Lower limb movement preparation in chronic stroke: a pilot study towards an NIRS-BCI for gait rehabilitation.

Rea M.\textsuperscript{1*} PhD, Rana M.\textsuperscript{1*}, Lugato N\textsuperscript{1}, Terekhin P.\textsuperscript{1} MD, Gizzi L.\textsuperscript{2} PhD, Brötz D.\textsuperscript{1}, Fallgatter A.\textsuperscript{3} PhD, Birbaumer N.\textsuperscript{1,4} PhD, Sitaram R.\textsuperscript{1,5,6#} PhD, Caria A.\textsuperscript{1,4#*}, PhD

\textsuperscript{1} Institute of Medical Psychology and Behavioral Neurobiology, University of Tübingen, Tübingen, Germany
\textsuperscript{2} Georg-August University of Göttingen, Göttingen, Germany
\textsuperscript{3} Department of Psychiatry and Psychotherapy, Tübingen, Germany
\textsuperscript{4} Ospedale San Camillo, Istituto di Ricovero e Cura a Carattere Scientifico, Venezia – Lido, Italy.
\textsuperscript{5} Department of Biomedical Engineering, University of Florida, Gainesville, USA.
\textsuperscript{6} Sri Chitra Tirunal Institute of Medical Sciences and Technology, Trivandrum, India.

* These authors contributed equally to this work
# Both senior authors contributed equally to this work.

**Corresponding author:**
Massimiliano Rea
Institute of Medical Psychology and Behavioral Neurobiology,
Eberhard-Karls-University of Tübingen, Gartenstrasse 29, D-72074 Tübingen, Germany
e-mail: massimiliano.rea@uni-tuebingen.de
Phone: +49-7071-29-74513
Fax: +49-7071-29-5956

Number of words:
Number of figures: 6
Abstract

Background. Thus far, most of the BCIs developed for motor rehabilitation used electroencephalographic signals to drive prostheses that support upper limb movement. In comparison, only few BCIs used hemodynamic signals or were designed to control lower extremity prostheses. Yet, recent developments in fNIRS based BCIs suggest that they are more suitable for rehabilitation of lower limb movement due to the reduced problems of head motion artifacts corrupting the signal. Objective. The aim of this proof of concept study was to assess whether hemodynamic signals underlying lower limb motor preparation in stroke patients can be reliably measured and exploited for the implementation of a BCI for post-stroke gait rehabilitation. Methods. fNIRS data were acquired during preparation of left and right hip movement in chronic stroke patients. Results. Single trial analysis indicated that specific hemodynamic changes associated with left and right hip movement preparation can be measured with fNIRS. Moreover, offline linear classification of paretic versus non-paretic movement preparation-related hemodynamic signals in the premotor and posterior parietal cortices, bilaterally, showed above chance accuracy for all patients. Conclusion. The results provide first evidence that fNIRS can detect brain activity associated with single trial lower limb motor preparation in stroke patients. These findings encourage further investigation of fNIRS suitability for implementation of a BCI for gait rehabilitation in patients with lower limb motor impairment after stroke.

Key Words: stroke; fNIRS; gait; BCI; motor preparation; EMG.
Lower limb motor preparation in stroke

Introduction
Reduced gait performance is a common residual deficit in hemiplegic patients after stroke. The recovery of walking ability is generally observed in only 50–60% of patients [1]. At the time of discharge from rehabilitation and therapy clinics approximately 5% of patients are independent in stair climbing, 9% and 14% are able to walk outside and inside respectively, 27% to walk with cane or other aid, while 45% remain in a wheelchair [2]. Although some patients can walk independently, their gait disturbance limits performance of daily activities and makes them more susceptible to injury [3]. None of the existing gait rehabilitation techniques based on physiotherapy treatments has shown convincing evidence of effective recovery of lower limb functions in chronic patients after stroke [4]. Top-down strategies using BCIs that utilize neurophysiologic or metabolic brain activity to drive external devices may represent a promising approach to modulate brain reorganization and motor behaviour in stroke survivors [5-7]. BCI training is anticipated to induce brain plasticity and recovery by providing contingent afferent feedback to sensorimotor cortex. Good recovery is often associated with returning activity to the cortical areas near the lesion [8], and the stimulation and reinforcement of activity in the perilesional areas through BCI training demonstrated beneficial effects for motor rehabilitation after stroke [9-11]. Most of the BCIs developed for motor rehabilitation used electroencephalographic signals to drive prostheses that support upper limbs movements [12]. However, only a few BCIs used hemodynamic signals or were designed to control lower extremity prostheses [13, 14]. Yet, recent developments in fNIRS-BCIs suggest that they are more suitable for rehabilitation of lower limb movement due to the reduced problems of head motion artefacts corrupting the signal. [5].
The general aim of this proof of concept study was to assess to what extent brain activity associated with lower limbs motor preparation could be detected in stroke patients with fNIRS, and exploited for the implementation of a BCI for gait rehabilitation.

