Headmusic: Exploring the Potential of a Low-Cost Commercial EEG Headset for the Creation of NIMEs

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ABSTRACT

In recent years Electroencephalography (EEG) technology has evolved to such an extent that controlling software with the bare mind is no longer impossible. In addition, with the market introduction of various commercial devices even private households can now afford to purchase a (simplified) EEG device. This unlocks new prospects for the development of user interfaces. Especially people with severe physical disabilities could benefit by facilitating common difficulties (e.g. in terms of mobility or communication) but also for specific purposes such as making music. The goal of our work is to evaluate the applicability of a cheap, commercial EEG headset to be used as an input device for new musical interfaces (NIMEs). Our findings demonstrate that there are at least 7 input actions which can be unambiguously differentiated by machine learning and can be mapped to musical notes in order to play basic melodies.

1. INTRODUCTION

Music is a fundamental expression of the human being. People with disabilities are often excluded from this form of expression, even if they have the creative potential for productive musical exchange.[1] For example, physical disabilities can complicate the use of musical instruments that have complex user interfaces to a considerable extent or even make them impossible. For this reason, there have been various approaches, particularly in the research field of New Interfaces for Musical Expression (NIME), towards the design of novel instruments that are better suitable for people with different disabilities (e.g. [2],[3],[4]). In cases of serious and severe physical disabilities, event-related potentials (ERP) from the electroencephalogram (EEG) could be used to overcome access barriers to music performance and composition.

Brainwaves are a reflection of the processes of the brain and thus a conscious manipulation of brainwaves is possible, for example through relaxation or complex thinking[5]. However, these general cognitive states are by no means quickly changeable. Although people who are experienced with meditation can change them more efficiently, this change would be still not fast enough to play a piece of music. Another problem is the fact that high-quality medical grade EEGs are too expensive for every-day use and furthermore require considerable time and effort to operate. Thus, the goal of this work is to test whether a commercial, low-cost EEG system like MUSE could be used as an input device for musical activities like improvising or reproducing music. We will assess the possible input actions we can capture by EEG and then create a first mapping from actions to musical notes. With the resulting prototypical implementation of our proposed new musical interface 'Headmusic' it should be possible to play a given musical piece.

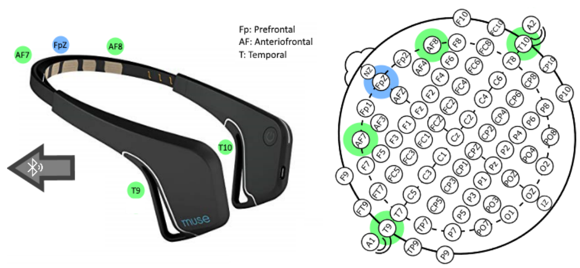

Figure 1. left: location of sensors (green) and reference sensor (blue) at the MUSE headset[6], right: MUSE sensor positions in the context of all possible sensor positioned according to Oostenveld et al.[7]

2. RELATED WORK

Despite the relevance of the topic, research in the EEG domain has mostly been devoted to other aspects than those described in this paper. While there exists a large body of work on brain-computer interfaces (BCI) for people with physical impairments, such works remain limited in terms of latency and real-time requirements, which are essential for musical instruments. Some studies already proved the general possibility of consciously manipulating alpha waves, which would consequently enable a classification of thoughts to notes/sounds. For example, Corralejo et al. demonstrated the possibility to classify optically triggered ERP with machine-learning methods - in their concrete research case for the control of SmartHome applications[8]. However, it cannot be assumed that this approach could be used for the development of musical instruments, since the latency of more than 300ms would be too high. There are other examples and previous BCIs that have contributed to the creation of music interfaces, starting with Alvin Lucier's experimental piece "Music for Solo Performer", where the brain waves of a performer were used to control percussion instruments[9, 10]. Pinegger et al. focused their work on music-related topics and developed a system that utilizes the P300 pattern to compose music[11]. Their study shows the reliable functionality of the user interface and the participants enjoyed the brain composing process. Yet their P300 based approach cannot be used to play music directly, since the delay between thoughts and notes to be played would be the same as in the work of Corralejo et al. Folgieri and Zichella tried to solve this problem using an approach, where different stimuli are combined in order to play music notes with thinking (e.g. the users associate a color, a sound and a gesture with a sound to be played). The immediate success rate albeit is at a mere 40 to 50 percent[12]. Other BCI research projects which are related to music focus more on enjoyment evaluation[13], EEG soundscapes for meditation[14] or sleep sonification[15]. Furthermore there are many NIMEs based on emotion sonification[16, 17, 18, 19].

