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Visuomotor behaviors and performance in a dual-task paradigm with and without vibrotactile feedback when using a myoelectric controlled hand

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ABSTRACT
Prosthesis users allocate visual attention to their prosthetic hand while performing activities of daily living (ADLs), due to absence of sensory feedback. Dual-task assignments present competition for visual attention and may affect the performance of ADLs. Vibrotactile feedback (VTF) is a frequently-used method to provide prosthesis users with tactile feedback. However, the effect of adding VTF on visual attention and performance in a motor dual-task paradigm has not been investigated. Our aim was to compare visual attention and performance during ADLs in a motor dual-task paradigm when using binary VTF and without using VTF. Forty-three able-bodied subjects (age 26 ± 6.6 years) had a myoelectric-controlled hand attached to their right hand. The dual task comprised of a computer game played with the left hand, while manipulating objects with the artificial hand. This was performed with and without VTF in a counter-balanced order of two conditions. An eye-tracker monitored visual attention, while time to complete each task and the time the virtual car went off-road were recorded. No significant differences were found in visual attention or in performance time between the two conditions. Further examination of adding VTF to prosthesis users is recommended, with disrupted visual feedback and basic grasping tasks.

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Introduction

Despite technological advancements in upper limb prosthetics, the level of daily use among prosthetic users is low (Biddiss & Chau, 2007). Myoelectric prostheses, the current state-of-the-art, are activated by electrical signals produced by the residual muscles. However, in order to activate the prosthesis, the amputee must adapt to an abnormal motor control (i.e., learn to manipulate and control movement of his or her new artificial hand by contracting specific muscles). Using a myoelectric prosthesis during daily tasks (e.g., grasping and holding a spoon or opening a jar) may therefore prove to be a complex task (Fougner, Stavdahl, Kyberd, Losier, & Parker, 2012). Further difficulty is attributed to the lack of sensory feedback from the artificial hand—compelling the user to allocate visual attention to the prosthesis while manipulating objects. Sensory feedback is an essential part of upper limb control (Biddiss, Beaton, & Chau, 2007). The role of sensory feedback is to allow a bidirectional flow of information between the hand and the central nervous system. In the biological hand, information regarding the shape, texture, weight, temperature, and other physical properties of objects is detected and used to perform the task. The natural biological sensors also provide information regarding the current position of the hand in space, which is critical for the deep mental body representation (McGlone & Reilly, 2010). The users of mechanical prostheses can sense the state of the prosthesis (i.e., closed or open prosthetic hand) with or without weight-bearing, since the grip force is transferred through the control cable and harness attached to the body of the user. However, this is not the case when using a myoelectric prosthesis, where no harness or cables are required. In order to compensate for the loss of sensory feedback in this advanced technology, the users of myoelectric prostheses increase their visual attention toward the prosthesis, thus elevating visual demands during motor performance (Blank, Okamura, & Kuchenbecker, 2010; Gillespie et al., 2010).

Daily motor tasks are often performed simultaneously while performing other activities (e.g., reading a paper while holding a cup of coffee). These simultaneous motor activities may compete for visual attention, thereby slowing the actions of the amputee or increasing the probability of failure. It can therefore be assumed that performance of dual tasks using a myoelectric hand that does not provide sensory feedback may be highly challenging. When evaluating the performance difficulty levels of functional tasks, two aspects may be observed: the nominal task difficulty, which refers only to the perceptual and motor performance requirements of the task; and the functional task difficulty, which takes into account the level of user experience and the specific environmental terms (Guadagnoli & Lee, 2004). Opening and closing the artificial hand may be referred to as the nominal difficulty, with a moderate level of difficulty. However, the functional difficulty must also be considered (i.e., that the task is performed in the context of various activities of daily living [ADLs] under different conditions, which might raise the level of difficulty). As noted, an important aspect of performing concurrent

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motor tasks is the allocation of visual attention resources. Since the prosthesis user frequently focuses visual attention on activating the artificial hand, rather than paying attention to a parallel task, cognitive–motor interference is increased (McIsaac, Lamberg, & Muratori, 2015).