Until now, BCIs have largely utilized the neurophysiologic brain signals associated with motor imagery [15], as consistent evidence has been provided in favour of close similarities between the overt and covert motor activity (motor imagery) [16]. However, motor imagery vividness can vary substantially among healthy individuals as well as in patients after stroke [17]. In particular, motor imagery vividness of the affected side is reduced in patients with stroke [18].

The use of motor preparation and intention for BCI control is more ecological and motivating, as patients are encouraged to prepare and attempt to execute real movements (Belda Lois; Birbaumer 2007; Daly 2008). This strategy could then represent an added value to promote functional recovery.

In this study fNIRS signals were acquired in chronic stroke patients during preparation of hip movement, a motor act critical for balance and posture retention during standing and walking. Based on prior literature on motor preparation and intention [19-22], we expected that frontal premotor and posterior parietal activations could be detected by fNIRS on a single trial level. In this study, sensitivity to motor preparation activity is explored using single trial analysis of hemodynamic signals in the ipsilesional hemisphere, contralateral to the intended movement.
Methods

Patients

Seven right handed chronic stroke patients participated in the study (mean age 54.7±14.10; 3 female). All participants suffered from severe hemiparesis as a result of a single unilateral cerebrovascular incident. The following criteria were adopted to include patients with stroke: 1) interval since stroke at least 12 months; 2) no psychiatric or neurological condition other than stroke; 3) no cerebellar lesion or bilateral motor deficit; 4) ability to understand and follow instructions (S1). Patients showed comparable scores of Fugl-Meyer (F-M) motor assessment subscales specific for lower extremity functionality [23] (S1 and S2). All recruited patients have no severe stenosis of carotid or intracranial major vessels including middle and anterior cerebral arteries. The study was approved by the ethics committee of the Faculty of Medicine of the University of Tübingen (Germany) and all procedures were in accordance with the declaration of Helsinki in its latest revision.

Task

The paradigm consisted of two sessions of eleven 'left hip' (9s, 10s, 11s) and eleven 'right hip' movement preparation (9s, 10s, 11s ) followed by movement execution (3 s) either of left or right hip and interspersed with 23 periods of rest (15s, 20s, 25s) presented in a pseudo-randomized order (Figure 1A). Random selection of duration of preparation and rest condition as well the inclusion of shorter preparation trials (1s, 3s, 6s) aimed to reduce task predictability and habituation. Participants, sitting on a chair, used a mechanical device (pedals) that permitted to perform hip movements while constraining knee and ankle movements (Figure 1B). Participants were visually cued for left and right hip preparation and execution (Figure 1A).
**fNIRS data acquisition**

