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A comparative study of virtual hand prosthesis control using an inductive tongue control system

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\textbf{ABSTRACT}

This study compares the time required to activate a grasp or function of a hand prosthesis when using an electromyogram (EMG) based control scheme and when using a control scheme combining EMG and control signals from an inductive tongue control system (ITCS). Using a cross-over study design, 10 able-bodied subjects used a computer model of a hand and completed simulated grasping exercises. The time required to activate grasps was recorded and analyzed for both control schemes. End session mean activation times (ATs; seconds) for the EMG control scheme grasps 1 - 5 were 0.80, 1.51, 1.95, 2.93, and 3.42; for the ITCS control scheme grasps 1 – 5 they were 1.19, 1.89, 1.75, 2.26, and 1.80. Mean AT for grasps 1 and 2 was statistically significant in favor of the EMG control scheme ($p = 0.030; p = 0.004$). For grasp 3 no statistical significance occurred, and for grasps 4 and 5 there was a statistical significance in favor of the ITCS control scheme ($p = 0.048; p = 0.004$). Based on the amount of training and the achieved level of performance, it is concluded that the proposed ITCS control scheme can be used as a means of enhancing prosthesis control.

\textbf{Introduction}

Most commercially available electrical hand prostheses implement the three-finger precision pinch involving the thumb, index, and middle finger of the hand prosthesis. An example of such a prosthetic device is the SensorHand Speed\textsuperscript{a} from Otto Bock\textsuperscript{a}, Germany. However, the precision pinch only covers 20\% of the activities of daily living (ADL) (Sollerman & Ejeskär, 1995), and therefore, these prostheses have limited functionality in the context of ADL.

These limitations have also been confirmed through questionnaires and surveys (Kyberd et al., 2007; Pylatiuk, Schulz, & Döderlein, 2007). In addition to lighter, more reliable, and more anthropomorphic prostheses, the general demand among users of hand and arm prostheses was to have improved digit movement and grasp functions (Kyberd et al., 2007), (Pylatiuk et al., 2007).

These user demands are reflected in new advanced prostheses implementing a higher number of degrees of freedom (DoF). Therefore, more grasp and pinch patterns can be implemented, and with new grasps/pinches added these prostheses have the potential to provide increased functionality to the amputee. Examples of such prostheses are the Vincent Hand (Vincent Systems), the i-Limb (Touch Bionics), the Michelangelo Hand (Otto Bock) and the SmartHand (Prensilia S.R.I.). These hand prostheses implement grasps and pinches that, when combined, cover up to 79\% of ADL (Sollerman & Ejeskär, 1995).

The requirement for new easy and intuitive prostheses control schemes increases for each new grasp, pinch, and function implemented in the prostheses. Recent research in the field of control signals and control schemes for hand and arm prostheses includes electromyogram (EMG) signals as well as alternative control signals.

EMG signals recorded from the arm or forearm of the amputee are the single most used type of control signals in prosthesis control, and several new control schemes have been proposed using pattern recognition algorithms to extract more information from the available muscles and in this way improve the EMG-based control schemes (Ajiboye & Weir, 2005; Hargrove, Guanglin, Englehart, & Hudgins, 2009; Hargrove, Scheme, Englehart, & Hudgins, 2007; Lukai, Pu, Clancy, Scheme, & Englehart, 2012; Nielsen et al., 2009; Zhang, Chen, Li, Hu, & Zhu, 2011; Sebelius, 2004). Further, within the field of implantable myoelectric sensors (IMES) several studies have been carried out in order to eliminate some of the problems related to the use of surface EMG, e.g., displacement of the electrode and changes in skin impedance during use (DeMichele, Troyk, Kerns, & Weir, 2008; Lichter, Lange, Riehle, Anderson, & Hedin, 2010; Weir et al., 2009).
However, the usability of control schemes based on surface EMG and IMES recorded from the arm is highly influenced by the level of amputation. As the level of amputation moves toward the shoulder, the number of available muscles decrease and the amount of functionality to be recovered through the prosthesis increases. Therefore, the use of other types of control signals has been investigated. This includes, e.g., foot switches, shoulder joysticks, and using a throat microphone (Carrozza et al., 2005; Losier, Englehart, & Hudgins, 2007; Mainardi & Davalli, 2007). However, none of these alternative control signals have been able to outperform and replace the use of surface EMG and IMES recorded from the arm.

