# SUREHand: A Self-Stretching Device for One-Handed Use by Stroke Survivors

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***Abstract*—Upper limb impairment and spastic hypertonia following a stroke often necessitates constant wrist stretching for symptom relief and functional recovery. Most existing rehabilitative devices, however, can be difficult for stroke survivors to don and operate with one functional hand, which creates a barrier to at-home, self-administered therapy. To address this, we present SUREHand, a novel, passive wrist exoskeleton specifically designed for hemiparetic stroke survivors to independently don and use with one hand. The device features a pneumatic support system with an inflatable air bladder to ensure a secure, comfortable fit and a body-powered ratchet mechanism that allows users to manually induce and maintain wrist extension. We recruited three stroke survivors (N=3) to evaluate the device's mechanical performance and device usability. All participants operated the device independently in under 20 minute of training, with average donning times of 72 seconds and wrist extension with the device achieving their maximum passive range of motion. High scores on the System Usability Scale and comfort survey suggest that the SUREHand is an effective, low-cost, and accessible solution for wrist rehabilitation and stretching.**


Fig. 1. The SUREHand device shown providing wrist extension. The device uses an internal air bladder to provide a pressurized, circumferential fit around the forearm for one-handed securing. Users wind a cable with the manual ratchet mechanism to stretch their wrist into extension.

## I. Introduction

A key challenge for upper limb rehabilitation is spasticity in the wrist flexors, which can present as spastic extension activation of the wrist flexors with voluntary wrist extension or attempted hand grasping. This spasticity can consequently cause pain, decrease wrist passive range of motion, and impair functional hand grasping [1–3]. To prevent further joint deformity and contracture formation due to spasticity, therapists will encourage stroke survivors to perform daily wrist stretching for self-management [3–5]. Thus, developing methods to promote wrist stretching habits is an important component for functional joint recovery and mobility.

However, many devices for wrist stretching require two able hands to don and operate, and often a therapist assists in this process [6–8]. For stroke survivors with upper limb hemiparesis and only one functional arm, this can create a barrier to regular use. Self-donning is thus a critical part of device design to foster a sense of autonomy and ensure the user can safely and reliably use the tool.

We present a device designed to allow stroke survivors to independently perform wrist flexor stretching. Our device, which we call the SUREHand (Self-donning User-controlled Rehabilitation Exoskeleton for the Hand), is a passive, single degree of freedom exoskeleton to assist stroke survivors in wrist extension. Self-donning is a key component of the design, where stroke survivors can place their affected limb in the device and secure it via an inflatable pneumatic support. Another feature is its one-handed use: the SUREHand can be operated completely with the stroke survivor's unimpaired hand using a manual ratchet system to stretch the wrist within safe limits and maintain a desired level of extension. The current prototype of SUREHand weighs 390 grams and is fully self-contained, allowing some mobility for the wearer; future iterations will aim to further reduce its weight and dimensions to reduce obtrusiveness and possible interference with activities of daily living.

We demonstrate that stroke survivors can don, use, and doff the device independently—without physical assistance—in a single session with about 20 minutes of training. Furthermore, we evaluate the device's efficacy through participant surveys that focus on comfort and usability. The main contributions of the work are as follows:

- We present SUREHand, a rehabilitative device for wrist stretching designed for self-donning and one-handed use. To the best of our knowledge, we are the first to design and evaluate with stroke survivors a wearable, self-donning device capable of wrist stretching.
- We demonstrate that stroke survivors can don, use, and

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doff the device independently within a single 90-minute session, with the donning process taking just over one minute. Participants use the self-powered, manual ratchet to stretch their wrist to the same maximum wrist extension achieved by an occupational therapist.
- Positive comfort ratings and high system usability scores from the feedback surveys support the usability and comfort of the SUREHand for independent use, suggesting its potential as an at-home rehabilitative device.

## II. Related Work

Although current stroke rehabilitative tools are designed to improve the independence of survivors, they are often difficult to put on without assistance. For example, the HERO Glove [9] uses tight, high-friction fabric to ensure that sensors and actuators stay in place, inadvertently making it difficult for patients with tightly clenched fingers to don with one functional hand. Furthermore, innate rehabilitation strategies of devices such as the HandSOME II [10] require the patient to use their unaffected hand to simultaneously pry their fingers open, hold a resistive spring, and secure Velcro straps. Users often need physical assistance to don these devices, demonstrating a clear need for an easy attachment method that can be applied independently.

