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# UNDERSTANDING THE USER PERCEPTION GAP: OLDER ADULTS AND SIT-TO-STAND ASSISTANCE

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## ABSTRACT

*There is an urgent need to provide ways to help a fast-growing older adult population to maintain daily mobility. A great deal of work exists in medical devices and robotics to generate effective assistive solutions, yet at the same time, limits have been observed in the adoption of such systems. In this paper we explore possible factors in adoption from a user-centered design perspective. We investigated user needs surrounding the act of standing up from a seated position and older users' attitudes toward assistive device prototypes.*

*Older adults completed a standard timed-up-and-go mobility assessment, rated their own difficulty standing, participated in interviews, and shared responses to "look-and-feel" prototypes, all in an effort to uncover latent needs. A licensed physical therapist rated videos of the subjects while standing up and the two ratings were compared. While the physical therapist's rating of difficulty increased as subjects' performance on the clinical mobility assessment worsened, subjects' self-ratings did not significantly correlate with mobility performance, even when timed-up-and-go performance indicated a risk of falling.*

*Subjects expressed preferences for potential assistive devices that were more discreet, lightweight, and flexible over devices that were bulkier, heavier, and rigid. In general, subjects' attitudes toward assistive devices for their own sit-to-stand use were similar regardless of their demonstrated need. The results highlight the challenges designers may face when creating products for older adult users and underline the importance of a user-centered design process. Implications for assistive technology design are discussed.*

Keywords: user-centered design, collaborative design, assistive technology, sit-to-stand

## 1. INTRODUCTION

The United States and many other nations are undergoing a major demographic shift as life expectancies grow longer. In the U.S., by 2060 35% of the population will be over the age of 55, compared to 28% in 2016 and 18% in 1960 [1].

Falls are a major cause of functional loss and death in older people [2]. In 2020, over 40,000 adults aged 55 or older died of a fall-related injury in the United States [3]. Non-fatal falls often lead to comorbidities and loss of functional capacity [4]. Regular exercise and balance exercises in particular are some of the most common recommendations for fall prevention [5]. However, a prerequisite for balance and mobility is the ability to stand.

As humans age, muscular tissue begins to lose its strength and endurance. This process is the development of *sarcopenia*, the age-related loss of primarily type II muscle fibers and motor neurons [6]. Anterior thigh muscles atrophy earlier, which can lead to difficulty sitting and standing [7]. This can make normal daily activities such as sit-to-stand (STS) quite difficult and even impossible without assistance. Sarcopenia is also combatted by exercise, but if difficulty standing leads to less mobility and exercise, the problem may worsen, leading to a vicious downward spiral of functional loss.

Most commercially available mechanical devices for STS assistance are bulky, such as specialized recliners or spring-loaded cushions that the user must carry between seats. Most of these devices are not particularly effective, and none have been widely adopted. Wearable devices such as powered exoskeletons are not widely accessible or desirable to older adults [8]. Most

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adults choose to remain living in their own homes as they age [9], meaning that any stand-assist device meant for regular use should be easy to operate by the user without help from a caregiver.

As more people live longer, the need for eldercare services and devices will grow as well. We are interested in developing solutions that preserve older adults' mobility, independence, and dignity for as long as possible. There is an unmet need to assist otherwise healthy senior citizens in STS. This study advances that goal by including potential users in the design process by observing them as they engaged in STS to identify any needs they might have or workarounds they engage in, and gathering their feedback and perceptions of the process. Previous work has shown the importance of involving older people in the technology design process [10]. However, a recent review found only three studies that considered the perspectives of exoskeleton users [11], while we found no studies that considered older adults' perspectives for STS assistive device design.

In this study, we investigated strategies that older adults use for STS. The experimental protocol consisted of both a standard clinical mobility assessment and subjects' subjective ratings of their own ability to stand. We further interviewed subjects about their experiences standing up and their opinions about and ideas for devices to assist with STS. These interviews employed "look-and-feel" prototypes (prototypes that look like a final prototype, but do not offer realistic functionality), "works-like" prototypes (prototypes that are functional but do not have the visual appearance of a final product), and existing products in order to elicit feedback from users without the need to create a fully functional prototype [12]. We showed subjects a variety of prototype concepts with different form factors (e.g., size, weight, rigidity, aesthetic, texture) to help us uncover participants' expressed and latent needs. A latent need is a need that the user may not be aware of consciously but that can be identified through observation. Latent needs are particularly powerful because they are non-obvious and may offer unique opportunities for innovative products. We have found that much of the technology development in the current literature may have overlooked these needs, and our aim is to encourage other designers to see the benefit and ultimately incorporate these practices in their studies. When such key needs are addressed, products may have a stronger chance of eventual success [13,14].

This study sought to investigate the following research questions:

- What are the differences between older users' perceptions of their ability to go from a sitting to a standing position and external metrics such as standardized assessments and professional evaluation?
- What functional and aesthetic preferences do older people have for devices that can help in STS, and do they change with age or ability?
- Can those preferences be elicited using look-and-feel prototypes?

