Feasibility of Submaximal Force Control Training for Robot–Mediated Therapy After Stroke

Guillermo Asín-Prieto[1](✉), Aitor Martínez-Expósito[1], Fady Alnajjar[2], Shingo Shimoda[3], José L. Pons[1], and Juan C. Moreno[1]

[1] Neural Rehabilitation Group, Spanish National Research Council, Madrid, Spain
guillermo.asin.prieto@csic.es
[2] College of Information Technology, United Arab Emirates University, Al Ain, United Arab Emirates
[3] Intelligent Behavior Control Unit of RIKEN Brain Science Institute, Nagoya, Japan

Abstract. We investigate the use of submaximal force production as a targeted functionality in a rehabilitation task for early rehabilitation after stroke. We present the detailed assessment of related metrics of force production and position control, their correlation with submaximal force production control learning and their feasibility for robot–mediated therapy after stroke.

1 Introduction

Recent projects highlight how motor learning and a high level of attention control can potentially improve submaximal force production during recovery. Stroke patients might benefit as this pathology affects each year to 17 million people worldwide, being the second leading cause of disability [1]. We already provided preliminary evidence of the facilitation of learning processes from a kinematic point of view in healthy subjects with robotic devices [2]. Robotics can be used not only as standalone devices, but also in combination with virtual environments, providing the possibility of showing the patient and the physiotherapist the feedback of the performance of the task, which has been proven to improve rehabilitation [3]. In our previous work, we introduced the use of "tacit adaptability" (TA) –a symbiotic control strategy based on biomimetic mechanisms, which is based on "tacit learning" [4]– with a stroke patient [5], walking on a treadmill, modulating the compliance with attention levels estimated from EEG signals. Marchal–Crespo et al. [6] showed that random disturbances improved

---

This research has been funded by the Commission of the European Union under the BioMot project - Smart Wearable Robots with Bioinspired Sensory-Motor Skills (Grant Agreement number IFP7-ICT- 2013-10- 611695), also under the ASTONISH Project - Advancing Smart Optical Imaging ans Sensing for Health (Grant Agreement number H2020-EU.2.1.1.7. - ECSEL-04-2015 - 692470), and partially supported with grant RYC-2014-16613 by Spanish Ministry of Economy and Competitiveness.

L. Masia et al. (Eds.): ICNR 2018, BIOSYSROB 21, pp. 256–260, 2019.
https://doi.org/10.1007/978-3-030-01845-0_51

motor learning in the performance of a simple dorsi–plantarflexion task, because this variability may increase recovery by increasing the needed effort and attention into the task.

This study focuses on the assessment of detailed metrics of force production and position control and their correlation with submaximal force production control learning, as improving regularity in submaximal force production might help improve functionality and reduce disability [7] during a new task consisting in maintaining the position for early rehabilitation after stroke. Our aim is to characterize the capacity to perform the precision task of maintaining the position with a submaximal force production in healthy subjects, by using the game we have designed that addresses the important factors for motor training: precision, speed, and path directness toward the specific targets presented on the screen [8]. We provide a novel approach in using TA to modulate the compliance of a torque control, to in the end modulate the difficulty of the task and thus play around the concept of the "challenge point theory" [9] to try accelerate the rehabilitative process. We intend to improve the therapy for stroke by training the ability of maintaining the position of the foot, addressing the typical problem for these patients of drop foot, as we focus our actuation on dorsi/plantar–flexion.

2 Materials and Methods

In this section, we briefly present the platform we use for this study and expose the methodology.

2.1 Experimental Platform

A Motorized Ankle Foot Orthosis (MAFO) is used for this study, with a zero–torque control. This robotic platform permits to exert controlled torque profiles to the ankle joint of the subject. The TA module is explained in Fig. 1, as well as the rest of the platform.

2.2 Participant

One healthy subject, right–handed, 30 years old, was enrolled for this experiment.

2.3 Task

The experiment consisted in following the trajectories depicted via the visual paradigm, while the robot disturbed the movement by performing plantar and dorsiflex interleaved torque patterns (see Fig. 2 for explanation on the torque profiles). The aim was to improve the motor control by learning how to maintain the position to follow the trajectory in the screen, compensating the perturbations.

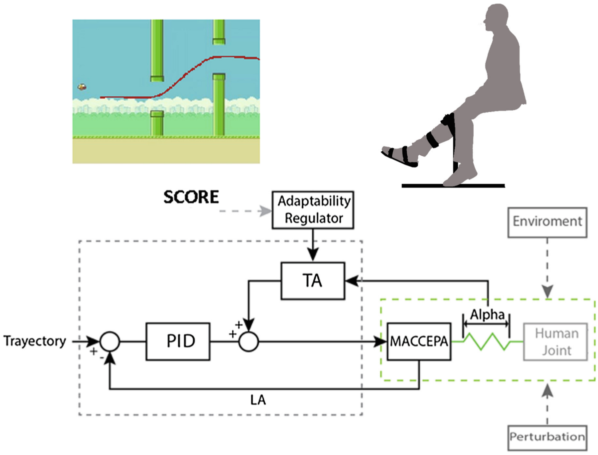

Fig. 1. Experiment set–up. The controller of the robotic platform consists on a zero torque controller (PID), with the addition of the TA component (TA constant –K_{TA}– multiplied by alpha, angle between the robot and the subject, proportional to the interaction), modulating K_{TA} with the score. The user controls the position of the bird with the angular position of the ankle.