Several sensory feedback systems have been developed and applied to upper limb prosthetics (Schofield, Evans, Carey, & Hebert, 2014). Vibrotactile feedback (VTF), attached to the proximal location on the residual limb, has been shown to be a viable feedback mechanism in upper limb prostheses, improving grip control and reducing the number of errors during a single task execution (Antfolk et al., 2013). In a recently published study, it was found that adding VTF to a virtual myoelectric prosthesis, with an auditory counting task as a secondary task, the virtual hand positioning was improved, and the subjects perceived the secondary task to be less difficult (Witteveen, De Rond, Rietman, & Veltink, 2012). However, to the best of our knowledge, the effect of adding VTF to a myoelectric prosthesis on visual attention in a dual-task paradigm has not been investigated. Therefore, the aim of this study was to evaluate the effects of using binary VTF on visual attention and performance in a dual-task paradigm, while using a myoelectric-controlled artificial hand in healthy individuals.

Methods

Participants

We calculated the sample size for the repeated measures design using MorePower software version 6.0.1 (Campbell & Thompson, 2012). A preliminary experiment with 5 subjects showed that the standard deviation of our primary outcome measure, the percentage of time the gaze was on the screen, was 20%. If the expected difference in the mean response between the trials of with and without feedback is 10%, then the calculated sample size is 34 subjects with power of 80% and$\alpha = .05$. Forty-six healthy subjects were recruited for the study. Inclusion criteria were right-handed individuals with normal or corrected eyesight. The data of three subjects were discarded due to technical issues. Overall, data collected from 43 subjects were analyzed (18 males and 25 females, mean and standard deviation age of 26 ± 6.6 years old). The study was approved by the Institutional Ethics Committee of Tel Aviv University. All subjects read and signed an informed consent form pretrial.

Study protocol and tools

The trial setup is depicted in Figure 1. Before the beginning of the actual trial, the subjects were requested to perform the dual-task trial once with their own hands for practice, and the system recorded the acquired data. Then, a myoelectric-controlled artificial hand was attached at the distal end of an off-the-shelf hand brace with Velcro straps (Manu Immobil Long 50P11, Ottobock, Germany) with the wrist and fingers of the right hand constrained in a functional position (wrist at 30 extension, proximal interphalangeal joints at 50 flexion). Electromyographic (EMG) signals were recorded telemetrically from the forearm muscles, targeted to the flexor carpi radialis and extensor carpi radialis longus muscles. This was done at 1,500 Hz (Myon Radio Frequency Transmitting Devices (RFTD), Myon Aktiengesellschaft (AG), Switzerland (CH)) using surface bipolar Ag/AgCl electrodes (Ambu Blue Sensor N electrodes, Ambu A/S, Denmark). The activation of each of the aforementioned muscles at a predefined threshold opened or closed a plastic artificial hand (Standard Gripper Kit B, Actobotics, USA) in real time, similar to the configuration of a myoelectric prosthesis. Two thin force sensors (Flexiforce, Tekscan Inc., USA) were attached to the two terminals of the myoelectric-controlled artificial hand. An elastic strap containing eight vibrotactile actuators (Shaftless vibration motor, Pololu, USA) in its interior

