# Formative Usability Evaluation of WiGlove – A Home-based Rehabilitation Device for Hand and Wrist Therapy after Stroke

Vignesh Velmurugan
University of Hertfordshire
Hatfield, UK
v.velmurugan2@herts.ac.uk

Luke Jai Wood
University of Hertfordshire
Hatfield, UK
l.wood@herts.ac.uk

Farshid Amirabdollahian
University of Hertfordshire
Hatfield, UK
f.amirabdollahian2@herts.ac.uk

## ABSTRACT

WiGlove is a passive dynamic orthosis aimed at home-based post-stroke rehabilitation of the hand and wrist. This paper highlights results from WiGlove's formative evaluation as the first step towards its deployment. In this study, twenty healthy participants evaluated the usability and safety of the WiGlove compared to its predecessor, the state-of-the-art SCRIPT Passive Orthosis (SPO). In this within-subject experiment, they performed various tasks such as donning/doffing, adjusting the tension, grasping, etc., with both gloves and rated them using a Likert scale-based questionnaire. The results showed improvements in several aspects of usability and safety. This study provides preliminary evidence of WiGlove's fitness for the next assessment with its intended users, people recovering from stroke with sustained hand and wrist impairment.

## CCS CONCEPTS

• **Human-centered computing** → **Usability testing**; **User studies**; • **Hardware** → *Emerging interfaces*; *Biology-related information processing*; *Hardware validation.*

## KEYWORDS

Stroke rehabilitation, Usability, Orthosis, Hand, Wrist, Home-based therapy, Exoskeleton

**ACM Reference Format:**
Vignesh Velmurugan, Luke Jai Wood, and Farshid Amirabdollahian. 2023. Formative Usability Evaluation of WiGlove – A Home-based Rehabilitation Device for Hand and Wrist Therapy after Stroke . In *Companion of the 2023 ACM/IEEE International Conference on Human-Robot Interaction (HRI '23 Companion), March 13–16, 2023, Stockholm, Sweden.* ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3568294.3580087

## 1 INTRODUCTION

Motor function deficits of the hand, observed in 60% of stroke survivors severely impairs their strength and dexterity to manipulate objects, impacting their independence in performing activities of daily living. Effective rehabilitation of the wrist and hand is essential to regain the ability to perform activities of daily life (ADL) [13]. With the ability to offer high-intensity task-specific training, robot-aided rehabilitation therapy(RAT) can complement conventional one-to-one therapy. This enables stroke survivors to train longer and more frequently in their own homes which has been shown to improve recovery [5, 10]. The benefits of therapy at home are more pronounced in case of situations such as the COVID-19 pandemic, where such devices allow for a safe training environment and continuation of repeated exercise for the stroke survivors while allowing the therapists to monitor their progress remotely.

The central aim of this research is to develop a wearable robotic orthosis that facilitates training the hand and wrist together to account for the synergy between them. The work entailed using learnings from the SCRIPT Passive Orthosis(SPO) developed in a European Framework 7 project, SCRIPT [2]. In prior work by [15], a review of the state of the art involving task analysis, exclusion audit and analysis of studies by the SCRIPT researchers was used to define a list of requirements underpinning new developments. Based on these requirements, in a user-centred approach, a passive dynamic orthosis labelled the 'WiGlove' was designed.

The contribution of this research is extending the state of the art from 2014(SPO) by developing a new rehabilitation orthosis called the WiGlove. While most similar works focus on testing functionality, usability is often neglected at the formative stage. Hence this paper focuses on the evaluation of WiGlove's usability and provides preliminary evidence of its improvements in several elements over the current state of the art. This paper presents the methodology and results of this first formative evaluation of the glove with twenty healthy participants.

## 2 BACKGROUND

Lack of early initiation of training the distal segment of the arm in conventional post-stroke therapy could result in improvements in motor assessment scores not translating to functional recovery [8, 9]. While there have been several attempts [1, 6–8] at addressing this with RAT approaches, a recent survey found that only two robotic devices were designed to allow the user to train both the wrist and the fingers together in order to account for the synergy between them [13]. Of these, only SPO [2] was found to be suitable for home-based rehabilitation. Due to the unique functional and usability challenges that arise with the design of such a device, SPO acts as the only ideal state-of-the-art for this application and hence we benchmark our glove against it.

