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Clinical evaluation of Guido robotic walker

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Abstract—The Guido is a robotic walker that provides navigation and obstacle-avoidance assistance. Engineering tests have found that the device performs adequately and presents no hazard to the user. The performance of the Guido was compared with a low-tech mobility aid, the Assistive Mobility Device (AMD) developed at the Atlanta Department of Veterans Affairs Medical Center, in trials involving older adults with visual impairments. The purpose of this study was to determine whether the Guido could increase the safety and mobility of elderly visually impaired individuals in supervised care facilities. Subjects traversed an obstacle course with the Guido and the AMD. Completion time, obstacle/wall contacts, and reorientations were compared for both devices. No significant differences were found between the devices for any of the tests. The Guido did not perform better than the AMD during the trials. Revisions to the device as well as a change in subject requirements and testing protocol may produce different results.

Key words: clinical testing, mobility aid, navigation assistance, obstacle avoidance, older adults, rehabilitation, robotic walker, safety, visual impairment, walker.

INTRODUCTION

Recent studies have shown that people are living longer [1]. As the generation of baby boomers from the 1940s and 50s becomes older, the number of people 65 and over will be higher than ever before [2]. In 1997, the number of persons aged 65 and older who lived in nursing homes was approximately 1.5 million [3], and this number is predicted to rise to 3 million by 2030 [4]. Residents of nursing homes are generally frailer than seniors living in the community. They also tend to be older, have more cognitive impairments, and experience more serious falls [5]. Rubenstein et al. found that as many as 75 percent of nursing home residents fall annually [6].

Older adults are also more likely to have visual impairments. Changes in the visual system associated with aging include reduced visual acuity, reduced contrast sensitivity, reduced color discrimination, increased time taken to adapt to large and sudden changes in luminance, and increased sensitivity to glare [7]. Among adults aged 66 to 74, 13.2 percent report some form of visual impairment, and the percentage rises to 22 percent

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Abbreviations: AMD = Assistive Mobility Device, ANOVA = analysis of variance, ETA = electronic travel aid, ISO = International Organization for Standardization, PAMM = Personal Aid for Mobility and Monitoring, PWS = preferred walking speed, VA = Department of Veterans Affairs, VAMC = VA medical center.

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for adults aged 75 and over [8]. Among nursing home residents, visual impairment is even more common. A study in 1997 discovered that almost 30 percent of all nursing home residents had difficulty seeing, even with glasses, and almost 10 percent were severely limited or completely blind [4].

Among older adults, the strong correlation between reduced physical activity and functional decline is well established [9] and evidence exists that a program of regular walking may have a protective effect on fall prevention and postural stability [10]. Unfortunately, despite its positive influence on a variety of health outcomes (e.g., reduced risk of coronary heart disease, obesity, non-insulin-dependent diabetes mellitus, and osteoporosis; increased longevity; and lower rates of disability), physical activity is not part of the usual daily routine for more than one in five (22%) older adults in the community [11].

Originally constructed of wood and used during recuperation from hip fractures [12], the walker has evolved over the last 80 years to include an array of designs. These range from aluminum frames with or without wheels or glides to the increasingly popular collapsible three- or four-wheeled rollators made of metal and accessorized with brakes, seats, baskets, trays, and bags [13]. All these devices principally help individuals with mobility impairment move about their environment by providing a portable base of support that compensates for difficulties with balance, strength, endurance, and pain [14]. The most prevalent conditions necessitating use of mobility devices by the elderly living in the community include osteoarthrosis; cerebrovascular disease; orthopedic impairment of the lower limb, hip and/or pelvis, back or neck; senility; heart disease; and rheumatoid arthritis [15].

Walkers, including rollators, are used by 1.8 million community-residing Americans, 78 percent of whom are aged 65 or older. Elderly women who use walkers outnumber men by a ratio of nearly 2 to 1, with usage higher for Native Americans (9.2%) and African Americans (5.2%) than whites (4.5%). Those with family incomes below $10,000 are about 2.5 times more likely to use a walker than those with incomes of $35,000 or more. Those with lower incomes are also far more likely to report fair or poor health (64.0%) than their age-matched peers in the general population who use no mobility devices (22.6%). Approximately 20 percent of elderly walker users in the community need help from another person, need to be reminded to use their walker, or need to have someone close by when walking indoors [15]. In assisted living facilities, 30 percent of residents use walkers [16].

