Preliminary Findings of Feasibility of a Wearable Soft-robotic Glove Supporting Impaired Hand Function in Daily Life

A Soft-robotic Glove Supporting ADL of Elderly People

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Abstract: Elderly people frequently encounter difficulties in independently performing activities of daily living (ADL) due to a reduced hand function. Robotic assistive devices have the potential to provide the assistance that is necessary to perform ADL independently without the need of personal assistance. Therefore, the objective of the present study was to explore feasibility of a wearable soft-robotic glove (ironHand (iH) system) that can support hand function of elderly people in daily life. Thirty elderly people (>56 years) with a reduced hand function resulting in difficulties in performing ADL were recruited to perform six functional tasks three times with and without the iH system. Evaluation measurements consisted of functional tasks performance times and user-acceptance of the iH system, measured by the System Usability Scale (SUS). Participants improved their functional task performance after multiple attempts either with and without the glove, but performed significantly faster without the glove ($p \leq 0.032$). Besides, the mean of the SUS score for the iH system was 70.1%. Although this indicates a good probability for acceptance in the field, several design adaptations are necessary to have a user-friendly and accepted assistive device.

1 INTRODUCTION

In general, the elderly population frequently experiences a decline in hand function due to deterioration of handgrip strength (Carmeli et al., 2003; Ranganathan et al., 2001). The decline in hand function can lead to a negative effect on the ability to grip and manipulate an object (Kinoshita and Francis, 1996). This results in difficulties in independently performing activities of daily living (ADL), such as holding (heavy) objects, writing and manipulating small objects (Hackel et al., 1992; Shiffman, 1992). These limitations often have an impact on elderly's quality of life (Ranganathan et al., 2001).

To overcome limitations in ADL, elderly often need personal assistance and/or assistive devices to carry out ADL. However, personal assistance results in an increased dependency in performing ADL for the elderly person him/herself, while assistive devices do have the potential to contribute to functional independence (Hoenig et al., 2003). There are several assistive devices available that people can use to compensate for the loss of functionality in hand motor function (Maciejasz et al., 2014). However, the functionality of simple assistive devices (e.g., a knife with adapted handle) is limited to the specific application (e.g. cutting), whereas fully robotic assistive devices (e.g., a robotic arm and gripper (JACO)) are often expensive, not portable and not easy to use in daily life (Frappier, 2011, Maciejasz et al., 2014). Other robotic hand devices are aimed at rehabilitation (Balasubramanian et al., 2010), not to support the hand directly during ADL over prolonged periods at home.

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Therefore, an easy to use wearable soft-robotic glove is being developed in the ongoing ironHand (iH) project, namely the iH system, that can support hand function in a wide range of ADL. By adding a personalized computer gaming environment, specific training exercises can be provided as well. As a first step, this study explores whether use of such an assistive glove during functional tasks can enhance task performance. Since this device should be usable independently during daily life, user acceptance is assessed as well.

2 METHODS

2.1 Participants

In this study, elderly (≥55 years) with hand function problems resulting in difficulties in performing ADL were included across four clinical sites: National Foundation for the Elderly (NFE), Bunnik and Roessingh Research & Development (RRD), Enschede in the Netherlands, Eskilstuna Kommun Vård- och omsorgsförvaltningen (ESK), Eskilstuna in Sweden and terzStiftung (TERZ), Berlingen in Switzerland.

Participants had to meet the following inclusion criteria: (1) at least 10 degrees of active flexion and extension movement of the fingers; (2) sufficient cognitive status to understand two-step instructions; (3) having (corrected to) normal vision; (4) living at home; (5) and provided written informed consent prior to the start of the study.

Exclusion criteria for this study were: (1) severe sensory problems of the hand; (2) severe acute pain of the hand; (3) wounds on their hands that may create problems when using the glove; (4) severe contractures limiting passive range of motion; (5) co-morbidities limiting functional use/performance of the arms/hands; (6) insufficient knowledge of the Dutch, Swedish or Swiss-German language to understand the purpose or methods of the study; (7) and participation in other studies that can affect functional performance of upper limb.

This study was approved by the local Medical Ethical Committees (MEC) in the Netherlands, Sweden and Switzerland.