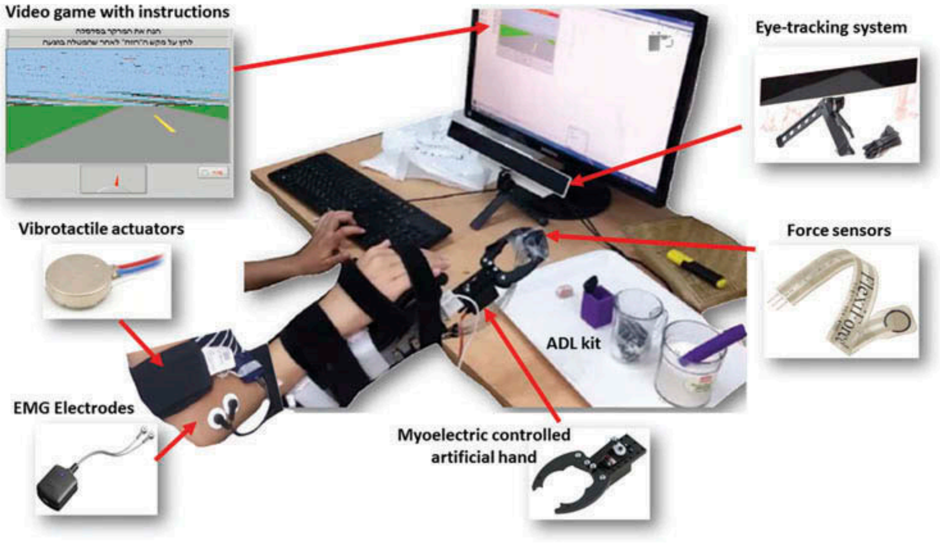

Figure 1. Dual tasking setup with a myoelectric-controlled artificial hand. The display on the screen is a stay-on-the-road driving game controlled by the right and left arrow keys using the left hand. On-screen instructions to manipulate different activities of daily living (ADLs) with the myoelectric-controlled artificial hand appear 10s after the completion of the previous task. The artificial hand is controlled by electromyographic (EMG) signals from the Flexor Carpi Radialis and Extensor Carpi Radialis Longus muscles. The vibrotactile feedback (VTF) is activated via force sensors located on the artificial hand, and the vibrotactile actuators placed on the right forearm. The gaze location on the screen is monitored by an eye-tracking system.

was wrapped around the right arm. The vibrotactile actuators were activated when the force perceived by the force sensors was above a predetermined noise level. The vibration motors used in our study were previously used in several studies (Witteveen et al., 2012, 2014). The overall performance for vibrotactile frequency discrimination was found to be similar for either hairy or glabrous skin, except when frequency is at the range of 50 Hz (Mahns, Perkins, Sahai, Robinson, & Rowe, 2006). Since the vibration frequency used in our study was approximately 233 Hz, we did not find it relevant to measure the resolution of skin discrimination. We took care in placing the cuff with the vibration motors on skin locations and avoided scars, in order to maximize immediate and easy detection of vibration for the subject. It should be noted that we did not focus on investigating the changes in VTF levels according to applied force, but rather on a binary distinction indicating whether the subject is holding the object or not. The motors were powered by a 3-V power supply and were activated at the maximum amplitude when the applied force was above a predetermined threshold level. The subjects were introduced to the VTF as follows: “The cuff placed on your arm will vibrate when you are holding one of the objects with the robotic hand. If you do not feel a vibration, then you are not holding the object.” The visuomotor behavior of the subjects was recorded using an eye-tracking system (GP3 Desktop eye tracker, Gazepoint, Canada) placed under a 22-in computer screen. The subjects were seated in front of the computer screen, and were instructed to toggle two arrow keys on a standard keyboard with their left hand in order to keep a virtual slowly-advancing car on a marked path (programmed for this study in LabView software, version 13, National Instruments, Austin, TX). They were instructed to keep the car from deviating to the sidelines, where the road visualization would be agitated as if the car was now rolling on gravel. A second task comprised of five tasks: ADLs, grasping, and manipulating objects. When choosing the objects for the subject to grasp in our trial, we selected objects that were reliably detected by the force sensors, therefore excluding objects that could not produce sufficient VTF (e.g., a plastic disposable cup). During the trial, instructions for each of the five functional tasks appeared on the screen, on top of the game, in the following order: (1) transfer the marker pen from the holder to the basket, (2) place the eraser in the trash bin, (3) transfer sugar with the teaspoon from the container to the glass, (4) mix the sugar in glass 3 times, and (5) place the key on the shelf. We chose these specific tasks due to their importance of functionality during ADLs. All five grasping tasks in our study represent different grasping patterns that would have been used with the biological hand (thumb three-finger for the marker, tripod for the eraser, index finger extension to transfer and mix sugar, and pinch for the key). These patterns were found to be commonly used in home and work environment (Bullock, Zheng, De La Rosa, Guertler, & Dollar, 2013). The first instruction appeared 10 seconds after starting the game. The subjects were instructed to keep playing the game with their left hand, while completing each functional task with their right hand, using the myoelectric-controlled artificial hand. After completing each task, the subjects were asked to press the space bar with their left hand and the instruction was automatically removed from the screen. Ten seconds after the completion of the previous task, the next instruction appeared on the screen, repeatedly, until all five tasks were completed. The subjects were instructed to rest their right hand on the table between the tasks.