We hypothesized that there would be a correlation between age and poorer performance on assessments. We also hypothesized that there would be a preference for sleek and discreet devices compared to bulky devices that might evoke social stigmas for older adults. In both cases, it was expected that as subjects' mobility performance decreased, they would rate their difficulty standing higher and be receptive to a wider range of devices.

## 2. BACKGROUND LITERATURE

### 2.1 Assistive Devices for Older Adults

Many attempts have been made to design assistive devices such as large mechanical lifts to aid older adults in STS [15–18]. Most of these devices offer impressive technology and are aimed towards a demographic of people who cannot stand up on their own at all or require substantial assistance, compared to the vast majority who may need only limited assistance. Due to this narrow design scope, many devices are large, expensive, may require the user to change their behaviors significantly, and were not originally intended to be used at home or in everyday situations for the target population. These devices tend not to solicit user input early in during the design process, and most designs have been slow to create lasting impact.

In more recent years, researchers have begun to develop devices such as both passive and active exoskeletons intended to assist STS in older adults for whom standing may be difficult, but who do not yet require full transfer assistance [19,20]. While these devices appear less cumbersome, it is not clear yet that they can provide a sufficient level of physical assistance or how involved older subjects were in testing.

### 2.2 Identifying User Needs

A key principle of user-centered design is an early focus on users and understanding the tasks they engage in in order to identify user needs [21]. Many methodologies have intended to refine the process to allow for easier and more efficient uncovering of user needs, including those which are non-obvious, also called latent needs. Latent needs are typically the most difficult to identify as the users tend not to be aware of them consciously. For example, working with what are called "lead users" has been proven to be highly valuable. These are users who have experienced unusual circumstances or use cases out of which come new strategies or workarounds for the product being developed [22,23]. A simple example of a lead user workaround that has been widely adopted can be found in the way users with reduced mobility retrofit a walker by installing glides made of cut up tennis balls. This workaround suggests an opportunity to re-design walkers in such a way that doesn't require this DIY retrofit. Working with these users compared to non-lead users has been shown to help designers more quickly identify these latent needs, which ultimately leads to further customer satisfaction.

Allowing users to be at the center of the need-finding process can be of value to creating a successful product. This can include letting them run the flow of research and having them be the core source of creating priorities for the project [24].

## 2.3 Designing for Older Adults

Insufficient understanding of older adults' needs is one factor that can contribute to the creation of technology or products that are not widely adopted. Older adults are a user base for whom understanding needs is particularly important, because the typical designer is not a member of the older population and may find it easier to design for someone more similar in age to themselves [25,26]. There are additional challenges for older populations such as mental, physical, social, and economic factors. These additional considerations may partially explain why, despite a large growth in technologies made for the aging population, products are not widely adopted despite the immediate utility they could bring to older adults' lives [26]. In order to elicit insightful responses from older users in the data gathering process, it is important that words used to describe the technologies are understandable and hands-on elements are used wherever possible [27].

Based on the above literature review, there are many efforts towards designing assistive devices for older adults, but there are variable levels of adoption in the real world. A clear need exists to design accessible and desirable products for the elderly, and through the lens of human-centered design we hope to help clarify why these devices are not being adopted using a sit-to-stand device as a case study.

## 3. METHODS

We assessed and interviewed 15 older adults in the Boston Area (5 male, 10 female; age: 75.1 ± 11.7 years), recruited through the MIT AgeLab, with no self-reported history of neurological or musculoskeletal disorder or injury that would compromise their ability to stand. All subjects provided written informed consent and all procedures were approved by the Committee on the Use of Humans as Experimental Subjects at the Massachusetts Institute of Technology. Experiments were conducted in a lab at MIT (7 subjects) or in subjects' homes (8 subjects). The protocol consisted of a clinical mobility assessment, a self-evaluation, and a structured interview about assistive devices, including the use of a variety of prototypes to elicit feedback. Both the mobility assessment and interview were recorded. We also took note of any workarounds or equipment that subjects might use to help them stand up. Each session was designed to be 60-90 minutes long. Subjects were not compensated for their participation.

Each subject was asked for consent, then asked to identify a chair within their home to conduct the standard Timed-Up-and-Go (TUG) mobility assessment. In the TUG assessment, subjects were asked to stand from a seated position, walk to a line 10 feet away at their normal pace, turn around and return to the chair at their normal pace, and sit back down. Timing started when subjects began the standing motion and ended when they sat down. TUG performances were video recorded for later analysis.

Subjects were asked to rate their difficulty standing up on a Likert scale, responding to the prompt, "Rate your experience standing up from 1-5, 5 being the most difficult experience and 1 being the easiest experience."

The interview consisted of questions regarding subjects' previous experiences standing and subjects' experiences with and impressions of assistive devices to help with STS. Some key questions included: "Have you ever gotten help from somebody else to stand up? If so, describe how they helped." and "What would/wouldn't you want from a device that helps you stand up?".

