriminant analysis and a 5×5 nested cross-validation with margins of 5.

The participant was subsequently guided to the Room of Stillness, and the calibrated classifier was applied online to continuously assess the participant's state of relaxation.

Online: Feedback and Visualisation
The participant was seated centrally in the room facing the painting (as in Figure 2), and was instructed to contemplate the painting. Meanwhile, their current brain activity was classified at a rate of 10 Hz. The current state of relaxation was taken to be the mean classification value over the past four seconds.

Figure 2: A participant sitting in the Room of Stillness, seen from the side room.

The participant was given auditory feedback based on their current state of relaxation in the form of a recording of wind blowing. The closer they were to achieving a brain state comparable to the one recorded during the 'relaxation' calibration phases, the lower the amplitude of the wind recording would be, and vice versa. In effect, we implemented a positive feedback loop with a decrease in relaxation leading to louder wind, making it more difficult to focus.

In a different room, a varying audience of up to approximately 20 people was given visual feedback illustrated in Figure 3. When the participant was relaxed, they were given a clear view of the painting. The further the participant deviated from the calibrated state of relaxation, the more would the painting be covered by red clouds, until it was no longer visible. As the painting is intended to reflect tranquillity, its visibility/occlusion thus reflects the measurements of the participant's mental state. Additionally, a graph traced the history of these mental state measurements. Furthermore, a camera inside the room aimed at the participant's face provided the audience with a view of the participant's expressions.

Results

This was primarily a demonstration, and not a scientific experiment. As it was conducted in a public setting, data collection was limited. It was however necessary to record calibration data. The offline estimated classification accuracies are reported in Table 1. With chance level at 50% and significance reached at 57% (with $\alpha = 5\%$), significance is reached for all participants. This means that the BCI system was capable of reliably distinguishing the participants' mental states—'relaxed' versus 'engaged' as induced by the calibration paradigm—based on their EEG.

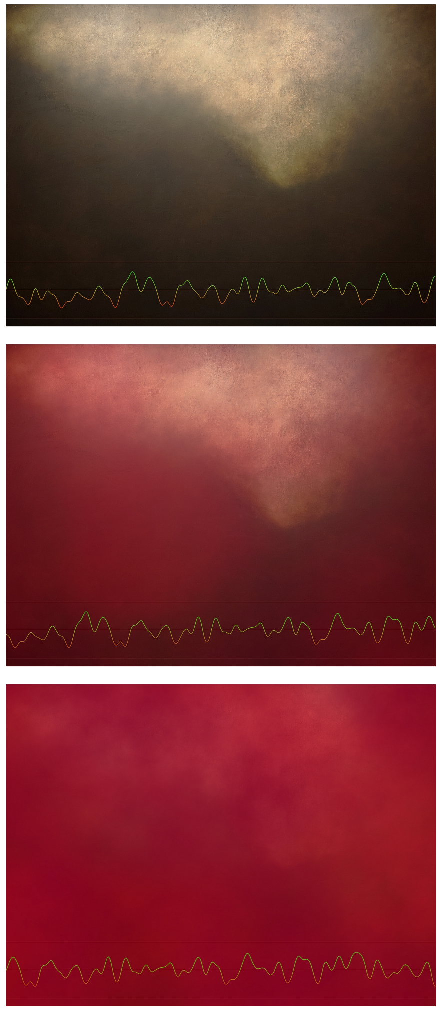

Figure 3: The audience feedback shows the painting occluded to various degrees depending on the participant's state of relaxation. A (for this figure pseudorandom) time trace of this state is shown at the bottom; the current value at the right.

Participant	**TP**	**TN**	**Acc**
1	87	78	82
2	89	87	88
3	84	81	82
4	92	87	89
5	85	73	79
6	67	60	63
Mean	**84**	**78**	**80**

Table 1: Offline estimates of the classifier accuracies in percentage. TP: True positive; TN: true negative; Acc: overall accuracy. Significance is reached at 57%.

Discussion

We presented the set-up we used to give a passive BCI demonstration in the Museum of Stillness, focusing on relaxation and contemplation as enabled by art.

In a more scientific context, we could use a similar set-up to test the hypothesis that the Room of Stillness does indeed induce a state of tranquillity in its observers. At least one additional condition would have to be present, where participants are confronted with a different room with a different artistic arrangement. The analysis would focus on the difference between the mental states induced by the two rooms, the hypothesis being that one induces states more similar to the calibrated state of 'relaxation' than the other. There would be no auditory feedback.

Aside from the data in Table 1, we currently have no hard numbers to present at this time. Due to, among other things, the focus on speed and flexibility for the demonstration's sake, and the presence of the audience, no meaningful online measurements would have been possible.

The results do however show that high classification accuracies are possible using only ten dry electrodes and a

200-second calibration phase.

As a demonstration, it was well received by both the participants and the audience. The participants were generally intrigued by the auditory feedback given to reflect their mental state, and although it distracted them at times, they reported that it could also help them focus their thoughts. The audience was positive. The live video feed helped them to correlate the graph with the participant's state as they perceived it themselves. In particular, they recalled an episode where one participant appeared to be in a state of complete relaxation at all times: the painting was fully visible, and also the graph indicated no deviation in the mental state towards engagement. Usually, participants were only able to hold a state of relaxation for a certain period of time, with short relapses into seeming distraction in between. After verifying that the equipment was in order, we questioned the participant, who reported being highly experienced in zazen seated meditation, which she performed during the experiment. The measurements thus accurately reflected her ability to sustain a consistent state of mind, as reflected in her EEG. The role that the Room of Stillness may have played in this ability remains to be investigated, but the passive BCI's ability to accurately reflect this, after merely a very short, 10-electrode training session, speaks in favour of such an investigation being possible.

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