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Adding vibrotactile feedback to a myoelectric-controlled hand improves performance when online visual feedback is disturbed

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ABSTRACT

We investigated whether adding vibrotactile feedback to a myoelectric-controlled hand, when visual feedback is disturbed, can improve performance during a functional test. For this purpose, able-bodied subjects, activating a myoelectric-controlled hand attached to their right hand performed the modified Box & Blocks test, grasping and manipulating wooden blocks over a partition. This was performed in 3 conditions, using a repeated-measures design: in full light, in a dark room where visual feedback was disturbed and no auditory feedback – one time with the addition of tactile feedback provided during object grasping and manipulation, and one time without any tactile feedback. The average time needed to transfer one block was measured, and an infrared camera was used to give information on the number of grasping errors during performance of the test. Our results show that when vibrotactile feedback was provided, performance time was reduced significantly, compared with when no vibrotactile feedback was available. Furthermore, the accuracy of grasping and manipulation was improved, reflected by significantly fewer errors during test performance. In conclusion, adding vibrotactile feedback to a myoelectric-controlled hand has positive effects on functional performance when visual feedback is disturbed. This may have applications to current myoelectric-controlled hands, as adding tactile feedback may help prosthesis users to improve their functional ability during daily life activities in different environments, particularly when limited visual feedback is available or desirable.

1. Introduction

1.1. Use of feedback resources during grasping

Grasping and manipulating an object, as simple as it may seem, requires a complicated motor control process, using visual, proprioceptive, and tactile feedback mechanisms (Flanagan, Merritt, & Johansson, 2009). Visual and proprioceptive feedback are used to guide the hand to the chosen position and to determine the correct distance to the object. When the hand is grasping the object, tactile feedback provides information about the shape, texture and size of the object. In this way, a successful performance of grasping or manipulating of an object can be achieved (Flanagan, Bowman, & Johansson, 2006).

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1.2. Lack of tactile feedback when using an artificial hand

In chronic deafferentation, when no tactile feedback is possible, deficits are observed in performance despite full vision of the object (Hermsdörfer, Elias, Cole, Quaney, & Nowak, 2008). Following limb loss, amputees may use myoelectric prosthesis, in which the artificial hand is activated by signals from the muscles of the residual limb. This is done by recording electrical activity (surface EMG) via two electrodes placed on the muscles of the forearm. When the prosthesis user contracts his or her muscles, the electric signal generated by the muscles is detected by the electrodes, and translated into a hand movement, e.g. opening or closing the prosthetic hand (Farina & Amsüss, 2016). Using these state-of-the art devices for functional grasping tasks may be a complex task. Since the prosthesis is controlled by contracting the residual muscles in order to activate different hand movements, this non-natural hand control is not trivial (Fougner, Stavdahl, Kyberd, Losier, & Parker, 2012).

Another difficulty in using myoelectric prostheses arises from the lack of tactile feedback from the artificial hand. Since tactile feedback is missing, the prosthesis user has to compensate using his or her visual feedback resources during performance of functional tasks (Cordella et al., 2016). A study that examined the correlation between functional performance and visual attention found that prosthesis users who were less successful in functional task performance tended to allocate their visual attention to their artificial hand (Bouwsema, Kyberd, Hill, van der Sluis, & Bongers, 2012). In a recently published study, Parr and colleagues analyzed the gaze behavior during the functional task of picking coins. They found that when using the prosthesis simulator, subjects focused significantly more on their hand, and their task performance time was prolonged (Parr, Harrison, Vine, & Wood, 2017). These results suggest that when using a prosthesis, the natural mechanism of eye-hand coordination during task performance is affected, so that visual feedback is used more prominently. Therefore, performance of simple tasks using a myoelectric-controlled hand, which does not provide tactile feedback, can be highly challenging for the common user (Wijk & Carlsson, 2015). This may be even more relevant to users with poor daily performance, where visual feedback is used as the main resource to provide data about the grasped object.

1.3. Grasping when visual feedback is disturbed

Due to the loss of tactile feedback following a limb loss, when encountering different scenarios in real life, where visual feedback is disturbed, prosthesis users may face a challenge not faced by other individuals. For example, they can be required to perform a dual task, where they need to divide their visual attention between both hands, e.g. holding a coffee cup while reading a paper. Since tactile feedback is missing from the artificial hand, this is not a trivial functional task. In order to evaluate the relationship between tactile feedback and visual attention levels during functional tasks, we have recently examined the effects of adding vibrotactile feedback (VTF) to a myoelectric-controlled hand on visual attention and performance in a dual-task paradigm (Raveh, Friedman, & Portnoy, 2017). In our study, the subjects were required to perform a functional task with the artificial hand, while controlling a video game with the other hand, repeated in two conditions: with and without VTF. However, no significant differences between the two conditions were found. These results could be attributed to the complexity of the dual-task scenario, making it difficult to assess the actual effect of tactile feedback on task performance.

In order to examine this effect from a different perspective, we examined the role of tactile feedback when visual feedback is disturbed. In this scenario, prosthesis users have to utilize their prosthetic hand in a dark environment, where they cannot rely on their visual resources. This may happen when they try to turn the light on in a dark staircase corridor, when they search for their keys in a bag, or in any other case where visual feedback is not available. In these cases, tactile feedback plays an essential role during grasping, and its lack is significant for the prosthesis user (Cordella et al., 2016). A recent study assessed daily prosthesis usage using wireless activity monitors, and found that the prosthesis users barely used the artificial hand during the evening times (Chadwell et al., 2017). This could be explained due to the additive challenge of using a prosthesis in nighttime, when there is less visual feedback, increasing the risk for dropping objects. Although prosthesis users are unlikely to use their artificial hand in the dark, it is important to examine the performance in a surrounding where visual feedback is limited or disturbed, in order to have more knowledge of the actual role of tactile feedback in the grasping process.

1.4. Disturbing visual feedback

Several studies used different methods to disturb visual feedback in order to evaluate the effects of adding tactile feedback to prosthesis users. One method is to cover the objects with dark material, so that the subjects cannot see the hand and its movements. Using this method with healthy subjects fitted with a robotic hand in a grasping task and tactile feedback, researchers showed that performance was improved (Saunders & Vijayakumar, 2011). Another method is to use a blindfold, so that the subject cannot see the object at all. This method was used in a novel case study with implanted tactile feedback, in order to examine if he could identify the stiffness and shape of three different objects by exploiting their different characteristics (Raspopovic et al., 2014).

1.5. Assessment of performance during grasping

All the aforementioned studies examined the effects of the addition of tactile feedback on performance time. Nevertheless, improvement in performance does not relate only to reduced performance time, but also to having the task performed in an accurate manner. Both time and accuracy are two important aspects of performance, and their assessment was widely studied (Latash & Fundamentals of Motor Control, 2012). In a review on using sensory feedback in upper limb prosthetics, the possible mechanism in which VTF has positive effects on the grasping of prosthesis users is working through a better control of grip force, and by lowering