The Guido (Haptica, Inc; Boston, Massachusetts; http://www.haptica.com) (originally known as the PAM-AID) is a robotic walker that has been designed to provide navigation and mobility assistance to frail elderly individuals who are visually impaired [17] (**Figure 1**). The device was designed to help reduce the number of falls in supervised care facilities, as well as increase the independence and activity of seniors with visual impairments.

Investigators at the Human Engineering Research Laboratories performed both engineering and clinical

Figure 1.
Front view of Guido robotic walker.

evaluations of the Guido in order to determine whether the walker could improve the safety, efficiency, and activity of elderly visually impaired individuals in a supervised care facility. The first phase of testing (described in an earlier publication [18]) involved conducting safety and performance testing on the device. Customized tests were designed, drawing from both the International Organization for Standardization (ISO) standards for walkers [19] and the American National Standards Institute/Rehabilitation Engineering and Assistive Technology Society of North America wheelchair standards [20]. The Guido was run through a battery of tests to ensure that it performed in a safe and effective manner under various circumstances and conditions. Testing included sections on static stability; maximum range; maximum effective speed; obstacle climbing ability; climatic conditioning; power and control systems; and static, impact, and fatigue strength. Major results included—

- The Guido surpassed all ISO static stability requirements.
- The Guido is likely to meet a frail older adult's daily mobility needs on a single battery charge.
- The Guido's maximum effective speed is sufficient for the target user population.
- The Guido passed all of the climatic conditioning tests without any failures.
- The Guido was unable to negotiate a 12 mm-high obstacle, which was considered insufficient performance.
- Electronic failure should not present safety hazards to the user.
- The structural strength of the Guido satisfies all of the criteria for the static, impact, and fatigue testing.

Following the engineering evaluation, we conducted trials of the Guido with potential users (described in the following sections). Subjects were tested on a 36.6 m obstacle course using the Guido; the Assistive Mobility Device (AMD), designed at the Atlanta Department of Veterans Affairs (VA) Medical Center (VAMC); and their own device, if they used one.

RELATED RESEARCH

The use of electronic travel aids (ETAs) has been researched since the late 1940s as a form of assistance for visually impaired individuals. ETAs are devices that can help to transform environmental information that is normally relayed through vision into a form that can be transmitted through a different sensory modality [21]. Effective ETAs can help to provide environmental information not available from walking canes or guide dogs. They can detect and locate objects and provide information that allows the user to determine range, direction, and dimensions of the object. Many of the currently available devices pass information to the user through tones or vibrations. The user must then take the required corrective actions to avoid colliding with an object.

Robotic ETAs reduce the amount of cognitive load placed on the user. The robot interprets the sensory information and allows for detailed descriptions of the environment to be passed to the user. Corrective actions can then be performed by the robot before any collisions occur. Several ETAs based on walkers are currently in development. **Table 1** lists some of the assistive mobility devices currently under development, as well as their main features and target populations.

Researchers at the Massachusetts Institute of Technology have developed a prototype walking aid to assist the elderly who are either living independently or in assisted living facilities [22]. The Personal Aid for Mobility and Monitoring (PAMM) has omnidirectional drive wheels, locates itself by reading sign posts, detects and avoids obstacles, and measures the forces and torques on the handle to estimate the user's intent. The device uses both user input and obstacle detection to prevent collisions. However, the user has control over which obstacle-free path to traverse.

The PAMM has four different control modes. The first mode gives full control of the device to the user. The controller performs path planning and obstacle avoidance in mode two, and the user responds to and directs the device. In mode three, the PAMM performs path planning, navigation, and localization while the user supplies the desired destination. Mode four involves task planning and communication by the walker.

The Medical Automation Research Center at the University of Virginia has also developed a pedestrian mobility aid for the elderly [23–24]. It consists of a commercially available, three-wheeled walker frame, sonar and infrared sensors, a front wheel motor, and force sensors in the handles. This walker can detect and avoid obstacles and vary its goals and level of activity based on an estimation of the user's intentions.

The Fraunhofer Institute of Manufacturing Engineering and Automation has developed an intelligent walking

Table 1.
Mobility aids for navigation and obstacle avoidance.

