論文 / 著書情報
Article / Book Information

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Title(English)	A Brain-signal Decoder Based on Cortical Current Source Estimation for Walking
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論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

The impaired ability to walk results in the need of transportation systems for daily use. A wheelchair well accomplishes this objective, however its use in the long term has some drawbacks including muscle atrophy, pressure sores, etc. To overcome these drawbacks, alternatives such as exoskeletons and functional electrical stimulators (FES) have been developed. An exoskeleton is a robotic frame that moves the legs in a pre-programmed walking sequence. FES applies electrical current to the muscles to generate leg flexion and extension. Both systems allow its users to stand up and take steps, however these rely on the residual motor control of the user in order to be activated, thus the activities of daily living are limited while using them.

As an alternative of control for exoskeletons and FES, brain-computer interfaces (BCI) are a promising option. BCIs record brain activity and translate it into control commands. Among non-invasive brain signal recording methods, electroencephalography (EEG) is widely use for BCIs because it is easy to use, portable and applicable to a large population. EEG measures the electrical brain activity over the scalp and therefore it has a low spatial resolution but a high temporal resolution. In contrast, other techniques such as functional magnetic resonance imaging (fMRI) has high spatial resolution, but low temporal resolution.

Various EEG-based BCI studies have developed brain-signal decoders that detect the intention of movement (binary decoding) to trigger a pre-programmed walking sequence on an exoskeleton or FES. Good classification accuracies have been achieved, however the user has little control over the walking sequence. To design a more natural BCI for walking, more walking-related tasks should be decoded first. This is a challenging task considering the anatomical representations of the left and right feet in the brain are closely located to one another, and therefore decoding various lower limb movements is difficult with low spatial resolution methods such as EEG.

This research is focused on the classification of ankle flexion and extensions, at two force levels in the both legs, since these tasks are fundamental in the human walking cycle. In total, 9 classes consisting of 8 active ankle movements and 1 control task, were decoded. This 9-class decoding was approached by first estimating cortical current sources from EEG using prior information from fMRI, with a hierarchical Bayesian (VBMEG) method. Then, the estimated current sources time-series were decoded with a sparse logistic regression (SLR) method. Using these methodology, two topics were addressed in this study.

The first topic addressed the feasibility of successfully decoding 9 walking-related tasks, using current sources estimated from the brain areas related to motor planning and execution. Brodmann areas 4 (primary motor cortex), 6 (supplementary motor cortex and premotor cortex), and 1, 2, and 3 (primary somatosensory cortex), were the primary regions of interest (ROI). Estimation and decoding of current sources was done using both brain hemispheres (all tasks), and left and right hemispheres separately (right and left leg movements, respectively). Decoding accuracies of current sources, were in the range of 65 - 73%, significantly higher than EEG classification accuracies and chance levels. Besides the primary ROI, sources in the operculum (OP) 3 and 4 and the inferior parietal cortex (IPC) were also selected by the classifier. These results are in line with previous studies suggesting a role of the OPs in sensory-motor integration, and the functional connection of the IPC to motor, premotor, and somatosensory areas.

For the second topic, the feasibility of obtaining good classification accuracies with reducing EEG electrodes and without using fMRI information, was approached. The purpose was to take a step closer towards a more general methodology for a future BCI implementation, with a lower number of electrodes encouraging the regular use of the BCI. Classifications were performed for current sources estimated from arrangements of 32, 16 and two configurations of 8 electrodes. As expected, the accuracies decreased when the number of electrodes decreased however, a significant difference was found only between one configuration of 8 channels versus all the other configurations. Based on the results obtained, using 16 or 8 electrodes might be enough for the purpose of this decoder of ankle movements.

To our knowledge, this is the first study to decode 9-classes of ankle movements from non-invasive recordings and using VBMEG and SLR. Together, these results show the potential of developing multi-class brain-signal decoders for persons with walking impairments resulting from stroke or spinal cord injury (SCI). In the case of a stroke, neuroplastic changes can be captured with fMRI and be translated into decoders fitting the changing motor control strategies. For the SCI patients with the intact brain, it might be possible to use only EEG and a few number of electrodes to design multi-class decoders for walking. Further parameter tuning is needed to increase the classification accuracies before moving on to a real-time BCI.