Recently, researchers have explored several methods of improving device wearability. For example, the Self-Securing Soft Robotic Hand Exoskeleton uses an air-filled robotic sleeve to grip the user's hand [11]. Other work has investigated hybrid rigid-soft hand exoskeletons that use ergonomic frames to help with self-donning [12]. Additionally, soft assistive gloves, such as the RELab tenoexo, use simplified straps to allow for quicker donning [13]. For wrist-specific support, soft exoskeletons using Shape Memory Alloy (SMA) actuators have been introduced to make the donning process less complicated [14].

This need has led to the exploration of pneumatics to safely secure a device to the impaired limb. In current rehabilitation research, pneumatics are primarily used to actuate hand movements, often inspired by artificial muscle behavior. Systems such as the PneuGlove [15], AirExGlove [16], and [17] use pressurized air to force the fingers to extend. However, in these existing designs, the attachment to the patient still relies on traditional components such as fabric sleeves. Thus, there is currently a research gap in using air pressure to actively secure the hand, which is what our work aims to address.

Several works focus on addressing wrist flexor spasticity through dedicated stretching devices, yet these designs rely on straps to secure the forearm. Similarly to the SUREHand, these devices use a ratchet-based wrist stretching mechanism that allows for controlled wrist stretching, but such rigid frames and traditional straps may not always securely fasten to a spastic forearm [18–22]. While some pneumatic systems like the one proposed by Ledoux et al. [17] address finger and wrist stretching, their device still relies on manual finger and forearm straps. Consequently, there is a lack of passive, wrist-stretching devices that incorporates pneumatics for a uniform, circumferential fit to maintain alignment during stretching.

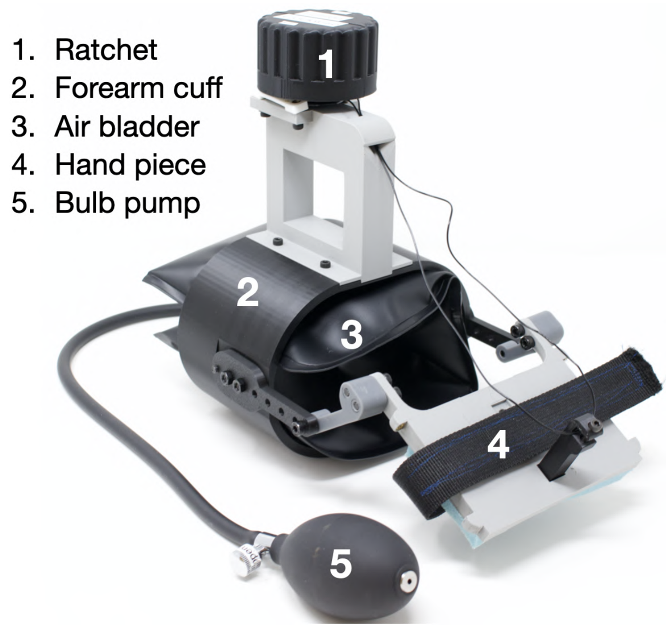


Fig. 2. SUREHand device components.

## III. Device Design

Our primary goal is to develop a rehabilitative device for body-powered wrist extension that stroke survivors could don independently using only their unaffected hand. The device must enable controlled wrist extension within a safe range of motion and maintain a specific degree of stretch statically for a therapeutic duration. The device also has to provide a quick-release function for user safety and convenience.

### A. Exoskeleton Design

The exoskeleton is composed of two main elements: a rigid hand piece and a rigid forearm cuff, fabricated from resin and 3D-printed PLA [Fig. 2]. The hand piece is secured to the dorsal side of the hand with a single, palmar Velcro strap for easy adjustability. The two pieces are connected via a bilateral pin joint, which the participant aligns their wrist flexion/extension axis with when donning the device. The ratchet system [23] connects the forearm cuff to the hand piece such that rotating the ratchet reels in a a cable, which pulls the hand piece upward to induce wrist extension.

