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Providing proprioceptive feedback by means of vibrotactile stimuli: A way to improve body integration of a prosthetic arm*

M. Auvray, Y. Kechabia, G. Arnold, and N. Jarasse

Abstract— The aim of the study reported here was to ease the learning of prostheses involving myoelectric control in upper limb amputees. To do so, the proprioceptive cue of wrist rotation was coded into vibro-tactile feedback. Training with this sensory feedback improved performance in terms of movement preparation time. Thus, vibro-tactile feedback as a cue for wrist rotation ease learning of prosthetic devices and thereby might favor their body integration.

I. INTRODUCTION

Prosthetic arms allow amputees to perform a broad range of movements. However, these technologies still face some limitations. The lack of some active joints, the absence of sensory feedback, the complexity of the command, and the resulting cognitive load lead many amputated patients to stop using their prosthesis: 38% in [1], 20% in [2]. For those still using them, these issues limit the overall ease with the device and reduce their users' capabilities and autonomy [3]. In particular, the absence of sensory feedback forces amputees to rely on vision only. This results in slow and cognitively heavy processes, insufficient to appreciate physical interactions [3]. It has been underlined that one of the main requests from users is to have control mechanisms that require less visual attention [4]. A promising way to achieve this goal consists in developing artificial tactile or vibro-tactile feedback. To do so, methodologies were borrowed from sensory substitution, that is, the projection of information from one deficient sensory modality to an intact one, as is commonly used in the field of assistive technologies for visual impairments [5, 6, 7].

Attempts to provide proprioceptive feedback were done both in invasive and non-invasive ways [8]. In particular, previous studies coded proprioceptive cues by tactile feedback in the context of prosthetics. These studies focused on information about hand opening [9] and grasping force [10, 11], useful for grasping tasks, location of the prosthetic hand [12], and sense of position and motion, this time by inducing rotational skin stretch on the user's skin [13]. In the study reported here, the proprioceptive cue of wrist rotation was coded into vibro-tactile feedback. We investigated if this sensory feedback allows improving performance with a prosthetic arm.

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II. METHODS

Participants. Twenty three healthy participants completed the experiment (12 females, mean age: 23.4, ranging between 21 and 32 years). All the participants provided informed consent and were naive to the purpose of the experiment, which took approximately 30 min to complete.

Materials. The materials consisted of a prosthetic arm and a vibro-tactile bracelet. In order to control the prosthesis, two cutaneous electrodes, with an acquisition frequency of 10 Hertz, were used to receive the electromyographic signals. The electrodes were placed on two muscles on the participants' arm: the flexor and the extensor. Whenever there was a muscle contraction, signals were generated, filtered, and amplified inside the electrode. The tactile feedback was given through a bracelet made of scratch on which 6 vibrators (Haptuator Mark II, Tactile Labs, Montreal, Canada) were equidistantly located, so that they were separated by a 30° angle (see Fig. 1).

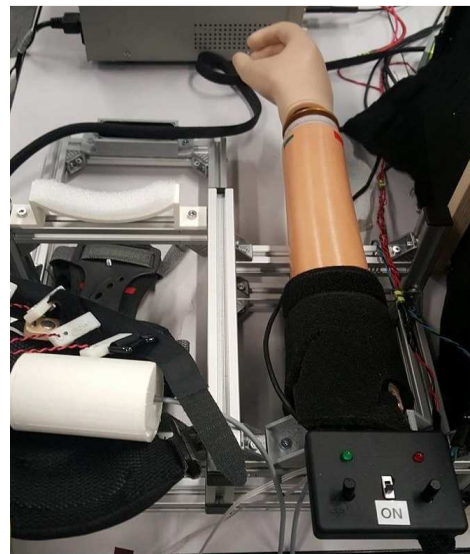


Figure 1. Image of the experimental set-up

Procedure. The experiment was divided into four successive steps.

Step 1. Familiarization with the set-up. The participants were first trained to use the myoelectric command without feedback during a couple of minutes. Then, they were explained the functioning of the vibrotactile bracelet.

Step 2. Pre-test. The participants completed 2 successive series of 6 orientations to reach (12 trials in total). At the beginning of each trial, the participants received information about the starting orientation of the hand which was set at

0°. Then, one of the 6 vibrators was activated, which corresponded to one of the 6 orientations to reach [-90°, -60°, -30°, 30°, 60°, 90°]. The participants were asked to perform a movement by pronosupination of the prosthesis' wrist by means of the myoelectric command, in order to reach the target orientation. The participants held a go-no-go button that they had to press just before initiating a movement and again once they reached the target orientation. At the end of each trial, the prosthesis was automatically repositioned at the 0° starting orientation.

Step 3. Learning phase. The participants had to complete 5 successive series of 6 orientations to reach (30 trials in total). The procedure was similar to step 2, except that, this time, the participants chose the orientations to reach. The 6 possible hand orientations were shown visually. The participants had to complete an entire grid of 6 orientations before completing the next grid. The participants' task was to move the prosthesis by pronosupination of the wrist so that their prosthesis and the corresponding image have the same orientation. In order to measure the influence of vision on learning, half of the participants completed step 3 with vision and the other half without. In the condition without vision, a cover fell back on the prosthesis during movement.

Step 4. Post-test. Identical to step 2.

III. RESULTS



Figure 2. Percentage of spatial error and Movement preparation time obtained in the conditions with vibration and vision (VV) and with vibration and no vision (VN).

Two dependent variables were computed: Percentage of spatial error and Movement preparation time. Repeated measures ANOVAs were conducted on these two dependent variables with the factors Learning (pre-test versus post-test) and Visual condition (with vision versus without vision during the learning phase). Regarding the Percentage of spatial error, the analysis showed a significant effect of Visual condition [F (1, 22): 10.63, $p < 0.01$], no effect of Learning, and no significant interaction between these two factors (both $p > 0.05$). Regarding Movement preparation time, the analysis showed a significant effect of Learning [F (1, 22): 5.22, $p < 0.05$], no effect of vision, and no significant

interaction between these two factors (both $p > 0.05$), see Fig. 2.

IV. CONCLUSION

Our results show that training with a vibro-tactile feedback about wrist rotations allows improving participants' performance in terms of movement preparation time. Regarding spatial accuracy, our results does not show significant improvement after training. Although there was a numerical trend in this direction, more participants are needed to confirm this trend. In addition, our results do not allow for now concluding on the interest of vision during learning. Interestingly, the learning protocol used here allowed performance improvement in as few as 30 trials, which is promising for further attempts of providing proprioceptive feedback by means of tactile stimuli. Our next steps will involve testing our protocols with transhumeral amputees and extend our findings to additional artificial sensory feedbacks on proprioceptive information.

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