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As Published: https://doi.org/10.1145/3586182.3615803

Publisher: ACM|The 36th Annual ACM Symposium on User Interface Software and Technology

Persistent URL: https://hdl.handle.net/1721.1/152898

Version: Final published version: final published article, as it appeared in a journal, conference proceedings, or other formally published context

Demonstration of Joie: A Joy-based Brain-Computer Interface (BCI) with Wearable Skin Conformal Polymer Electrodes

Angela Vujic
avujic@mit.edu
MIT Media Lab
Cambridge, MA, USA

Ashley Martin
ashleyma@mit.edu
MIT Media Lab
Cambridge, MA, USA

Shreyas Nisal
snisal@mit.edu
MIT Media Lab
Cambridge, MA, USA

Manaal Mohammed
manaal@mit.edu
MIT Media Lab
Cambridge, MA, USA

Pattie Maes
pattie@media.mit.edu
MIT Media Lab
Cambridge, MA, USA

ABSTRACT

We designed Joie, a joy-based electroencephalography (EEG) brain-computer interface (BCI). Users interact with Joie by imagining joyous thoughts and images that alter their prefrontal EEG asymmetries. These asymmetries control their character's movement in an endless runner video game, where joyous thoughts cause left prefrontal asymmetry that leads to receiving a reward. In this demonstration, we present Joie with a wearable, dry skin conformal polymer electrode EEG headband. We conducted a pilot evaluation (11 participants, 3 training sessions per participant) to assess neuro-feedback efficacy and workload. We observed that our participants were able to perform relative left activation significantly greater than right activation and create single-session improvements in resting baseline asymmetry. We also report on perceived user demand, effort and performance.

CCS CONCEPTS

• **Human-centered computing** → **Human computer interaction (HCI)**; • **Hardware** → *Emerging technologies.*

KEYWORDS

Brain-computer interfaces (BCI), Wearable technology, Affect

ACM Reference Format:
Angela Vujic, Ashley Martin, Shreyas Nisal, Manaal Mohammed, and Pattie Maes. 2023. Demonstration of Joie: A Joy-based Brain-Computer Interface (BCI) with Wearable Skin Conformal Polymer Electrodes. In *The 36th Annual ACM Symposium on User Interface Software and Technology (UIST '23 Adjunct), October 29–November 01, 2023, San Francisco, CA, USA.* ACM, New York, NY, USA, 3 pages. https://doi.org/10.1145/3586182.3615803

1 INTRODUCTION

In human-computer interaction (HCI), we have seen brain-computer interfaces (BCIs) for meditation [18], attention [10], personalized learning [19], gaming [3], and more. However, emotion regulation and modulation has received little to no attention, despite the growing challenge of anxiety and depression that impacts up to 32.3% of U.S. adults [16].

Creating emotion-based BCIs is challenging due to a number of factors, including difficulty in recording affect that may originate from deep brain structures [8], the requirement of high-density EEG caps or significant data collection to achieve sufficient model performance [7], and selecting EEG features that are well-studied and defined for their role in affective processes. However, as demonstrated by Aranyi et al., left and right prefrontal cortical asymmetries can be used to create an anger-based BCI with minimal training [2]. They adapted the model of approach and withdrawal motivation to show that increased relative left frontal activity can serve as an index of anger [6]. Approach motivation has also been associated with happiness or excitement, such as when infants see happy faces [4]. With Joie, we demonstrate how approach motivation can enable "joy and excitement" as BCI input.

In our work at UIST, we designed and evaluated Joie, a novel joy-based EEG-BCI which helps users learn strategies for eliciting positive emotions. In a placebo-controlled trial (20 participants, 15 training sessions per participant), we found that our experiment group instructed to imagine positive music, winning awards, and similar strategies, had a significant group-level increase in relative left frontal activity, compared to our placebo and control groups which had non-significant changes. We demonstrated this interaction with EEG, where prior work was only shown with fNIRS. Compared to fNIRS, EEG can be more easily integrated into eyeglasses [10], headphones [12], headbands [11], and AR/VR headsets [3] to benefit a wider number of users in real-world environments.

In this demonstration, we present a wearable, dry-electrode Joie system along with results from a pilot study with 11 participants and three training sessions. We observed that participants were able to use joyous thoughts and images to perform relative left activation significantly greater than right activation and create single-session improvements in relative left prefrontal brain activity. We also assessed workload in surveys and conducted post-game interviews.

