

Tyler Rist completed his Bachelor of Science degree in Biomedical Engineering with minors in Biology and Chemistry. He graduated *summa cum laude* with University Honors with Thesis. Tyler received the Cecil C. Humphreys Presidential Scholarship and the Helen Hardin Honors Non-Resident Honors Student Award. He was also an Emerging Leader Scholar and played on the University of Memphis Men's Soccer Team for 4 years. Tyler is currently a medical student at the University of Tennessee Health Science Center in Memphis and will be pursuing a residency position in Otolaryngology after graduating from medical school in May 2019.

This article originated from an Honors thesis project completed by a team of University of Memphis undergraduate students in the departments of Biomedical Engineering (Tyler Rist) and Mechanical Engineering (Cody Bateman, Joel Berreta, John Flores, Jeremy Galloway, and Micah Kassner). Tyler Rist served as the liaison between the project team and the client. He also authored the article presented here with the mentorship of Dr. Joel Bumgardner.

**Tyler Rist*, Dr. Joel Bumgardner*, Cody Bateman#,
Joel Berretta#, John Flores#, Jeremy Galloway#,
Micah Kassner#, Dr. Hsiang Lin#, Dr. Teong Tan#,
and Dr. Ruth Mulvany^**

Lift Walker: Developing an Inexpensive and Lightweight Stand-
Assist Device

Faculty Sponsor
Dr. Joel Bumgardner

*University of Memphis Biomedical Engineering

#University of Memphis Mechanical Engineering

^University of Tennessee Health Science Center

Abstract

The growing senior population (2014 United States Census, 2014) and the documented importance of mobility and transferring in the United States (Desai, Lentzner, & Weeks, 2000) highlight the need for assistive technologies. Specifically, there is a need for inexpensive powered stand-assist technology that can be easily used in a home environment. This project explored the feasibility of developing inexpensive and lightweight powered stand-assist technology by building a device for an elderly man of the Memphis community. The device was less expensive than most commercially available powered devices and weighed approximately 80 pounds (36.3 kg). The device was able to lift the client, but the size and operation of the device made it difficult to use and maneuver in home. Follow-up analysis suggests that with reduction in size/dimensions of the device and improved instructional training for proper use, a less expensive household stand-assist device is possible.

Introduction

Activities of daily living (ADLs) are the “basic tasks of everyday life” (Wiener, Hanley, Clark, & Nostrand, 1990). One of the six main ADLs is transferring, which is defined as moving “in and out of bed independently” and “in and out of chair independently (may or may not be using mechanical supports)” (Katz, Ford, Moskowitz, Jackson, & Jaffe, 1963). Among older adults (70 years of age or older), it was estimated that almost 2.5 million have difficulty transferring (Desai, Lentzner, & Weeks, 2000). This transferring ability and the overall mobility of an individual is often studied in the elderly population due to its close association with a loss of independence (Parker & Thorslund, 2007), increased cost of care (Wiener et al., 1990), increased falls and injuries (Baumgartner, Garry, Romero, Vellas, & Wayne, 1997), and a decline in overall health (Wiener et al., 1990).

An example of a condition that often leads to a loss of mobility and difficulty in performing other ADLs is peripheral neuropathy. According to the National Institutes of Health, approximately 20 million people in the United States of America have peripheral neuropathy. Peripheral neuropathy is caused by damage to the peripheral nervous system. The condition has over 100 different varieties and a wide array of symptoms that include motor nerve damage with associated muscle weakness especially in arms and legs, sensory nerve damage that interferes with the ability to touch or feel pain, and autonomic nerve damage that can disrupt involuntary bodily functions such as sweating or bladder control. The peripheral nervous system can often be damaged by a sudden or prolonged trauma, endocrine conditions such as diabetes, autoimmune diseases such as lupus or rheumatoid arthritis, cancers, benign neurological tumors, certain infections like AIDS or Lyme disease, and toxins from chemicals or alcohol. In many cases, the onset of the condition cannot be determined (Peripheral Neuropathy Fact Sheet, 2015). This loss of sensation and accompanying problems like muscle weakness, especially in lower extremities, can lead to difficulty with transferring and mobility activities such as walking, balancing, and standing up.