### B. Pneumatic Support

To facilitate independent, single-handed donning, the device uses a pneumatic fastening system to secure the exoskeleton to the forearm. We repurpose an inflatable air bladder from a sphygmomanometer to encircle the inside of the rigid forearm cuff. Once the participant slides their paretic arm through the cuff, they use the attached bulb pump to inflate the bladder with their unaffected hand. The inflated air bladder provides a uniform, circumferential fit to secure the device firmly to the paretic arm. We instruct the users to

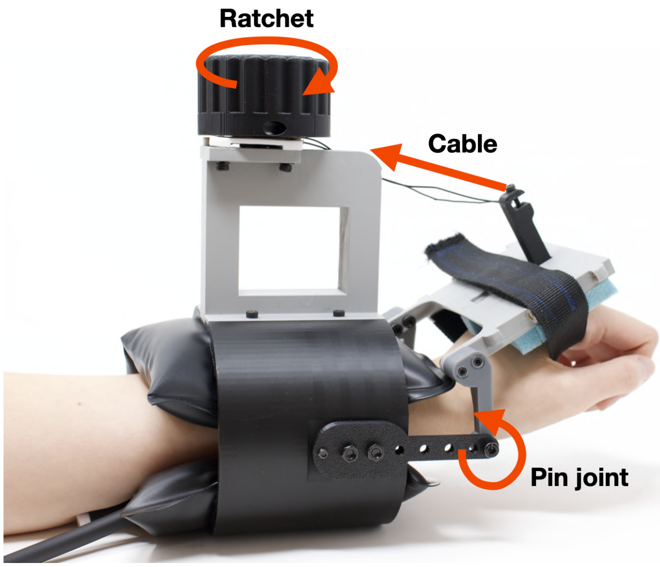


Fig. 3. SUREHand wrist stretching mechanism. Manually rotating the ratchet winds the cable to lift the hand and rotate the wrist about the pin joint axis. The cable connection height and pin joint position can be modified to adjust to different users.

inflate the bladder to their personal comfort level to ensure the device remains stable during wrist stretching without causing circulatory constriction.

### C. Adjustable Wrist Position

The device operates with a single degree of freedom, constrained by the bilateral pin joint in parallel with the flexion/extension axis of the wrist joint. Users can adjust their preferred amount of wrist extension by rotating the ratchet to tighten the cable that connects to the hand piece [Fig. 3]. To account for the elevated muscle tone present in stroke survivors with spastic wrist flexors, the geometry of the device optimizes the applied torque at the wrist joint. By increasing the vertical height of the ratchet housing and connection point on the hand piece, the design increases the effective moment arm for wrist extension. Furthermore, an additional housing for the ratchet improves grip to rotate the ratchet.

This mechanical advantage at both the wrist joint and the ratchet allows the user to generate greater stretching torque with lower input forces, making the device easy to use. To release tension, the user can easily lift the ratchet to unlock the cable. To re-enable cable ratchet mechanism, the user presses on the ratchet to re-engage it.

## IV. Methods

We designed our protocol to evaluate the feasibility of SUREHand as a self-donning device and its performance as a therapeutic tool for wrist stretching with three stroke survivors. We conducted the experimental protocol in a clinical setting over a single 90-minute session, structured into four phases: a clinician-led guided training, independent device

TABLE I
Wrist Range of Motion: Passive vs. Active

| | Passive ROM | | Active ROM | |
|---|---|---|---|---|
| Subject | F | E | F | E |
| S1 | 70° | 60° | 50° | −20° |
| S2 | 60° | 55° | 0° | 45° |
| S3 | 75° | 40° | 40° | 15° |

*F: Flexion, E: Extension*

donning and doffing timed trials, wrist stretching evaluation, and a subject usability and comfort assessment.

All participants were seated in a standardized position with their forearm resting on the table with their elbow at a 90° angle. Before the donning the exoskeleton, the occupational therapist performed the baseline clinical assessment to record the Modified Ashworth Scale score, Fugl-Meyer Score, and the active and passive range of motion of the wrist [Table I]. Here, active refers to the participant's unassisted range of motion, while passive refers to the range of motion when the wrist is manually moved by the occupational therapist.

### A. Experimental Protocol

*1) Guided Training:* During the guided training, we explained the purpose of the device and demonstrated the mechanisms for donning/doffing, the ratchet mechanism for locking and unlocking, and how to inflate the pneumatic support with the bulb pump. We then allowed the patient to interact with and experiment with the device and answered any questions they may have.

*2) Independent Don/Doff Timed Trials:* Then, under our instructions to move at a comfortable pace, participants completed two unassisted timed trials for both donning and doffing. Measurement began at first contact with the device and ended when the device is fully secured or the hand is free (don and doff).

