# SMAller Aid: Exploring Shape-Changing Assistive Wearables for People with Mobility Impairment


Amanda McLeod
Carleton University
Ottawa, ON, Canada
amanda.mcleod@carleton.ca

Sara Nabil
Carleton University
Ottawa, ON, Canada
sara.nabil@carleton.ca

Lee Jones
Carleton University
Ottawa, ON, Canada
lee.jones@carleton.ca

Audrey Girouard
Carleton University
Ottawa, ON, Canada
audrey.girouard@carleton.ca



## ABSTRACT

Individuals with mobility impairments often discuss the challenges associated with donning and doffing shirts (i.e. putting them on and taking them off). Limited previous work has tackled this issue, but the comfort and aesthetic integrity of the shirt is often forgotten. In this paper, we co-designed an adaptive shirt with individuals with mobility impairments and personal support workers. With the insights from these discussions, we developed an augmented top that transforms wide sizes (for the easy donning and doffing) into their preferred fit. The study resulted in the design of *SMAller Aid*, which uses Shape Memory Alloy (*SMA*) springs to retract to a smaller size. The shirt adapts to their needs while retaining its aesthetic integrity to empower them with independence and no required assistance.



## CCS CONCEPTS

• **Human-centered computing~Human computer interaction (HCI)**; Accessibility technologies; Shape changing interfaces.

## KEYWORDS

Donning; Doffing; Shape Memory Alloy; Shape-changing Interfaces; wearables; soft actuation; Mobility Impairments.

**ACM Reference format:**

Amanda McLeod, Sara Nabil, Lee Jones, and Audrey Girouard. 2020. SMAller Aid: Exploring Shape-Changing Assistive Wearables for People with Mobility Impairment. In *Adjunct Proceedings of the 2020 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2020 ACM International Symposium on Wearable Computers (UbiComp/ISWC '20 Adjunct), September 12--16, 2020, Virtual Event, Mexico. ACM, New York, NY, USA, 4 pages.* https://doi.org/10.1145/3410530.3414418.




ACM ISBN 978-1-4503-8076-8/20/09.
https://doi.org/10.1145/3410530.3414418


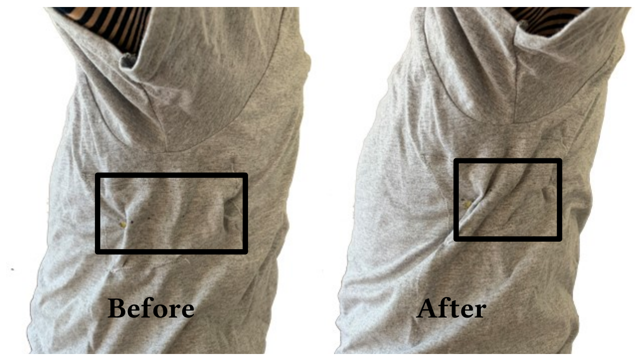


**Figure 1. Before and after the shirt is cinched using SMAllerAid to transform baggy T-shirts of people with mobility impairment into a regular fit.**

## 1 Introduction

Donning and doffing are the act of putting on and removing an article of clothing. Donning and doffing clothes is a daily activity that presents challenges for many individuals with mobility impairments [5]. For example, if you have limited range of motion in your arms, putting on a T-shirt and putting your arms through the sleeves may present a challenge. The objective of our research is to support people with mobility impairments by identifying the most challenging areas while putting on a t-shirt and propose a solution. Our goal is to develop an accessible and user-friendly way to ease the process of donning and doffing while taking into account the practical, technical and aesthetic considerations of such embodied interaction.

To better understand the most challenging areas while donning and doffing a T-shirt, we ran a study with four participants: two people with a mobility impairment and two people who are personal support workers (i.e. professional care takers of someone with a mobility impairment). We then designed the SMAller Aid prototype, a shirt that begins in a loose state, then retracts its SMA spring once actuated, cinching the shirt in a tight area (Figure 1). Our three key contributions are:

1. Engaging and co-designing with people with mobility impairments and their carers to understand their needs.
2. Exploring the potential of SMA in shape-changing wearables with both assistive/functional and aesthetic considerations.