### 2.1 SCRIPT Passive Orthosis

SCRIPT (Supervised Care and Rehabilitation Involving Personal Tele-robotics) Passive Orthosis was developed as a home-based,


*HRI '23 Companion, March 13–16, 2023, Stockholm, Sweden*

ACM ISBN 978-1-4503-9970-8/23/03…$15.00
https://doi.org/10.1145/3568294.3580087

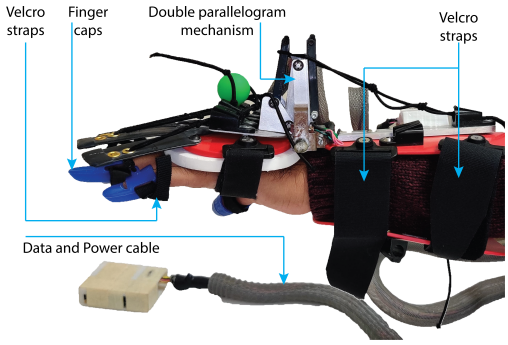


**Figure 1: Script Passive Orthosis(SPO)**

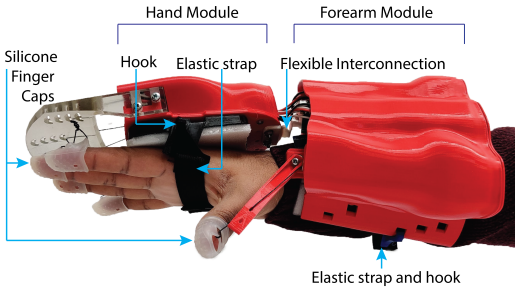


**Figure 2: WiGlove**

post-stroke rehabilitation system that allows stroke survivors to train their hand and wrist (Fig 1). Stroke survivors experience increased involuntary flexion in the joints of their hands, often leaving them with a closed fist and a fully flexed wrist. The SPO uses elastic cords to offset this hyperflexion while the user performs flexion of the wrist and fingers. It also includes a user interface that allows both the stroke survivor and the therapist/clinician to monitor the progress of the training. A study involving 23 stroke survivors verified the feasibility of the system with an average system usability scale of 69% [2]. However, their studies also identified several limitations with its usability[4].

## 2.2 Observations and Remedies

$Obs_1$ : An earlier study reported that stroke survivors with reduced dexterity found it difficult to slide their arms into the SPO's shell and pass the Velcro straps through its loops [4]. Being a home-based device, it is imperative that the user can don/doff it easily without assistance. Hence in WiGlove's design, this donning mechanism is replaced by an elastic strap and hook approach whose tension can be adapted to suit the user.

$Obs_2$ : Similarly, SPO's finger caps, required strapping individual Velcro straps for each finger that often get entangled due to their proximity and require separation before donning. This would be difficult for stroke survivors with one free hand [4]. This has been overcome in WiGlove's design using silicone finger caps that cling to the fingers by virtue of their inherent elasticity, thereby eliminating the need for straps.

$Obs_3$ : Since the amount of assistive force required for extension depends on the severity of the stroke and varies with recovery, SPO requires the user to adjust the length of the elastic cord using cord stops. Stroke survivors could find it difficult to perform this and therefore, WiGlove uses a slider interface on a touchscreen tablet to make it easier. It controls an actuator that modifies the assistance.

$Obs_4$ : The double parallelogram mechanism in SPO significantly restricts the ab/adduction of the wrist, which could lead to hypertonia due to non-use. Instead, by using flexible interconnection between the forearm and hand modules, WiGlove attempts to unblock this DoF.

$Obs_5$ : The rigid finger caps of SPO, made of plastic, block the tactile sensation of the fingertips while interacting with objects. The absence of tactile feedback makes it difficult to grasp small objects and prevents sensory stimulation that could affect recovery [12]. This is compounded by its smooth surface finish that offers a very low coefficient of friction while grasping. WiGlove overcomes these issues with silicone finger caps that offer a high coefficient of friction and tactile transparency. Furthermore, unlike SPO, WiGlove's finger caps do not block the DIP (distal interphalangeal) joint, allowing for easy grasping of large objects.