Subjects were shown several "look-and-feel" and "works-like" prototypes, as illustrated in Fig. 1. The prototypes included existing devices that were designed to assist with STS, and others meant to mimic the form factor of potential devices to be developed. Prototypes were selected by reviewing the literature for investigational devices, by finding commercially available consumer products with some evidence of adoption, and through ideation of designs that could be effective for STS assistance. Shown in Fig. 1, the prototypes included:

A. a variable-force wearable prototype device currently under development (works-like, video)
B. a wearable chair that did not function as an STS device but gave a sense of what an STS device might look like (look-and-feel, physical object)
C. a commercially available pneumatic spring cushion for STS assistance (real product, physical object)
D. a soft posture-support device that did not function as an STS device but gave a sense of what an STS device might look like (look-and-feel, physical object)
E. elastic resistance bands that did not function as an STS device but gave a sense of what an STS device might look like (look-and-feel, physical object)
F. an inflatable cushion to be worn that did not function as an STS device but gave a sense of what an STS device might look like (look-and-feel, image)
G. a hinged knee brace that did not function as an STS device but gave a sense of what an STS device might look like (look-and-feel, physical object)
H. athletic leggings that did not function as an STS device but gave a sense of what an STS device might look like (look-and-feel, image)

The prototypes employed were a mixture of images, videos, and physical artifacts. Subjects were allowed to touch and interact with the physical artifacts if they desired. Prototypes were chosen to establish a broad design space. Form factors ranged from low-profile (the leggings) to cumbersome (the hinged knee brace). Materials included cloth, canvas, synthetic fibers, rubber, rigid plastic, and metal. Prototypes interfaced with the body in diverse ways, alternatively running along the backs of the legs, the sides of the legs, anchoring to the upper or lower back, or providing support primarily under the rear end. Subjects were asked how likely they would be to use each prototype if it helped them to stand up and responses were graded on a 3-way scale (yes, maybe, no).

After all the experiments were conducted, a licensed physical therapist viewed de-identified video recordings of the subjects performing the TUG assessment and rated the subjects' performance rising from sitting to standing on the same global 1-5 scale, independent of subject age. To make a judgment, the physical therapist evaluated subjects' trunk and hip flexion, anterior knee translation over toes, and standing up to full knee and hip extension.


**FIGURE 1:** LOOK-AND-FEEL AND WORKS-LIKE SIT-TO-STAND PROTOTYPES.

## 4. RESULTS

### 4.1 Timed-Up-and-Go Assessment

All subjects were able to complete the TUG assessment. According to the Centers for Disease Control (CDC) STEADI criteria, an older adult who takes 12 seconds or longer to complete the TUG assessment is at risk for falling [28]. The average time for healthy 20- and 30-year-olds is 8.56 seconds [29]. The oldest subject, aged 98, took considerably longer than the others to complete the assessment, taking a total of 74.0 seconds. This subject was excluded from subsequent TUG statistical analysis but included for age. Without this subject, the mean TUG time was 11.5 ± 2.4 seconds, as shown in Fig. 2. Longer performance on the TUG assessment was positively correlated with age (Pearson correlation coefficient r = 0.74, p = 0.003).

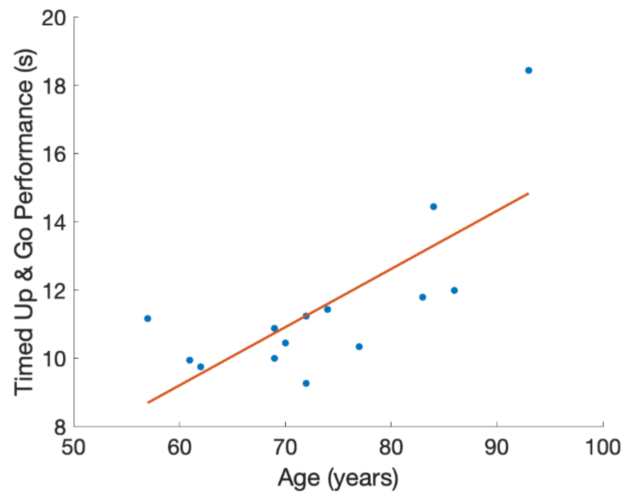
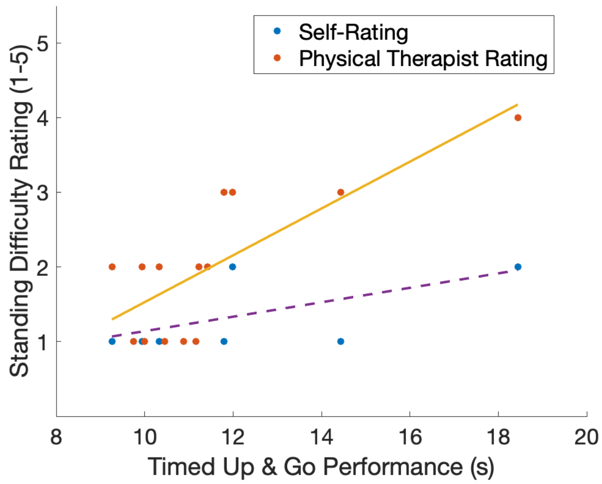