3. Creating a design that augments everyday garments to improve the process of donning and doffing within users living with mobility impairments.

## 2 Related Work

Adaptive clothing is an industry that designs accessible clothes for individuals with disabilities [4]. Some ready-to-wear brands such as IZ Adaptive (https://izadaptive.com/) create adaptive clothing designs, whereas others like Tommy Adaptive (https://usa.tommy.com/en/tommy-adaptive) add accessible features to items from their main line. An alternative approach, co-designing custom adaptive clothes, involves working with individuals with disabilities to design garments to suit their individual needs through interviews [7], shadowing [13], or wardrobe studies [8]. Though custom co-design is resource intensive, it can lead to useful insights for adaptive lines. Co-design can also be used to develop dressing aids, as well as accessible maker tools so individuals can adapt their own clothes [3]. Overall, researchers emphasize the importance of working with individuals with disabilities *before* an item is designed.

Though an underexplored area for adaptive clothing, shape-changing clothes could help with the clothing barriers found in previous work, and especially automatic or supported donning and doffing [5]. Previous work in shape changing clothes has included mechanical shape change such as Fleurtech [9] and Kino [6], and well as thin shape memory alloy wires which are promising due to their ability to be sewn. The most recent work on embedding SMA explores using scalable and replicable methods such as machine-sewing to incorporate SMA wire into fabrics and wearables to enable morphological capabilities [11]. Although some have explored using hand-crafting techniques to aesthetically alter articles of clothing [9, 12], few have explored the opportunities of SMA wire from an assistive garment perspective [8]. Additionally, there are limited prior works on the topic of fully excluding additional embedded circuitry within a wearable [1]. Researchers have proposed supporting patients with cerebral palsy with SMA actuated fabrics through an origami technique that caters to the desired folds by SMA wire [10]. Others looked into minimizing circuitry by maximizing additional mechanisms within a wearable [1].

In this paper, we explore a discrete embedded method for SMA using machine-sewing for practical and aesthetical considerations. In addition, we exclude incorporated circuitry and eliminate additional mechanisms which may compromise any desired aesthetical integrity.

## 3 Method

Prior to exploring solutions to the issue of donning and doffing a T-shirt, we wanted to gain insight from individuals who experience this challenge on a daily basis. Therefore, we ran a user study to co-design with people with mobility impairments to understand their needs while designing for/with them. We received approval from our institution's research ethics board to conduct this study.

We conducted a series of individual semi-structured interviews of approximately 45 minutes, with individuals who have had or currently have a mobility impairment (MI) and personal support workers (PSW) who have experienced professionally helping someone put on a T-shirt before. We recruited 2 MI participants (2 women), and 2 PSW participants (1 woman, 1 man).

Each study began with an introduction to the definition of donning and doffing and the article of clothing in question, a T-shirt. Following the interview, we planned two activities to prompt further discussion.

1. We asked participants to point on a mannequin as well as lay stickers on a shirt template to indicate the problematic area in which they find the most restrictive while putting on and taking off a T-shirt (Figure 2).
2. To explore the materiality of the wearable garment, we handed participants a 4 × 4 inch piece of Kevlar fabric and asked "Is this fabric soft or rough and would you find it comfortable or uncomfortable to wear?"

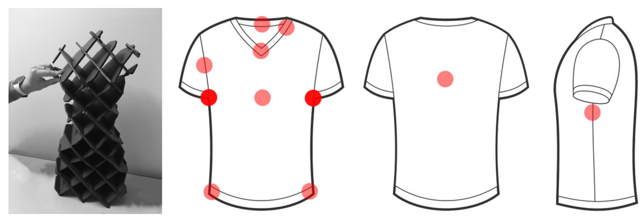

**Figure 2. Participants identified the most problematic areas while donning and doffing a T-shirt, on a mannequin (left) and a t-shirt template (right). Most common areas, such as the underarm, are visible in darker red.**

## 4 Results

Our gathered data included their marked T-shirt template, their indicated pain point area on the 3D mannequin, as well as our field notes and observations. We performed a thematic analysis on observations and notes. This method helped us determine patterns and recurring themes within the qualitative data. We found three main themes useful to take into consideration while designing assistive wearables: frustration, materiality, and restrictive areas on a T-shirt. Participants are identified by PSW1, PSW2, MI1, or MI2.