$Obs_6$ : Given its home-based application, several potential risk factors were identified in SPO such as pinch points in the double parallelogram, entanglement, and tripping hazards from the wire. These factors were addressed in WiGlove's design by replacing the double parallelogram with a flexible joint and enabling wireless operation.

$Obs_7$ : Finally, unlike SPO's bare robotic appearance, WiGlove was designed to be more aesthetically appealing to help enhance the device's acceptance.

## 2.3 WiGlove

WiGlove(Fig 2) is a passive dynamic orthosis that was designed to address the limitations of SPO. It requires the user to actively initiate and perform flexion exercises against the resistive force of an extension spring while passively helping it with extension. With the help of built-in sensors to measure joint angles, it allows the user and the therapists to monitor the progress of the therapy remotely. Furthermore, wireless Bluetooth connectivity with the tablet interface frees the user from a desktop workstation which is reported to reduce mental fatigue. The user can also use the glove to play games on the tablet to improve engagement. Additionally, it is designed to be also usable in absence of the tablet interface, and while performing activities of daily living, thus providing support for the person's independence during their recovery. The glove remains passive throughout its operation and hence is safe to operate without supervision.

# 3 EXPERIMENT

WiGlove's usability is evaluated in a comparative analysis with SPO. This is accomplished using a quantitative comparison of the following aspects of the gloves: Ease of donning and doffing, Ease

of adjusting the assistance, Unrestricted natural DoF, suitability for ADL and Perceptions of aesthetics and safety.

This study was approved by the university's Ethics Committee before participants were recruited (Ethics protocol number: SPECS/ PGR/ UH/ 04896). The experimental setup consisted of the participant seated in front of a desk that had both gloves, a laptop with the questionnaire and a tablet that interacts with the WiGlove. This study involved twenty healthy participants over eighteen years of age. It was ensured that they were not suffering from any injuries to their hand and wrist at the time of their participation. Voluntary participants were recruited from the university's staff and students. The participant demographics of this study are presented in table 1.

**Table 1: Demographics of the study's participants**

| Participants | Number | Mean Age (Years) |
|---|---|---|
| Female | 5 | 31.8 (SD = 4.9) |
| Male | 15 | 26.6 (SD = 4.0) |
| Total | 20 | 27.9 (SD = 5.2) |

## 3.1 Procedure

This study was conducted as a within-subject experiment where the twenty participants were counterbalanced into two groups of 10 that tried both gloves in the opposite order. In line with traditional approaches for the evaluation of the usability of upper limb prosthesis, we developed a custom framework involving tasks designed to comparatively evaluate specific features of WiGlove that affect its usability with those of SPO. However, since the participants of this preliminary study were healthy individuals, traditional usability scales such as System Usability Scale (SUS) that were designed for end users could not be used. Therefore, a custom questionnaire was designed to evaluate the above-mentioned aspects on a 7-point Likert Scale. For instance, the first question asked the participants to rate the ease with which they could don the forearm module of the glove. In each session which lasted for about 45 minutes, participants performed a set of tasks with both gloves and recorded their feedback using questionnaires. The experiment protocol is shown in figure 3.

How easy is it to don the forearm module of the glove ?

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Very Difficult | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Very Easy |

Experiment tasks were tailored to evaluate the glove's performance in the above-mentioned categories. Although both gloves do not offer assistance with performing wrist ab/adduction, it is essential to verify that this natural DoF is not blocked to prevent hypertonia. Therefore, the participants were asked to perform wrist ab/adduction and rate the ease of doing so. Participants were also asked to grasp a key, bottle and a ball to evaluate the ease of performing palmar pinch(Fig 4a), cylindrical(Fig 4b) and spherical grasp(Fig 4c) respectively while wearing the two gloves. These account for