**FIGURE 2:** TIME TO COMPLETE THE TUG ASSESSMENT WAS POSITIVELY CORRELATED WITH SUBJECT AGE.

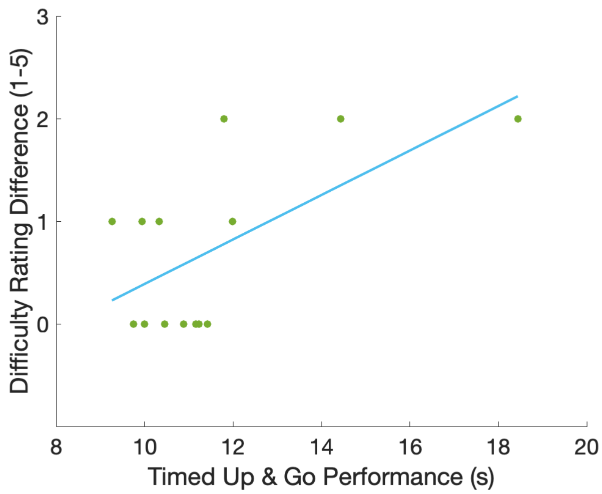
### 4.2 Perceived Difficulty Standing

In response to the prompt, "Rate your experience standing up from 1-5, 5 being the most difficult experience and 1 being the easiest experience," subjects consistently reported low difficulty standing, as shown in Fig. 3.a. No subject rated their difficulty standing above a 3 on the Likert scale; the only subject to choose a difficulty rating of 3 was the outlier with a TUG time of 74 seconds. A one-way ANOVA revealed no significant gender differences in self-rating (p = 0.41).

The mean self-rating was 1.40 ± 0.63, while the mean physical therapist rating was 2.20 ± 1.21. There was no significant correlation between TUG performance time and self-rating (r = 0.49, p = 0.076), but there was a significant positive correlation between TUG performance and physical therapist rating (r = 0.77, p = 0.001). The significant and non-significant correlations of TUG time with physical therapist rating and self-rating are shown by the solid yellow and dashed purple lines, respectively, in Fig. 3.a. The physical therapist consistently rated subjects' difficulty standing the same or higher than subjects rated themselves, a gap which widened with increasing TUG performance time. Figure 3.b shows a significant positive correlation between the difference of the difficulty ratings (PT rating - self rating) and TUG performance (r = 0.62, p = 0.02).




(a) LONGER TUG TIME WAS CORRELATED WITH HIGHER PHYSICAL THERAPIST RATING BUT NOT HIGHER SELF-RATING.

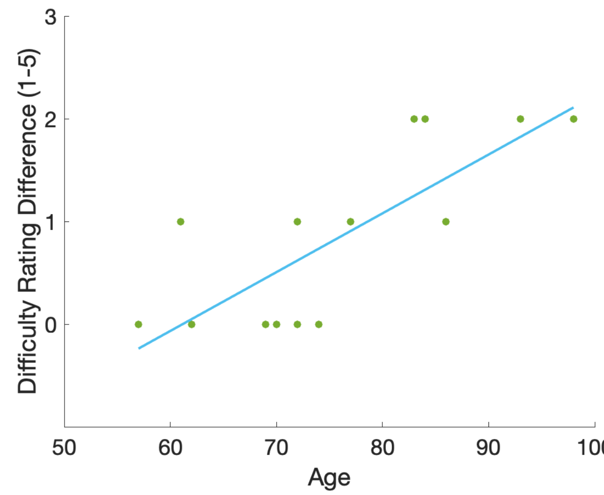



(b) DISCREPANCY BETWEEN SELF-RATING AND PHYSICAL THERAPIST RATING INCREASED AS TUG PERFORMANCE WORSENED.

**FIGURE 3:** TUG PERFORMANCE VS. DIFFICULTY RATINGS.

The relationship between age and self-rating was also inspected, as shown in Fig. 4. There was a significant positive correlation between age and self-rating ($r = 0.68$, $p = 0.006$), as well as a more positive and significant correlation between age and physical therapist rating ($r = 0.91$, $p = 0.000002$). We also found a significant positive correlation between age and the difference between ratings ($r = 0.78$, $p = 0.0006$).


(a) AGE WAS POSITIVELY CORRELATED WITH DIFFICULTY RATINGS.




(b) DISCREPANCY BETWEEN SELF-RATING AND PHYSICAL THERAPIST RATING INCREASED WITH SUBJECT AGE.

**FIGURE 4**: AGE VS. DIFFICULTY RATINGS.

The differences between professional ratings and self-ratings that increased with both TUG performance time and age may indicate that older adults do not adjust their self-perceptions as they age and their physical abilities decline. These data are summarized in Table 1.