A very promising alternative to surface EMG and IMES recorded from the arm is named targeted muscle reinnervation (TMR). TMR utilizes the transfer of major arm nerves to a group of muscles in the chest region. These muscles need to be denervated from their original innervation. The reinnervated muscle group is then used for EMG control, and possibly for feedback to the user (Kuiken et al., 2007; Miller, Stubblefield, Lipschutz, Lock, & Kuiken, 2008; Zhou et al., 2005). With TMR the training required and the cognitive load during use can be reduced substantially. However, TMR requires complex surgery and time-consuming donning and doffing of the surface electrodes for daily use.

The present article describes a comparative study between the control scheme for a hand prostheses and a conventional EMG control scheme. The control scheme uses control signals from an inductive tongue control system (ITCS) (Struijk, 2006) in combination with standard surface EMG recorded from the forearm of the subject. The conventional EMG control scheme is based on surface EMG recordings from the forearm of the subject.

Methods

The ITCS

The ITCS is a fully integrated wireless inductive tongue interface (Struijk, 2006). The ITCS currently incorporates 18 separate inductive sensors (Struijk et al., 2009) and consists of a mouthpiece unit, an activation unit, and a central unit. Each mouthpiece unit was built using an upper palate dental imprint taken by a dentist, and during use it was placed in the upper palatal area, similar to a dental brace. Embedded in the mouthpiece unit were the required electronic circuits, a rechargeable battery, and two printed circuit boards (PCBs) with 10 and eight inductive sensors, respectively (see Figure 1A).

These sensors were activated using a ferromagnetic activation unit. The activation unit was made from dental alloy (DYNA EFM ALLOY) used for casting root caps. It had a diameter of 4 mm and a height of 2 mm. The activation unit was glued to the tip of the tongue using tissue glue (Histoacryl®; see Figure 1B), and when placed on a sensor, the sensor was activated. The on-board electronics scanned the 18 inductive sensors at a frequency of 30 Hz. The sensor output was amplified, rectified, low pass filtered, and transmitted, using a 2.4-GHz radio, to the central unit of the ITCS, which processed the signal values to obtain a decision whether or not a sensor had been activated (Struijk et al., 2009).

The initial purpose of the ITCS was to provide people with muscular dystrophy or spinal cord injuries with a control system that was mobile, wireless, intuitive, and invisible during use. The first commercial application of the ITCS allowed for text and mouse input to a computer utilizing the anterior sensor PCB for text input and the posterior sensor PCB for mouse control. However, several other applications of the ITCS have been investigated. Among these is the implementation of the ITCS in prosthetic control aiming to enhance the control of new, advanced multiple DoF arm and hand prostheses.

The ITCS control scheme

The ITCS control scheme for hand prostheses provided the user with the possibility to directly select and activate the desired functions of the prosthetic device using the ITCS. Opening and closing of a selected pinch/grasp or operating a function, e.g., wrist rotation, was performed using EMG signals recorded from the forearm of the subject. In order to allow for more intuitive control of, e.g., speed or force when manipulating a specific DoF or pinch/grasp, the ITCS control scheme still implemented the use of EMG signals.

For this study, a central unit implementing the ITCS control scheme was developed. The control scheme implemented the five most often used pinches/grasps: precision pinch (20% in ADL), lateral pinch (20% in ADL), diagonal volar grasp (15% in ADL), transversal volar grasp (14% in ADL), and tripod pinch (10% in ADL; see Figure 2). The combination of these grasps gave a total representation of 79% in ADL (Sollerman & Ejeskär, 1995).

