Grasp-IT Xmod: A Multisensory Brain-Computer Interface for Post-Stroke Motor Rehabilitation

Grasp-IT Xmod : Une interface cerveau-ordinateur multisensorielle pour la rééducation motrice post-AVC

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ABSTRACT

Grasp-IT Xmod is a multisensory and gamified brain-computer interface designed to support post-stroke motor rehabilitation of the upper limb. Indeed, stroke survivors require extensive rehabilitation work, including kinesthetic motor imagery (KMI), to stimulate neurons and recover motor function. Yet, KMI remains intangible without sensory feedback . In our system, after recording the electrical brain activity with an electroencephalographic system during KMI, multisensory feedback is given according to the quality of the KMI. This feedback consists of a visual environment and, more originally, a vibrotactile device placed on the forearm. In addition to an affording and motivating situation, the vibrotactile feedback, synchronous to the visual one, aims to promote the incorporation of the imagined movement in the user to improve their KMI performance and consequently the rehabilitation process.

CCS CONCEPTS

• **Human-centered computing** → *Haptic devices.*

KEYWORDS

Brain-Computer Interface, Vibrotactile Feedback, Multisensory Feedback, EEG, Kinesthetic Motor Imagery, Stroke

RÉSUMÉ

Grasp-IT Xmod est une interface cerveau-ordinateur ludifiée qui vise à améliorer la rééducation motrice du membre supérieur post-accident vasculaire cérébral. En effet, les survivants d'un AVC ont besoin d'un important travail de rééducation comprenant de l'imagerie motrice kinesthésique (IMK) pour stimuler les neurones et récupérer la fonction motrice perdue. Mais l'IMK est intangible sans retours. Après avoir enregistré l'activité électrique du cerveau à l'aide d'un système électroencéphalographique pendant l'imagerie motrice kinesthésique (IMK), un retour multisensoriel est donné en fonction de la qualité de l'IMK. Ce feedback est composé d'un environnement visuel et, de manière plus originale, d'un dispositif vibrotactile placé sur l'avant-bras. En complément d'une situation affordante et motivante, le retour vibrotactile, synchrone au retour visuel, vise à favoriser l'incorporation du mouvement imaginé chez l'utilisateur afin d'améliorer ses performances d'IMK et par conséquent le processus de rééducation.

MOTS-CLÉS

Interface Cerveau-Ordinateur, Retour Vibrotactile, Retour Multisensoriel, EEG, Imagination Motrice Kinesthésique, AVC

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1 INTRODUCTION

Kinesthetic motor imagery (KMI)-based brain-computer interfaces (BCI) hold great promise for the rehabilitation needs of stroke patients because of their ability to stimulate brain plasticity [3]. Interaction with this type of interface is based on the electrical brain activity generated during the execution of a KMI, recorded by electroencephalography (EEG). KMI consists of imagining a movement without execution, focusing on the haptic sensations experienced during the real movement (e.g., tactile, proprioceptive, and kinesthetic) [1, 5]. Unfortunately, KMI is a demanding task that does not generate sensory feedback on its quality, limiting the users' ability to evaluate themselves in their execution qualitatively. Therefore, to address the users' needs (i.e., patients and the therapists) to perceive the KMI performance, we developed a KMI-based BCI allowing multisensory feedback (Figure 1). This interface provides visual and vibrotactile stimuli to give situated and embodied information about the quality of the user's KMI.

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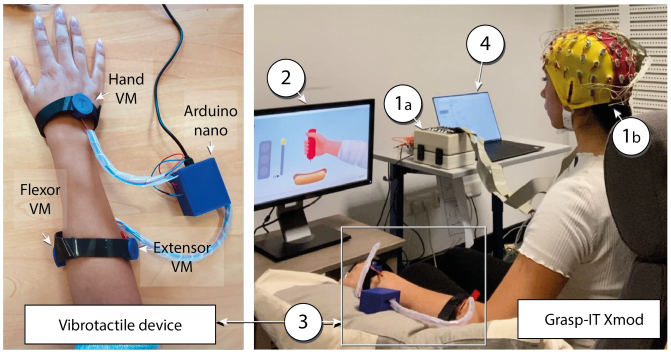


Figure 1: Right) Grasp-IT Xmod: 1a) Electroencephalography acquisition system with 1b) referring to the electrode cap. 2) Screen used for the visual feedback. 3) Vibrotactile device used for haptic feedback. 4) Experimenter computer to control the BCI and analyze the EEG signal. Left) Details of the vibrotactile device with three vibration motors (VM).

According to results from preliminary tests, we selected the feedback that proved to be more comfortable, coherent, and synchronized with the virtual environment. Our aim is that by providing thoroughly designed feedback, the users will increase their performance of the KMI through better training, resulting in an improvement of the BCI accuracy in combination with a better user experience.