A 48-channels ETG-4000 (Hitachi Medical Systems GmbH, Tokyo, Japan) with continuous wave laser diodes with wavelengths of 695 nm and 830 nm and sampling rate of 10 Hz was used. The optodes were applied sagittally covering the frontal regions, bilateral premotor cortex (PMC), supplementary motor area (SMA), primary and secondary motor areas, and somatosensory areas (Figure 1C-D). Based on the International 10-20 System for EEG electrode placement, Cz was used as a reference point for positioning the optodes. fNIRS channels were defined as the midpoint of the corresponding light source-detector pair (Figure 1C-D). The fixed inter-optodes distance is 3cm. At this typical source–detector separation (Watanabe et al 1996; Okada and Delpy 2003; Sato et al 2006; Obata et al 2003) the contribution of the grey matter to the light absorption has been estimated in the order of 20–30% (Toronov et al 2000). The positions of the optodes were marked by means of a 3D digitizer in all patients (Fastrack; Polhemus Inc., Colchester, Vt., USA). For co-registration purposes a T1-weighted anatomical MR image was acquired of each patient using a 3 Tesla Siemens MRI system (Siemens TIM Trio, Erlangen, Germany) with a 1 mm isotropic MPRAGE sequence and the following parameters: TR = 2300 ms; TE = 3.03 ms; TI = 1100 ms; flip angle = 8°; FOV = 256 x 256; matrix size = 256 x 256; number of slices = 176; slice thickness = 1 mm, bandwidth = 130 Hz/Px. Spatial registration of channel locations was performed using Statistical Parametric Mapping software package (NIRS-SPM; SPM5; Welcome Trust Centre for Neuroimaging, London, UK). NIRS channel positions in real coordinates obtained from a 3D digitizer were projected onto the cortex of the anatomical MR image of the 7 patients using Horn's algorithm (Horn, 1987). The cortical regions and Brodmann's areas (BA) corresponding to each channel were defined using Automated Anatomical Labeling (AAL) available on the MRIcron software [24-27] (Figure 1C-D).
EMG data acquisition

EMG activity was recorded using a BrainVision QuickAmp amplifier (Brain Products GmbH) from two active electrodes on five patients. Bipolar EMG electrodes were placed along muscle fibers of femoris quadriceps muscle/sartorius muscle of both legs (Figure 1B) according to SENIAM recommendations [28]. Electrode impedances were kept below 5 kΩ by careful skin abrasion. We applied standard pre-processing for surface EMG with a band pass filter 10-400Hz and notch filter 50Hz [28]. The reference electrode was placed over the clavícula.

fNIRS data analysis

fNIRS data were pre-processed and analyzed using Statistical Parametric Mapping software package (NIRS-SPM, SPM5; Welcome Trust Centre for Neuroimaging, London, UK). Statistical analyses of NIRS data is based on a mass-univariate approach derived from the general liner model (GLM). A GLM model was generated using standard hemodynamic response function (HRF) as basis function. The wavelet-minimum description length (MDL) algorithm has been applied for removing unknown global trend due to breathing, cardiac, vaso-motion and experimental noise (Jang et al. 2009). This preprocessing step by decomposing NIRS measurements into global trends, hemodynamic signals and uncorrelated noise enables to reduce spurious components but it has limited efficacy in reducing task-evoked intrinsic contaminant such as skin blood flow effect (Takahashi 2011). Subsequently, a gaussian low-pass filter with 4 s full-width-half-maximum (FWHM) was used to estimate and remove temporal autocorrelation.
The concentration changes of oxy-hemoglobin (oxyHb) and deoxy-hemoglobin (deoxyHb) and total hemoglobin (totHb) calculated from optical density changes, were obtained using the modified Beer-Lambert law (Cope and Delpy, 1988).

To minimize the effect of contamination of subsequent movement execution on the hemodynamic response of preparation condition only motor preparation trials with duration of 9s, 10s and 11s were considered (73% of all trials).

Cortical activations related to hip movement preparation were obtained at single-patient level by separately comparing left and right hip movement preparation to rest. Single patient parametric maps were thresholded using a significance level of $p < 0.01$ corrected for multiple comparisons using Sun’s tube formula (Sun 1993). First level contrast images relative to totHb only (Gagnon et al 2012) were also entered into a second-level (random-effects) group analysis. Only stroke patients with lesions in the right hemisphere (6 out of 7) were included in the second level random-effect analysis to avoid miscoregistration due to image flipping. The resulting parametric maps were thresholded using a significance level of $p < 0.01$ uncorrected due to small sample size and also because specific activations in premotor and parietal cortices were expected.

Selection of channels in the corresponding regions of interest was then performed anatomically and functionally, based on single patient parametric t-maps of totHb (highest t-value). It has been recently shown that totHb signal provides better spatial specificity in cerebral activity mapping as its variations are much less sensitive to pial vein contamination (Gagnon et al 2012). Time-series of oxyHb, deoxyHb and totHb changes for each trial were extracted from selected channels corresponding to PMC and PPC on each patient.