**TABLE 1:** TUG ASSESSMENT RESULTS AND STANDING DIFFICULTY RATINGS.

| Subject Age (years) | TUG Time (s) | Self-Rating (1-5) | Physical Therapist Rating (1-5) |
|---|---|---|---|
| 57 | 11.2 | 1 | 1 |
| 61 | 9.9 | 1 | 2 |
| 62 | 9.7 | 1 | 1 |
| 69 | 10.9 | 1 | 1 |
| 69 | 10.0 | 1 | 1 |
| 70 | 10.5 | 1 | 1 |
| 72 | 9.3 | 1 | 2 |
| 72 | 11.2 | 2 | 2 |
| 74 | 11.4 | 2 | 2 |
| 83 | 11.8 | 1 | 3 |
| 84 | 14.4 | 1 | 3 |
| 86 | 12.0 | 2 | 3 |
| 93 | 18.4 | 2 | 4 |
| 98 | 74.0 | 3 | 5 |

### 4.3 User Responses to Prototypes

In each interview subjects were shown different "look-and-feel", works-like, and real prototypes [12]. They were then asked how likely they would be to use each device if it helped them stand up on a scale from 1 to 3, 1 being a no, 2 being a maybe, and 3 being a yes. Prototypes characterized by being lighter and more discreet were rated higher on average than heavy and bulky prototypes with rigid members, as seen in Fig. 5. Error bars represent plus or minus one standard deviation. In particular, subjects rated the "leggings" prototype as significantly more likely to be used than most other prototypes, and the "knee brace" as significantly less likely to be used than most other prototypes. We found no correlation between subject mean prototype rating and subject age ($r = -0.14$, $p = 0.63$) or mobility performance ($r = 0.08$, $p = 0.77$), shown in Fig. 6. The oldest subject, who had the longest TUG performance time, did not rate any prototype higher than a "maybe." A one-way ANOVA found no evidence that ratings differed due to prototypes being presented as images, videos, or physical objects ($p = 0.67$).

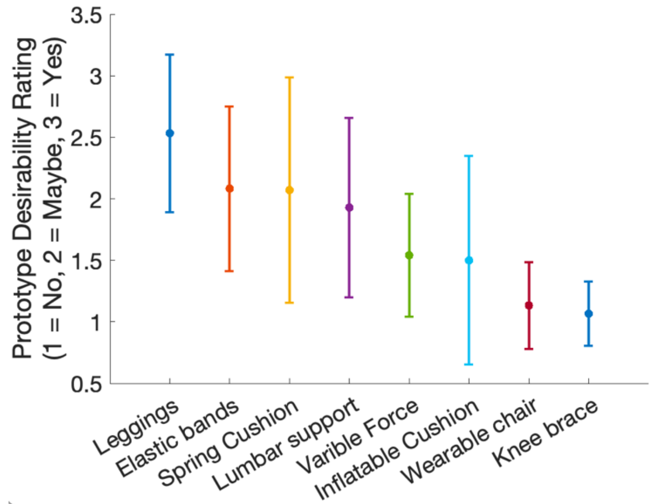
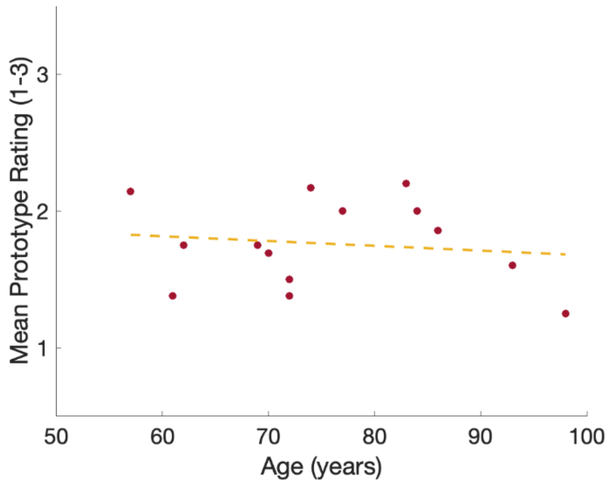


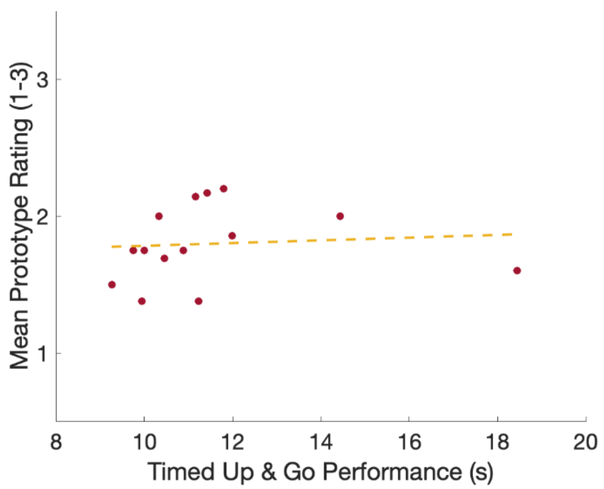

**FIGURE 5:** MEAN PROTOTYPE DESIRABILITY RATINGS.

Subjects commented that the leggings were "invisible" and therefore "perfect," and imagined wearing them underneath their regular clothing. Subjects also liked the "soft," "stretchy," and "lightweight" elastic resistance bands. The posture-assist device was described as "awkward" and "geeky," though some found it comfortable to wear, saying it "feels really great." Subjects found the variable-force works-like prototype "simple" and "intriguing," but were concerned that the mechanism was "clunky" and could not fit under a coat. In considering the knee brace and wearable chair prototypes, subjects wondered if they would be able to be hidden beneath clothing. Some said they would have to be "pretty disabled" to consider using these prototypes.

