Weight carrying assistive robots (WeCAR) for physical access and transportation: needs, issues, and user opinions

Hongwu Wang[1], Raghuveer Chandrashekhar[1]

[1]University of Florida

INTRODUCTION

Mobility-vulnerable populations, i.e., individuals lacking the ability and/or resources to be mobile due to permanent or temporary factors, include many people with disabilities (PWDs). The autonomy to be mobile independently allows greater participation in community and family activities, job opportunities, and access to healthcare and education. However, transportation has been, and remains, among the most challenging barriers to full inclusion, self-sufficiency, and independence for PWDs, often placing a burden on paid or unpaid caregivers [1]. While tremendous efforts, including the emergence of self-driving vehicles, implementation of accessible features and transportation systems have been made, walking between home and bus stops [2-4], traversing vehicle boarding and disembarking, and ensuring the safety of passengers and their personal belongings are well-known issues and sources of injury for PWDs [5-7]. It gets more challenging and dangerous when PWDs carry weight, such as medical equipment (i.e., oxygen cylinders, ventilators), suitcases, and shopping bags. Holding asymmetrical loads is common during many daily and occupational activities; however, depending on the load mass, it may alter postural stability and lead to falls [8]. Different solutions for PWDs carrying weight, such as mobile carts, backpack or fanny packs, smart home technologies, autonomous delivery robots (ADR), and weight carrying assistive robots (WeCAR), were developed to support PWDs. However, the challenges and issues PWDs encountered have yet to be addressed fully with existing solutions. To our knowledge, no study has comprehensively assessed the 5A's (Availability, Accessibility, Acceptability, Affordability, and Adaptability as defined in Table 1) of those solutions. While weight carrying assistive robots (WeCAR) are emerging, how PWDs perceive these technologies are not yet understood. This paper aimed to gather information about the current technology solutions for carrying weight for PWDs during physical access and transportation, assess those solutions in 5A's, and collect user opinions on a commercially available weight carrying robot.

Table 1. The description of 5A's for technology and services to support weight carrying for PWDs [9, 10]

Specific A's	Description
Availability	Technology or service is available when needed (e.g., technology is at hand, evenings and/or weekends).
Acceptability	Deals with standards relating to conditions such as appearance (e.g., appropriate across age and disabilities); safety (e.g., not harmful to PWDs, their pets, and surroundings); and user friendliness (e.g., tech/service providers are courteous and helpful).
Accessibility	Technology or service can be reached and used (e.g., different items can be stored; interfaces are easily understood and operated; items can be loaded/unloaded across disabilities).
Affordability	Deals with costs (e.g., fees are affordable; fees are comparable to or less than hiring a personal assistant; vouchers or coupons help defray out-of-pocket expenses).
Adaptability	Technology or service can be modified or adjusted to meet specific needs (e.g., wheelchair can be accommodated; trip chaining ((several stops in one trip)) is possible).

METHODS

We evaluated the current industry and research in providing weight carrying support for PWDs and their 5A's. We reviewed lower and high-tech technologies and services available. This included the collection of brochures, technical specifications and diagrams, and descriptions of any user interfaces and controls. We reviewed the last ten years of research published on ADR and WeCAR designed specifically for PWDs and assessed their 5A's. We then demonstrated a commercially available weight carrying robot (Gita robot, as shown in Figure 1) to nine community dwelling older adults with different impairments and two physical therapists for a senior living community via a focus group study. We collected their opinions regarding the potential usefulness of the robot and the features/functions they would like to include in the robot. Thematic analysis was used to explore and identify themes regarding the use cases and the needs of the Gita robot.

Figure 1. The Gita robot

RESULTS

The state-of-the-art technology to support PWDs carrying items and how each technology meets the 5A's was summarized in Table 2. The low techs are more affordable and available but less accessible, adaptable, and acceptable for PWDs, as they could cause difficulty navigating, safety concerns in crowded conditions, problems with boarding and disembarking, or strain injuries and pain. The high techs, such as robots and delivery services, are more adaptable and accessible but less affordable and acceptable as PWDs were not included during the design and development.