Based on the knowledge of the accessibility of the ITCS sensors (see Figure 3A; Caltenco et al., 2012), each of the five pinches/grasps were allocated to sensors in the mouthpiece unit. With 18 sensors available, 10 were used in the proposed ITCS control scheme.

The 10 sensors on the anterior PCB of the mouthpiece unit were grouped into five sensor pairs, see Figure 3B, and the most used pinch or grasp was allocated to the sensor pair that had the highest combined accessibility. Pairing of the sensors was performed in order to decrease the complexity of the
The EMG control scheme was based on EMG recordings from the forearm of the subject. The EMG used for closing grasps was recorded from the wrist flexor muscles, and the EMG used for opening the hand was recorded from the wrist extensor muscles. The EMG control scheme implemented the same five grasps and pinches as the ITCS control scheme in this study. These five grasps and pinches were arranged in the following order: (1) precision pinch, (2) lateral pinch, (3) diagonal volar grasp, (4) transversal volar grasp, and (5) tripod pinch. The subject activated the grasps by performing a number of contractions equal to the position of the desired grasp or pinch; e.g., to activate the lateral pinch (grasp number two), two co-contractions would be needed. Opening and closing of the pinch or grasp was then performed using the EMG recorded from either wrist flexors or extensors.

Experimental setup

In order to carry out the comparative study of the ITCS and EMG control schemes, a computer model resembling the movements of the SmartHand prosthesis was used (Prensilia-TKS, 2010). This computer model was based on the VirtualHand software from Virtual Technologies Inc., USA, and was an 18-DoF computer model of the human hand. The original VirtualHand computer model was altered to allow the use of the five implemented pinches/grasps. Figure 2 is based on screenshots of the model performing the five implemented grasps/pinches.

When a pinch or grasp was selected using a co-contraction or the ITCS, the computer model assumed the unique preshape position of that pinch or grasp, and the pinch or grasp was then closed or opened, either fully or partially, using the recorded EMG.

The computer model is normally interfaced using a standard keyboard. To allow for control of the computer model using the ITCS, a wireless USB keyboard emulator was connected to the ITCS central unit. EMG and ITCS control signals were processed in the ITCS central unit and sent to the USB keyboard emulator and translated into normal ASCII characters, thus enabling the control of the computer model. The different preshapes of the computer model could then be activated using either the ITCS or through EMG-recorded
co-contractions, and for both control schemes the closing and opening of pinches/grasps were performed using the recorded EMG.

For this study the mouthpiece unit used in the ITCS control scheme was a prototype. This prototype mouthpiece unit held the sensors of the ITCS while the related electronics were located externally to the mouth. The sensors were connected to the electronic circuit of the ITCS mouthpiece through a wire protected by a silicone rubber tube exiting at the corner of the right side of the mouth.

For both of the control schemes, EMG was recorded using two 13E200 MYOBOCK surface electrodes, Otto Bock®, connected to the central unit (Otto Bock HealthCare GmbH, 2013). The output of the 13E200 was an amplified, filtered, rectified, and enveloped representation of the EMG. Both electrode output signals were sampled at 30 Hz.

To ensure correct placement of the electrodes, the subjects were asked to complete a series of wrist flexions and extensions. Since the 13E200 MYOBOCK was a dry electrode, the skin preparation consisted only of cleansing using an alcohol swab. The electrode for closing pinches/grasps was placed on the wrist flexor muscles (flexor carpi radialis and palmaris longus) located on the anterior side of the forearm, and the electrode for opening was placed on the wrist extensor muscles (extensor digitorum) located on the posterior side of the forearm. The individual electrode gain was set by having the subject perform a series of maximum voluntary contractions of the corresponding wrist muscles. The electrode gain was then increased until the electrode output of a maximum voluntary contraction reached 3.4 V, thus securing saturation of the central unit microcontroller analog to digital converter (ADC) input channel (3.3 V). The gain was then fine-tuned until the subject was able to easily perform and distinguish between the EMG control signals used: EMG Not Active (8-bit ADC value below 30), EMG Active (8-bit ADC value above 50), and EMG Full Activation (8-bit ADC value of 255).