First, the training comprised of opening and closing the robotic hand via the EMG signals for approximately 15 minutes. In this time, the improvement of performance in speed and accuracy was noted in all subjects, so that the trial did not commence before they could open and close the hand for at least five subsequent cycles without subjective effort reported. Then, the dual-task trial was performed twice: once with the VTF activated and once without a VTF (the vibrotactile actuators were still attached to the subjects, but were turned off). A 10-minute rest period was provided to the subjects between the two trials. In order to prevent an order effect in learning the task, the study was performed in a repeated-measures design with a counter-balanced order of two conditions, so that half the subjects started the trial with feedback and repeated the trial without feedback, and vice versa for the other half.

Post analysis

For the virtual game, we calculated the time that the virtual car was off-road, as a percentage of the total game time. Improvement in performance of this task was reflected by a lower percentage of time the subjects went off-road. For the object manipulation task, comprised of five functional assignments, the time to complete each task (in seconds) was calculated as the time between the appearance of a new instruction until the subject pressed the space bar. In addition, the total time of the trial (in seconds) was calculated.

The visuomotor behavior was evaluated by calculating the time during which the subjects’ gaze focused on the screen, as percentage of the trial duration. A high percentage of visual attention time indicated less attention levels allocated to manipulating the myoelectric-controlled artificial hand. In addition, we calculated the number of times the subjects shifted their gaze from the screen to the myoelectric-controlled artificial hand during each of the five tasks.

We used SPSS (Version 21, IBM, USA) for statistical analyses. The Shapiro-Wilk test was used to test for normality of distribution of continuous variables, and showed that some of the outcome measures were normally distributed (data are presented as average and standard deviation), and some of them were not normally distributed (data are presented as median and interquartile range). In order to use parametric analysis, we transformed the variables by taking their common logarithm, after which most of the data was then normally distributed. We compared the two conditions of the counter-balanced order using the Mann Whitney *U* test, and found no significant difference between the outcome measures of the subjects who began the trial with the VTF activated compared to the subjects who began with the VTF off, so that no learning effect was detected while repeating the trial. Since we had multiple outcome measures with two conditions (with and without feedback) and five tasks, and the log transformed data were normally distributed, we used a repeated-measures multivariate analysis of variance (ANOVA) analysis (MANOVA) to counteract multiple comparisons. The outcome measures were the time to complete each task, the number of times the gaze shifted, and the duration of gaze focus on the screen, with factors feedback (with and without) and task (five tasks). The percentage of time that the virtual car went off the road was compared in a separate repeated-measures ANOVA (as this data was only available in aggregate for each feedback condition, but not for each trial). Results were considered statistically significant if $p < 0.05$.

Results

The results of the practice trials, when the subjects used their own hands to perform the dual-task trial before the beginning of the actual trial, were partially saved. The median interquartile range (IQR) time in seconds for transferring the marker, the eraser, getting the sugar, mixing the sugar, and transferring the key were: 6.2 (6.4), 4.9 (2.9), 7.9 (4.2), 6.6 (3.1), 5.3 (3), respectively. The percentage of time the virtual car went off road was 22.2 (15.1). The results of using the myoelectric hand in the dual-task trial (i.e., the time to complete each functional task [seconds]), the number of times that the gaze shifted from the screen to myoelectric-controlled artificial hand, the duration of gaze focus on screen (% task time), and time the virtual car went off-road (% duration of whole game), under both conditions (with and without VTF), are presented in Table 1.