Table 2. The 5A's of current related techniques for PWDs carrying their items for PAT

Type of PWDs	5A's	Cane/ walker	Service animals	Backpack or fanny pack	Rolling shopping cart	Assistive Robot and manipulator	Delivery service	Personal assistance
Visual impairment	A1	☺	😐	☺	☺	😐	😐	😐
	A2	😐	☺	😐	😐	😐	😐	☺
	A3	☺	☺	☺	☺	😐	😐	😐
	A4	☺	😐	☺	☺	😐	😐	😐
	A5	😐	😐	😐	😐	☺	😐	☺
Hard of hearing or Deaf	A1	☺	☹	☺	☺	😐	😐	😐
	A2	☹	☹	😐	😐	😐	😐	😐
	A3	☺	☹	☺	☺	😐	😐	😐
	A4	☺	☹	☺	☺	☹	😐	☹
	A5	😐	☹	😐	😐	☺	😐	☺
Physical disability	A1	😐	😐	😐	😐	😐	😐	😐
	A2	😐	😐	😐	😐	😐	😐	☺
	A3	😐	😐	😐	😐	😐	😐	☺
	A4	☺	☹	☺	☺	☹	😐	☹
	A5	☹	😐	☹	☹	😐	😐	😐
Mild cognitive impairment	A1	☺	😐	☺	☺	😐	☺	😐
	A2	☹	😐	😐	😐	😐	😐	😐
	A3	☺	😐	😐	😐	😐	😐	😐
	A4	☺	😐	☺	☺	☹	😐	☹
	A5	☹	😐	☹	☹	😐	☹	😐

Keys: A1: availability; A2: acceptability; A3: accessibility; A4: affordability; A5: adaptability. Meanings of the symbol: Smile face ☺ (J): the technology meets the specific A in large. Neutral face 😐 (K): the technology meets the specific A but has limitations. For example, not available for all; acceptable but may have safety concerns, cause strain or pain; not accessible for all; not affordable for all; or limited adaptability. Frown face ☹ (L): the technology fails to meet the specific A's in large.

When specific weight carrying robots were examined, ADRs were gaining popularity due to their potential to revolutionize delivery systems and their wide applications in various sectors, such as retail, hospitality, and healthcare [11, 12]. ADRs include sensors and navigation technologies that enable them to travel on roads and/or sidewalks without a human operator. Although several commercial ADRs [13-17] are available, they are not readily usable for PWDs as they are not designed to interact directly with PWDs. For example, most ADRs do not have accessible features as they were developed mainly for delivering food and grocery between different locations. They may even bring obstacles to PWDs. The University of Pittsburgh suspended the Starship ADR as it got wheelchair user accessible challenges and safety hazards [18]. While the Gita robot [19] is designed to help people carry personal items, its application to the 5A's for PWDs is limited and untested. Labrador robots [20] were designed to move large loads and keep smaller items within reach at home. There were some reported user cases from people with Multiple Sclerosis and stroke, but their availability, acceptability, and usability were largely scarce. The 5A's of ADRs and two WeCARs were summarized in Table 3.

Table 3. Existing Commercial Weight-carrying Robots and their 5A's for PWDs

Product (year)	Robot Key Specs	A1	A2	A3	A4	A5
Starship Robot [13] (2015) Autonomous consumer delivery robot	6 wheels. Dimensions (in.): 27×22×22. Weight: 50 lb. Payload: 22 lb. Speed: 3.7 mph Distance: 3–4 miles Sensors: Stereo and TOF cameras, distance sensors, radar	Unavailable for personal use. Offering On-demand package delivery	NA	No accessible features for PWDs. Streets and sidewalks.	$5,500 for robot only	Not adaptable to PWDs
Serve robot [14] (2019) Autonomous food delivery	4 wheels. Dimensions (in): 31×26×41. Weight: 161 lb. Payload: 50 lb. Speed: 6 mph	Unavailable for personal use. Business use such as Uber and 7-Eleven.	NA	No accessible features for PWDs. Sidewalks only.	NA	Not adaptable to PWDs