Parameter	Assistive Device			
	PAMM [1–2]	MARC [3]	Care-O-bot® [4]	GuideCane [5]
Investigative Center	Massachusetts Institute of Technology	Medical Automation Research Center, UVA	Fraunhofer Institute of Manufacturing Engineering and Automation	University of Michigan
Design	Motorized walker	3-wheel rollator	Motorized robot	Cane with wheeled sensor array
Target Population	Elderly, cognitive/physical impairments	Elderly, home environment	Elderly	Blind
Obstacle Avoidance	Yes	Yes	Yes	Yes
Navigation Assistance	Autonomous navigation	None	Autonomous navigation	None
Modes	4 modes: user control; controller path planning and obstacle avoidance; controller path planning, navigation, and localization; controller task planning and communication	User control; shared-control	Direct user control; target mode	Obstacle avoidance with active steering
Propulsion	Passive	Passive	Passive/active	Passive
Human/System Interface	Handlebars	Handlebars	Walking aid handles	Mini joystick
Steering	Omnidirectional drives	Motorized front wheel	Motorized wheels	Two wheels
Sensors	Computer vision, sonar, wheel encoders	Laser range finder, infrared range finder, wheel encoders	Laser range finder, gyroscope	Sonar, wheel encoders

1. RESNA, American National Standards Institute. Wheelchair standards. Washington (DC): RESNA; 1998.
2. Spenko M, Yu H, Dubowsky S. Robotic personal aids for mobility and monitoring for the elderly. IEEE Trans Neural Syst Rehabil Eng. 2006;14(3):344–51. [PMID: 17009494]
3. Wasson G, Gunderson J, Graves S, Felder R. An assistive robotic agent for pedestrian mobility. In: Proceedings of the 5th International Conference on Autonomous Agents; 2001; Montreal, Canada. p. 169–73.
4. Wasson G, Gunderson J, Graves S, Felder R. Effective shared control in cooperative mobility aids. In: Proceedings of the 14th International Florida Artificial Intelligence Research Society Conference; 2001 May 21–23; Key West, Florida. Menlo Park (CA): AAAI Press; p. 509–13.
5. Graf B, Hans M, Schraft RD. Mobile robot assistants. IEEE Rob Autom Mag. 2004;11(2):67–77.
PAMM = Personal Aid for Mobility and Monitoring, UVA = University of Virginia.

aid system based on the Care-O-bot® [25]. The device performs autonomous obstacle avoidance and path planning. In direct user control mode, the user pushes the robot, and in target mode, the user follows the robot to a specified goal along a preplanned path.

Investigators at Carnegie Mellon University and the University of Pittsburgh have developed a series of robotic walkers. Robotic walker 1 was a self-powered walker with a haptic interface [26–27]. A software control system enabled data from force-sensing resistors to direct actuators in an existing mobile robotic platform, the XR4000, to move in the user's intended walking direction. The XR4000 was equipped with a laser range finder and ringed at the top and bottom with sonar sensors for obstacle detection and avoidance. Preliminary user testing with five nondisabled, young adults between 20 and 30 years of age revealed that users felt safe operating the walker after only brief instruction in the operation of the haptic devices [26–27].

Robotic walker 2 was developed by modifying a wheeled walker (rollator) to include autonomous navigation capability, as well as self-parking and retrieval functionality actuated through a remote control mechanism. In addition to observing residents of a retirement community using a variety of wheeled and unwheeled unpowered walkers, students in our robotics course met with an advisory panel of older walker users to obtain input and feedback regarding the robotic walker design. Feedback from older users was positive: during informal testing, users successfully navigated to a chosen destination within the retirement community by using the screen-based interface and they also expressed enthusiasm for the device. Further modification of this walker resulted in robotic walker 3, which has been used in a series of experiments to successfully predict people's walking activities [28].

GUIDO ROBOTIC WALKER

Hardware

The Guido provides the physical support of a traditional walker frame coupled with obstacle-avoidance and navigation assistance. It is a passive device that must be propelled by the user. The Guido has three different control modes. Manual mode provides the user with complete control over the direction of the walker, while the information gathered by the sensors is presented to the user through auditory messages. In automatic mode, control of the walker is shared by both the user and the control system. The user can direct the walker unless an obstacle is encountered, at which point the control system takes over and directs the walker around the obstacle using motors connected to the front two wheels (**Figure 2**).

Figure 2.
Motors connected to front casters allow device to control direction of Guido robotic walker.

In this mode, the controller will override any user input that would result in a collision. Park mode is the third option. In this mode, the front two wheels of the walker lock in an orientation that prevents the device from moving (**Figure 3**). This allows for the user to transfer to and from the walker if necessary.