Both control schemes were executed using the mouthpiece unit microcontroller. At a frequency of 30 Hz, the mouthpiece unit scanned the sensors, and the values were then sent to the central unit. Upon receiving the sensor values from the mouthpiece unit, the central unit compared the sensor values to a preset ITCS activation threshold value. Subsequently, both of the electrode output signals were sampled and compared with the preset EMG activation threshold values. Depending on the control scheme being active (ITCS or EMG), the according control commands were then sent to the PC for control of the computer model. The processing time for the control signals was the same for both of the two control schemes. Using a 30-Hz scanning frequency meant that an ITCS sensor activation or EMG control signal needed to be sustained for up to 33 ms in order to ensure detection of the intended control signal.

Subjects
Ten healthy adults (seven females, three males, mean age 27.7 ± 1.2), with no prior training with the ITCS, were included in the study. All subjects had a dominant right hand. This was to ensure that any differences found in the performance of the two control schemes were not influenced by the subjects having different dominant hands. All subjects gave their voluntary, written, and informed consent for their participation.

Experimental design and protocol
The protocol used in this study was approved by the local ethics committee. The study implemented a cross-over design. The subjects were randomly placed into one of two groups (five in each) and asked to complete 2×3 training sessions. Group 1 completed three sessions using the ITCS scheme and then three sessions using the EMG scheme. Group 2 started using the EMG and then changed to the ITCS scheme. The training sessions using the same control scheme were planned on three consecutive days.

At the start of each training session, the subject was placed in front of a computer screen displaying the computer model (Part II.E). Then the recording electrodes were placed on the left forearm. Before the start of a training session using the ITCS control scheme, the activation unit was glued to the tip of the tongue of the subject with tissue glue, Histoacryl®. This allowed for fixation of the activation unit for 2–3 hours. After fixation of the activation unit the mouthpiece was placed in the upper palate of the mouth.

Each training session consisted of 25 exercises. Each session included six precision pinch exercises, six lateral pinch exercises, five diagonal volar grasp exercises, five transversal volar grasp exercises, and three tripod pinch exercises. The number of times that each exercise was included in the training sessions was based on the representation of the involved pinch or grasp in ADL (Sollerman & Ejeskär, 1995). This was done in order to ensure that the subject was trained in a way that resembled the normal use of a prosthesis, which was required for a subsequent study.

The order of the exercises was randomized for each training session. Each exercise was started by the researcher. The right hand of the computer model displayed the selected grasp or pinch in a completely closed position, and further, a text stating the grasp/pinch number and name of the started exercise was displayed to the subject. An exercise was completed by correctly activating the displayed pinch or grasp of the left hand of the computer model, then completely closing it, and finally completely re-opening it and thereby resetting the hand for the next exercise. Since closing and opening of the computer model hand was performed in the same way for both control schemes, only the time used to activate the correct preshape was used in the data analysis. The closing and opening of the computer model hand was performed with the purpose of allowing the subjects to associate the preshapes with the actual grasps, which again was required for a subsequent study.

For each of the 25 exercises in a training session, the time required to activate the correct preshape, and the total time required to complete the exercise, was recorded. If the subject performed incorrect selections of grasps during an exercise, the total time to correct and complete the exercise without any limitations was recorded, i.e., subjects kept trying to activate the correct grasp and complete the exercise until
they succeeded. Recorded times were then included in the analysis on equal terms with exercises with no incorrect selections.