	Distance: 30 miles Sensors: Lidar					
DeliRo [15] (2020) Autonomous delivery bot	4 wheels. Dimensions (in.): 20×20×16. Weight: 161 lb. Payload: 110 lb. Speed: 3.7 mph Distance: NA Sensors: cameras and laser	Unavailable for personal use. Not available for personal usage	NA	No accessible features for PWDs. Streets and sidewalks.	NA	Not adaptable to PWDs
KiwiBot [16] (2017) Autonomous food delivery	4 wheels. Dimensions (in.): 22×17×22. Weight: 161 lb. Payload: NA Speed: 1.5 mph Distance: NA Sensors: GPS, 6 front cameras, a rear wide-angle 180° camera, laser distance sensor, and spotlights	Unavailable for personal use. Not available for personal usage	NA	No accessible features for PWDs. Streets and sidewalks.	NA	Not adaptable to PWDs
Amazon Scout [17] (2019) Autonomous delivery robot	6 wheels. Dimensions (in.): 30×24×29. Weight: 100 lb. Payload: 50 lb. Speed: 15 mph Distance: 3–4 miles Sensors: cameras and sensors	Unavailable for personal use. Not available for personal usage. Amazon only	NA	No accessible features for PWDs. Sidewalks only.	NA	Not adaptable to PWDs
Gita [19] (2019) Human-following cargo robot	2 wheels. Dimensions (in.): 30×24×29. Weight: 50 lb. Payload: 40 lb. Speed: 6 mph Distance: 4 hr. run time per charge Sensors: Depth and color sensors and lidar	Can be purchased directly from the manufacturer.	NA	Physical buttons, MyGita app. The robot follows a human walker.	$3,475 for GitaPlus $1,850–$2,175 for GitaMini	Not adaptable to PWDs
Labrador [20] (2023) Autonomous indoor carrying robot	4 wheels. Dimensions (in.): 30×28×23. Weight: 50 lb. Payload: 25 lb. Speed: NA Distance: NA Sensors: Depth, load, and cliff sensors	Can be purchased by the end of 2023	No data yet	Physical buttons, tablet interface (Echo Show) Indoor only	$299 /month (single unit) $500 /month (group-care unit)	Adaptable height and Labrador trays

Keys: A1: availability; A2: acceptability; A3: accessibility; A4: affordability; A5: adaptability; NA: not available

The focus group was conducted at the resident activity center in a senior living community. Nine senior adults (three with hard of hearing and deaf, three with mobility impairment, two with visual impairment, and one with mild cognitive impairment) and two physical therapists joined the demonstration and discussion. The authors demonstrated the existing features and function of the Gita robot and how to load, unload, and set up the robot. The participants were allowed to ask questions and try the robot during the demonstration. The attendees were excited to learn about the Gita robot and its various applications. They suggested many ideas to improve the device and make it more useful for individuals with different impairments. Three themes were identified from the discussions: 1) physical robot design, where the participants loved the overall appearance and load capacity but suggested a modular design (to allow different users to carry different objects, such as garden tools, books, cakes, and to enable different users to benefit from different features and functions) with a smaller footprint (to go through narrow space and under tables). 2) safety of the robot, where the attendants expressed their concerns about the items being transported and the safety of the user and individuals in their home and community. 3) additional use cases where all participants wanted features such as health metric monitoring (synchronized with other wearables and devices), fall detection (as the robot follows the user, it could detect the falls and inform 911 or family members or caregivers), and sitting on the robot for taking rest. A few participants wanted to modify the robot to be fully autonomous instead of following a human. Individuals with hard of hearing raised concerns about how to communicate with the robot (the robot has a built-in speaker but is not used for talking with a user).

DISCUSSION AND CONCLUSIONS

Public transportation use is associated with multiple benefits for PWDs, such as increased physical activity, improved access to services and employment for PWDs, reduced transportation and healthcare costs, lower carbon emissions, better mental health, and greater transportation safety. However, PWDs are experiencing challenges to fully benefit from the current, even the future public transportation as technologies such as self-driving evolve. It is recognized by the literature and voices of PWDs and their assistants that carrying weight is one of those challenges that limit not only their access to public transportation but also physical access and mobility. Findings from this paper suggested that existing solutions, including low and high technology and services, were not addressing the issues in 5A's. The application of robotics and automation can potentially improve opportunities for an equitable transportation chain that meets the needs of the diversity of travelers with disabilities. Our focus group results indicated the enthusiasm of PWDs on WeCAR and provided insights for the further development of WeCARs to meet the 5A's. Additionally, it is crucial to include the PWDs in the technology design and development.

