Evaluation of MI-BCI Performance in Ten Spinal Cord Injured End Users

M. Rohm, M. Schneiders, R. Rupp
University Hospital, Spinal Cord Injury Center, Heidelberg, Germany

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

Abstract. Highly paralyzed people have only a few residual motor functions that can be used for control of conventional assistive devices (ADs). These devices can be extended to accept input from a Motor-Imagery-Brain-Computer Interface (MI-BCI) to make them accessible for such individuals. However, it is still unclear to what extend disabled individuals are able to control an MI-BCI. In this study, the outcomes of MI-BCI training sessions with ten high spinal cord injured (SCI) subjects are presented. Only one subject achieved a performance greater than 70%, three subjects were around 70%. The average performance of all subjects was 70.5%, which is significantly lower than in healthy subjects.

Keywords: EEG, BCI, Motor Imagery, tetraplegia, performance

Introduction

Individuals with a spinal cord injury (SCI) suffer from restricted limb functions depending on the level of lesion. [Zickler et al., 2011] have shown that the main needs of highly paralyzed individuals are manipulation and communication. However, in highly 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 non invasive Brain-Computer Interfaces (BCI) exploiting the subject’s electroencephalogram (EEG) are combined with standard interfaces of ADs offering a new opportunity for access. In even higher lesioned subjects in whom residual movements are mostly absent, the BCI remains the last option for control.

However, it is still unclear to what extend highly disabled individuals are able to control a Motor-Imagery-Brain-Computer Interface (MI-BCI). In this study, the outcomes of MI-BCI training sessions with ten SCI subjects are presented.

End user and BCI-training description

The participants are ten high spinal cord injured individuals with a level of lesion at C4/5 (characteristics and neurological status listed in table 1). They have been trained with the Graz-BCI and EPFL-BCI in offline and online training sessions. Offline training consisted of a three-class paradigm (right hand vs. left hand vs. feet), the online sessions of a two-class-paradigm without a resting state.

For the Graz-BCI training 13 EEG electrodes (Laplacian montage over C3, C4 and Cz) were used. All channels were referenced to the left mastoid and grounded to the right mastoid. Impedances were below 10 kΩ. The EEG was amplified with a g.tec USB amplifier (g.tec, Graz, Austria), bandpass (8th order butterworth) filtered between 0.5 and 100 Hz and sampled at 512 Hz. A proprietary offline analysis software developed in Matlab was used to perform Distinction Sensitive Learning Vector Quantization (DSLVQ [Pregenzer et al., 1995]). Subject specific spatio-frequency features that maximize the separability between the different mental tasks have been obtained for online training. For the EPFL-BCI, 16 electrodes at similar positions were used and a Gaussian Classifier was calculated after analysis of the offline data.

Results

In table 1 the number of recorded runs and the achieved online performance is listed. Only evaluable online runs were taken into account (free of artefacts, no speech during runs).

HE11IM was trained with the Graz-BCI, but no online runs were recorded. These offline runs suggest a high performance (~90%), which was not seen in the EPFL-BCI online runs. The reason for this remains unclear. A similar behaviour could be seen in GU26HE, who was extensively trained with the Graz-BCI and achieved an average performance of 70% (training since August 2011; performance varying over time). However, the EPFL-BCI suggested a performance below 60% after 27 offline runs.

In GE26EN EEG signals were generally contaminated with EMG artefacts. The main difficulty is that this subject became tired very quickly during BCI training sessions.
The inhomogeneity in the number of runs arises from the fact that some subjects were visited more often due to the distance of their home, their availability and their involvement in further studies.

Both online and offline runs consisted of 30 trials/run except for GU26HE (24 trials/online run).

Subject description and results (SD=rounded standard deviation). *Due to low information content in the offline data, the online classifier was difficult to train.