In many studies research is exclusively based on the use of sophisticated medical EEG devices or focused on developing advanced technology for EEG devices (e.g. in the paper of Aranyi et al. where anger is used to control a virtual character[20]). Nevertheless in 2017 Krigolson et al. compared the MUSE headband with a classical EEG, the ”Brain Vision ActiChamp System”[21]. Two experiments were carried out in two groups of 60 persons, one group using MUSE and the other group using ActiChamp. Their results show *”that with a single computer and a portable EEG system such as the MUSE one can conduct ERP research with ease thus greatly extending the possible use of the ERP methodology to a variety of novel contexts”*[22], but on the other hand they also found that data quality and sampling rates could be a problem.

3. TECHNICAL REALIZATION

As shown in figure 1 the MUSE headset provides 7 EEG sensors of which two are located on the left and right side of the forehead and two are placed behind the ears (all marked in green). Additionally, three reference sensors are placed in the middle of the forehead (marked with blue). Furthermore, the headset tracks the movement of the head with an integrated gyroscope and accelerometer. The system sends the sensor data via Bluetooth, so that it can be received, displayed and passed over for subsequent processing using a software called ”Muse Direct”.

There are different approaches to use the EEG data for controls. One such method is the P300 response, which is based on a brain signal that occurs in response approximately 300ms after a particularly external stimuli. It is well known for the use case of selecting letters from a matrix to spell out words.[23] Yet this approach is not suitable for the creation of musical instruments, since the feedback for user actions does not follow immediately. For this reason, our approach is to identify actions that produce instant, unique and recognizable patterns with the help of supervised machine learning. We use ”Wekinator”[24], which is a machine learning tool based on the ”Weka” software, to train models that can detect these action patterns. Wekinator listens for OSC input messages. Each input must be sent as a float in this message. However, Muse Direct send its data stream in a different format.

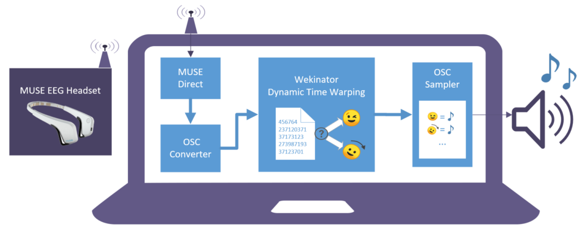

Figure 2. Headmusic system structure

To address this we developed a small, lightweight converter that transforms the output of Muse Direct to a format that can be used by Wekinator (see data flow and system structure in figure 2). The converter uses the open source library OSCP5 to receive and send OSC messages. Once the program is started, it listens to the specified input port. As soon as it receives a signal, the 4 EEG values and the gyroscope data are read, converted into float type values and sent to the output. Wekinator has three main output types: Classification outputs, Numeric outputs and Dynamic time warping event outputs (DTW). We chose the DTW type, since it is most suitable for the detection of gestures from inputs that change over a defined period of time.[25] DTW events can be trained to the model by recording the user actions using the record-button in Wekinator. Unlike the other output types, DTW requires only a single sample, therefore it must be ensured during recording that no inaccurate actions are trained.