### 4.1.1 Feeling Frustrated; Common Restrictive Areas

All four participants identified the activity of putting on a T-shirt as being "*frustrating*", or using any word or sound of the sort to describe frustration (i.e. annoying, irritating). PSW2 "*Urg or a grunt of frustration seems to be a common one within my clients*". All identified the underarm area as the most challenging while donning and doffing a T-shirt (Figure 2). The second most common area identified by PSW1, PSW2, and MI1 was the collar.

### 4.1.2 Aesthetic Compromise

Both MI1 and MI2 mentioned that their desired aesthetic choices for shirts have been altered due to their impairments. MI1 answered "*100% yes!*" to their style choices being hindered due to inaccessible articles of clothing. MI2 mentioned their style choice to be forced into a corner of "*only wearing tanks*". All participants (including both PSWs) mentioned they would like for the T-shirt to begin in a baggier state for the donning and doffing process, however, would like for the shirt to be a proper fit post donning for aesthetical reasons. MI1 added that their shirts were "*too tight at first*".

#### 4.1.3 Material Matters

During the study, we established a discussion around the materiality of the wearable fabric. All our participants described the Kevlar as "*soft and comfortable*". We also asked participants what T-shirt material they gravitate towards. They answered either "*100% cotton*" or a polyester mix for its soft and stretchy nature. Both findings above are significant in driving our design decisions during the prototyping phase.

#### 4.1.4 Summary of Study

While we expected participants to experience challenges in waist-sides, in reality, our participants indicated underarm and collar as most problematic. This proves the importance and value of engaging the intended users in a co-designing process.

## 5 Prototyping SMAller Aid

The result of our co-design with people living with mobility impairments and personal support workers informed our design of the assistive wearable "SMAller Aid". SMAller Aid is a plausible solution to the challenges associated to donning and doffing a T-shirt. The cotton shirt is augmented with an SMA spring in a patch under the armpit. The interior Kevlar patch is sewn as a heat-resistive fabric to protect the user's skin from the exposed wire. SMAller Aid is connected to a detachable Arduino circuit that serves as a controller attached to a power supply that are only needed for the moment of cinching. A rechargeable LiPo battery can replace the power supply that we used for rapid prototyping. Once the SMA actuates and retracts the fabric, it preserves its shape-memory until it is stretched by force of hand when doffing the T-shirt.

### 5.1 Design Decisions

#### 5.1.1 Shape-change

We sourced the SMA spring from Kelloggs Research Labs with a wire diameter size of 0.25 mm, a mandrel size of 1.6 mm, a pitch of 0.5 mm, and a transition temperature of 35 °C. This moderate transition threshold allows for proper retraction of the spring once it is acute to the corresponding temperature. We selected the desired properties by the pull-force the SMA requires to have a visible shape-changing effect on a material such as cotton fabric.

#### 5.1.2 Wearable Fabric

Based on our results, we choose a 100% cotton T-shirt as it was the favoured material by participants in terms of comfort. As all participants reacted positively to the comfort of the piece of Kevlar presented, we placed a patch of Kevlar on the inside of the shirt covering the SMA spring to avoid skin contact, as the SMA does become warm when activated.

#### 5.1.3 Circuit Design

Two gator clips leading to an Arduino Uno microcontroller board deliver power to the SMA wire. We used a transistor to regulate a higher current reading since nitinol springs only start to actuate around 200 mA. As SMA springs must only be actuated for seconds at a time, it is suggested that the current must not run through the wire for over 2 to 5 seconds. Therefore, we digitally controlled our high pin to delay 1.5 seconds to allow the wire to actuate without over-heating.