REFERENCES

[1] American Association of Retired Persons. Caregiving in the U.S. AARP Public Policy Institute [Internet]. 2015. Available from: https://www.aarp.org/content/dam/aarp/ppi/2015/caregiving-in-the-united-states-2015-report-revised.pdf.

[2] Stanesby O, Morse M, Magill L, Ball K, Blizzard L, Harpur S, et al. Characteristics Associated with Willingness to Walk Further Than Necessary to the Bus Stop: Insights for Public Transport-Related Physical Activity. Journal of Transport & Health. 2021;22:101139.

[3] Bezyak JL, Sabella SA, Gattis RH. Public Transportation: An Investigation of Barriers for People with Disabilities. Journal of Disability Policy Studies. 2017;28(1):52-60

[4] Hess DB. Walking to the Bus: Perceived Versus Actual Walking Distance to Bus Stops for Older Adults. Transportation. 2012;39(2):247-66

[5] Frost KL, Bertocci G, Sison S. Ingress/Egress Incidents Involving Wheelchair Users in a Fixed-Route Public Transit Environment. Journal of Public Transportation. 2010;13(4):3.

[6] Frost KL, Bertocci G, Smalley C. Ramp-Related Incidents Involving Wheeled Mobility Device Users During Transit Bus Boarding/Alighting. Archives of physical medicine and rehabilitation. 2015;96(5):928-33.

[7] Haubert LL, Mulroy SJ, Hatchett PE, Eberly VJ, Maneekobkunwong S, Gronley JK, et al. Car Transfer and Wheelchair Loading Techniques in Independent Drivers with Paraplegia. Frontiers in bioengineering and biotechnology. 2015;3:139.

[8] Hill MW, Price MJ. Carrying Heavy Asymmetrical Loads Increases Postural Sway During Quiet Standing in Older Adults. Aging clinical and experimental research. 2017;30(9):1143-6.

[9] Senior Resource Alliance. Transportation Facts for Seniors 2.1 Senior Friendly Transportation: Beverly Foundation. Available from: http://seniorresourcealliance.org/wp-content/uploads/2012/04/seniorfriendlytrans2_1.pdf.

[10] Dabelko-Schoeny H, Maleku A, Cao Q, White K, Ozbilen B. "We Want to Go, but There Are No Options": Exploring Barriers and Facilitators of Transportation among Diverse Older Adults. Journal of Transport & Health. 2021;20:100994

[11] Figliozzi M, Jennings D. Autonomous Delivery Robots and their Potential Impacts on Urban Freight Esumption and Emissions. Transportation Research Procedia 2020;46:21–8. https://doi.org/10.1177/0361198119849398.

[12] Pani A, Mishra S, Golias M, Figliozzi M. Evaluating public acceptance of autonomous delivery robots during COVID-19 pandemic. Transportation Research Part D: Transport and Environment 2020;89:102600.

[13] Starship Technologies: Autonomous robot delivery. Starship Technologies: Autonomous Robot Delivery n.d. https://www.starship.xyz/ (accessed February 19, 2023).

[14] Serve Robotics. Serve Robotics n.d. https://www.serverobotics.com (accessed February 19, 2023).

[15] Delivery robot - DeliRo. Home Delivery Robot "DeliRo" / "DeliRo Truck" n.d. https://www.zmp.co.jp/products/lrb/deliro (accessed February 19, 2023).

[16] Kiwibot Delivery Service n.d. https://www.kiwibot.com/ (accessed February 19, 2023).

[17] Meet Scout. US About Amazon 2019. https://www.aboutamazon.com/news/transportation/meet-scout (accessed February 19, 2023).

[18] Martines J. Pitt suspends delivery robots after wheelchair user reports safety hazard. TribLIVECom 2019. https://triblive.com/local/pittsburgh-allegheny/pitt-suspends-delivery-robots-after-wheelchair-user-reports-safety-hazard/ (accessed February 20, 2023).

[19] Gita robots - Piaggio Fast Forward - Piaggio Fast Forward. Gita - Piaggio Fast Forward n.d. https://mygita.com/ (accessed February 19, 2023).

[20] Labrador Systems - A New Generation of Assistive Robots. Labrador Systems n.d. https://labradorsystems.com/ (accessed February 19, 2023).