4. PRELIMINARY EXAMINATION

Before implementing the mapping of actions to musical notes, we first manually checked how different actions are represented in their graphs using the graphical representation of the sensor data provided by Muse Direct. To do this, we reviewed different actions, starting with bare thinking of specific notes. As expected, these imagined notes are not distinguishable. Muscular artifacts, on the other hand, are much easier to detect: when wiggling the feet, for example, a noticeable peak can be seen in the graphs. Based on this finding, we prepared a list of the individual actions and their recognizability (see table 1).

Rank	*Action*	*Recognizability*
1	Head movement	very good (98%)
2	Blink with both eyes	very good (94%)
3	Blink with one eye	good (81%)
4	Raise Eyebrows	differing individually
5	Pull up cheek	differing individually
6	Move lower body parts	very bad
7	Thinking notes	not recognizable

Table 1. Ranked actions and recognizability using MUSE EEG and Wekinator DTW

The actions detected by the headset’s motion sensors (e.g. tilting the head sideways, forward or backward) are more easy to distinguish and provide the best accuracy.

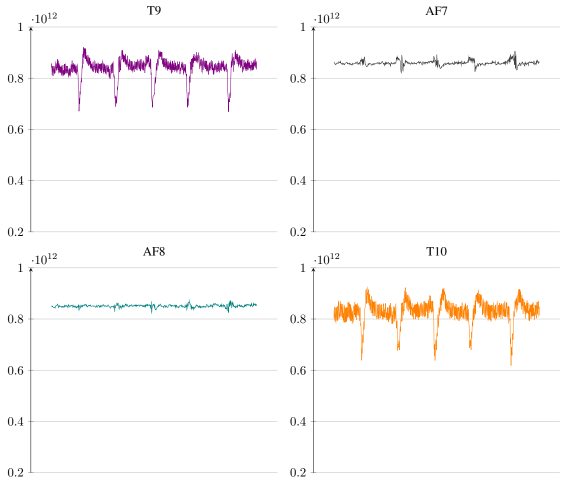

Figure 3. Resulting data for action "blinking with both eyes"

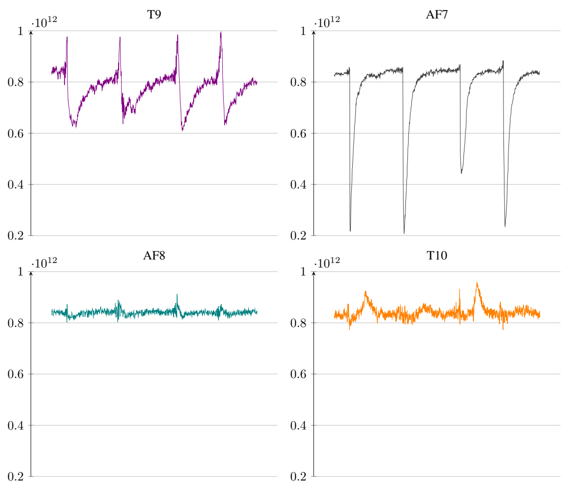

Figure 4. Resulting data for action "blinking with left eye"

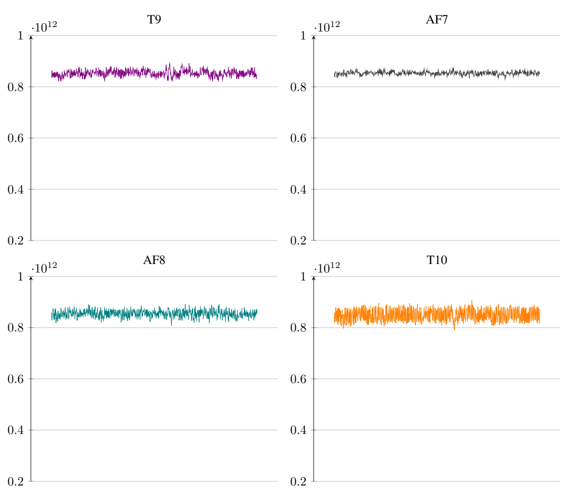

Figure 5. Resulting data for no action / idle state

Nevertheless, there are also actions we could detect by the EEG sensors: Particularly noteworthy are all actions that affect the movement of the eye muscles (e.g. blinking). A distinction between movements of other facial muscles, like for example moving the cheeks or mouth, is only possible within one session and would therefore have to be trained anew for each session. In addition, these patterns are very similar so that they are often confounded. All other tested actions were in effect either varying between sessions or were very similar to one of the previous actions, but in a less pronounced way.

