Metadata of the chapter that will be visualized in SpringerLink

Book Title	Converging Clinical and Engineering Research on Neurorehabilitation III	
Series Title		
Chapter Title	EEG Decoding of Overground Walking and Resting, a Feasibility Study	
Copyright Year	2019	
Copyright HolderName	Springer Nature Switzerland AG	

Corresponding Author	Family Name	**Artoni**
	Particle	
	Given Name	**Fiorenzo**
	Prefix	
	Suffix	
	Role	
	Division	Bertarelli Foundation Chair in Translational Neuroengineering, Center for Neuroprosthetics, Institute of Bioengineering, School of Engineering
	Organization	École Polytechnique Fédérale de Lausanne
	Address	Lausanne, Switzerland
	Division	The BioRobotics Institute
	Organization	Scuola Superiore Sant'Anna
	Address	Pisa, Italy
	Email	fiorenzo.artoni@epfl.ch
Author	Family Name	**Massai**
	Particle	
	Given Name	**Elena**
	Prefix	
	Suffix	
	Role	
	Division	Bertarelli Foundation Chair in Translational Neuroengineering, Center for Neuroprosthetics, Institute of Bioengineering, School of Engineering
	Organization	École Polytechnique Fédérale de Lausanne
	Address	Lausanne, Switzerland
	Email	
Author	Family Name	**Micera**
	Particle	
	Given Name	**Silvestro**
	Prefix	
	Suffix	
	Role	
	Division	Bertarelli Foundation Chair in Translational Neuroengineering, Center for Neuroprosthetics, Institute of Bioengineering, School of Engineering
	Organization	École Polytechnique Fédérale de Lausanne
	Address	Lausanne, Switzerland
	Division	The BioRobotics Institute

Organization	Scuola Superiore Sant’Anna
Address	Pisa, Italy
Email	

Abstract

Prompt detection of movement intention is fundamental to increase the reliability in prostheses control and increase the effectiveness of robotic devices for rehabilitation. A machine learning approach is proposed here to perform activity recognition (overground walking vs rest) using muscles or brain activity. EMG and EEG signals were preprocessed, features in the frequency domain were extracted and the achieved decoding accuracy was around 90%. Although extensive validation is still required, the results constitute a first step towards the goal of predicting gait initiation in real life.

EEG Decoding of Overground Walking and Resting, a Feasibility Study

Fiorenzo Artoni[1,2(✉)], Elena Massai[1], and Silvestro Micera[1,2]

[1] Bertarelli Foundation Chair in Translational Neuroengineering, Center for Neuroprosthetics, Institute of Bioengineering, School of Engineering, École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland
fiorenzo.artoni@epfl.ch
[2] The BioRobotics Institute, Scuola Superiore Sant'Anna, Pisa, Italy

Abstract. Prompt detection of movement intention is fundamental to increase the reliability in prostheses control and increase the effectiveness of robotic devices for rehabilitation. A machine learning approach is proposed here to perform activity recognition (overground walking vs rest) using muscles or brain activity. EMG and EEG signals were preprocessed, features in the frequency domain were extracted and the achieved decoding accuracy was around 90%. Although extensive validation is still required, the results constitute a first step towards the goal of predicting gait initiation in real life. AQ1 AQ2

1 Introduction

In recent years, brain computer interfaces (BCI) have received increasing attention in recent years mainly due to their potential for rehabilitation protocols optimization and prostheses development [1]. Fast detection of the user's intention of movement is in fact fundamental both to increase the actuation reliability of robotic devices/prostheses, especially for amputees, and promote motor recovery at the cortical level through neural plasticity for instance with robot-assisted therapy, functional electrical stimulation or spinal cord stimulation [2].

Electromyographic (EMG) activity may be used to directly activate an external device as it is a direct result of a movement attempt, however it does not provide information on motor intention [3, 4]. On the contrary, recent studies have highlighted significant modifications of brain activity related to movement [5], even in tasks such as stereotyped walking [6, 7], that may be used as features to decode movement intentions. Electroencephalography (EEG) has been reported to contain artifacts, phase and time locked to movement, especially during gait e.g., cable sway, gel-electrode coupling etc. [8]. Notwithstanding its limitations, the EEG is the only imaging modality that has sufficient portability and resolution to allow investigation of brain activity during dynamic daily activities (e.g., locomotion [7]). Here we evaluated the feasibility of EEG-based decoding of rest (standing) and movement (overground walking) conditions.

This work was supported by the European Union's Horizon 2020 research and innovation programme under Marie Skłodowska Curie Grant Agreement No. 750947 (project BIREHAB).

