Evaluation of Three BCI-controlled AT Devices in a Highly Paralyzed End User

M. Rohm¹, L. Tonin², M. Quek³, R. Murray-Smith³, J.d.R. Millan², R. Rupp¹
¹University Hospital, Spinal Cord Injury Center, Heidelberg, Germany; ²École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland; ³University of Glasgow, Glasgow, Scotland

Correspondence: M. Rohm, University Hospital, Heidelberg, Germany. E-mail: martin.rohm@med.uni-heidelberg.de

Abstract. Three BCI-controlled AT devices namely a Functional Electrical Stimulation (FES)-hybrid orthosis, a telepresence robot and a music player were tested and evaluated in a highly paralyzed subject (C3 Tetraplegic since 2010, 42 years old, BCI-naïve). He went through an extensive Motor-Imagery-Brain-Computer Interface (MI-BCI) training of 102 runs and achieved an average performance >80%. He successfully passed all three testing protocols, stated a low to medium workload and was satisfied with their use. He could imagine using improved versions in his daily life.

Keywords: Electroencephalogram (EEG), Brain-Computer Interface (BCI), Evaluation, Assistive technology

Introduction

Spinal cord injured (SCI) individuals suffer from restricted limb functions depending on the level of lesion. [Zickler et al., 2011] has shown that the main needs of highly paralyzed individuals are manipulation and communication. However, in high lesioned tetraplegic subjects only a few residual motor functions are preserved that can be used for control of conventional assistive devices (ADs). For this purpose Brain-Computer Interfaces (BCI) exploiting the subject’s electroencephalogram (EEG) are connected with such ADs offering a new opportunity for access. In even higher lesioned subjects in whom residual movements are mostly absent, a BCI remains the last option for control of ADs.

The aim of this study is to evaluate the BCI performance and end user satisfaction for three different AT prototypes namely an upper extremity hybrid neuroprosthesis [Rohm et al., 2011], a telepresence robot [Tonin et al., 2011] and a music player in a highly paralyzed end user.

Study participant and methods

The individual (G.S.) included in this single case study is a right-handed 42-year-old man with a traumatic spinal cord injury since August 2010. He is affected by a motor complete lesion with a level of injury of C3. He has a limited passive range of motion in the elbow with a flexion deficit at 110°. He has no active hand, wrist and elbow movement on both sides, only pro-/retraction and elevation/depression of his shoulders and head movements are preserved.

He has never participated in any clinical trial before and was naïve to BCI or FES applications. The TUEBS questionnaire, the ATDPA and a Visual Analog Scale (VAS) were used to assess the user satisfaction and the NASA-TLX to measure the subjective workload.

Results

3.1. Results from MI-BCI Online Training Sessions

Due to the fact that G.S. lives 400km away from Heidelberg, only five sessions of BCI training have been conducted. 102 MI-BCI runs have been recorded since August 2011. 65 of these runs were recorded with feedback (online sessions) and 51 were evaluated. With the Graz-BCI he achieved an average performance of 78%, with the EPFL-BCI 85%.

3.2. Prototype Testing

G.S. drove a telepresence robot which was located ~720km away from his home along three different paths in a real working space, passing through pre-defined target locations first controlled mentally and, second by two buttons activated by residual head movements. During the telepresence trial G.S. was able to complete all the paths in both conditions. The times to complete the tasks were similar (on average 96.80+/−35.83s (BCI) and 82.6+/−32.25s (buttons)). These results are in line with previous work [Tonin et al., 2011]. He stated that he likes how the device looks and that it is small and can turn quickly. He could imagine using it as intended. However, he’d like to have a smaller system
with a smaller display integrated in his bed/wheelchair. He liked the device (VAS 9/10, TUEBS 4.3/5) and stated a low workload (NASA-TLX: 30/120).

G.S. also tested the FES hybrid-orthosis, which aims at restoring grasping and reaching function via muscle stimulation, a passive orthosis and an electrical drive to lift the lower arm. He was quite satisfied with the device (TUEBS: 4/5) and claimed a low workload (NASA-TLX: 24/120). However, assessing the ATDPA the end user found both devices semi-useful (31/60 and 34/60). He securely grasped an ice cone from a special holder, lifted it to its mouth and licked it without haste (Fig. 1). During the task he elicited one unintended switch from arm- to hand control that he undid in a few seconds. All other BCI switches were elicited as intended. He overall liked the neuroprosthesis (8/10) but he stated that the whole system could be smaller when produced by a company and tailored to his body. Concerning aesthetic design, he stated that it does not matter in his highly paralyzed state.

On day three, G.S. reported being rather fatigued and his classifier appeared biased towards one class. By the end of the experiment, his NASA-TLX scores for the binary BCI feedback paradigm were 98/120, 62/120 for the REx paradigm and 49/120 for the music player. He was able to complete 19/20 of the music player tasks with an effective accuracy of 80%. G.S. overall liked the music player (4/5). Further discussion about the end user's performance and preferences regarding the music player can be found in [Quek et. al. (in the same proceedings)].

Discussion

It was shown that all three BCI controlled prototypes worked well in the highly paralyzed subject and provided the functionality as intended. He liked all three devices and could imagine using them in his daily life and gave recommendations for their future improvement.

It is worth noticing that if there was no actual task, G.S. became tired easily. In contrast a demanding task made him completely attentive. He needed several breaks during the testing sessions.

During the music player trial he desired to select a particular album for himself and achieved this goal with an accuracy of 100% (13/13 selections). He reported that he really liked to be able to select his own album ("this is cheering me up more than the other BCI trials"), and that it was quickly done. However, the workload was fairly high. It is unclear whether this was due to the novel control paradigm, the high number of preceding trials or the biased classifier.

At the end of day three, G. S. was unhappy that the BCI experiments were finishing and that he really hopes this research work will continue.

Acknowledgments

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References