Furthermore, during our first attempts we encountered some problems with the technical system (MUSE headset and computer system) and the software:

- The MUSE EEG sensors can easily be displaced since the contacts dry and looser than the gel contacts used in medical EEG devices. Solution: Sit still, fixate the headband with an additional bandeau.

- In some cases the MUSE device sends distorted signals after a longer time of usage (>10min), since perspiration accumulates between the electrodes and the skin. Solution: Avoid movement and excitement, avoid settings with high temperature and humidity.

- During longer sessions wearing the device will feel uncomfortable to the user. Thus for most users sessions should not be longer than 30 minutes.

- The EEG patterns are highly dependent on the mode of application of the headband and even when considering the same manner of application each time, differences may occur at the previous session. Solution: Rigorous positioning and calibration.

- Especially the software 'Muse Direct' is computationally intensive, which leads to transmission glitches. The standard setup requires ˜1.5GHz CPU capacity on the Win 10 system we work with. A minimum setup (EEG data only, no pre-processing) requires ˜1.0GHz CPU capacity. Solution: Implementing a lightweight alternative to 'Muse Direct' that sends the output directly to Wekinator.

5. PROTOTYPE

After the preliminary exploration of possible input actions, we decided to use 4 different head movements and 3 eye movements and mapped them to 7 notes:

Note	*Action*
D4	Tilt head right
E4	Blink with both eyes
F$^{\#}$4	Tilt head back
G4	Tilt head left
A4	Tilt head front
H4	Blink with left eye
D5	Blink with right eye

Table 2. Headmusic mapping from actions to notes

Whenever the system identifies one of this actions, the corresponding sound samples are triggered. For the current version of the prototype we used freely available violin samples recorded by Philharmonia orchestra players [1].

6. ALTERNATIVES & DIFFERENTIATION

In principle, the input actions specified for the prototype are also realizable through other approaches without EEG technology. One possible approach would be, for example, the detection of blinking and head movements with the help of camera-based facial and movement recognition. With this approach, however, users would constantly be forced to focus on the camera system. The advantage of a wireless EEG headset is therefore the ability to move around and have the freedom to interact with other musicians.

7. EVALUATION

The aim of the current study is to explore the accuracy and user-acceptance of the Headmusic prototype. This preliminary evaluation with non-disabled users should be the proof of concept before testing the system with a group of participants with disabilities. Therefore, we performed two brief experiments with a small group of test subjects (n=8, 3 with long hair, 5 with short hair). First, we investigated the usability of the instrument for improvising (Experiment 1) and then reproducing written music (Experiment 2). The experiments were conducted in a soundproofed room. Only the participant and one guiding person were in this room. We avoided additional audience in order to minimize pressure or distraction. We provided an overview screen with the assignments of actions to corresponding sounds / note values and the score sheet for the piece to be played including assigned actions (see fig. 7).

7.1 Experiment 1: Improvisation

For the first experiment, the users were asked to use the instrument in order to improvise freely for a (maximum) duration of 10 minutes. During this task, they were supposed to learn how to use the system and how input actions are mapped to sounds. Hence, the guiding person introduced them to the mapping before the test persons started to improvise. All participants first tried to play the given notes in a scale. In most cases they learned the actions after a short time and were then able to improvise more freely with the instrument.