Many older adults with such mobility impairments employ assistive devices to aid in daily activities and retain independence. In 2000, it was reported that over 6.8 million people in America used some kind of mobility assistive device (i.e., wheelchair, walker, cane, etc.) and older

adults make up the vast majority of consumers who utilize these assistive devices (Kaye, Kang, & LaPlante, 2000). Furthermore, the elderly population (ages 65+) in the United States will more than double between the years 2015 and 2060 according to 2014 US Census data (2014 United States Census). These data clearly show the growing need for assistive technology to compensate for the rapid aging of the United States' population.

A specific type of assistive device that targets mobility impairments and transferring issues is known as a stand-assist device. This type of device aids a person to move from a sitting or supine position to an upright, standing position and vice versa. These devices help people overcome the large biomechanical stresses on the lower extremities required to move from a sitting to standing position. Individuals who cannot easily make this transition are mobility-impaired because they are often stranded in a sitting position. Currently, there are stand-assist devices on the market. The lift-like devices that are intended for clinical settings are generally too large and heavy-duty for use in a home environment and also can be a serious financial burden to many families. The market price of many of the other powered stand-assist devices that can be independently used without assistance generally cost from \$2,500 to upwards of \$20,000 US dollars (e.g. Lumex® Easy Lift Sit-to-Stand Device model LF2020 (market price at \$2,660.00 US dollars); the Easy Walking Inc. Adult Up n' Go® device model 100-10-000M (market price at \$2,650.00 US dollars); the Joerns-Hoyer® Ascend Stand Assist Lift (market price at \$6,460.10 US dollars); and the more intensive Tek Robotic Mobilization Device® (market price at \$18,000 US dollars). Stand-assist devices that are less expensive than \$2,500 often do not provide the power or automation required in many situations.

This study was initiated when an 81-year old man from the Memphis community approached the Biomedical Engineering department at the University of Memphis for help with his mobility and transferring issues. He reported having peripheral neuropathy and intermittent episodes of sensory loss and weakness that would leave his lower extremities unusable. The onset of his condition was unknown. His wife did not have the physical ability to help him, so he was often stranded in his chair or bed. He expressed a desire for a stand-assist device that easily fit in his house while being relatively inexpensive. His concern with the current

technology on the market is that devices are “prohibitively expensive and overly-heavy duty.” His primary desire was for a device to help him stand, but also that could be used as a walker around the house. He lived in a one-story house with level floors.

The goal of this project was to design and construct a lightweight and inexpensive stand-assist device for the client who weighted 250 pounds (113.4 kg) and was 70 inches (177.8 cm) tall to use in his home. The following criteria were established to guide the subsequent design and manufacturing process:

The device will:

- Safely lift a 250-pound (113.4 kg) client from a sitting to standing position.
- Be used independently without any assistance.
- Weigh less than 100 pounds (45.4 kg).
- Cost less than the market price of many of the comparable commercial offerings.
- Be mobile so that it can be used as both a lifting mechanism and a pseudo-walker.

Materials and Methods

Design considerations were based on input from the client, his family, a physical therapist, and review of several different currently available stand-assist devices. The design involved a mechanism for lifting the client from the buttocks and lower back region. This design took into account that the client still had ample upper body strength without any complaints of weakness and avoided issues associated with lifting from the underarm region, which may damage vital neurovascular tissues required for upper extremity functions. The design also included a linear actuator-pulley system to lift or lower the client. The actuator-pulley system was designed to be operated by the user with a simple switch. The frame was designed to be made out of aluminum to provide a lightweight and sturdy structure and to mimic a walker with wheels so that it could be easily maneuvered around the client’s house.