The repeated measures MANOVA showed only a main effect for task [F (12,16) = 4.99, p = 0.002], but not for VTF [F (3,25) = 0.33, p = 0.805] or the interaction of task and VTF. We did not further analyze the main effect of task, because it was expected that the different tasks would take different times, and this is not relevant for the research question we were examining. Similarly, a repeated measures ANOVA on the percentage of time the car went off-road during the whole game did not show a main effect of VTF [F (1,36) = 0.095, p = 0.76].

Discussion

In this study, we evaluated the effects of adding VTF to a myoelectric-controlled artificial hand on the visuomotor behavior and performance of functional tasks in a dual-task paradigm. Since adding VTF to a myoelectric-controlled hand did not reduce the visual attention or improve the performance during dual-task assignments in healthy subjects, our hypothesis was not supported. It is well established that during performance of grasping tasks, both visual and tactile feedback play an important part in object detection, object size estimation, and continuous update of the visual representation, necessary to make the final grasp correct and precise (Johansson, 1998). Myoelectric prosthesis users, who lack the important capability of tactile feedback, usually compensate by using visual feedback as their main feedback resource (Childress, 1980). Since our main goal was to evaluate the effects of adding tactile feedback to a myoelectric-controlled hand, we used a dual-task paradigm in order to disrupt the visual feedback of the subjects by shifting it to the secondary motor task. During the last decades, several studies examined the benefits of adding VTF to myoelectric prostheses on different outcome measures (Antfolk et al., 2013). However, only one study used VTF in a dual-task paradigm, where the primary task was grasping virtual objects and the secondary task was a non-motor task of counting auditory signals (Witteveen et al., 2012). Generally, when VTF was available, the subjects exhibited more correct hand positions and fewer errors during virtual grasping of the objects, despite the cognitive load of a secondary task. However, the time needed to perform the task was increased. In order to better understand the cognitive mechanism of dual-task performance, and explore the source of dual-task paradigm limitations, Han and Marois (2013) used an experimental setup that consisted of an easy visuo-vocal task, paired with a more demanding audio-manual task. They found that it was highly difficult for the subjects to perform both tasks in a parallel manner, which indicates that there is an inherent cognitive bottleneck that forces the sensory-motor system to perform dual-task assignments in a serial way (e.g., one task at a time; Han & Marois, 2013). Our study is the first to challenge visual attention demands in a complex dual-task paradigm, comprising of two motor tasks. Under these new conditions, the addition of VTF did not affect the performance levels in the two motor tasks. This could be a result of an inherent cognitive mechanism, which was active when the subjects performed the primary and secondary tasks. That is, the disruption of visual feedback may not have been effective, making the addition of

Table 1. Median and interquartile ranges (in parentheses) of study parameters in two conditions (with versus without VTF).

Parameter	Task	With feedback	Without feedback
Time to complete the functional motor task (sec)	Transfer marker to basket	12.9 (9.9)	12 (11.2)
	Throw eraser into trash bin	17.4 (13.6)	12.8 (12.5)
	Use a spoon to put sugar in a glass	12.5 (19.9)	14.6 (13.3)
	Mix the sugar three times	10.4 (9.4)	14 (16.2)
	Place the key on the shelf	15.9 (17.4)	16.2 (16)
Number of times the gaze shifted from the screen to the myoelectric hand	Transfer marker to basket	13 (10.7)	14 (11.7)
	Throw eraser into trash bin	14 (13.2)	10.5 (16.7)
	Use a spoon to put sugar in a glass	17 (23.2)	17 (17.7)
	Mix the sugar three times	12.5 (7.5)	17 (17.7)
	Place the key on the shelf	14.5 (11.7)	15 (14.2)
Time of applying visual attention to the screen (% time to complete the task)	Transfer marker to basket	51.1 (16.8)	44.6 (39.3)
	Throw eraser into trash bin	40.4 (31.6)	37.8 (41.8)
	Use a spoon to put sugar in a glass	42.7 (23.8)	45.8 (26.7)
	Mix the sugar three times	48.7 (31.8)	52.3 (20.8)
	Place the key on the shelf	35 (31.3)	39.8 (29.2)
Total time that the virtual car was off-road (% time of whole game)		45.8 (17.5)	48 (15.5)