*3) Wrist Stretching Evaluation:* Participants used the ratchet to incrementally increase wrist extension only to their comfort limit and not exceeding their passive ROM as measured by the occupational therapist. For data collection, we recorded the wrist angle, defining 0° as a neutral wrist position using a goniometer. Subject S1 was unable to bring his wrist from flexion into neutral with volitional effort, thus making his active ROM −20° for wrist extension [Table I].

*4) Subject Usability & Comfort:* To evaluate the user experience of the device, participants finished the trial by completing two qualitative surveys. The first was a four item survey using a 5-point Likert scale (1 = Very Difficult/Uncomfortable, 5 = Extremely Easy/Enjoyable) to assess donning, doffing, wearing comfort, and stretching enjoyment. The comfort survey included the following questions:

1) How would you rate the ease of putting on this device?
2) How would you rate the ease of taking off this device?
3) How would you rate the comfort of wearing this device?
4) How would you rate the enjoyment of stretching your wrist using this device?

The second was the System Usability Scale, a standardized, 10-item scale used to evaluate the overall complexity, learnability, and integration of the device [24].

### B. Participants

We recruited three stroke survivors with chronic upper limb hemiparesis for feasibility testing in a clinical setting under supervision of an occupational therapist. The participants met the following inclusion criteria: (1) at least 18 years old; (2) at least 6 months post-stroke; (3) muscle tone and spasticity scoring MAS $\leq 2$ in digits, wrist, and elbow; (4) sufficient functional capability in the unaffected hand to manipulate the device; (5) ability to consent and follow instructions during the session. Participant characteristics are summarized in Table II. Testing with all participants was approved by the Columbia University Institutional Review Board (IRB-AAAS8104).

TABLE II
PARTICIPANT CHARACTERISTICS

| Subject | S1 | S2 | S3 |
|---|---|---|---|
| Gender | M | F | F |
| Age | 52 | 58 | 74 |
| Years Since Stroke | 12 | 4 | 10 |
| Affected Side | L | L | L |
| FM-UE Total | 29 | 35 | 34 |
| Wrist Subscore | 0 | 4 | 4 |
| MAS | | | |
| Elbow Flexor | 1+ | 1+ | 2 |
| Wrist Flexor | 2 | 2 | 2 |
| Index Finger Flexor | 1+ | 1+ | 1 |

## V. RESULTS & DISCUSSION

To assess the device regarding both mechanical efficiency and user experience, we recorded objective and subjective outcome measures. For the objective outcomes, we recorded the time taken to don and doff the device, as well as the maximum wrist extension achieved with the device. For the subjective outcomes, we gathered participant feedback on comfort and usability of the device with two surveys.

### A. Independent Don/Doff Timed Trials

During these timed trials, we found that all participants were were able to successfully don, doff, and use the device within a two minute time frame by the second time trial [Table III]. While the initial guided training time was variable among the participants, with some requiring little over 3 minutes, and others taking around 20 minutes to become familiar with the device and understand its function, all participants were able to follow instruction to use the device as intended during the session. Specifically, the average donning time for the second trial was 72 seconds, just over one minute. One participant, S3, needed verbal reminders for sequence of steps in device donning and doffing, but suggested we provide a written step-by-step instruction sheet for future sessions.

The ability of the participants to easily and independently don the SUREHand device within two minutes using only their unaffected hand suggests that the pneumatic fastening system is a viable alternative to traditional Velcro straps. By reducing the time and effort for the donning process to a quick, one-handed task, the SUREHand could potentially increase the frequency of at-home therapy compliance.

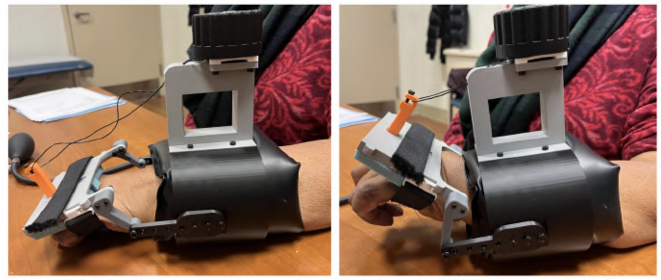

Fig. 4. Stroke participant (S3) using the SUREHand to stretch her wrist to her maximum passive range of motion.