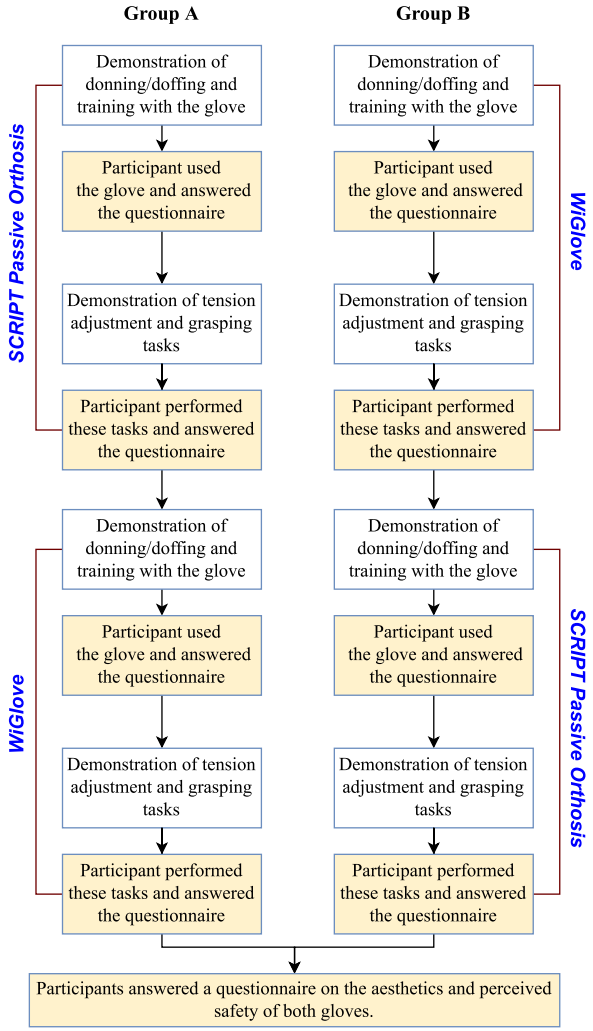


**Figure 3: Experiment flow**

**(a) Palmar Pinch (Key)** **(b) Cylindrical grasp(bottle)** **(c) Spherical grasp(bottle)**

**Figure 4: Grasping Tasks**

both precision (key) and power (bottle & ball) grasps and are important in performing most activities of daily life such as eating with a spoon, combing hair, drinking from a bottle etc [11]. The size of the bottle (75 mm) was chosen such that it requires the flexion of all three finger joints to exert adequate gripping force[3, 14].

**Table 2: Statistical results of comparative evaluation (SD - standard deviation, IQR - Interquartile Range, r - effect size)**

| | WiGlove | | | SPO | | | Wilcoxon signed-rank test results | | |
|---|---|---|---|---|---|---|---|---|---|
| | Median | SD | IQR | Median | SD | IQR | Z | p | r |
| Ease of donning the forearm module | 6 | 1.005 | 1 | 6 | 1.637 | 3 | - 1.754 | 0.079 | 0.392 |
| Ease of donning the hand module | 6 | 1.525 | 2.75 | 6 | 1.635 | 2.75 | - 0.712 | 0.476 | 0.159 |
| Ease of donning the fingercaps | 7 | 1.386 | 1 | 4.5 | 1.932 | 3.75 | - 3.337 | 0.001* | 0.746 |
| Ease of doffing the forearm module | 7 | 0.759 | 1 | 6.5 | 1.45 | 1 | - 2.145 | 0.032* | 0.48 |
| Ease of doffing the hand module | 6 | 1.361 | 1.75 | 6 | 1.387 | 2 | - 0.051 | 0.959 | 0.011 |
| Ease of doffing the fingercaps | 7 | 0.754 | 1 | 6 | 1.916 | 3.75 | - 2.958 | 0.003* | 0.661 |
| Ease of performing ab/adduction of the wrist | 6 | 1.399 | 2 | 3 | 1.292 | 2 | - 3.543 | < 0.001* | 0.792 |
| Ease of adjusting the tension | 7 | 0.82 | 1 | 5 | 1.273 | 1.75 | - 2.583 | 0.01* | 0.578 |
| Ease of performing a palmar pinch | 6 | 1.657 | 2 | 3 | 1.765 | 3.75 | - 3.396 | < 0.001* | 0.759 |
| Ease of performing a cylindrical grasp | 7 | 1.436 | 1 | 2 | 1.605 | 2.75 | - 3.698 | < 0.001* | 0.827 |
| Ease of performing a spherical grasp | 6 | 1.791 | 2.5 | 6 | 1.333 | 1.75 | - 0.642 | 0.521 | 0.144 |
| Suitability for ADL | 6 | 1.308 | 1 | 3 | 1.605 | 3 | - 3.504 | < 0.001* | 0.784 |
| Aesthetic appeal | 6 | 1.005 | 2 | 4 | 0.94 | 1 | - 3.79 | 0.001* | 0.847 |
| Perception of user safety | 6 | 1.356 | 2 | 4 | 1.663 | 3 | - 2.393 | 0.017* | 0.535 |
| Perception of safety for the family | 6 | 1.372 | 2 | 4 | 1.638 | 2 | - 3.093 | 0.002* | 0.692 |