The size of the device was determined by measurements made in the client’s house along with force and moment calculations that were performed to ensure the safety of the client. Tipping was one of the main

safety concerns with this device. Using the given weight of the client and results from anthropometry studies to obtain average sizes of different body parts, free-body diagrams were developed to determine the optimal height and length of the device to lower the risk of tipping. Finding the optimal dimensions for the device was a process that took into consideration several different characteristics that had to be balanced. If the device was too tall, the moment exerted on the vertical supports became too large. If the device was too short, the lifting mechanism would be pulling the client in a horizontal direction and not lifting in the desired vertical direction. The optimum value for the vertical support columns was determined to be 48.0 inches (121.9 cm) tall. Again, the process of finding the size of the horizontal supports was also a balancing act. If the lower horizontal supports were too long, it would interfere with the mobility of the device. If the lower horizontal supports were too short, the risk for tipping increased. The optimum value for the lower horizontal supports was determined to be 34.7 inches (88.1 cm). This value was increased to 36.0 inches (91.4 cm) for simplicity's sake. Calculations were then performed based on the force assumptions and the optimal size of the device to determine how thick the aluminum bars needed to be to withstand the calculated forces and movements. The best size for the vertical column support bars was determined to be 1.5 inches (3.8 cm) wide and 0.5 inches (1.3 cm) thick. The best size for the lower horizontal supports was determined to be 1.0 inches (2.5 cm) wide and 1.0 inches (2.5 cm) thick.

A local sheet metal worker from Standard Sheet Metal Works, LLC (Memphis, TN) performed much of the aluminum welding for the main structure. The machine shop in the engineering department of the University of Memphis helped perform much of the smaller metal tooling. The initial meeting with the client occurred in December 2013, and the device was completed and delivered in May 2014. Final cost of parts and labor before tax and shipping and handling was \$2,054.46 US dollars.

A survey was given to the client in October 2014 to evaluate the usability of the device and client satisfaction. The survey consisted of 16 different questions. The survey was retrieved after 4 months of use by the client. The questions included:

- How often do you use the device?
- Can you successfully use the device independently or do you require assistance?

- Are you able to roll the device around and use it similar to a walker?
- In what situations is the device most helpful? Least helpful?
- Does the device accommodate you in all areas of your house? (i.e. bathroom, bedroom, living room, kitchen, etc.)
- When using the device, do you feel safe and secure? If not, what parts of the device make you feel unsafe?
- Are the frame of the device and the attached parts durable? Does any part of the device feel like it may be breaking?
- When operating the device, do you use every part? (i.e. kneepad, foot steps, handles, harness, lift button, ect.)
- Does the size and shape of the device comfortably accommodate your body? If not, what parts of the device seem to be interfering or causing problems?
- In your personal opinion, what changes would you make to the device to make it most helpful to you?

Results

The constructed and assembled device is shown in Figure 1. The main frame was assembled out of solid bars of aluminum T-6 6061 alloy, and hollow tubes of aluminum T-6 6061 alloy were used to make the extended handlebars (Figure 1C-vii). The overall dimensions of the frame were 53 inches tall, 22 inches wide, and 42 inches long, (134.6 cm tall, 55.9 cm wide, and 106.7 cm long) and the whole device weighed approximately 80 pounds (36.3 kg). These dimensions were specifically crafted based on measurements of his house and safety calculations.

Two 400-pound (1,779.3 Newtons) rated linear actuators (Figure 1B-v) were attached to the either side of the bottom front of the aluminum frame. Both of the actuators were powered by one 12-volt rechargeable battery (Figure 1B-vi) that was mounted at the bottom front of the aluminum frame between the two actuators. Each actuator was attached to coated industrial grade steel wire (Figure 1A-iii) that ran up through the top of the aluminum frame and around a pulley system (Figure 1B-iv). The wires then attached to either side of a lumbar lifting harness with metal quick release clips (Figure 1A-iii). This system made up the lifting mechanism of the device.

A bidirectional switch (Figure 1C-viii) was installed into the right handle bar to control the actuators and lifting mechanism. The bidirection-

al ability of the switch allowed the device to be used to both lift the client from a sitting to a standing position and lower the client in the opposite direction. The actuators only move when the switch is activated, so the movement can be stopped at any time during the lifting or lowering process.