A linear classification method was then used to discriminate left hip movement preparation trials with respect to right hip movements preparation trials. The mean of
oxyHb and totHb changes for each trial in the selected channels, corresponding to contralateral and ipsilateral PMC and PPC, were considered for linear classification. Based on the assumption that changes of oxyHb and totHb in the contralateral sensorimotor regions are larger compared to those in the ipsilateral regions during separate lower limb movements, the difference between the mean values of the ipsilateral side and the contralateral side channels is used to predict left and right movement preparation trials. The choice of discriminating between left and right movement preparation trials instead of between movement preparation and rest relies on the fact that during gait left and right lower limbs movements are alternated in a continuous fashion. Therefore, a BCI for gait rehabilitation that aims to control an external effector (e.g. Lokomat orthosis, Duschau-Wicke A et al. 2010) should be able to predict left and right lower limb movements or movement preparation/intention when its associated brain activity is compared to each other.

**EMG data analysis**

As for fNIRS analysis only trials with a preparation phase of 9s, 10s and 11s were considered. These trials were full-wave rectified and low-pass filtered at 10 Hz in Brain Vision Analyzer (Version 1.04 - Brain Products GmbH, Munich, Germany), normalized with respect to maximal activation during movement and offline segmented into 12 s epochs, including 9 s of movement preparation (back-averaging with a start point from the movement trigger) and 3 s of movement execution (averaging with a start point from the movement trigger). EMG activity of each hemisphere was then expressed as a percentage of the maximal value of motor execution. A threshold of 30% was used to define the EMG activity as tonic activity. This threshold had the only purpose of discriminating voluntary from non-voluntary activity (i.e. to detect the onset of the
Lower limb motor preparation in stroke

movement). This moment can be clearly distinguished by the sudden increase in RMS value during movement performance (see figure 4).

Results

Group analysis of paretic hip movement preparation showed extended bilateral activations - increased totHb – in SMA, premotor cortex, sensorimotor regions and frontal areas, with a maximum peak in the ipsilesional premotor area, contralateral to the movement (Figure 2). Group analysis of non-paretic hip movement preparation showed more focal activations with clusters in the PMC and PPC bilaterally, with a maximum peak in the contralateral PMC (Figure 2). No significant changes of deoxyHb were measured during both paretic and non-paretic hip movement preparation.

Individual cortical activation patterns of oxyHb and totHb changes are reported in Figure 3. Despite inter-patient variability, common activations in the contralateral PMC and PPC were generally observed during movement preparation in all patients (Figure 3) and, more importantly, in the ipsilesional hemisphere during movement preparation of the paretic limb.

EMG analysis revealed only tonic activity during movement preparation trials (Figure 4). In the remaining two patients, in whom EMG was not acquired, visual inspection ensured no lower limb movements during motor preparation.

Time-series of averaged oxyHb, deoxyHb and totHb changes, in the selected channels corresponding to PMC and PPC contralateral to the movement preparation, of each patient along with t values relative to changes of totHb in these channels are shown in figure 5. Significant increases of oxyHb and totHb during paretic and non-paretic hip movement preparation in the contralateral PMC and PPC were observed. No significant
changes of deoxyHb were observed during both conditions in contralateral and ipsilateral hemisphere.

The results of offline single trial linear classification showed above chance accuracy in predicting paretic \textit{versus} non-paretic hip movement preparation, either considering PMC, PPC or PMC and PPC combined, ranging between 53,1\% and 71,9\% for oxyHb, and ranging between 52,3\% and 65,6\% for totHb, in all patients (see Figure 6).

\textbf{Discussion}

The present proof of concept study investigated the possibility to detect hemodynamic signals associated with preparation of lower limb movements and to assess the feasibility of an fNIRS based BCI for gait rehabilitation.

Results of group and single patient analyses during movement preparation of the paretic limb showed main activations of contralateral and ipsilesional premotor and sensorimotor regions, but involvement of ipsilateral and contralesional regions was also observed.