2 DESIGN

We assembled a prototype of a dry-electrode EEG headband (Figure 1). The headband records electrode locations Fp1, Fp2, Af7, and Af8 of the International 10-20 system. We created the prototype with following components: a OpenBCI Cyton board [13], IDUN

UIST '23 Adjunct, October 29–November 01, 2023, San Francisco, CA, USA

ACM ISBN 979-8-4007-0096-5/23/10.
https://doi.org/10.1145/3586182.3615803

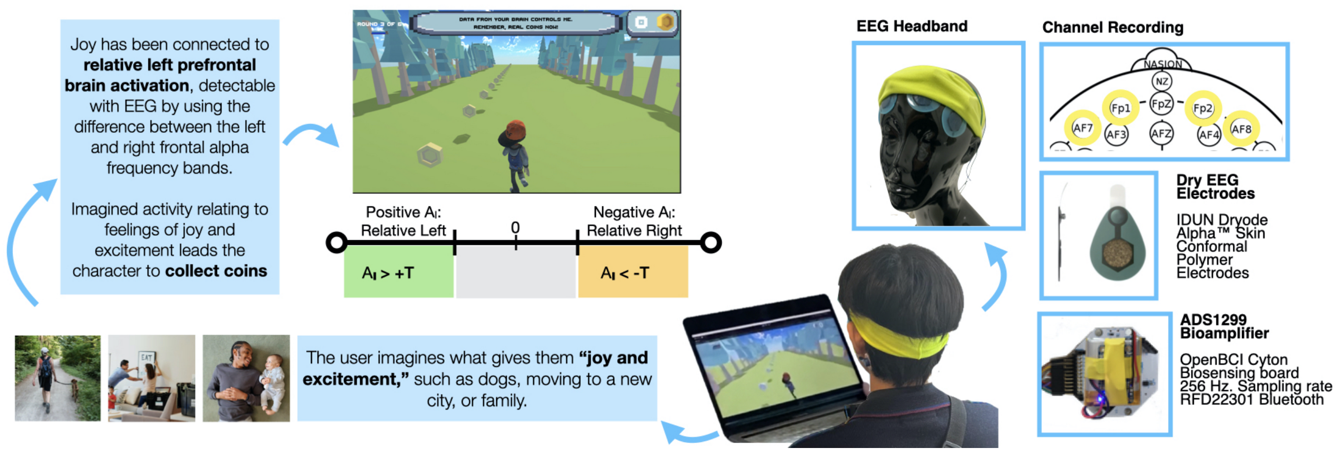

Figure 1: Joie's neurofeedback design with a wearable, dry electrode headband. The user imagines joyous thoughts activate prefrontal left asymmetries that cause their character to collect coins as a reward.

conformal polymer dry EEG electrodes [15], an AA battery pack, and a fabric headband with sewn-in snap electrode cable connectors. The device has a 256 Hz sampling rate and communicates via Bluetooth. The EEG signal was captured by a Python script using the Python interface to LabStreamingLayer, PyLSL [14], and EEG preprocessing, feature extraction and classification was performed using MNE Python [5]. Classification results were communicated to a Unity front-end via WebSockets. We were motivated to use prefrontal locations on the forehead as it is an area without hair and can eventually be integrated into head-mounted display (HMD) applications such as VR headsets [3]. Further details on our signal processing and feedback pipeline are provided in Vujic et al. [17].

3 METHODS AND RESULTS

All procedures were approved by the MIT Committee on the Use of Humans as Experimental Subjects (COUHES). We recruited participants (N = 11, ages 20 to 57, μ_{age} = 32.0, 5 males, 5 females, 1 unspecified) to play a single session of Joie with 3 trainings. After consent procedures, the forehead was prepared with a 70% isopropyl alcohol swab. We placed the headband, adjusted the electrodes, and performed a visual inspection of the EEG signal in the OpenBCI GUI [13] with blink and jaw clench tests. Once signal was stable and not displaying high-frequency noise components, the participant completed a pre-survey. Afterwards, the participant played a round of Joie and completed post-surveys including perceived joy, attention levels, a description of mental strategies used, the NASA Task Load Index (TLX) survey, and an interview.

$$A_i = \log_{10}(\mu(Af8_\alpha, Fp2_\alpha)) - \log_{10}(\mu(Af7_\alpha, Fp1_\alpha)) \quad (1)$$

We analyzed the ability for participants to increase their resting asymmetry scores. Resting asymmetry can serve as an indicator of neurofeedback efficacy, as it is a period in which alpha scores are not influenced by attention levels, and alpha suppression occurs during cognitive tasks [9]. To calculate asymmetry, we adapted the most well-studied alpha asymmetry index from cognitive science literature on approach and withdrawal motivation [6]. Our equation is given in 1.