### 5.2 Design Process

We cut the SMA spring to approximately 1.5 inches. We measured, marked and pinned in five main areas of the SMA spring in a stretched position of approximately 4 inches (Figure 3a). We sewed the stretched out spring at both extremities (Figure 3b), with the following sewing machine setting: satin stitch (tight zigzag); smallest length of stitch (setting 1); medium width of stitch: medium (setting 3). We cut holes on the outside of the shirt at the extremities of the spring. This allowed us to have access to actuate the spring from the outside of the shirt. Next, we clamped conductive beads to the outside extremities of the coil to allow for a bigger access point for the power supply to connect to (Figure 3c). Finally, we sewed a patch of Kevlar inside the shirt onto the spring to avoid skin contact (Figure 3d).

### 5.3 Initial Evaluation

To evaluate our prototype, we asked another two participants (postgraduate students: 1 male and 1 female, neither with a

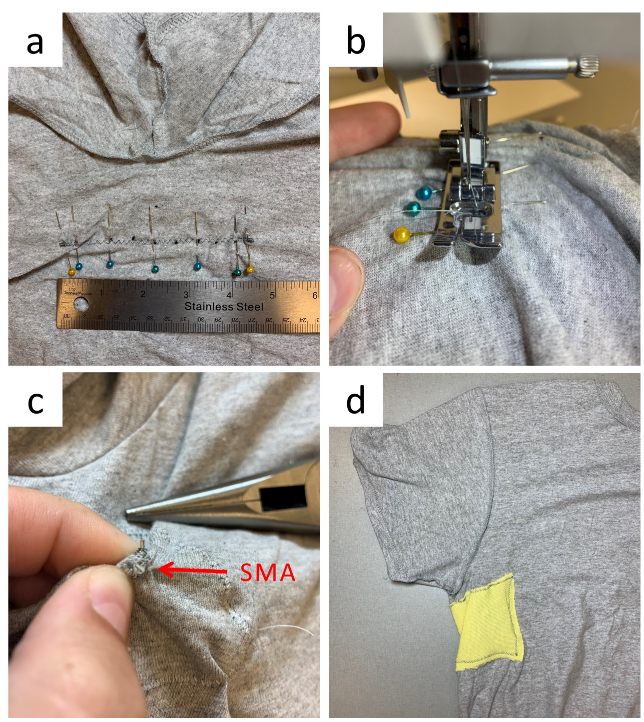


**Figure 3. The design process: a) Stretched and pinned SMA; b) Machine-sewing the SMA; c) Attaching conductive beads; and d) Sewing Kevlar patch on the inside**

mobility impairment) to put on the SMAller Aid T-shirt prototype so we could gain initial insights on the impact of the cinching on the fitting of the shirt. Once on, we then proceeded to hook up the external Arduino circuit to the shirt then left it to actuate for a few seconds before disconnecting the circuit. Participants discussed their experience with the shirts capabilities. They were impressed by the cinching capabilities of the SMAller Aid T-shirt. Both mentioned liking the gradual cinching of the wire and its ways of hugging their chest area without being too restrictive. One said *"It makes it a lot more fitted, yet still feels free".*

## 6 Discussion and Conclusion

Donning and doffing, the act of putting on and taking off a T-shirt, is a fundamental everyday action. However, many may face this task as a challenge. Prior to contriving a solution, we gained insight from those who experience these challenges. By co-designing with the targeted users, we were able to explore the real-world challenges and practical concerns that need to be taken into account, such as that the underarm and collar are most problematic areas for this daily task. Based on the insights of engaging with both people with mobility challenges and support workers, we co-designed and prototyped SMAller Aid. This assistive T-shirt discreetly incorporates machine-sewn SMA springs [11] in both underarm regions to transform wide tops into preferred fits. SMAller Aid is a design-led plausible solution to donning and doffing a T-shirt despite mobility impairments, while retaining aesthetical considerations.