The five grasp types used in this study have different representations in ADL. Therefore, the time to activate (activation time [AT]) the most frequently used grasp will have a greater impact on the overall performance of the control scheme than grasps and functions not used as frequently.

The impact of each grasp on the ADL normalized mean AT for each control scheme can be calculated using the specific grasp mean AT and the corresponding grasp representation in ADL as reported by Sollerman and Ejeskär (1995; Grasp Impact = Grasp mean AT * Grasp representation in ADL). The sum of these grasp impacts can be interpreted as an ADL normalized mean AT. Using the ADL normalized mean AT to compare the performance of different control schemes will ensure that the effect of different grasp representations in ADL is accounted for.

**Results**

The time to activate the correct pinch or grasp preshape was extracted from the dataset for each exercise using MATLAB and then grouped according to training session (1, 2, or 3) and control scheme (EMG or ITCS). For each type of the five grasps/pinches, a Bonferroni corrected repeated measures analysis of variance (ANOVA) was performed using SPSS. Estimated marginal means (EMM) of the AT and the corresponding 95% confidence intervals (CIs) for both control schemes were plotted by session number for all five grasps/pinches (see Figure 4). Selected p-values from the repeated measures ANOVA are presented in Table 1.

From the subplots of Figure 4, it is evident that the EMM of the AT decreased by each session for all five grasps when using the EMG control scheme. The CI also decreased by each session for all grasps with the exception of grasp 2 from sessions 1 to 2 and grasp 4 sessions from 1 to 2. For the ITCS control scheme the EMM of the AT clearly decreased by each session for grasp 1 and 5, and the tendency was evident for grasps 2–4 as well. However, more fluctuations were seen between ITCS sessions when compared with the EMG control scheme plots. The CIs on the ITCS plots also tended to decrease by session, but again more fluctuation was seen in the CIs of the ITCS control scheme when compared with the EMG control scheme.

For the data from session 3 of the EMG control scheme a linear relationship was seen between AT and grasp number. For each co-contraction required to activate a grasp, the EMM of the AT increased by 0.65 seconds on average, from around 0.80 seconds for grasp 1 to 3.42 seconds for grasp 5 (see Table 2). For the ITCS control scheme session 3 EMM of the AT for grasp 1, which was located at the easiest accessible sensor, was 1.19 seconds and session 3 EMM of the AT for grasp 2–5 located at equally accessible sensors (see Figure 3) averaged around 2.15 seconds (see Table 2).

When comparing the EMM of the AT of the EMG and the ITCS control schemes (Figure 4 and Table 2), the EMG control scheme outperformed the ITCS for grasps 1 and 2 by having lower EMM of the AT for each of the 3 sessions. For grasp 3 the performance of the two control schemes was comparable, and for grasps 4 and 5 the ITCS control scheme

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**Table 1.** Selected p-values from the repeated measures analysis of variance (ANOVA; selected p-values from repeated measures ANOVA; factors: control scheme and session).

<table>
<thead>
<tr>
<th>Grasp</th>
<th>Session 1 and 2</th>
<th>Session 2 and 3</th>
<th>Session 1 and 3</th>
<th>Interaction: Control Scheme, Session</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.030*</td>
<td>0.122</td>
<td>0.026*</td>
<td>0.000**</td>
</tr>
<tr>
<td>2</td>
<td>0.004**</td>
<td>0.013*</td>
<td>1.000</td>
<td>0.171</td>
</tr>
<tr>
<td>3</td>
<td>0.718</td>
<td>0.412</td>
<td>0.002**</td>
<td>0.000**</td>
</tr>
<tr>
<td>4</td>
<td>0.048*</td>
<td>0.008**</td>
<td>1.000</td>
<td>0.001**</td>
</tr>
<tr>
<td>5</td>
<td>0.004**</td>
<td>0.026*</td>
<td>0.186</td>
<td>0.003**</td>
</tr>
</tbody>
</table>

Notes. *Bonferroni. **Greenhouse–Geisser. *Statistical significant difference of p < 0.05. **Statistical significant difference of p < 0.01.