* Statistically significant difference.

## 4 RESULTS AND DISCUSSION

Wilcoxon signed-rank test was performed to analyse if there were any statistically significant differences between the participants' scores for the two gloves. The statistical results are summarised in Table 2

The results show a significant difference in the participants' scores where they predominantly found it easier to don and doff the finger caps of the WiGlove compared to the SPO. This affirms our second observation ($Obs_2$). Such improvement is not visible for WiGlove's forearm and hand module in the counterbalanced results. However, the scores of the individual groups show that the participants who tried WiGlove first and had this as a reference rated SPO to be less easy to don than the former. Notwithstanding this, a median score of 6 shows that these participants predominantly also found it easy to don SPO's hand and forearm modules. However, we hypothesize that these small positive differences would matter more for stroke survivors as discussed in ($Obs_1$). While its impact was not visible in donning, it can be attributed to WiGlove's higher median scores for doffing its forearm module than that of SPO with a statistically significant difference.

Meanwhile, no significant difference was observed in doffing the hand module of WiGlove. During the study, it was observed that some participants found it a little hard to release the hook of WiGlove's hand module due to tension from the elastic strap. This could be corrected by adjusting the length of the straps using the attached buckle to suit the user. This will be verified in the next evaluation.

WiGlove's attempt to make tension adjustment easier is reflected in the slightly higher median score for WiGlove. Although the healthy participants of this study rated SPO's approach also as relatively easy, we hypothesize that stroke survivors would find it more difficult to make the adjustments that require fine-motor manipulation in cramped spaces such as SPO's hand module ($Obs_3$). Furthermore, the median scores for the ease of performing ab/adduction with the wrist show that the flexible interconnection between the two modules made a significant difference in unblocking this DoF, thereby eliminating concerns of hypertonia ($Obs_4$).

In $Obs_5$ we discussed the limitations of SPO's finger caps while grasping objects and WiGlove's approach to addressing this with silicone finger caps. This design decision is validated by WiGlove's median scores for performing palmar pinch and cylindrical grasps that are 3 and 5 points higher than those of SPO. The participants' scores show a significant difference between the two gloves in favour of WiGlove.

Additionally, the participants were asked about their overall opinion on the two gloves being suitable to wear while performing activities of daily life such as having a hot drink and preparing food. They largely judged WiGlove to be more suitable with a statistically significant difference. Given that the objective of this work is to help the user perform such activities, this result is particularly promising. Finally, the participants gave a higher score for their perception of WiGlove's safety for both the user and the family compared to SPO with a statistically significant difference. This supports WiGlove's design decisions to address the risk factors of SPO ($Obs_6$). Furthermore, WiGlove's higher median score for its aesthetic appeal could potentially enhance its acceptance as discussed in $Obs_7$.

## 5 CONCLUSION

The results of this comparative formative evaluation, indicate that overall, WiGlove performed better than Script Passive Orthosis (SPO), in aspects such as donning/doffing, suitability for activities of daily life, freedom of abduction/adduction, ease of adjusting the assistance and perception of aesthetics and safety. Although this serves as a preliminary validation of the glove's wearability and usability, they might not translate to stroke survivors. Hence, the next phase involves further assessment by stroke clinicians, therapists and stroke survivors. These formative steps will be used to improve WiGlove's design prior to a long-term home-based study to assess its utility in the context of stroke rehabilitation.