<table>
<thead>
<tr>
<th>Subject ID</th>
<th>S</th>
<th>Level of injury</th>
<th>Date of injury</th>
<th>ASIA impairment scale</th>
<th>Age</th>
<th>Handedness</th>
<th>Number of offline runs</th>
<th>Number of online runs</th>
<th>Average of online performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>GU26HE</td>
<td>m</td>
<td>C4</td>
<td>2009</td>
<td>AIS B</td>
<td>41</td>
<td>right</td>
<td>57</td>
<td>415</td>
<td>70%</td>
</tr>
<tr>
<td>HE08RF</td>
<td>m</td>
<td>C3</td>
<td>2010</td>
<td>AIS B</td>
<td>42</td>
<td>right</td>
<td>37</td>
<td>51</td>
<td>81%</td>
</tr>
<tr>
<td>UL23EN</td>
<td>m</td>
<td>C3</td>
<td>2007</td>
<td>AIS B</td>
<td>21</td>
<td>right</td>
<td>36</td>
<td>25</td>
<td>69%</td>
</tr>
<tr>
<td>HE11IM</td>
<td>m</td>
<td>C4</td>
<td>2002</td>
<td>AIS A</td>
<td>32</td>
<td>right</td>
<td>15</td>
<td>5</td>
<td>68%</td>
</tr>
<tr>
<td>GI21EN</td>
<td>f</td>
<td>C5</td>
<td>2008</td>
<td>AIS B</td>
<td>49</td>
<td>right</td>
<td>5</td>
<td>1</td>
<td>30%(*)</td>
</tr>
<tr>
<td>MA26ER</td>
<td>m</td>
<td>C4</td>
<td>2004</td>
<td>AIS A</td>
<td>53</td>
<td>right</td>
<td>10</td>
<td>13</td>
<td>65%</td>
</tr>
<tr>
<td>GE26EN</td>
<td>m</td>
<td>C5/6</td>
<td>1991</td>
<td>AIS B</td>
<td>38</td>
<td>right</td>
<td>16</td>
<td>10</td>
<td>60%</td>
</tr>
<tr>
<td>PA19MI</td>
<td>m</td>
<td>C5</td>
<td>2006</td>
<td>AIS A</td>
<td>34</td>
<td>left</td>
<td>11</td>
<td>15</td>
<td>66%</td>
</tr>
<tr>
<td>SI07CH</td>
<td>m</td>
<td>C5</td>
<td>2008</td>
<td>AIS B</td>
<td>23</td>
<td>right</td>
<td>3</td>
<td>4</td>
<td>61%</td>
</tr>
<tr>
<td>IR26IM</td>
<td>m</td>
<td>C4</td>
<td>2011</td>
<td>AIS A</td>
<td>52</td>
<td>n/a</td>
<td>9</td>
<td>6</td>
<td>51%</td>
</tr>
</tbody>
</table>

Discussion

Only one out of 10 SCI subjects achieved an average performance greater than 70% which is in line with results from [Pfurtscheller et al., 2009]. In [Onose et al., 2012] the course and performance of an MI-BCI training with the goal of controlling a robotic arm in chronic SCI subjects has been investigated. The authors have included two C4, three C6 and four C7 end users, who – like our end users – achieved an average performance of 70.5%, which is also in line with our results. This is in contrast to the mean classification accuracies of healthy, BCI-naive subjects who achieve between 80.0% and 83.3% for left versus right hand MI and hand versus feet MI [Alkadhi et al., 2005]. A low correlation of 0.18 between time since injury and BCI performance in our end users indicates that the low performance is not associated to negative long term plasticity. If the moderate performance is sufficient for AD control was not in scope of our study nor to compare different BCI systems.

The reason for the low average performance of tetraplegic user is unclear. It can be speculated that the missing sensory loop restricts the vividness of the imagined movements and therefore the performance [Pfurtscheller et al., 2008]. More investigations in a larger population of individuals with high SCI are necessary to gain more insights in SCI induced changes on brain oscillations.

Acknowledgments

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References