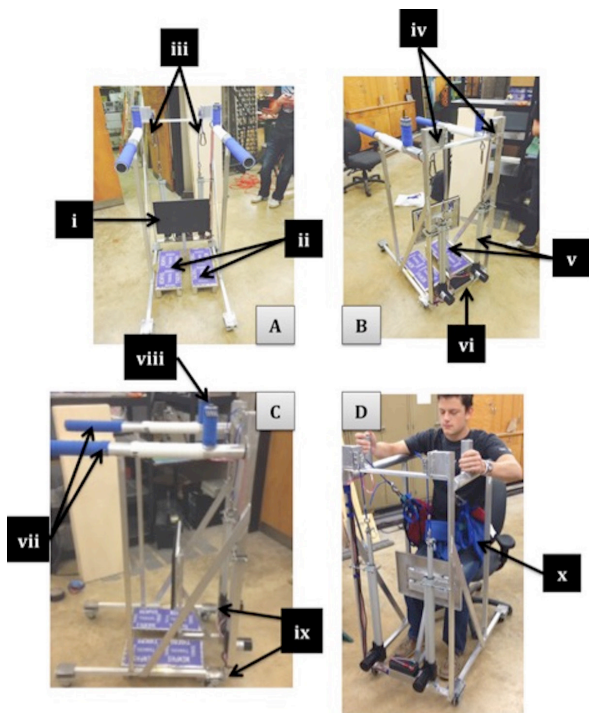


Figure 1. 1A, 1B, 1C, and 1D give an overview of the final design of the lift-walker. 1A, 1B, and 1C highlight different parts of the device without an individual using the device, where 1D shows an example of how the individual is intended to fit in the device. i – Aluminum kneepad with foam padding on surface; ii – Two steel footpads with grip tape on top; iii – Two easy release clips attached to industrial strength steel wire; iv – Two steel pulleys at top of device. Wire in iii for the lifting mechanism runs over the top of these; v – Two 400-pound (1,779.3 Newton) rated linear actuators (Firgelli Automations™); vi – 12-volt battery (Firgelli Automations™); vii – Hollow aluminum tubing extended handlebars; viii – Bidirectional switch (Firgelli Automations™); ix – Two front wheels with locking mechanisms (Albion Industries™); x – Lumbar Harness (Chattanooga Group™).

A wheel was attached to each bottom corner of the aluminum frame. The two front wheels (Figure 1C-ix) had locking mechanisms that were used to increase stability. The use of the long handlebars (Figure 1C-vii) at the top of the device along with the wheels gave the device the ability to move around on hard surfaces easily and be used as a pseudo-walker.

The harness (Figure 1D-x, and Figure 2) lifting mechanism had the ability to lift the user about 18 inches (45.7 cm) higher than a full sitting position. At that point, the user would be able to use the remaining amount of his leg strength combined with his upper body strength to lift into a full standing position. The aluminum tube handlebars (Figure 1C-vii) were designed to be long so the client could use them to lift up on and also to provide extra stability when trying to transfer from the device to a common walker. The shape of the whole aluminum frame was designed so that it could fit around places in the home where the client would commonly be sitting like a recliner or toilet.

The device was designed so that it could be easily operated without any assistance. Figure 2 gives an overview of the operational movement of the stand-assist device. The instructions for operation of the device were:

1. Pull the device around the structure you are sitting on.
2. Unhook the lumbar harness and secure it around your lower back and gluteus muscles.
3. Attach the two quick-release clips to the lumbar harness.
4. Place your feet and knees against the footpads and kneepads respectively.
5. Once secure, push the switch in the up direction and let the actuators pull the harness upward until it stops.
6. Grip the handlebars and use your upper body strength to fully stand up.
7. Once standing, the device can be used as a walker itself, or a support system to transfer to a typical walker.
8. To sit down, lower back down into a sitting position by reversing these steps.

The user survey was retrieved from the client after 4 months of use. A follow-up visit with the client and examination of responses from the survey revealed that the client had attempted to use the device only

two to three times at most. The survey and follow-up visit revealed that the client had many issues with the design and operation of the device. The major criticisms included:

- The device was considered too big and bulky.
- The harness slid up the client's back when attempting to lift.
- The device did not fit into certain rooms.
- The turning radius prevented turning the device in a hallway.
- Certain pieces such as the footpads and kneepad were not useful.