tactile feedback insignificant. In order to evaluate the effects of tactile feedback when visual feedback is disrupted in a more efficient manner, one may consider a study setup with a direct visual disruption (e.g., a dark room, so the cognitive load will not be a confounding factor). However, our current setup of two motor tasks performed in parallel is important since it describes a condition which may account for a daily activity of dual tasking (e.g., driving a car [visual attention on the road] and shifting gears with the prosthetic hand), where the VTF may not prove effective and the prosthesis user may divide visual feedback between tasks. As suggested in a recently published review on prosthetic hands and the use of different tools for various real-word activities (Maat et al., 2017), external adaptations of the prosthesis user's vehicle may improve driving capability. Future implementation of VTF to prosthesis hands may serve as an internal adaptation for helping improve this important daily function.

Another aspect of the absence of tactile feedback in prosthesis users is the allocation of visual attention to the myoelectric-controlled hand (Blank et al., 2010). In order to evaluate the allocation of visual attention, we used an eye-tracking system in our study, which analyzed the gaze patterns of the subjects during the dual-task assignment. As indicated by recent studies, gaze patterns during task performance are a promising outcome measure in the field of prosthetic rehabilitation, as it may reflect upon the strategies that prosthesis users adopt in order to compensate for the lack of sensory feedback (Saunders & Vijayakumar, 2011). A study that examined experienced prosthesis users found correlation between good performance levels of functional tasks and lower visual attention levels, so the use of visual feedback is less prominent (Bouwsema, Kyberd, Hill, Van Der Sluis, & Bongers, 2012).

In the present study, no statistically significant differences between visuomotor behavior with and without tactile feedback were found. One possible explanation for our results could be the complexity of the study setup, which combined several demands: manipulation of a new myoelectric robotic hand, internalization of an external sensory feedback, and confronting a motor dual-task paradigm. During performance of a motor grasping task in a dual-task paradigm, healthy subjects can rely on their tactile feedback received during object grasping and manipulation. However, when using a myoelectric-controlled prosthesis in such a task, without any tactile feedback, visuomotor behavior may be affected, and the users will mostly allocate their attention to the hand. The highly demanding setup may have affected the visuomotor behavior of the subjects, so that they were watching the robotic hand, regardless of feedback, to make sure it opened and closed properly during the different grasping tasks. We noted that significant differences were not observed in the amount of visual attention given when VTF was present, as might have been expected. Furthermore, it is possible that the cognitive load in this study was higher, competing for the same resources; whereas in previous studies, the dual tasks were more distinct. A recent study examined the visuomotor behavior when using a myoelectric prosthesis, compared to subjects using their biological arm, in a task of pouring water from a carton. During reaching, subjects using a myoelectric-controlled hand allocated their attention extensively to their hand, and to areas critical to grasping the carton, while the subjects using their biological arm did not focus specifically on their hand (Sobuh et al., 2014). These results were explained by the lack of tactile feedback from the prosthetic hand—compelling the user to allocate visual attention directly to the myoelectric hand in order to improve control during grasping. One of the important roles of tactile feedback during grasping and manipulation of objects is to secure and prevent the object from falling, thus improving performance time needed to complete the required task. In our study, we hypothesized that adding VTF will reduce performance time of the functional tasks. However, the performance time to complete each task with the VTF was not reduced. As mentioned, we could see that the performance time with and without VTF was not consistent for all five functional tasks. This result could be explained by the difference between the characteristics of grasping and manipulating tasks. Four out of five tasks (moving a marker, throwing an eraser in a trash bin, putting sugar in a glass, and placing a key on a shelf) were move-to-target tasks, where the subject was required to transport the object to a specific target, therefore usually requiring visual attention at the beginning and end of the task. However, during one task, namely mixing sugar in a glass, the object was already placed at the target, and the feedback was informative regarding the grip status so that the subject was able to focus his or her attention on the screen, thereby expectantly reducing the time that the car was off-road. In a review of control strategies in object manipulation tasks (Flanagan, Bowman, & Johansson, 2006), it was asserted that during object manipulation, gaze is directed to the grasp site, the object, and the place where it should be transferred to. Gaze is allocated to each location ahead of the hand, and also remains there until the grasp is completed. Therefore, it may be more effective to examine the effect of VTF in simpler motor tasks of holding and manipulating an object in a specific location (e.g., mixing sugar in a cup, rather than when while moving the object from one place to another).