L. Masia et al. (Eds.): ICNR 2018, BIOSYSROB 21, pp. 1–4, 2019.
https://doi.org/10.1007/978-3-030-01845-0_87

2 Materials and Methods

One healthy subject performed six 5-min overground walking trials (intermittent walking, back and forth, with 10 s respite) following a 5 min sitting and standing resting phase. EMG (Gastrus Medialis GM, Tibialis Anterior TA, Vastus Medialis VM, Biceps Femoris BF) and 64 channel EEG (Ant Neuro) were simultaneously collected at 2 kHz. EEG data were preprocessed with a causal high-pass filter with a cut-off frequency of 2 Hz. Data with considerable nonstationary, high-amplitude and non-stereotyped artifacts, were removed (visual inspection). Stereotyped muscular, and

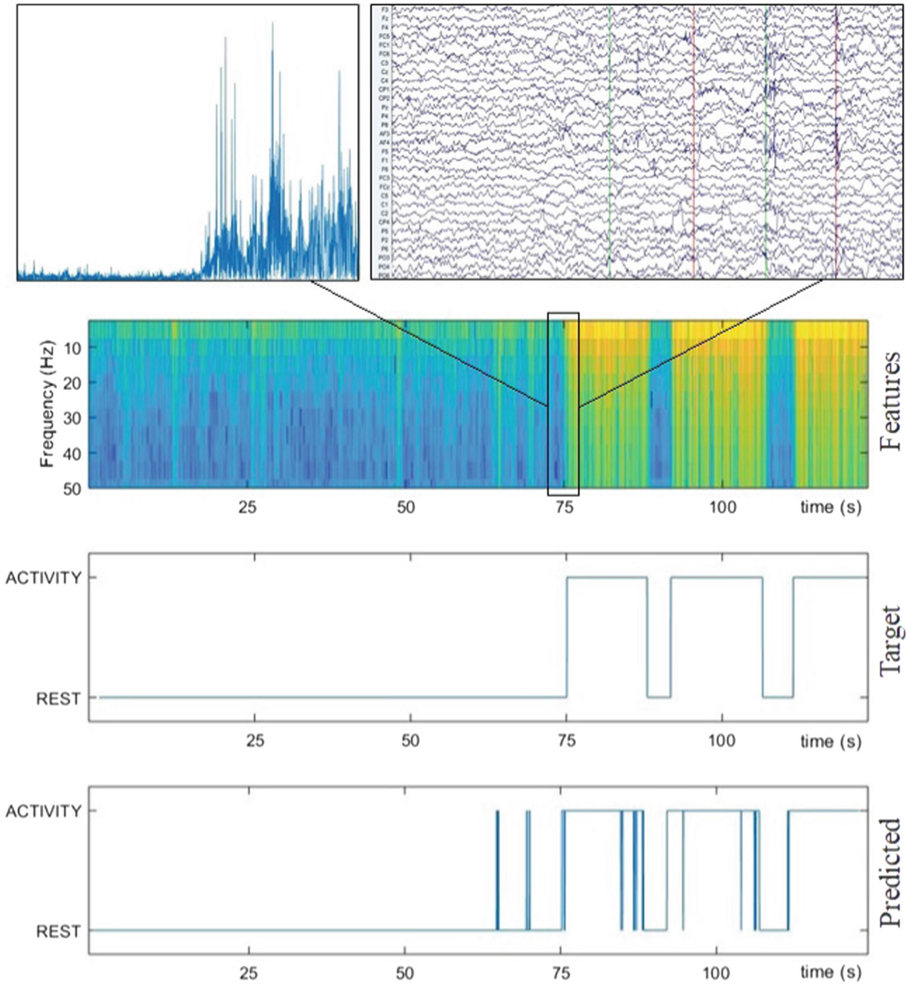

Fig. 1. An example of classification from an EEG channel. Rest is followed by intermittent walking. From top to bottom, EMG data (left), EEG data (right), the data given to the classifier as test set (Features), the binary target provided (Target), and the output predicted by the model (Predicted).

ocular artifacts were removed via Independent Component Analysis (ICA) - see [7]. Binary (Rest vs Activity) classification was performed via Linear Discriminant Analysis (LDA) with 10-fold cross validation and a sliding windows approach (200 ms, 150 ms overlap) for each EEG and EMG channel independently. Power at frequencies in the [2–50] Hz and [10–400] Hz ranges were used as features for EEG and EMG respectively.

3 Results

Activity Vs Rest EEG decoding showed overall performance ranging from 88.52% and 95.60% (Fig. 1) Similar performance was achieved with the EMG. It can be observed (Fig. 1) that Power spectra variations allow to visually identify task changes, i.e., walking phases from rest.

4 Discussion

The results presented constitute a first step towards demonstrating the feasibility of task decoding for overground walking using the EEG. Results show that it was possible to detect the activity phase with comparable performance to the EMG. In agreement with [7] the results constitute indirect evidence of the possibility of retrieving meaningful information from EEG even during dynamic tasks such as overground walking. However further validation (e.g. with source localization as in [7]) is necessary to exactly quantify the role that residual artifacts, time-locked to the gait phases, may have had on the decoder performance. Further studies will also be directed to better quantifying the extent to which the EEG, compared to EMG, allows to predict, as opposed to detect, movement onset.