7.2 Experiment 2: Reproduction

For the second experiment the users were asked to play a given piece using the instrument. The maximum test duration for this part of the test was 5 minutes. For the second task we decided to use a short and easy children's song (see figure 6), which consists of only 7 different notes in total and can therefore be played with the 7 most distinguishable actions. The piece is 12 bars long and contains a total number of 40 notes of which 10 have to be played with blinking and 30 by head movement. We logged all user actions inside the Headmusic system and compared them with the intended input actions for the piece in order to calculate the accuracy. With the help of video recordings, we could distinguish between inputs, that were wrong because of wrong user movements and inputs, that were wrong because of wrong identification.

7.3 Results and Discussion

All users were able to use the instrument on their own after a very short period of familiarization. In general the different Headmusic input actions did not cause major difficulties for any of the participants to learn or perform.

Figure 6. The score of the german song "Alle Vögel sind schon da"[26]

Usability: All users stated, that they would rate the usability and the latency as good. However, after a certain period of time, the muscles of the eyes became tired from blinking, and some users reported experiencing occasional confusion in their actions. A severe issue occured with 50% of the participants: The headset could not be positioned correctly due to ill-fitting and unfortunate hairstyle of the respective persons, which consequently made it impossible to continue the test, since the accuracy for actions based on EEG sensor values was not good enough.

Limitations: The test persons with more experience in musical performance criticized the restriction of notes and would have liked to be able to adjust the mapping themselves, especially for the use case of improvising freely. Furthermore, some participants mentioned the missing possibility to influence the duration of notes which leads to the problem, that the rhythm of a musical piece is not fully reproducible.In terms of accessibility it should be mentioned, that the mapping for Headmusic, which is in parts based on head movement, requires users to have at least basic control of their neck muscles. Thus, the use of head movement for musical input actions excludes some people with muscular control problems.

Accuracy: In those cases where the musicians played the piece rather slowly (less than 70BPM) and carefully, an accuracy of almost 100% was achieved. For the faster playing testers, the overall accuracy average was 84%. The detection errors mainly arose for blinking actions, while the

[1] from: www.philharmonia.co.uk/explore/sound_samples/violin

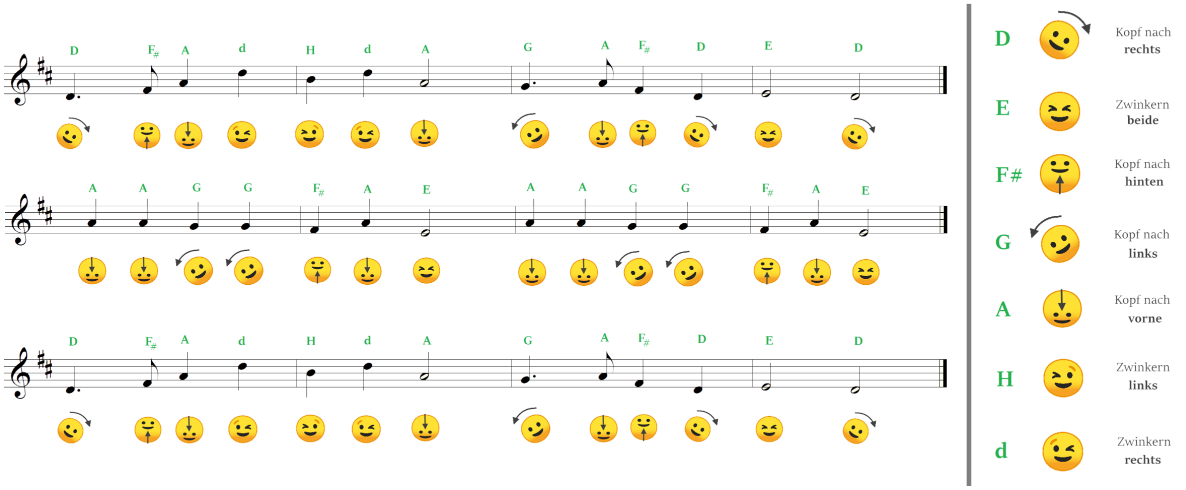

Figure 7. left: simplified score for the german song "Alle Vögel sind schon da" by Hoffmann von Fallersleben[26], with guiding input action emojis for each note. right: instruction for mapping between input actions and notes

fault rate was nearly 0% for the movements of the head. This could be improved by implementing the system with individually customized Machine Learning code instead of the prototyping tool Wekinator. The choice of another commercial EEG Headset, like the EMOTIV Epoc[27] for example, could possibly also increase the accuracy and should be tested.