We uncovered various latent needs throughout the interview process. One participant initially stated that she needed no assistance to stand; however, when asked to perform STS from various seated positions, she placed a pillow that she regularly carried with her from room to room on the seat to increase the height of her torso, ultimately putting less strain on her hips and knees and making standing more comfortable. This pillow is a workaround, which indicates a potential need for a portable device to assist STS from various positions. Other subjects reported adopting similar strategies. We also found many participants preferring higher chairs in their homes and avoiding lower seating arrangements such as couches. This again is a workaround, pointing to a need for a device that allows these older adults to stand from any seated position. Finally, we noted many individuals using their hands to grab and push on their surroundings, like nearby tables or rails, when standing from chairs without arms. All of these participants stated that using their hands made them feel safe. This workaround suggests a need for a device that allows older adults to feel supported when standing from any seat.




(a) NO CORRELATION BETWEEN AGE AND PROTOTYPE RATING.




(b) NO CORRELATION BETTWEEN TUG PERFORMANCE AND PROTOTYPE RATING.

**FIGURE 6:** AGE AND TUG TIME VS MEAN PROTOTYPE RATING.

## 5. DISCUSSION

This study assessed older adults' ability to stand as well as their perceptions of their own abilities and attitudes toward assistive technology in order to design devices with a higher likelihood of user acceptance. A finding of this study is that older adults may not see themselves as needing assistance even when objective performance measures and expert professional opinion both suggest they do. This problem is compounded by an aversion to existing assistive technology. Taken together, these results underline the need to involve such users in the design of new assistive technology in order to increase the product acceptance rate.

As subjects' age increased, their TUG time also increased, which has been correlated with a higher risk of falling. Self-ability ratings did not have a statistically significant relationship with TUG performance time, meaning that as objective mobility worsened, the subjects' own ratings stayed the same. Of the 14 participants, 8 rated their difficulty standing lower than did the physical therapist. Of these 8 participants, 3 had a TUG time over 12 seconds, indicating a risk of falling by the CDC's STEADI criteria. When interviewing the three subjects within the risk of falling category about potential devices, there was a consistent theme of comments such as "I would use this *if* I needed it" and "*If* I couldn't stand at all this could be helpful." From these results, we infer that older adults may not be open to help in the area of mobility when it could be beneficial to them, especially if the help is explicitly tied to old age; only 35 percent of people over the age of 75 report feeling "old" [30,31]. Instead, they may not accept assistance until an accident happens or until there is a complete dependence on a device to stand.

In each interview we also showed the participants a range of prototypes with the goal of uncovering their underlying needs, lowering the barriers to entry around older adults using assistive technology. We were motivated by the understanding that including end users as co-designers in early stages of development can lead to a higher acceptance rate of the technology created [32]. We found that participants overwhelmingly wanted something that was not bulky and either hidden under clothes or easily put in a purse or bag. They repeatedly mentioned not wanting to "look old" or "look disabled", and that they didn't want to be treated as someone with extra needs, even though some of them objectively had a high fall risk, according to their TUG time. A handful of subjects had developed their own workarounds to help with standing up, which is a strong indicator of the need. The perception associated around the use of assistive technology for mobility is real and quite powerful among the older adult population. We can see this in how different prototypes were rated, the sleekest and most inconspicuous designs scoring higher than the bulkiest and most intrusive.

These findings are relevant for engineers and designers who seek to create mechanical or robotic assistive devices. These devices hold great potential for assisting older users, but our findings suggest that even older adults who demonstrate significant need may reject more obtrusive devices. This underscores the importance of designing devices that not only are functional but also desirable. This information may be beneficial to creators of assistive and rehabilitative devices, as many previous designs have been made without taking user preferences into account [11].

When designing devices that augment older adults' mobility needs and seek to meet their latent social needs, there must be an effort to lessen the stigma of these devices being associated with weakness and disability. The goal of making devices that are not only functional but that also bring some neutral or positive social utility to the user in an effort to honor their humanity is integral to the success of these devices and to the safety of the expanding elderly population.

## 6. CONCLUSIONS AND FUTURE WORK

This study examined older adults' self-perception of ability compared to their ability as determined by a standardized assessment and expert opinion. We also explored the latent needs around assistive technology for this demographic. The results suggest the following answers to the proposed research questions:

*1. What are the differences between older users' perceptions of their ability to go from a sitting to a standing position and external metrics such as standardized assessments and professional evaluation?*

We found that there was a lack of self-awareness or possibly denial among the population of people who are at risk of falling. For these users, assistive devices to preserve mobility are thus a latent need of which they remain unaware. When creating devices for older adults, engineers and designers cannot solely rely on functional performance measures to ensure eventual adoption.