5 Conclusion

Cortical activity measured by means of EEG may be used to discriminate rest and overground walking conditions with performance comparable to the EMG. These results constitute a first step towards the implementation of brain activity decoders to detect movement intentions, which may prove useful in the future to optimize control algorithms for robotic devices and lower limb prostheses. However, further studies are still required to quantify the effect of artifacts on the decoder performance.

References

1. Wang, P.T., King, C.E., Chui, L.A., Do, A.H.: Self-paced brain-computer interface control of ambulation in a virtual reality environment. J. Neural Eng. **9**(5), 056016 (2012)
2. Enders, H., Nigg, B.M.: Measuring human locomotor control using EMG and EEG: current knowledge, limitations and future considerations. Eur. J. Sport Sci. **16**(4), 416–426 (2016)

3. Zecca, M., Micera, S., Carrozza, F.M.C., Dario, P., Smith, B.: Control of multifunctional prosthetic hands by processing the electromyographic signal. Crit. Rev. Biomed. Eng. **30**, 4–6 (2002)
4. Atzori, M., Müller, H.: Control capabilities of myoelectric robotic prostheses by hand amputees: a scientific research and market overview. Front. Syst. Neurosci. **9**, 162 (2015)
5. Sahyoun, C., Floyer-Lea, A., Johansen-Berg, H., Matthews, P.M.: Towards an understanding of gait control: brain activation during the anticipation, preparation and execution of foot movements. NeuroImage **21**, 568–575 (2004)
6. Gwin, J.T., Grassman, K., Makeig, S., Ferris, D.P.: Electrocortical activity is coupled to gait cycle phase during treadmill walking. NeuroImage **54**, 1289–1296 (2011)
7. Artoni, F., Fanciullacci, C., Bertolucci, F., Panarese, A., Makeig, S., et al.: Unidirectional brain to muscle connectivity reveals motor cortex control of leg muscles during stereotyped walking. NeuroImage **159**, 403–416 (2017)
8. Castermans, T., Duvinage, M., Cheron, G., Dutoit, T.: About the cortical origin of the low-delta and high-gamma rhythms observed in eeg signals during treadmill walking. Neurosci. Lett. **561**, 166–170 (2014)
9. Makeig, S., Gramann, K., Jung, T.P., Sejnowski, T.J., Poizner, H.: Linking brain, mind and behavior. Int. J. Psychophysiol. **73**(2), 95–100 (2009) AQ3
10. Menicucci, D., Artoni, F., Bedini, R., Pingitore, A., Passera, M., Landi, A., et al.: Brain responses to emotional stimuli during breath holding and hypoxia: an approach based on the independent component analysis. Brain Topogr. **27**(6), 771–785 (2014)

Author Query Form

Book ID : **472703_1_En**
Chapter No : **87**

Please ensure you fill out your response to the queries raised below and return this form along with your corrections.

Dear Author,
During the process of typesetting your chapter, the following queries have arisen. Please check your typeset proof carefully against the queries listed below and mark the necessary changes either directly on the proof/online grid or in the 'Author's response' area provided below

Query Refs.	Details Required	Author's Response
AQ1	This is to inform you that corresponding author has been identified as per the information available in the Copyright form.	
AQ2	As Per Springer style, both city and country names must be present in the affiliations. Accordingly, we have inserted the city name in all affiliation. Please check and confirm if the inserted city name is correct. If not, please provide us with the correct city name.	
AQ3	References [9 and 10] are given in the list but not cited in the text. Please cite this in text or delete this from the list.	

MARKED PROOF

Please correct and return this set

Please use the proof correction marks shown below for all alterations and corrections. If you wish to return your proof by fax you should ensure that all amendments are written clearly in dark ink and are made well within the page margins.

Instruction to printer	*Textual mark*	*Marginal mark*
Leave unchanged	• • • under matter to remain	
Insert in text the matter indicated in the margin		New matter followed by or
Delete	/ through single character, rule or underline or through all characters to be deleted	or
Substitute character or substitute part of one or more word(s)	/ through letter or through characters	new character / or new characters /
Change to italics	under matter to be changed	
Change to capitals	under matter to be changed	
Change to small capitals	under matter to be changed	
Change to bold type	under matter to be changed	
Change to bold italic	under matter to be changed	
Change to lower case	Encircle matter to be changed	
Change italic to upright type	(As above)	
Change bold to non-bold type	(As above)	
Insert 'superior' character	/ through character or where required	or under character e.g. or
Insert 'inferior' character	(As above)	over character e.g.
Insert full stop	(As above)	
Insert comma	(As above)	,
Insert single quotation marks	(As above)	or and/or or
Insert double quotation marks	(As above)	or and/or or
Insert hyphen	(As above)	
Start new paragraph		
No new paragraph		
Transpose		
Close up	linking characters	
Insert or substitute space between characters or words	/ through character or where required	
Reduce space between characters or words	between characters or words affected	