Figure 8. User testing the system by playing the given musical piece

8. CONCLUSION AND WORK IN PROGRESS

In this paper we proposed a new interface for musical expression using a low-cost commercial EEG headset. With the prototype it is possible to play melodies that need a maximum of 7 different notes. This could be especially interesting for people with disabilities, who are excluded from making music (solo or in ensembles) because of their impairment. A preliminary experimental evaluation with non-disabled users showed that the Headmusic system in most cases works as intended and features a good accuracy and latency. Nonetheless, the experimental evaluation also revealed current limitations of this work, especially containing the issues with the fitting of the headset, which need to be solved, in order to use it more comfortably and without time-consuming preparation. In the next step, the amount of recognized actions needs to be extended in order to allow users to play more and different notes. Furthermore, we plan to enhance the prototype in terms of sound choice and accuracy and then evaluate the system with disabled users in order to improve it according to their feedback and special requirements.

9. REFERENCES

[1] J. Larsen, D. Overholt, and T. Moeslund, "The Prospects of Musical Instruments For People with Physical Disabilities," in *Proceedings of the International Conference on New Interfaces for Musical Expression*, 2016.

[2] M. Luhtala, T. Kymäläinen, and J. Plomp, "Designing a Music Performance Space for Persons with Intellectual Learning Disabilities," in *Proceedings of the International Conference on New Interfaces for Musical Expression*, 2011, pp. 429–432.

[3] A. J. Hornof, T. Rogers, and T. Halverson, "EyeMusic : Performing Live Music and Multimedia Compositions with Eye Movements," in *Proceedings of the International Conference on New Interfaces for Musical Expression*, 2007, pp. 299–300.

[4] C. Tam, H. Schwellnus, C. Eaton, Y. Hamdani, A. Lamont, and T. Chau, "Movement-to-music computer technology: a developmental play experience for children with severe physical disabilities," *Occupational Therapy International*, vol. 14, no. 2, pp. 99–112, 2007.

[5] P. Bashivan, I. Rish, and S. Heisig, “Mental State Recognition via Wearable EEG,” *CoRR*, vol. abs/1602.00985, 2016.

[6] I. Inc., “MUSE - How it works,” Website, 2019, retrieved December 8, 2019 from https://choosemuse.com/how-it-works/.

[7] R. Oostenveld and P. Praamstra, “The five percent electrode system for high-resolution EEG and ERP measurements,” *Clinical neurophysiology : official journal of the International Federation of Clinical Neurophysiology*, vol. 112, pp. 713–9, 05 2001.

[8] R. Corralejo, L. Luis, D. Alvarez, and R. Hornero, “A P300-based brain-computer interface aimed at operating electronic devices at home for severely disabled people,” *Medical biological engineering computing*, vol. 52, 08 2014.

[9] A. Lucier and D. Rosenboom, “Biofeedback and the Arts: Results of Early Experiments,” 1976.

[10] A. Lucier, *Music for solo performer*. Lovely Music, 1982.

[11] A. Pinegger, H. Hiebel, S. C. Wriessnegger, and G. R. Müller-Putz, “Composing only by thought: Novel application of the P300 brain-computer interface,” *PLOS ONE*, vol. 12, no. 9, pp. 1–19, 09 2017.

[12] R. Folgieri and M. Zichella, “A BCI-based Application in Music: Conscious Playing of Single Notes by Brainwaves,” *Comput. Entertain.*, vol. 10, no. 1, pp. 1:1–1:10, Dec. 2012.