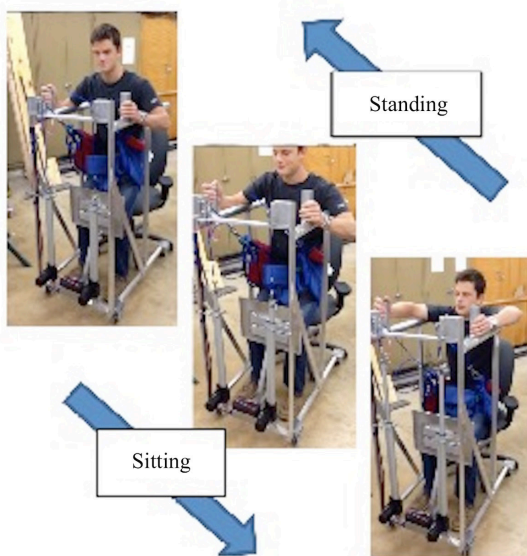


Figure 2. Series of photographs demonstrating how device lifts individual from a seated position to standing and back to sitting. The picture on the right shows the individual seated in a chair with the harness secured around the lower back and gluteus region. The picture on the far left shows the position of the user when the device is fully extended in the lifting direction. In all the pictures, it can be seen how the user is using the bidirectional switch with his right hand.

During the follow-up visit, it was discovered that the client had disassembled part of the device. He had used some of the pieces from the device to build an example of some of the changes that he wanted to make. Despite the clear medical consequences that had been explained to him,

the client was still fixated on making a device that would lift him from under the arms.

Discussion

In this project, a powered stand-assist device was custom designed, constructed and evaluated to lift a 250-pound (113.4 kg) client safely from a seated position and vice versa. The device was constructed to also double as a walker with the use of the extended handlebars and four wheels. At only approximately 80-pounds (36.3 kg), the final device was within the 100-pound (45.4 kg) goal that was set. It was considered lightweight because it could be easily controlled and maneuvered by one individual. The dimensions of the device were designed to fit within certain areas of the client's house. The total cost of the device without taxes and shipping was \$2054.46 US dollars. The device was less expensive than the market price of most powered devices and more expensive than most general non-powered devices. The device was given as a gift to the client, so no financial burden was put on the client or his family. Results from the user survey, though, yielded several issues for why the device was not well-used by the client.

First, the client complained that the harness did not stay in one spot and slid up the back during lifting operation. This was due to improper placement and use of the harness by the client. The improper placement of the harness was attributed to limited coaching and instruction by the design team when the constructed device was delivered. The device was delivered and demonstrated to the client in one short visit. Unfortunately, observations of the client using the harness were not made and thus any difficulties the client may have had in using the device were not identified. Further, there was no follow-up from the design team, family members or health professionals after delivery. With extended instruction and coaching time by the team members and engagement of family and health professionals, this problem may have been addressed. Additionally, because of the weakness in legs of the client due to his medical condition, correct positioning of the harness may have resulted in an additional challenge in proper use of the harness. This issue will need to be addressed in future re-design and use assessments since this was not assessed in this project.

Next, the client expressed dissatisfaction with the size of the device which limited access and use in some areas in the home. While the device

was designed to operate in spaces initially identified by client, the results of the survey and information provided by client indicated that the client wanted the device to be able to be used more widely in the home. Not having a clear understanding of the client's medical condition, prognosis and how functional needs would vary led to the design being too focused on limited performance criteria. A physical therapist was consulted on the design, but the therapist was not specifically involved in the client's care and living environment. Involving a medical professional who had more direct knowledge of the client's medical condition, prognosis, and living environment would likely be useful in enhancing the design to better meet and anticipate the client's current and future needs, as well as teaching him how to successfully utilize the assistive technology to improve, or maintain his overall functional mobility in his home.