2.2 ironHand System

The iH system encompasses an iH Assistive System (iH AS), consisting of the glove and a control unit to support functional performance in a wide range of ADL directly; and an iH Therapeutic System (iH TS) with additional computer-game-like exercises to provide a specific training context (see Figure 1). This study focuses on the iH AS only.

The iH AS is based on the concept of the SEM™ glove (Nilsson et al., 2012) that provides support for grip of the thumb, middle finger and ring finger in a natural and intuitive way, but only if the user initiates the movement actively. Additionally, the iH AS provides support for hand opening via leaf springs attached to the top (dorsal side) of the glove fingers.

The support of grasping is controlled by touch sensors on the finger tips. These sensors send a signal to the control unit which pulls the artificial tendons, placed along the length of the fingers in the glove, such that the grip force is augmented. The extra force applied by the glove is in proportion to the force applied by the user. The amount of extra force can be tuned for the individual user. Further details can be found in Nilsson et al. (Nilsson et al., 2012).

2.3 Procedure

2.3.1 Study Design

A multicentre cross-sectional study design was used for this feasibility study, consisting of executing tasks with and without the iH AS.

These tests were performed in a simulated ADL environment at NFE, ESK and TERZ supervised by the researchers of NFE, ESK and TERZ and coordinated by RRD.

2.3.2 Experimental Protocol

Before the evaluation session started, demographic characteristics including age (years), gender, dominant hand and most-affected hand were collected.

Next, the sensitivity level and maximum force of the iH AS and the amount of leaf springs in the iH AS

Figure 1: The ironHand system.

were tuned for each participant, based on ability/need and the experienced comfort. Furthermore, instructions needed for proper use of the iH system were provided by the researchers, if necessary.

Thereafter, the participant was asked to independently perform six functional tasks with and without the iH AS. The functional tasks were based on real life situations and consisted of drinking, eating, household, reading (and writing), (un)dressing and door opening tasks (see section 2.4.1 for more details). All functional tasks were standardized to ensure uniformity in task execution within and between participants. Each activity was performed three times with and three times without the iH AS to observe the differences between both conditions in functional performance. From those three repetitions, the first two were dedicated to getting used to the system, and only the last repetition was used to compare the performance time between conditions with and without iH AS. For each participant, the order of functional tasks with and without the glove was randomized by using sealed envelops.

At the end of the evaluation session, the participant was asked about his or her experiences and perceived ability of using the iH system. For this purpose the System Usability Scale (SUS) was assessed (see section 2.4.2 for more details).

2.4 Evaluation

2.4.1 Functional Task Performance Test

Before the start of each functional task, the execution of the functional task was demonstrated by the researchers to the participants. In addition, the researchers provided verbal instructions about the execution of each task during its performance.

The six selected functional tasks were performed as described below:

1. **Drinking Task:** The participant opens a bottle of water (0.5L), pours some water in a cup, closes the bottle of water, takes a sip of water and returns the bottle and cup to the starting position.
2. **Eating Task:** The participant takes a knife, cucumber and plate to prepare 3 slices of cucumber. After cutting 3 slices of cucumber, the participants returns the knife, cucumber and plate to the starting position.
3. **Household Task:** The participant takes a cloth, wrings the cloth for three times and cleans the table.
4. **Reading (and Writing) Task:** The participant holds a book in the most-affected hand for 30 seconds and if possible, he/she writes the last word on the left page of the book on a paper and returns the book to the starting position.
5. **Dressing Task:** The participant takes jacket off the coat hanger, puts jacket on, closes the zippers/button, opens jacket and returns it to the coat hanger.
6. **Door Task:** The participant takes the key of the door from a seat, puts the key in the door, closes/opens the door and returns the key to the seat next to the door.

The researchers assessed the performance time for each activity by using a stopwatch.

2.4.2 System Usability Scale

The SUS is a simple ten-item questionnaire to assess system usability. It uses a 5 point Likert scale ranging from 'strongly disagree' till 'strongly agree'. The scores of the ten items were multiplied by 2.5, so that the total score is between 0-100% (Brooke, 1996).

A total score of <50% indicates that the system will almost certainly have usability difficulties in the field; 50-70% is a promising score, but guarantees no high acceptability in the field and more improvement is necessary; >70% indicates a high probability of acceptance in the field (Bangor et al., 2008).