*2. What functional and aesthetic preferences do older people have for devices that can help in STS, and do they change with age or ability?*

Older adults tend to prefer designs that are sleek, hidden, and flexible. They are not receptive to bulky, obtrusive, or rigid designs regardless of objective need. The desire not to be seen as "old" or "disabled" may be a stronger driver of behavior than physical needs. Assistive technology must be designed to meet older adults' physical needs, social needs, and aesthetic preferences simultaneously.

Designers and engineers must take the necessary time to employ user-centered design techniques to test out potential design concepts early in the process, such as the "Wizard of Oz" approach [33,34] of faking a user experience to obtain necessary feedback to decide if resources should be committed to develop a new technology. This approach will increase the likelihood that assistive devices will be embraced by an older population. Given the observed disparity between internal and external perceptions of ability, as well as the strong stigma associated with assistive technology, we must obtain a better assessment of the need before the need invites catastrophe.

We acknowledge that there may be potential limitations to our results due to the self-selected sample of older adults who responded to our call for participants potentially being biased toward a more self-sufficient attitude. We also acknowledge the imprecision of subjects' evaluations on a Likert scale to characterize self-perception, due to vague prompting and the possibility that subjects employed different internal metrics. Furthermore, we used a variety of prototypes – look-and-feel, works-like and real devices – that were presented as a mix of physical prototypes, videos and photographs. Other studies have shown that the ways in which prototypes are presented have the potential to influence responses [35,36], though in this study we did not find any significant difference in prototype ratings based on mode of presentation. Future development of assistive devices should measure subjects' ratings of look and feel in addition to their functional performance. These "soft" metrics may eventually prove to be as important to product adoption as power augmentation or metabolic rate reduction.

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## REFERENCES

[1] Bureau, U. C., "2017 National Population Projections Tables: Main Series," Census.gov [Online]. Available: https://www.census.gov/data/tables/2017/demo/popproj/2017-summary-tables.html. [Accessed: 12-Mar-2023].

[2] Vaishya, R., and Vaish, A., 2020, "Falls in Older Adults Are Serious," Indian J. Orthop., **54**(1), pp. 69–74.

[3] "Injury Data Visualization Tools | WISQARS | CDC" [Online]. Available: https://wisqars.cdc.gov/data/non-fatal/home. [Accessed: 12-Mar-2023].

[4] Ungar, A., Rafanelli, M., Iacomelli, I., Brunetti, M. A., Ceccofiglio, A., Tesi, F., and Marchionni, N., 2013, "Fall Prevention in the Elderly," Clin. Cases Miner. Bone Metab., **10**(2), pp. 91–95.

[5] Rubenstein, L. Z., 2006, "Falls in Older People: Epidemiology, Risk Factors and Strategies for Prevention," Age Ageing, **35 Suppl 2**, pp. ii37–ii41.

[6] Walston, J. D., 2012, "Sarcopenia in Older Adults," Curr. Opin. Rheumatol., **24**(6), pp. 623–627.

[7] KARA, M., KAYMAK, B., FRONTERA, W. R., ATA, A. M., RICCI, V., EKIZ, T., CHANG, K.-V., HAN, D.-S., MICHAIL, X., QUITTAN, M., LIM, J.-Y., BEAN, J. F., FRANCHIGNONI, F., and ÖZÇAKAR, L., 2021, "DIAGNOSING SARCOPENIA: FUNCTIONAL PERSPECTIVES AND A NEW ALGORITHM FROM ISarcoPRM," J. Rehabil. Med., **53**(6), p. 2806.

[8] Lo, C.-H., 2021, "A Study on Appearance Acceptance Appraisal of Elderly Mobility Assists," Sustainability, **13**(19), p. 10547.

[9] Coughlin, J. F., 1999, "Technology Needs of Aging Boomers," Issues Sci. Technol., **16**(1), pp. 53–60.

[10] Lindsay, S., Jackson, D., Schofield, G., and Olivier, P., 2012, "Engaging Older People Using Participatory Design," *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, Association for Computing Machinery, New York, NY, USA, pp. 1199–1208.

[11] Hill, D., Holloway, C. S., Ramirez, D. Z. M., Smitham, P., and Pappas, Y., 2017, "WHAT ARE USER PERSPECTIVES OF EXOSKELETON TECHNOLOGY? A LITERATURE REVIEW," Int. J. Technol. Assess. Health Care, **33**(2), pp. 160–167.

[12] Houde, S., and Hill, C., 1997, "Chapter 16 - What Do Prototypes Prototype?," *Handbook of Human-Computer Interaction (Second Edition)*, M.G. Helander, T.K.