Two pre-baselines and one post-baseline were recorded, each four minutes. We calculated asymmetry indices for each participant's pre-baseline and post-baseline and report on these results in Figure 2. First we tested if the pre- and post-baselines are normally distributed using a Shapiro-Wilk normality test and found both are normally distributed ($p > 0.05$) but have unequal variances. Thus we used a two-sided Welch two sample t-test. We observed a significant increase in resting asymmetries (t = -12.42, $p < 0.05^{**}$), which are shown in a box plot in Figure 2. Further, when we evaluated the proportion of left vs. right hits while omitting outliers, defined as left hits occurring greater than 95% or less than 5% of the time, the **average proportion of left vs. right hits was 72.27%** (μ = 72.27%, σ = 16.3%, N = 15 4-minute trainings)

The results of our administered NASA-TLX are shown in Figure 3. Our results suggest that the task requires "slightly high" mental demand (μ = 4.71, σ = 1.6, [2,7]) and effort (μ = 5.0, σ = 1.4, [2,6]) , and may involve frustration (μ = 3.42, σ = 1.7, [1,5]) as denoted by the Likert scale. Participants reported being "neither" successful nor unsuccessful, though interestingly, most participants were able to increase their post-game resting asymmetry to indicate neurofeedback success (Figure 2). These qualitative results suggest that the task is mentally demanding, however, participants reported in follow-up interviews that they gained value from the practice of "joyful" mental imagery, and also reported self-perceived feelings of "joy" during the task. Future work can evaluate methods to reduce workload for participants. Future work can evaluate methods to reduce workload for participants and compare joy-imagery tasks to other mental imagery tasks, such as imagined left and right arm movement used in motor imagery BCIs[1].

ACKNOWLEDGMENTS

We thank our research participants for their time and efforts and members of the Fluid Interfaces Group for their helpful feedback.

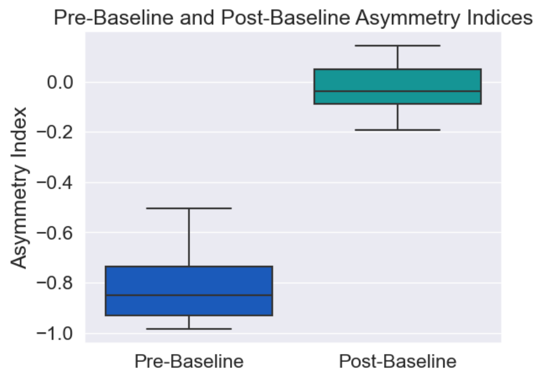

Figure 2: Single-session neurofeedback efficacy results. Box plot showing an increase in relative left frontal asymmetry before and after playing Joie. Asymmetry index defined in Equation 1. Participants were able to create a significant group-level increase in pre- and post-baseline scores.

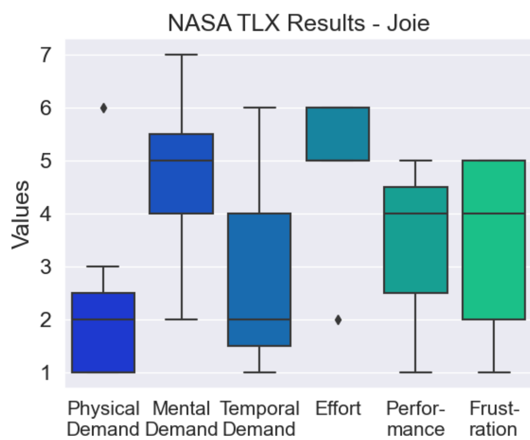

Figure 3: User perceived demand, effort and performance results. Box plot showing spread of reported NASA-TLX results after playing Joie

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