The Guido has four different types of sensors. The Sick laser measurement system sensor (Sick, Inc; Minneapolis, Minnesota) scanning laser range finder is the main sensor used for obstacle and landmark detection. The laser gives an accurate 180° horizontal view of the environment in front of the walker. Since the laser produces only a two-dimensional plane view, nothing above or below the height of the plane is visible to the laser. Sonar sensors are positioned around the front and sides of the walker to help detect objects out of view of the laser. They also detect glass and other transparent materials that the laser may not detect. **Figure 4** shows the laser range finder and sonar sensors on the walker. Two optical encoders are also positioned on the rear wheels of the walker. These encoders calculate the walker position and orientation in absolute values. The fourth sensor is a potentiometer on the steering wheel that receives user input. The signal is converted to an angle, –60° to 60°, from left to right and used to determine the direction of the front wheels.

The user directs the walker with spring-loaded handlebars (**Figure 5(a)**) that are equipped with sensors to determine the intended direction of travel. Turn buttons are located on the end of each handlebar. Depressing these buttons causes the front wheels to turn parallel to each other in the same direction and thus allows the

Figure 3.
View of Guido robotic walker front wheels in park mode.

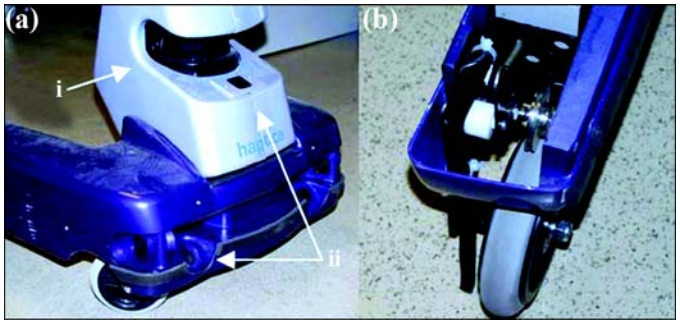

Figure 4.
(a) Some of the different sensors on Guido robotic walker: (i) laser range finder is main detection device, and (ii) sonar sensors provide coverage above and to sides of walker. **(b)** One of the encoders attached to rear wheels.

walker to rotate in a circle about its rear wheels. This feature was incorporated into the design because the obstacle-avoidance algorithm does not account for reversing. If the system detects a reversing motion, it can apply the brakes proportionally to reduce the walker's speed [29]. Brake levers are also positioned on the handle grips. If the user squeezes the brakes, the front wheels will both turn inward to stop the walker.

The control console (**Figure 5(b)**) consists of a key slot to turn on the device, a volume knob for auditory messages, and a switch for selecting the control mode. A voltmeter, fuse, and the recharging port are located on the back of the walker (**Figure 6**). The electronics and motors are run off of a 72 V system that is powered by four 12 V batteries that are located in the struts connecting the front and rear wheels.

Clean Sweep Obstacle-Avoidance Algorithm

The Guido needs to avoid obstacles in a smooth and predictable manner to guarantee the safety of users, a population that consists of individuals with reduced mobility and visual impairment. This requirement complicates the development of an effective obstacle-avoidance algorithm, since it disallows sharp and potentially hazardous turns [29]. Any actions taken by the Guido to avoid obstacles must also be balanced with the user's need to feel in control of the device.

The Guido uses what is known as the Clean Sweep obstacle-avoidance algorithm [29], which was designed to help the walker navigate through cluttered environments. The system is also intended to react quickly to user input so that it will go in the direction intended by the user. Clean Sweep is a geometry-based obstacle-avoidance method in which the area in front of the walker is searched geometrically for clear paths. As shown in **Figure 7**, the paths checked by the system consist of circular paths corresponding to a given steering angle. The system first checks between the minimum and maximum sweep edges. The second check detects points in front of the baseline. The next check tests inside of the search area circle. The last check uses the left and right side limits.

METHODS

Overview

The purpose of this study was to determine whether the Guido could increase the safety and independence of