**Table 2.** Estimated marginal means (EMM) of the activation time (AT) of session 3 of the electromyogram (EMG) and inductive tongue control system (ITCS) control schemes.

<table>
<thead>
<tr>
<th>Grasp</th>
<th>EMG EMM AT (±SEM)</th>
<th>ITCS EMM AT (±SEM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.80 (±0.04)</td>
<td>1.19 (±0.10)</td>
</tr>
<tr>
<td>2</td>
<td>1.51 (±0.07)</td>
<td>1.89 (±0.25)</td>
</tr>
<tr>
<td>3</td>
<td>1.95 (±0.07)</td>
<td>1.75 (±0.15)</td>
</tr>
<tr>
<td>4</td>
<td>2.93 (±0.16)</td>
<td>2.26 (±0.22)</td>
</tr>
<tr>
<td>5</td>
<td>3.42 (±0.21)</td>
<td>1.80 (±0.17)</td>
</tr>
</tbody>
</table>
outperformed the EMG by having lower EMM of the AT for each of the 3 sessions.

Table 2 show that the statistical significances found between the the control schemes are in favor of the EMG control scheme for grasp 1 and 2. For grasp 3 no statistical significance occurred, and for grasps 4 and 5 the statistical significance is in favor of the ITCS control scheme. Furthermore, Table 1 confirms that the EMM of the AT for all grasps, except grasp 2, was statistically significantly lower for session 3 compared with session 1, and that there was no interaction between the two factors of the ANOVA (control scheme and session).

Furthermore the ADL normalized mean AT was calculated for each of the five grasps of the two control schemes. The ADL normalized mean AT for using four grasps was 1.16 seconds for the EMG control scheme and 1.20 seconds for the ITCS control scheme, and the ADL normalized mean AT for using five grasps was 1.50 seconds for the EMG control scheme and 1.38 seconds for the ITCS control scheme. Table 1 show that the ITCS control scheme was significantly faster for activating grasp/function 4 and 5 in a prosthetic device when compared with the EMG control scheme. However, comparing the ADL normalized mean AT of the two control schemes and thus taking into account the more frequent use of grasp/function 1 and 2 will result in the EMG control scheme outperforming the ITCS control scheme for controlling up to four functions.

Discussion

The purpose of this study was to investigate the possible benefits of using the ITCS to enhance hand prosthesis control. The ITCS allow for easy reconfiguring of grasp layout, and if an amputee wanted to use a customized design of grasp allocation based on a user-specific profile of grasps used in ADL, this could easily be implemented in the ITCS control scheme. Also with regard to the design of the presented ITCS control scheme, the grasps and pinches chosen and the allocation of these in terms of ITCS sensor accessibility are based on the work by Sollerman and Ejeskär from 1995. It can be argued that the grasp types used and their representation in ADL as reported by Sollerman and Ejeskär (1995) have changed during the last two decades. However, if the work by Sollerman and Ejeskär was updated to present-day grasp types and representations in ADL, this could easily be implemented in the ITCS control scheme as well.

Differences in the distribution of grasps used in ADL could occur, and if a specific amputee primarily uses only two grasp types to perform ADL, then the EMG control scheme would easily outperform the ITCS control scheme. However, this would only apply for transradial amputees. Transhumeral amputees would need the use of elbow and wrist functions as well as grasping; therefore, such control schemes would always implement at least three functions. Considering the recent development of prostheses, new commercially available arm prostheses will most probably implement more than four grasps and functions (elbow, wrist, and three types of grasps).