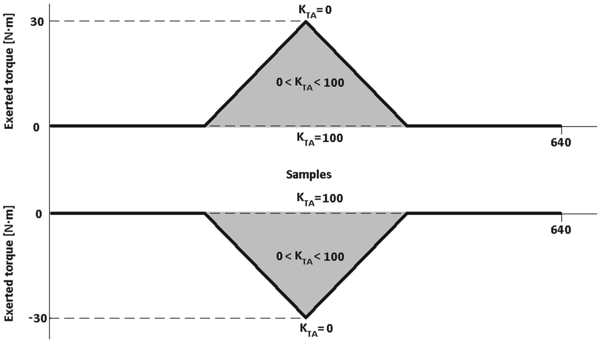

Fig. 2. Torque patterns. Torque to dorsiflexion (up) and plantarflexion (down) direction, with the behaviour of the TA module: (1) $K_{TA} = 100$ leads to zero–torque control; (2) $K_{TA} = 0$ leads to regular torque control, so up to 16 $\mathrm{N} \cdot \mathrm{m}$; and (3) K_{TA} between 0 and 100, closer to zero–torque control the higher K_{TA} is.

(1) Task Description: The task consisted on five sessions, of 61 trajectories: (1) first trajectory to understand the dynamics of the exercise; (2) the next ten assessed the performance before the training (at fixed torque); (3) forty training trials were performed; and (4) finally, the last ten trials assessed the performance after the training. The five sessions were separated by one day between them.

(2) Data Analysis: We analyzed the results by looking into the score, and the error between performed and prescribed trajectories, for ten trajectories before

(PRE) and after (POST) the 40 trials training. We provide standard deviation, and standard error, for score and root mean square error (RMSE) respectively, as a measurement of the dispersion on the performance over the assessments, meaning better motor control with higher homogeneity on the mean values, i.e. more similar values along the full assessment. We ran a 2–Way ANOVA of repetitive measures for the statistical analysis with assessment (PRE–POST) and session (1 to 5) factors and a Bonferroni's post–hoc analysis, with a $p = 0.05$.

3 Results

In the results we observed statistical (session factor, $p < 0.05$) increment on the score ($F(4, 36) = 15.8, \eta_p^2 = 64\%$) and reduction on the RMSE ($F(4, 36) = 15.5, \eta_p^2 = 63\%$). Post–hoc analysis revealed significant changes inter–sessions, as shown in Fig. 3. We found no intra–session significant changes.

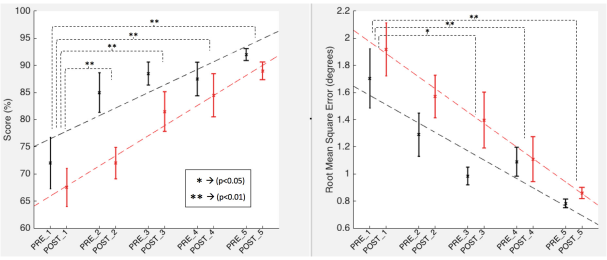

Fig. 3. Scores and RMSE (average, and standard deviation for score, and standard error for RMSE) before (PRE) and after (POST) each training assessments. Dotted line represents the linear fitting of the data for PRE (black) and POST (red) assessments.

4 Conclusions and Future Work

The reduction on the variability and the increase on the score and reduction on error along the sessions suggests that the protocol is a successful training for motor control; although the slight increment on the error and decrement on the score pre and post–training intra–session, not being significant though, may suggest that there is some attention decrease or fatigue.

Near future work includes enrollment of more subjects to statistically prove the validity of the platform and protocol for the training of motor control. Patients will be also enrolled to check the possibility of translating the platform to the clinical environment.

References

1. World Stroke Organization: World Stroke Organization (WSO) Annual Report 2016 (2016). http://www.world-stroke.org/images/Annual_Report_2016_online.pdf
2. Asín-Prieto, G., González, J.E., Pons, J.L., Moreno, J.C.: Robotic platform with visual paradigm to induce motor learning in healthy subjects. In: Iberian Robotics conference, pp. 569–579. Springer (2017)
3. Asín-Prieto, G., Cano-de-la-Cuerda, R., López-Larraz, E., Metrot, J., Molinari, M., van Dokkum, L.E.H.: Emerging perspectives in stroke rehabilitation. In: Emerging Therapies in Neurorehabilitation, pp. 3–21 (2014)
4. Shimoda, S., Costa, Á., Asín-Prieto, G., Okajima, S., Iáñez, E., Hasegawa, Y., AzorÍn, J.M., Pons, J.L., Moreno, J.C.: Joint stiffness tuning of exoskeleton robot H2 by tacit learning. In: International Workshop on Symbiotic Interaction, pp. 138–144. Springer (2015)
5. Asín-Prieto, G.: Tacit adaptability: EEG-informed symbiotic approach applied to rehabilitation robot control. Xmas Meeting. Cajal Institute, Madrid, Spain (2016)
6. Marchal-Crespo, L., López-Olóriz, J., Jaeger, L., Riener, R.: Optimizing learning of a locomotor task: amplifying errors as needed. In: 2014 36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), pp. 5304–5307 (2014)
7. Panjan, A., Simunic, B., Sarabon, N.: Maximal voluntary torque and the ability to finely grade submaximal torque are not related. Kinesiol. Slov. **17**(3), 5 (2011)
8. Marston, H.R. Smith, S.T.: Interactive videogame technologies to support independence in the elderly: a narrative reviewGAMES FOR HEALTH: Research, Development, and Clinical Applications, vol. 1, no. 2, pp. 139–152. Mary Ann Liebert, Inc., New Rochelle (2012)
9. Guadagnoli, M.A., Lee, T.D.: Challenge point: a framework for conceptualizing the effects of various practice conditions in motor learning. J. Motor Behav. **36**(2), 212–224 (2004)