Preparation of movements with non-paretic lower limb showed as well recruitment of PMC and PPC bilaterally, but activations were more focal and less spread at group level.

Bilateral sensorimotor activation during unilateral foot movement has been previously reported in fNIRS and magnetoencephalography studies (Miyai et al. 2001; Endo et al. 2004). However, results of single patient analysis, in particular those related to oxyHb signal, should be carefully interpreted as its statistical maps might be more affected by artefacts and noise (Gagnon et al. 2012).

The contribution of contralesional activity in movement preparation and execution in stroke patients is known and commonly interpreted as compensatory mechanism, although some studies indicate that the involvement of ipsilateral/contralesional sensorimotor regions might be unhelpful and maladaptive for motor recovery (Rossini
Lower limb motor preparation in stroke

(2003; Dobkin 2004; Ward 2005; Fregni 2006; Eyre 2007; Murphy 2009). Results from a combined transcranial magnetic stimulation and diffusion tensor imaging study (Madhavan et al. 2010) showed greater tracking error during antiphase bilateral ankle movement for patients with strong corticospinal tract conductivity from the non-lesioned hemisphere to paretic ankle than those with weak or no conductivity. These findings further support the hypothesis that after stroke the non-lesioned lower limb motor cortex may be maladaptive. Again, this interpretation should be as well cautious as patients with small subcortical lesion and relatively large cortical lesions, similar to those included in our study, might actually show quite different compensatory mechanisms.

Overall, our results are in line with those of previous studies highlighting the critical role of PMC and PPC in motor preparation of upper limb movements [20, 21, 29] as well as of lower limb movements in healthy individuals [30]. Recent fMRI studies using pattern recognition methods also demonstrated successful decoding of action intentions from preparatory blood oxygenation level dependent (BOLD) activity in multiple parietal and premotor brain areas [19, 22].

In general, our results support previous studies indicating fNIRS validity for assessing gait functions in healthy participants [31-34] and patients with stroke [35-37].

More importantly, this study indicates that using a general linear model and a simple linear classification approach, it is possible to detect and classify hemodynamic signals associated with single left and right lower limb movement preparation trials. In fact, offline linear classification of left and right movement preparation-related hemodynamic signals in the bilateral premotor and posterior parietal cortices showed above chance accuracy for all patients. Accuracy levels based on oxyHb and totHb signal changes in PMC, PPC and combined PPC and PMC varied across patients, and additionally, results obtained considering changes of oxyHb signal were overall slightly higher than those
obtained from changes of totHb. Though, classification based on totHb signals might be more reliable as oxyHb signal is more sensitive to noise and artefacts (Gagnon et al 2012).

Large variability of accuracy levels indicates that the here proposed linear classification method requires a careful patient specific customization of BCI implementation and application.

Nevertheless, these results are encouraging and suggest the possibility of using linear models for data analysis and classification of fNIRS signals associated with lower limb motor preparation to implement a BCI for rehabilitation after stroke. Several studies indicated that despite the intrinsic low temporal resolution of hemodynamic signals, fNIRS and fMRI based on univariate GLM analysis could be used for online application and BCI [39-43]. A recent pilot study showed that chronic stroke patients, trained with an hemodynamic BCI based on real-time functional MRI and GLM approach, were able to increase activity in the ipsilesional ventral premotor cortex that in turn led to a decrease of intracortical inhibition (Sitaram et al 2012).

Moreover, a recent fNIRS study demonstrated that using a multivariate pattern classification technique the latency to decode a change in finger tapping could be reduced by 50% (from 4.8 s to 2.4 s) [38]. The same approach might be beneficial for early detection of activity related to movement preparation. Sitaram and colleagues (2007) were the first to apply pattern recognition algorithms, Support Vector Machines (SVM) and Hidden Markov Model (HMM), to classify fNIRS data associated with motor activity. They used a continuous wave fNIRS system over the motor cortex of healthy participants to measure oxygenated and deoxygenated hemoglobin changes during left hand and right hand motor imagery. The results of signal analysis showed average classification
accuracy, of distinct patterns of hemodynamic responses for left and right hand imagery, of 73% with SVM and of 89% with HMM, for all volunteers.