### B. Wrist Stretching Evaluation

The efficacy of the SUREHand at wrist stretching was evaluated by comparing the participants' baseline passive range of motion (ROM) to the extension achieved using the device. For all participants, the SUREHand was capable of stretching the wrist to the maximum passive range of motion as measured by the occupational therapist [Fig. 4]. Users were able to incrementally increase tension using the ratchet and maintain a static stretch without mechanical failure or misalignment of the device.

All participants achieved their maximum passive range of motion with the SUREHand, the same stretch provided by an occupational therapist. In an at-home setting, this suggests that stroke survivors may be able to use SUREHand to stretch and maintain a comfortable wrist stretch for the prescribed duration of time as recommended by their health provider.

### C. Subject Usability & Comfort

After testing with the device, we gathered subjective feedback from the participants using a Likert-scale questionnaire and the System Usability Scale (SUS) [24]. Participants rated the ease of donning and doffing the SUREHand with high marks, as recorded in Table IV. The average SUS score, as calculated per standard usage, was $90.8 \pm 9.5$, which places the device in the $A$ category for usability according to standard benchmarks [24–26].

The high SUS scores and positive comfort ratings suggest the SUREHand device that is comfortable, easy to use, and effective at providing a functional wrist stretch for the user. The comfort of the device can be attributed to the repurposed sphygmomanometer bladder, of which the circumferential pressure can more uniformly distribute forces around the forearm for easy securing using the air bulb. These results indicate that the SUREHand is not only functionally effective, but also comfortable and simple enough to use for long-term daily intervention.

### D. Future Work & Limitations

This work offers interesting directions toward future devices that emphasize one-handed self-donning. Namely, the

TABLE III
TRAINING AND TRIAL PERFORMANCE ACROSS SUBJECTS

| Subject | Training Time | Donning Trial 1 | Donning Trial 2 | Doffing Trial 1 | Doffing Trial 2 |
|---|---|---|---|---|---|
| S1 | 19:42 | 1:30 | 1:45 | 30s | 25s |
| S2 | 3:06 | 42s | 31s | 47s | 36s |
| S3 | 11:50 | 1:40 | 1:21 | 36s | 23s |

TABLE IV
USER EVALUATION RESULTS: COMFORT AND USABILITY

| | Comfort Survey | | | | System Usability Scale | |
|---|---|---|---|---|---|---|
| Subject | Q1 | Q2 | Q3 | Q4 | Score | Scale |
| S1 | 4 | 5 | 4 | 5 | 80.0 | B |
| S2 | 4 | 4 | 5 | 5 | 97.5 | A+ |
| S3 | 5 | 5 | 5 | 5 | 95.0 | A+ |

use of an inflatable air bladder as a method to secure the device in a one-handed manner over traditional arm straps could aid in unassisted, at-home use. This circumferential air bladder can be applied to other devices to improve self-donning of stroke rehabilitation tools.

Currently, this device uses a passive, body-powered ratchet to enable wrist stretching. A future direction of this work could be automating this wrist extension with a motor that could even extend the wrist in a scheduled manner. Including a pressure sensor and air pump could also facilitate the self-donning process to allow for automatic self-inflation to a specific pressure around the arm.

Future development will focus on evaluating participant learning and the effects of extended wear-times under clinical supervision. Before transitioning to unsupervised, at-home use, we will assess carry-over learning and verify that participants can return in subsequent sessions and independently operate the device. Subsequently, we can evaluate efficacy and clinical outcomes with a randomized control trial to measure changes in MAS scores. By allowing participants to operate the device independently over an extended period, we can better understand the long-term rehabilitative potential of the device.

Limitations of this work include the small sample size of stroke participants. Expanding the number of stroke participants in the work would allow us to better evaluate the usability of the device across a varied population of stroke survivors with different levels of impairment.

## VI. CONCLUSION

In this work, we present the SUREHand, a low-cost, passive exoskeleton designed to facilitate independent wrist rehabilitation for stroke survivors. By integrating a pneumatic, self-donning interface with a manual ratchet mechanism, stroke survivors are able to don the device and administer their own wrist stretching. Our pilot study with three stroke survivors demonstrated that users could successfully don, operate, and doff the device independently in a single session and stretch their wrist to their maximum passive range of motion with minimal effort. The high usability and comfort scores from the usage surveys demonstrates that stroke survivors view the device favorably and find it easy and comfortable to use. Future directions can incorporate longitudinal home-use studies to further assess the device's role in improving functional outcomes and autonomy for stroke survivors with upper limb impairment.

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