2 SYSTEM DESCRIPTION

The Grasp-IT Xmod interface (Figure 1) consists four elements:

- The Biosemi ActiveTwo electroencephalographic system (Figure 1 - (1a)) to record the electrical brain activity with 64 active scalp electrodes (Figure 1 - (1b)) covering the motor and somatosensory cortices.
- The gamified virtual environment developed on Unity, that shows the tasks to execute (i.e., to grasp, pinch, rotate the wrist, or open the hand) and gives visual feedback about the participant's performance of their KMI, displayed on a screen placed in front of the participant (Figure 1 - (2)) . 16 mini-games may be selected and combined. For example, squeezing a ketchup bottle to put sauce on a hot dog or filling an aquarium with water to save a goldfish. The success rate depends on the KMI detection accuracy. In addition to the first-person view of the scene, a vertical performance bar indicates the user's current and best accuracies. A traffic light tells the participants the current stage (rest, prepare, perform KMI, feedback). At the lower part of the screen, there is a progression bar showing the current trial and how many are left.
- A vibrotactile device consisting of three vibration motors (Figure 1 - (3)) . The device consists of three eccentric rotation mass (ERM) vibration motors (Figure 1, left) of 10 millimeters controlled by an Arduino Nano. One motor is placed on the top of the hand, while the other two motors are placed on the forearm: one is placed on top of the flexor muscle, and the other one is on top of the extensor muscle. The motors are held in place with adjustable bracelets. The device stimulates the skin on top of some of the key muscles involved during a grasping movement [2].
- The operator's computer (Figure 1 - (4)) . It includes an interface for the therapists to allow them to adapt the KMI training program to the patients' personal needs, e.g., participant's physical characteristics (size, skin color, right/left), select the number of trials, the type of feedback, the KMI mini-games, etc. It also includes the OpenViBE software[4] to analyze of the EEG signal.

3 SYSTEM OPERATION

First, an EEG cap and the vibrotactile device are installed. The latter is placed on the non-dominant hand of the participant. The subject also holds a real object, similar to the one visible on the screen, e.g., a small bottle. Then, if novice, the subject learns to perform the KMI task following the procedure proposed in [6]. After that, a calibration phase, without any feedback, will take place for the system to learn and adapt to the participant's brain activity. The virtual environment provides visual cues via a traffic light, allowing the subject to easily identify when to perform the KMI task (green light) and the rest (red light) tasks. In addition, an orange light indicates the user to prepare before performing the KMI to ensure that the subject is fully relaxed during the resting task and to avoid any motor preparation during the resting state. The EEG signals are processed by a scenario on the software OpenViBE[4]. First, the signal analysis consists of a band-pass filter of 8-30 Hz, then the Common Spatial Patterns algorithm is applied to obtain the main features, and finally, the Linear Discriminant Analysis classifier is trained to classify rest versus KMI.

After the calibration phase, the participant uses the interface in a similar order. The difference is there will be multisensory feedback proportional to the accuracy of the KMI. After the green light, orange and red lights indicate the beginning of the feedback phase. In the case of the hot dog game, the virtual hand will press the bottle, and the sauce will be displayed. Simultaneously, a vibration will be given whose intensity will be proportional to the accuracy in four different levels: no vibration, low, medium, and high vibration intensity. The synchronization among the devices is guaranteed by LUA and Python scripts in the OpenViBE[4] scenario. The Python script is responsible for the communication with the Arduino of the vibrotactile device via a serial protocol and with the virtual environment via a VRPN protocol.

4 CONCLUSION AND PERSPECTIVES

In this demonstration paper, we presented the Grasp-IT Xmod BCI, whose goal is to enhance the post-stroke motor rehabilitation of the upper limb by improving the sensory perception of kinesthetic motor imagery. In the long-term, tests will be performed with post-stroke participants to evaluate the effects of the device in their motor rehabilitation, as well as the user experience for participants and therapists.

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REFERENCES

[1] Aymeric Guillot, Christian Collet, Vo An Nguyen, Francine Malouin, Carol Richards, and Julien Doyon. 2009. Brain activity during visual versus kinesthetic imagery: An fMRI study. *Human Brain Mapping* 30, 7 (2009), 2157–2172. https://doi.org/10.1002/hbm.20658

[2] M. Elise Johanson, Michelle A. James, and Stephen R. Skinner. 1998. Forearm muscle activation during power grip and release. *Journal of Hand Surgery* 23, 5 (1998), 938–944. https://doi.org/10.1016/S0363-5023(98)80177-9

[3] Floriana Pichiorri, Giovanni Morone, Manuela Petti, Jlenia Toppi, Iolanda Pisotta, Marco Molinari, Stefano Paolucci, Maurizio Inghilleri, Laura Astolfi, Febo Cincotti, and Donatella Mattia. 2015. Brain network modulation following motor imagery BCI-assisted training after stroke. *Clinical Neurophysiology* 126, 1 (jan 2015), e3. https://doi.org/10.1016/j.clinph.2014.10.028

[4] Yann Renard, Fabien Lotte, Guillaume Gibert, Marco Congedo, Emmanuel Maby, Vincent Delannoy, Olivier Bertrand, and Anatole Lécuyer. 2010. OpenViBE: An open-source software platform to design, test, and use brain-computer interfaces in real and virtual environments. *Presence: Teleoperators and Virtual Environments* 19, 1 (2010), 35–53. https://doi.org/10.1162/pres.19.1.35

[5] K. Richard Ridderinkhof and Marcel Brass. 2015. How kinesthetic motor imagery works: A predictive-processing theory of visualization in sports and motor expertise. *Journal of Physiology Paris* 109, 1-3 (2015), 53–63. https://doi.org/10.1016/j.jphysparis.2015.02.003

[6] Sebastien Rimbert, Laurent Bougrain, and Stephanie Fleck. 2020. Learning How to Generate Kinesthetic Motor Imagery Using a BCI-based Learning Environment: A Comparative Study Based on Guided or Trial-and-Error Approaches. *IEEE Transactions on Systems, Man, and Cybernetics: Systems* 2020-Octob (2020), 2483–2489. https://doi.org/10.1109/SMC42975.2020.9283225