2.4.3 Data Analysis

The data of the outcomes were analysed using the IBM SPSS Statistics software package version 23.0. The performance times of the functional tasks were checked for normal distribution by visual inspection of the q-q plot, the box plot, histogram plot and by the Shapiro-Wilks test, prior to the statistical analysis. Descriptive statistics were used for all outcomes measures.

In order to assess the direct influence of performance with and without the iH AS, a Wilcoxon signed rank test or a paired sample t-test was performed, depending on normal distribution of the outcome measures. The overall level of significance was set at $p< 0.05$.

3 RESULTS

3.1 Participants

In total, 30 elderly were included in this feasibility study with the current prototype of the iH system across the Netherlands (n=10), Sweden (n=10) and Switzerland (n=10). There were two drop outs in the Netherlands as a result of too much pain in their hand/fingers, which prevented the participant to be able to use the glove. Table 1 shows the characteristics of the remaining 28 individuals at baseline.

Table 1: Characteristics of participants at baseline.

	Participants (n=28)
Age (years)[a]	72 ± 8 (56-84)
Gender (male/female)	9/19
Living at home (yes/no)	28/0
Affected body side (right/left/both)	14/8/6
Dominant hand (right/left/both)	25/2/1

[a]Mean ± standard deviation (range

3.2 Functional Task Performance Test

The dressing task was excluded from analysis, because of many missing values. This task was difficult to perform due to the bulkiness of the iH AS. Furthermore, data of the reading (and writing) and door tasks were not complete. Both tasks have missing data of the third attempt with and without the glove for one participant and the door task is not executed at all by one participant.

Figure 2 shows the performances times of the 3 repetitions of each functional task with and without using the glove (data only available from NFE and ESK; n=18), respectively. This figure shows that the participants improved their performance time over the three repeated attempts either with or without the iH system (p≤0.045), except for the reading task without the glove.

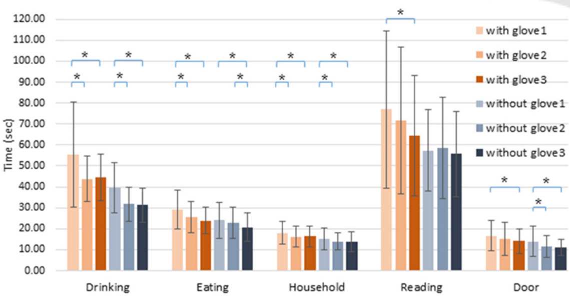

Figure 2: Performance times of the functional tasks. *significant difference between repeated attempts.

The last attempt of all five functional tasks with and without the glove are presented in figure 3 (n=28) to compare the performance time between conditions with and without iH AS. The participants performed significantly faster on all five functional tasks without the iH AS (p≤0.032).

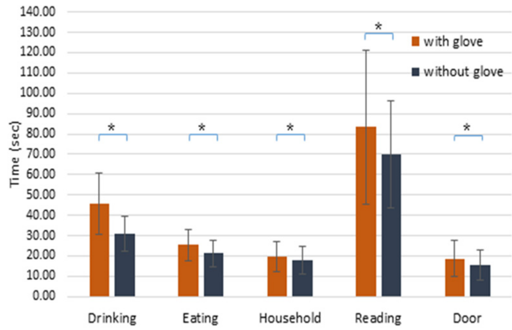

Figure 3: Performance times of the last attempt of the functional tasks. *significant differences.

During the performance of the functional tasks, researchers observed that participants had some difficulties when using the iH AS. The most frequently mentioned and observed issues with the iH AS during the performance of the functional tasks were difficulties with grasping the cap of the bottle, opening and closing the bottle, writing, grabbing the plate, grasping the pen and picking up the key.

However, most participants mentioned that they felt support of the iH AS during grasping the bottle, cutting food, wringing the cloth, turning the key (pinch grip well supported) and holding the book. They considered the support as helpful. In addition, they noticed that their performance with the iH AS improved after multiple attempts.

3.3 System Usability Scale

There was one missing SUS resulting in 27 completed SUS for the iH AS. The mean score on the SUS is 70.1% (SD=14.1) and only 7% of the participants scored lower than 50% (see figure 4).