# REFERENCES


[1] Hassanin Al-Fahaam, Steve Davis, Samia Nefti-Meziani, and Theo Theodoridis. 2018. Novel soft bending actuator-based power augmentation hand exoskeleton controlled by human intention. *Intelligent Service Robotics* 11, 3 (2018), 247–268.

[2] Farshid Amirabdollahian, Serdar Ates, Angelo Basteris, Alfredo Cesario, Jaap Buurke, H Hermens, Dennis Hofs, Ellinor Johansson, Gail Mountain, Nasrin Nasr, et al. 2014. Design, development and deployment of a hand/wrist exoskeleton for home-based rehabilitation after stroke-SCRIPT project. *Robotica* 32, 8 (2014), 1331–1346.

[3] Andrew A Amis. 1987. Variation of finger forces in maximal isometric grasp tests on a range of cylinder diameters. *Journal of biomedical engineering* 9, 4 (1987), 313–320.

[4] Serdar Ates, Beatriz Leon, Angelo Basteris, Sharon Nijenhuis, Nasrin Nasr, Patrizio Sale, Alfredo Cesario, Farshid Amirabdollahian, and Arno HA Stienen. 2014. Technical evaluation of and clinical experiences with the SCRIPT passive wrist and hand orthosis. In *2014 7th International Conference on Human System Interactions (HSI)*. IEEE, 188–193.

[5] Joni G Barry, Sandy A Ross, and Judy Woehrle. 2012. Therapy incorporating a dynamic wrist-hand orthosis versus manual assistance in chronic stroke: A pilot study. *Journal of Neurologic Physical Therapy* 36, 1 (2012), 17–24.

[6] Alberto Borboni, Maurizio Mor, and Rodolfo Faglia. 2016. Gloreha—hand robotic rehabilitation: Design, mechanical model, and experiments. *Journal of Dynamic Systems, Measurement, and Control* 138, 11 (2016).

[7] Tobias Bützer, Olivier Lambercy, Jumpei Arata, and Roger Gassert. 2021. Fully wearable actuated soft exoskeleton for grasping assistance in everyday activities. *Soft robotics* 8, 2 (2021), 128–143.

[8] Tianyao Chen and Peter S Lum. 2016. Hand rehabilitation after stroke using a wearable, high DOF, spring powered exoskeleton. In *2016 38th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*. IEEE, 578–581.

[9] Hermano Igo Krebs, Bruce T Volpe, Dustin Williams, James Celestino, Steven K Charles, Daniel Lynch, and Neville Hogan. 2007. Robot-aided neurorehabilitation: a robot for wrist rehabilitation. *IEEE transactions on neural systems and rehabilitation engineering* 15, 3 (2007), 327–335.

[10] Gert Kwakkel. 2009. Intensity of practice after stroke: More is better. *Schweizer Archiv fur Neurologie und Psychiatrie* 160, 7 (2009), 295–298.

[11] Beatriz Leon, Angelo Basteris, Francesco Infarinato, Patrizio Sale, Sharon Nijenhuis, Gerdienke Prange, and Farshid Amirabdollahian. 2014. Grasps recognition and evaluation of stroke patients for supporting rehabilitation therapy. *BioMed Research International* 2014 (2014).

[12] Paweł Maciejasz, Jörg Eschweiler, Kurt Gerlach-Hahn, Arne Jansen-Troy, and Steffen Leonhardt. 2014. A survey on robotic devices for upper limb rehabilitation. *Journal of neuroengineering and rehabilitation* 11, 1 (2014), 3.

[13] Bernardo Noronha and Dino Accoto. 2021. Exoskeletal devices for hand assistance and rehabilitation: A comprehensive analysis of state-of-the-art technologies. *IEEE Transactions on Medical Robotics and Bionics* 3, 2 (2021), 525–538.

[14] S Radhakrishnan and M Nagaravindra. 1993. Analysis of hand forces in health and disease during maximum isometric grasping of cylinders. *Medical and Biological Engineering and Computing* 31, 4 (1993), 372–376.

[15] Vignesh Velmurugan, Luke Wood, and Farshid Amirabdollahian. 2021. Requirements for a home-based rehabilitation device for hand and wrist therapy after stroke. In *UKRAS21: The 4th UK Robotics and Autonomous Systems Conference*. 23. https://doi.org/10.31256/Xw5Aj7Q