 

Landauer, and P.V. Prabhu, eds., North-Holland, Amsterdam, pp. 367–381.
[13] Von Hippel, E., 1978, "Successful Industrial Products from Customer Ideas: Presentation of a New Customer-Active Paradigm with Evidence and Implications.," J. Mark., **42**(1), pp. 39–49.
[14] Raviselvam, S., Subburaj, K., Wood, K. L., and Hölttä-Otto, K., 2019, "An Extreme User Approach to Identify Latent Needs: Adaptation and Application in Medical Device Design," American Society of Mechanical Engineers Digital Collection.
[15] Kim, S.-W., Song, J., Suh, S., Lee, W., and Kang, S., 2018, "Design And Experiment Of A Passive Sit-To-Stand And Walking (STSW) Assistance Device For The Elderly," *2018 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, pp. 1781–1784.
[16] Lou, S.-Z., You, J.-Y., Tsai, Y.-C., and Chen, Y.-C., 2021, "Effects of Different Assistive Seats on Ability of Elderly in Sit-To-Stand and Back-To-Sit Movements," Healthc. Basel Switz., **9**(4), p. 485.
[17] Rea, P., and Ottaviano, E., 2016, "Analysis and Mechanical Design Solutions for Sit-To-Stand Assisting Devices," Am. J. Eng. Appl. Sci., **9**(4), pp. 1134–1143.
[18] Médéric, P., Pasqui, V., Plumet, F., and Bidaud, P., 2004, "Design of a Walking-Aid and Sit-to-Stand Transfer Assisting Device for Elderly People."
[19] Lee, H., Kim, S. H., and Park, H.-S., 2020, "A Fully Soft and Passive Assistive Device to Lower the Metabolic Cost of Sit-to-Stand," Front. Bioeng. Biotechnol., **8**.
[20] Wang, Y., Zhao, G., Diao, Y., Feng, Y., and Li, G., 2022, "Performance Analysis of Unpowered Lower Limb Exoskeleton during Sit down and Stand Up," Robotica, **40**(5), pp. 1274–1292.
[21] Courage, C., and Baxter, K., 2005, *Understanding Your Users: A Practical Guide to User Requirements Methods, Tools, and Techniques*, Gulf Professional Publishing.
[22] von Hippel, E., 1986, "Lead Users: A Source of Novel Product Concepts," Manag. Sci., **32**(7), pp. 791–805.
[23] Lin, J., and Seepersad, C. C., 2009, "Empathic Lead Users: The Effects of Extraordinary User Experiences on Customer Needs Analysis and Product Redesign," American Society of Mechanical Engineers Digital Collection, pp. 289–296.
[24] Patnaik, D., and Becker, R., 1999, "Needfinding: The Why and How of Uncovering People's Needs," Des. Manag. J. Former Ser., **10**(2), pp. 37–43.
[25] Keates, S., and Clarkson, P. J., 2002, "Defining Design Exclusion," *Universal Access and Assistive Technology*, S. Keates, P. Langdon, P.J. Clarkson, and P. Robinson, eds., Springer, London, pp. 13–22.
[26] Lee, C., and Coughlin, J. F., 2015, "PERSPECTIVE: Older Adults' Adoption of Technology: An Integrated Approach to Identifying Determinants and Barriers," J. Prod. Innov. Manag., **32**(5), pp. 747–759.
[27] Eisma, R., Dickinson, A., Goodman, J., Syme, A., Tiwari, L., and Newell, A. F., 2004, "Early User Involvement in the Development of Information Technology-Related Products for Older People," Univers. Access Inf. Soc., **3**(2), pp. 131–140.
[28] Lusardi, M. M., Fritz, S., Middleton, A., Allison, L., Wingood, M., Phillips, E., Criss, M., Verma, S., Osborne, J., and Chui, K. K., 2017, "Determining Risk of Falls in Community Dwelling Older Adults: A Systematic Review and Meta-Analysis Using Posttest Probability," J. Geriatr. Phys. Ther. 2001, **40**(1), pp. 1–36.
[29] Kear, B. M., Guck, T. P., and McGaha, A. L., 2017, "Timed Up and Go (TUG) Test," J. Prim. Care Community Health, **8**(1), pp. 9–13.
[30] Taylor, P., Morin, R., Parker, K., Cohn, D., and Wang, W., "Growing Old in America: Expectations vs. Reality."
[31] Coughlin, J. F., 2017, *The Longevity Economy: Unlocking the World's Fastest-Growing, Most Misunderstood Market*, PublicAffairs.
[32] Slattery, P., Saeri, A. K., and Bragge, P., 2020, "Research Co-Design in Health: A Rapid Overview of Reviews," Health Res. Policy Syst., **18**(1), p. 17.
[33] Bobrow, D. G., Kaplan, R. M., Kay, M., Norman, D. A., Thompson, H., and Winograd, T., 1977, "GUS, a Frame-Driven Dialog System," Artif. Intell., **8**(2), pp. 155–173.
[34] Klemmer, S. R., Sinha, A. K., Chen, J., Landay, J. A., Aboobaker, N., and Wang, A., 2000, "Suede: A Wizard of Oz Prototyping Tool for Speech User Interfaces," *Proceedings of the 13th Annual ACM Symposium on User Interface Software and Technology*, Association for Computing Machinery, New York, NY, USA, pp. 1–10.
[35] Reid, T. N., MacDonald, E. F., and Du, P., 2013, "Impact of Product Design Representation on Customer Judgment," J. Mech. Des., **135**(9).
[36] Macomber, B., and Yang, M., 2012, "The Role of Sketch Finish and Style in User Responses to Early Stage Design Concepts," American Society of Mechanical Engineers Digital Collection, pp. 567–576.