4 DISCUSSION

After the identification of user requirements for the iH system (Radder et al., 2015), the current study examined the feasibility of the iH system by applying a user centred approach. It is important that end-users are involved early in the design and development process of new assistive technology to increase the probability of getting assistive technology adopted by users (Demain et al., 2013). From the present feasibility tests it became clear that the concept of the iH system is well received and appreciated to support ADL, but practical usability and performance of the current prototype should be improved further. These findings are in line with the study of Polygerinos et al. (Polygerinos et al., 2015).

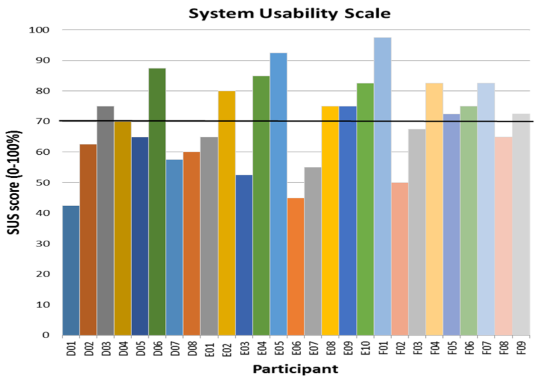

Figure 4: Individual SUS scores with the group mean score (black line).

The results of the functional task performance test showed that participants substantially improved task performance either with or without the glove within 3 attempts. However, at this moment, all functional tasks were performed faster without the glove than with the glove. During the current feasibility tests, some issues were observed that could explain these results.

First of all, elderly used the iH system only for a few minutes in which three repetitions of the functional task were done. During these three repetitions, participants showed improvements in their functional performance indicating a fast learning effect (see figure 2). The steep learning curve is promising because participants have probably not reached their plateau yet. This suggests that more progression is possible if participants have a longer time to get used to iH system (Prasad et al., 2002). The reason for having relatively short time for getting acquainted with iH AS, was to get a good idea of feasibility and usability for independent use. If too many instructions and repetitions are provided, no information about intuitive use is available. Future user tests should ideally include a longer acquaintance period.

Secondly, it is possible that the current functional tasks were not the most appropriate. In case of stroke patients, the most-affected hand is mainly used to support the other hand during the performance of ADL, instead of using the most-affected hand as primary hand for manipulating objects during ADL (Prange et al., 2015). However, the participating elderly performed the functional tasks with the glove worn on the hand they perceived as most affected, which was in most cases their dominant hand. Instead of using the gloved hand as supporting hand during functional tasks, the elderly attempted to perform finer motor activities with their gloved hand. Due to a limited sensation of the covered dominant fingers, the functional task performance may have been affected. Therefore, the role of the gloved, more affected hand in (bi-manual) functional tasks should be taken into account more specifically in subsequent studies with elderly participants.

Thirdly, several usability issues hindered functional task performance with the glove, indicating that the current iH prototype should be improved. For instance, the current fabric of the glove decreased the sensation of the fingertips during the performance of functional tasks with the glove, which made it very difficult for participants to perform fine motor activities such as grasping a cap of a bottle, opening and closing a bottle, writing etc.. Further design adaptations are needed to fulfil the expectation of participants that such robotic devices are easy to use and not too bulky to use unobtrusively in a wide range of ADL (Maciejasz et al., 2014). It is likely that an improved sensation will result in a better performance of the functional tasks relative to the performance without the glove.

Although some very important aspects for improvement of the iH system were formulated by the participants, averaged SUS score was 70.1%, which indicates good probability for acceptance in the field (Bangor et al., 2008). Other studies using the SUS for other types of technology showed similar or higher SUS scores (Ambrosini et al., 2014, Nijenhuis et al., 2015, Ni, 2013). The one study addressing actual use at home in addition to usability, where the mean SUS score was 67%, showed that people were able to independently use a robotic training device at home for on average 15 min/day over 6 weeks (Nijenhuis et al., 2015). This suggests that the iH AS could be usable at home.

In summary, the current results on user acceptance are promising for developing a user-friendly and acceptable assistive device. However, several design changes based on the results of the feasibility study are necessary to further enhance the chance for uptake of the iH system in daily life. This should also improve functional task performance with the glove beyond performance without the glove, before actual use of such assistive system will be beneficial for (and adopted by) elderly. In future studies, a next version of the iH system will be tested in daily life situations of elderly persons as part of the iterative, user-centred design process.

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