Our participants discussed the importance of having accessible clothes that adapted to them without compromising style. Whereas other adaptive clothing examples have developed separate accessible clothes from the ground up [10], we demonstrate a way that clothes could be adapted after purchase with augmented patches. This type of approach provides the opportunity for individuals to purchase items based on style and aesthetics, rather than focusing on functionality, and then add cinching patches for a better fit. While our patches were sewn in, one could imagine adhesives or maker kits being developed to support ease of use, such as Hack-Ability which is an accessible maker toolkit for adding adaptive pockets [3]. Our post-purchase alteration, and the development of maker kits, is a new approach that would situate the individual wearer as a designer of their adaptions rather than a consumer and give individuals greater control over their clothes [2]. In future work, we plan to evaluate this prototype with people with mobility impairments including people of different body shapes and sizes and further explore accessible maker toolkits as an approach to adaptive clothes.

## Acknowledgments

This project was supported and funded by Carleton University through an I-CUREUS award and by the Natural Sciences and Engineering Research Council of Canada (NSERC) through a Discovery grant (402494/2011), and the Collaborative Learning in Usability Experiences Create grant (465639-2015).

## References

[1] Clarke, M.E., Dunne, L.E. and Holschuh, B.T. 2016. Self-adjusting wearables: variable control through a shape-memory latching mechanism. *UbiComp '16 Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct* (Heidelberg, Germany, 2016), 452–457.

[2] Jones, L. 2019. A co-design toolkit for wearable e-textiles. *Proceedings of the 2019 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2019 ACM International Symposium on Wearable Computers* (2019), 363–366.

[3] Jones, L., Isagholi, M., Meiklejohn, E., Xu, S., Truskolawski, K., Hayon, J., Jun, G., Guvenc, P. and Mallon-Michalove, C. 2020. Hack-Ability: Using Co-Design to Develop an Accessible Toolkit for Adding Pockets to Garments Lee. *Proceedings of the 16th Participatory Design Conference 2020 - Participation(s) Otherwise - Volume 2* (2020), 95–99.

[4] Kabel, A., McBee-Black, K. and Dimka, J. 2016. Apparel-related participation barriers: ability, adaptation and engagement. *Disability and Rehabilitation.* 38, 22 (2016), 2184–2192. DOI:https://doi.org/10.3109/09638288.2015.1123309.

[5] Kabela, A., Dimkab, J. and McBee-Blackc, K. 2017. Clothing-related barriers experienced by people with mobility disabilities and impairments. *Applied Ergonomics.* 59, Part A (2017), 165–169.

[6] Kao, H.C., Ajilo, D., Anilionyte, O., Dementyev, A., Choi, I., Follmer, S. and Schmandt, C. 2017. Exploring Interactions and Perceptions of Kinetic Wearables. *Proceedings of the 2017 Conference on Designing Interactive Systems* (2017).

[7] Kidd, L.K. 2006. A case study: Creating special occasion garments for young women with special needs. *Clothing and Textiles Research Journal.* 24, 2 (2006), 161–172. DOI:https://doi.org/10.1177/0887302X0602400209.

[8] Klepp, I.G. and Bjerck, M. 2014. A methodological approach to the materiality of clothing: Wardrobe studies. *International Journal of Social Research Methodology.* 17, 4 (2014), 373–386. DOI:https://doi.org/10.1080/13645579.2012.737148.

[9] Lee, S., Koo, H. and Zhou, J. 2016. Fleurtech: Transformable Smart Dress. *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct* (2016), 491–494.

[10] Lin, J., Zhou, J. and Koo, H. 2015. Enfold: Clothing for People with Cerebral Palsy. *UbiComp/ISWC '15 Adjunct* (2015), 563–566.

[11] Nabil, S., Kucera, J., Karastathi, N., Kirk, D.S. and Wright, P. 2019. Seamless Seams : Crafting Techniques for Embedding Fabrics with Interactive Actuation. *Designing Interactive Systems* (2019).

[12] Von Radziewsky, L., Krüger, A. and Löchtefeld, M. 2015. Scarfy - Augmenting human fashion behaviour with self-actuated clothes. *TEI 2015 - Proceedings of the 9th International Conference on Tangible, Embedded, and Embodied Interaction* (2015), 313–316.

[13] Tan, J. and Jun, G. 2018. *Universal Materiality: Wearable Interaction Design and Computer Aided Process for Accessible Wearable Solutions.* The Hong Kong Polytechnic University (Exhibition Catalogue).