In case of a transradial amputee, the proposed ITCS control scheme would presumably not be a viable choice providing enhanced prosthesis control. However, for trans-humeral amputees who need more functionality to be restored and, therefore, need prosthetic devices allowing for the use of an increased number of functions (4+), the ITCS control scheme seems to have legitimacy. Furthermore, for each added grasp or function beyond five, the EMG control scheme will only have increasing ATs whereas the ITCS control scheme seems to have ATs leveling out around 2 seconds.

Concerning the results of this work, the protocol used only had subjects completing three training sessions with 25 exercises for each of the two control schemes, and the subjects were able-bodied and had no prior experience in using EMG or ITCS control schemes. Therefore, the performance for both control schemes is expected to improve with training. With respect to the the ITCS control scheme the work by (Caltenco et al., 2012) supports that performance improvements are expected with training beyond three sessions. (Caltenco et al., 2012) had subjects completing three trial sessions of 44 exercises.

In order to allow for more intuitive control of, e.g., speed or force when manipulating a specific DoF or pinch/grasp, the ITCS control scheme still implements the use of EMG signals. This causes limitations of the proposed ITCS control scheme as the user must have an amputation stump with enough remaining muscles to form an antagonistic muscle pair. Two of the ITCS sensors not used in the present control scheme could be included for closing and opening of grasps. Whether or not this is feasible should be the scope of a separate study.

Furthermore, using a prototype of the ITCS with mouthpieces that have a silicone tube exiting the corner of the mouth presumably has a negative effect on the ITCS control scheme performance; e.g., the higher AT mean for grasp 4 (see Figure 4) is assumed to be caused by the silicone tubing exiting the corner of the mouth around the sensors associated with grasp 4. However, using the commercial and completely wireless version of the ITCS, the ITCS control scheme would still carry the disadvantage of having to wear a device inside the mouth. However, the device will not be visible during use and, furthermore, could provide the user with the additional advantages of environmental (e.g., doors, windows, etc.) and computer control (Struijk, 2006; Struijk et al., 2009) for which the ITCS was originally developed. Especially, this could be beneficial for bilateral amputees. The level of discomfort experienced by the user when using the wireless ITCS has previously been evaluated with regard to talking and drinking with the mouthpiece inserted, and the level of discomfort was reported to be between 1 and 3 on a scale from 1 to 10 (1: no discomfort, 10: high discomfort; Lontis et al., 2010). If a user experiences involuntary activations of the ITCS sensors, e.g., during eating, talking and drinking, these can be removed by implementing a dwell time (e.g., 100 milliseconds) for the ITCS sensor activation. However, this will result in a corresponding delay in the performance of the task.

Conclusion

This article compares the time required to activate a specific grasp or function of a hand prosthesis using a classic EMG control scheme or a control scheme combining EMG and an
assisting device, the ITCS. The comparisons are based on simulated grasping exercises performed by using a computer model implementing the five pinches and grasps of a SmartHand prosthesis prototype.

Using a repeated measures ANOVA, significant differences in the AT were found in favor of the EMG control scheme for grasps 1 and 2 and in favor of the proposed ITCS control scheme for grasps 4 and 5.

In order to take into account that grasps have different representations in ADL, the ADL normalized mean ATs for each of the two control schemes were calculated. Based on these calculations, the ITCS control scheme would allow for faster activation for arm/hand prosthetics implementing more than four grasps/functions.

Based on the amount of training and the achieved level of performance by the subjects in this study, it is concluded that the proposed ITCS control scheme can be used as a mean of enhancing prosthesis control, primarily for transhumeral amputees. However, with more training the performance of the ITCS control scheme is assumed to increase.

Further studies should be carried out in order to validate the reported findings and investigate the effect of further training and whether faster ATs actually have a positive impact on the overall functional performance of a prosthesis control scheme from an amputee’s point of view. Such future studies should implement the control scheme on an actual hand prosthesis instead of a computer model. However, in future studies in the field of prosthesis control schemes the developed computer model could prove to be a valuable tool in the preliminary testing of prosthesis control schemes.

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