[13] M. Abujelala, C. Abellanoza, A. Sharma, and F. Makedon, “Brain-EE: Brain Enjoyment Evaluation Using Commercial EEG Headband,” in *Proceedings of the 9th ACM International Conference on PErvasive Technologies Related to Assistive Environments*, ser. PETRA ’16. ACM, 2016, pp. 33:1–33:5.

[14] K. A. Cochrane, L. Loke, C. de Bérigny, and A. Campbell, “Sounds in the Moment: Designing an Interactive EEG Nature Soundscape for Novice Mindfulness Meditators,” in *Proceedings of the 30th Australian Conference on Computer-Human Interaction*, ser. OzCHI ’18. ACM, 2018, pp. 298–302.

[15] C. M. Fernandes, D. Migotina, and A. C. Rosa, “Sonification of Sleep EEG,” in *Proceedings of the 8th International Conference on Digital Arts*, ser. ARTECH2017. ACM, 2017, pp. 161–164.

[16] G. Leslie and T. Mullen, “MoodMixer : EEG-based Collaborative Sonification,” in *Proceedings of the International Conference on New Interfaces for Musical Expression*, 2011, pp. 296–299.

[17] J. Eaton, W. Jin, and E. Miranda, “The Space Between Us. A Live Performance with Musical Score Generated via Emotional Levels Measured in EEG of One Performer and an Audience Member,” in *Proceedings of the International Conference on New Interfaces for Musical Expression (NIME)*, London, UK, 2014, pp. 593–596.

[18] X. Lu, X. Liu, and E. Stolterman Bergqvist, ““It Sounds like She is Sad”: Introducing a Biosensing Prototype That Transforms Emotions into Real-Time Music and Facilitates Social Interaction,” in *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems*, ser. CHI EA ’19. ACM, 2019.

[19] A. Kirke and E. R. Miranda, “Combining EEG Frontal asymmetry studies with affective algorithmic composition and expressive performance models,” in *Proceedings of 37th International Computer Music Conference (ICMC)*, 2011.

[20] G. Aranyi, F. Charles, and M. Cavazza, “Anger-based BCI Using fNIRS Neurofeedback,” in *Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology*, ser. UIST ’15. ACM, 2015, pp. 511–521.

[21] B. P. GmbH, “actiCHamp,” Website, 2019, retrieved December 17, 2019 from https://www.brainproducts.com/productdetails.php?id=42.

[22] O. E. Krigolson, C. C. Williams, A. Norton, C. D. Hassall, and F. L. Colino, “Choosing MUSE: Validation of a Low-Cost, Portable EEG System for ERP Research,” *Frontiers in Neuroscience*, vol. 11, p. 109, 2017.

[23] Y. Chieh ”Denise” Chew and E. Caspary, “MusEEGk: A brain computer musical interface,” in *Proceedings of the International Conference on Human Factors in Computing Systems (CHI), Extended Abstracts Volume*, 2011, pp. 1417–1422.

[24] R. Fiebrink, D. Trueman, and P. R. Cook, “A Meta-Instrument for Interactive, On-the-Fly Machine Learning,” in *Proceedings of the International Conference on New Interfaces for Musical Expression*, 2009, pp. 280–285.

[25] R. Fiebrink, “Dynamic Time Warping in Wekinator,” Website, 2019, retrieved December 18, 2019 from http://www.wekinator.org/detailed-instructions/#Dynamic_time_warping_in_Wekinator.

[26] L. A. Alojado Publishing, “Hoffmann von Fallersleben - Alle Voegel sind schon da,” Website, 2019, retrieved December 5, 2019 from https://www.lieder-archiv.de/alle_voegel_sind_schon_da-notenblatt_300044.html.

[27] Emotiv, “EMOTIV Epoc+ 14-Channel Wireless EEG Headset,” Website, 2020, retrieved January 22, 2020 from https://www.emotiv.com/epoc/.