Pattern recognition methods, which are less dependent from a priori assumptions but increase overall BCI complexity as they need larger data sets and algorithms’ testing and training, might as well provide higher accuracy in predicting lower limb movement or motor intention from hemodynamic patterns in patients with stroke.

Thus far, implementation and application of fNIRS-BCI for gait rehabilitation have not been reported and the results of the present study provide important indications towards this aim.

Acknowledgments

The present study was supported by EC grants: FP7-ICT-2009-247935 – BETTER: BNCI-driven Robotic Physical Therapies in Stroke Rehabilitation of Gait Disorders; FP7-ICT-2009 - HUMOUR: Human Behavioral Modeling for Enhancing Learning by Optimizing Human-Robot Interaction; Italian Ministry of Health GR-2009-1591908. We would like to acknowledge Dr. Ann-Christine Ehlis and Ramona Täglich for their technical support.

References

Lower limb motor preparation in stroke


Lower limb motor preparation in stroke


Lower limb motor preparation in stroke


Table and Figure Captions

**Figure 1.** Experimental setup. (A) The experimental paradigm consisted of alternated left right hip movement preparation interspersed with rest (empty rectangles), presented in a pseudo-randomized order. Movement preparation (green rectangles) was followed by movement execution (3s) triggered by increasing and decreasing thermometer bars simulating a single hip movement. (B) Mechanical pedals used to execute active hip movements while sitting on an armchair. EMG electrodes were positioned along muscle fibers of femoris quadriceps and sartorius muscles of both legs. (C-D) Schema of optodes’ location. The fNIRS system included 16 light source (red circles) and 16 detectors (blue circles) resulting in 48 measurement channels. Table D shows the corresponding anatomical location of each channel.

**Figure 2.** Maps of changes of totHb during paretic and non-paretic hip movement preparation trials threshold at p < 0.01 uncorrected.

**Figure 3.** Single patient’s maps of changes in oxyHb and totHb of paretic and non-paretic hip movement preparation thresholded at p < 0.01 corrected for multiple comparisons using Sun’s tube formula (Sun 1993). On the right side are shown axial views of T1-weighted anatomical images at coordinates z = 0, 59, 69. Pt.= patient; R=right; L=left. Statistical maps are displayed according to the neurological convention.

**Figure 4.** EMG activity during paretic and non-paretic hip movement preparation trials. EMG activity was recorded from two EMG electrodes placed on femoris quadriceps and sartorius muscles of both left and right leg. For each patient, tonic and phasic EMG
activity of each muscle were expressed as a percentage of the maximal values. EMG activity below 30% of the maximum values was considered as tonic EMG activity (movement = 100% - phasic). The graph indicates that all patients showed only tonic EMG activity during motor preparation.

**Figure 5.** Average time-course of totHb (green), oxyHb (red), deoxyHb (blue) during paretic hip movement preparation > rest in the contralateral (ipsilesional) PMC (A) and PPC (B). The vertical black line indicates the onset of movement execution (0 s). Tables show the selected channels in each patient, MNI coordinates and significance (* ‘tube formula’ correction). Pt.= patients; BA= Brodmann area; x, y, z = MNI coordinates.

**Figure 6.** Percentage accuracy of offline linear classification aiming to discriminate paretic hip movement preparation trials with respect to non-paretic hip movement preparation trials based on oxyHb (top) and totHb (bottom) signal changes in bilateral PMC, PPC and combined PPC and PMC across patients.
Figure 1

A

<table>
<thead>
<tr>
<th>Preparation (9, 10, 11 s)</th>
<th>Execution (3 s)</th>
<th>Rest (15-25 s)</th>
<th>Preparation (9, 10, 11 s)</th>
<th>Execution (3 s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right hip</td>
<td></td>
<td></td>
<td>Left hip</td>
<td></td>
</tr>
</tbody>
</table>