Third, the client did not attempt to use the device more than a few times since it did not perform as he had expected or imagined. Unfortunately, the client did not contact the design team with his issues. Instead, the client attempted to modify the device himself and to have the device lift him from his underarms. The reasons he tried to modify the device this way was due to an incorrect assumption that this would be a better way to lift an individual, that the harness could be more easily adapted to fit and would be easier to put on and take off. The design team explained to him again the dangers of lifting from the arms, and why lifting from the buttocks and lower back region was better. The client did not seem to want to accept this explanation. It is not clear if this was due to some issue with the client's understanding, or unwillingness to listen to the student design team. Again, involvement of a clinician directly involved in client's care may have improved client's willingness to understand that lifting from the underarms was not appropriate.

This device was a first generation design and constructed in a relatively short period of time. There was some degree of over-engineering done on this device to ensure the safety of the device. Areas of improvement that were identified after construction and use of the device by the client include:

- Lowering the extended handlebars six or more inches to better accommodate the arms when sitting.
- Streamlining the frame of the device by:
 - Using smaller gauge and hollow aluminum bars and tubes.

- Making the wheel fittings less bulky so the device could better fit around and under certain chairs.
- Reducing the dimensions, particularly the height and length to reduce overall size and bulk of the device and improve maneuverability.
- Evaluating the size and placement of the harness. A larger harness that covered more area of the back may provide more upper back support making the client easier to lift. This increased support and coverage could possibly reduce the chance that the harness would slip to the wrong area.
- Evaluating how the client would actually put on and take off the harness to ensure ease of use.
- Changing the switch location so that it can be better accessed from any of the many different situations in which the device is designed to be used.
- Involving clinicians with knowledge of client's condition, prognosis and living arrangements to help anticipate how device will be used, and in providing instruction and training on how to use the device.

The device was retrieved from client for re-design and construction. However, follow-up with client's family indicated that the client was no longer in a position to use the device.

Conclusion

A new stand-assist device was designed and constructed for use in a home environment. The device had the capability of lifting a 250-pound (113.4 kg) man from a sitting position without the assistance of other individuals. The final cost of this device was less than the market cost of many comparable powered devices on the market. The device was also lightweight and mobile enough to be easily handled and controlled by one individual. However, the device did not function well for client in his home environment. The main short-comings were the overall dimensions and weight of the device made it too bulky to easily move throughout the home, inability to properly use and wear the harness for correct operation, and lack of proper instruction and follow-up on device operation. This device should be re-designed to be more lightweight and to have smaller dimensions by using hollow aluminum bars, tubes, and reducing the height of the handle-bars. The harness for lifting the client should also be re-designed for an improved fit, and to make it easier for the client to put on. Additionally,

good instruction, coaching, and follow-up on proper use of device needs to be undertaken. Involvement of a physical or occupational therapist in client evaluation, education, and training with the device would also likely improve future outcomes.

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Figure Legends

Figure 1: 1A, 1B, 1C, and 1D give an overview of the final design of the lift-walker. 1A, 1B, and 1C highlight different parts of the device without an individual using the device, where 1D shows an example of how the individual is intended to fit in the device. Each part labeled with a roman numeral is described in detail in the results section of the paper: i - Aluminum kneepad with foam padding on surface; ii – Two steel footpads with grip tape on top; iii – Two easy release clips attached to industrial strength steel wire; iv – Two steel pulleys at top of device. Wire in iii for the lifting mechanism runs over the top of these.; v – Two 400-pound (1,779.3 Newton) rated linear actuators (Firgelli Automations™); vi – 12-volt battery (Firgelli Automations™); vii – Hollow aluminum tubing extended handlebars; viii – Bidirectional switch (Firgelli Automations™); ix – Two front wheels with locking mechanisms (Albion Industries™); x – Lumbar Harness (Chattanooga Group™)

Figure 3: Series of photographs demonstrating how device lifts individual from a seated position to standing and back to sitting. The picture on the right shows the individual seated in a chair with the harness secured around the lower back and gluteus region. The picture on the far left shows the position of the user when the device is fully extended in the lifting direction. In all the pictures, it can be seen how the user is using the bidirectional switch with his right hand.