Another factor that may have affected our results is that the VTF provided to the subjects had a higher level of uncertainty compared to the visual feedback during the dual tasks. As pointed out in several studies (Johnson, Kording, Hargrove, & Sensinger, 2014; Wei & Körding, 2010), there is always a level of uncertainty in the process of feedback evaluation during motor control. When several feedback channels are provided, the subjects tend to trust the feedback information, which is more certain. In other words, the subjects in our study might have experienced a level of uncertainty regarding the interpretation of the tactile feedback. As a result, they may have not trusted the available VTF, and thus did not use it efficiently during the dual tasks.

When analyzing the data from the practice trial, performed with the subjects' own hands (i.e., without the myoelectric hand), we found that the performance time of each functional task and the percentage of time the virtual car went off road were similar to these parameters extracted during the trials recorded with the myoelectric hand. These results suggest that the additional cognitive load of controlling the myoelectric hand did not have a significant effect on the performance levels of the tasks.

The main limitation of this study is its healthy population. Results may differ when repeating this trial with amputees. In addition, we chose different grasping tasks in order to simulate common ADLs. It could be that using a validated standardized test of grasping identical objects (e.g., box and blocks test) would have reduced the complexity of the dual-task paradigm, thus making it easier for the subject to notice the additive effect of the VTF. Another limitation might be the limited training time (15 minutes) given to the subjects to learn to manipulate the myoelectric-controlled artificial hand. The learning process of using an artificial hand is not trivial, and requires a well-organized method of motor learning in order to achieve good performance (Bouwsema, Van Der Sluis, & Bongers, 2014). A longer training time might have reduced the visual attention levels, since the subjects might have been more adapt to manipulating the myoelectric-controlled artificial hand so that their cognitive attention would have been more available to handling the dual-task demands. Similarly, the subjects were introduced to the VTF for the first time, so it is possible that they did not internalize the feedback in such a way that they would choose to prefer it over their visual feedback. As a result, the VTF did not play a significant role during the trials in improving performance and reducing visual attention. Similar results were found in a recent study, where the effects of VTF on the control of a prosthetic arm in healthy subjects were examined. The movement time and the angular error while moving a virtual prosthetic arm using myoelectric control were measured. No improvement in performance was found with the VTF. Moreover, the addition of VTF had a negative effect on performance in some individuals (Hasson & Manczurowsky, 2015). The authors suggested that the subjects may have had difficulty integrating the information received from the VTF into their control strategies.

Conclusions

In conclusion, no significant differences in visuomotor behavior and task performance were found in healthy subjects when adding VTF to a myoelectric-controlled hand in a dual-task paradigm. Further research should focus on prosthesis users, and use an additional setup for disruption of visual feedback. In addition, it may be more relevant to focus on performance of functional tasks of grasping and manipulating objects in place, rather than on object transfer tasks. We also recommend a longer training period in order to identify the possible effects of sensory feedback on the actual use of artificial hands, which may make a difference in several aspects of daily life activities.

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