B

C

<table>
<thead>
<tr>
<th>Channels</th>
<th>Brain Regions</th>
<th>Brodmann Areas (BA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-10</td>
<td>Associative cortex</td>
<td>7</td>
</tr>
<tr>
<td>11-17</td>
<td>Somatosensory cortex</td>
<td>1, 2, 3, 5</td>
</tr>
<tr>
<td>18-21</td>
<td>Primary motor cortex</td>
<td>4</td>
</tr>
<tr>
<td>22-31</td>
<td>Premotor cortex and supplementary motor area</td>
<td>6</td>
</tr>
<tr>
<td>32-34</td>
<td>Frontal eye fields</td>
<td>8</td>
</tr>
<tr>
<td>35-48</td>
<td>Prefrontal cortex</td>
<td>9, 10, 11, 46</td>
</tr>
<tr>
<td>Pt</td>
<td>OxyHb left &gt; rest</td>
<td>TOTHb left &gt; rest</td>
</tr>
<tr>
<td>----</td>
<td>-------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>1</td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
</tr>
<tr>
<td>2</td>
<td><img src="image6" alt="Image" /></td>
<td><img src="image7" alt="Image" /></td>
</tr>
<tr>
<td>3</td>
<td><img src="image11" alt="Image" /></td>
<td><img src="image12" alt="Image" /></td>
</tr>
<tr>
<td>4</td>
<td><img src="image16" alt="Image" /></td>
<td><img src="image17" alt="Image" /></td>
</tr>
<tr>
<td>5</td>
<td><img src="image21" alt="Image" /></td>
<td><img src="image22" alt="Image" /></td>
</tr>
<tr>
<td>6</td>
<td><img src="image26" alt="Image" /></td>
<td><img src="image27" alt="Image" /></td>
</tr>
<tr>
<td>7</td>
<td><img src="image31" alt="Image" /></td>
<td><img src="image32" alt="Image" /></td>
</tr>
</tbody>
</table>
Lower limb motor preparation in stroke
Lower limb motor preparation in stroke

Paretic hip movement preparation > rest

(A) PMC

(B) PPC

<table>
<thead>
<tr>
<th>Pt</th>
<th>BA</th>
<th>Ch</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>t value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
<td>20</td>
<td>11</td>
<td>18</td>
<td>65</td>
<td>3.31 p &lt; 0.05</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>22</td>
<td>24</td>
<td>6</td>
<td>74</td>
<td>4.79 p &lt; 0.01*</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>22</td>
<td>23</td>
<td>14</td>
<td>76</td>
<td>2.07 p &lt; 0.05</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>22</td>
<td>20</td>
<td>-15</td>
<td>77</td>
<td>3.36 p &lt; 0.01</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>29</td>
<td>10</td>
<td>22</td>
<td>67</td>
<td>4.62 p &lt; 0.001*</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>30</td>
<td>-18</td>
<td>19</td>
<td>67</td>
<td>3.85 p &lt; 0.01</td>
</tr>
<tr>
<td>7</td>
<td>6</td>
<td>22</td>
<td>24</td>
<td>-17</td>
<td>76</td>
<td>5.07 p &lt; 0.0001*</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pt</th>
<th>BA</th>
<th>Ch</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>t value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>12</td>
<td>10</td>
<td>-54</td>
<td>76</td>
<td>4.26 p &lt; 0.01*</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>11</td>
<td>38</td>
<td>-49</td>
<td>70</td>
<td>2.99 p &lt; 0.005*</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>12</td>
<td>13</td>
<td>-56</td>
<td>77</td>
<td>2.99 p &lt; 0.005*</td>
</tr>
<tr>
<td>4</td>
<td>7</td>
<td>11</td>
<td>33</td>
<td>-50</td>
<td>72</td>
<td>1.97 p &lt; 0.05</td>
</tr>
<tr>
<td>5</td>
<td>7</td>
<td>12</td>
<td>13</td>
<td>-59</td>
<td>75</td>
<td>6.36 p &lt; 0.0001*</td>
</tr>
<tr>
<td>6</td>
<td>7</td>
<td>17</td>
<td>-24</td>
<td>-46</td>
<td>69</td>
<td>5.77 p &lt; 0.05</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>11</td>
<td>33</td>
<td>-50</td>
<td>69</td>
<td>6.31 p &lt; 0.0001*</td>
</tr>
</tbody>
</table>
Lower limb motor preparation in stroke

**oxyHb**

**totHb**

Patients

- PMC
- PPC
- PMC&PPC