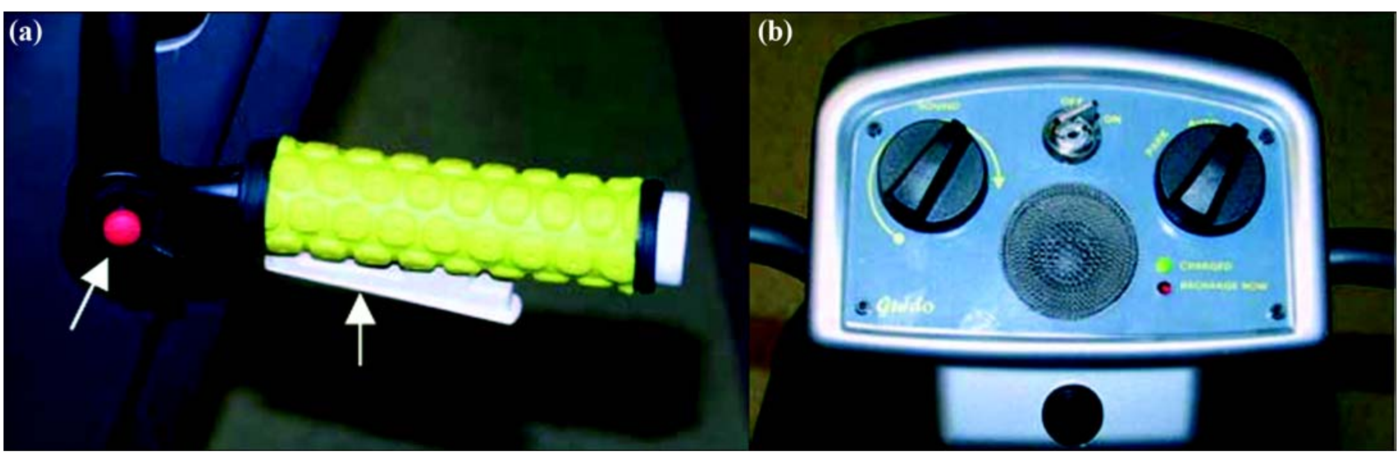

Figure 5.
(a) Guido robotic walker handgrip. Arrows are pointing to red turn button and white brake lever. **(b)** Control console of device.

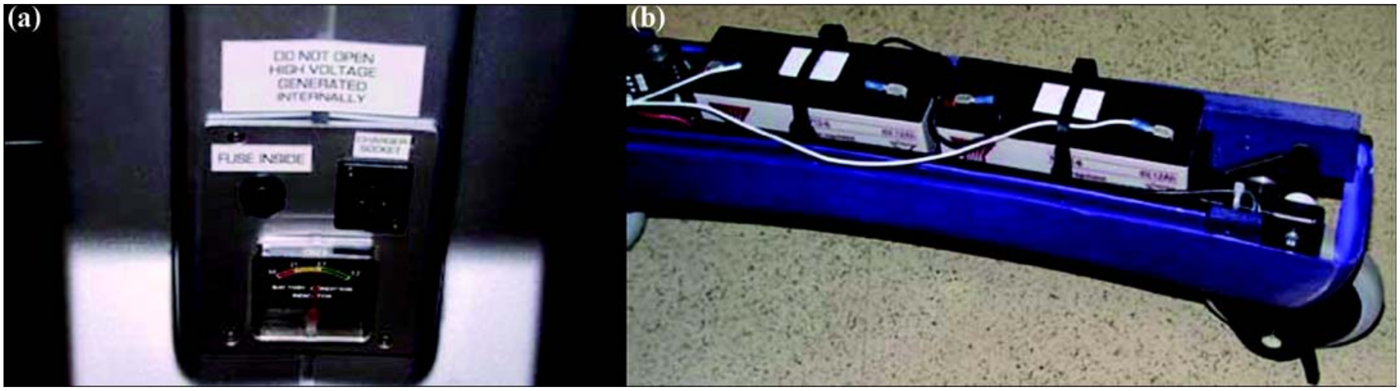

Figure 6.
(a) Rear of Guido robotic walker, including battery level indicator and charging port. **(b)** Position of batteries along right leg of walker.

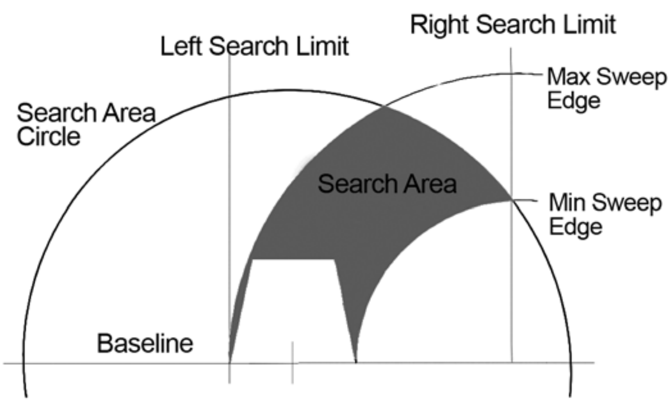

Figure 7.
Clean Sweep obstacle-avoidance algorithm uses Guido robotic walker's turn angle to determine if its projected path of travel is free of obstacles. Max = maximum, Min = minimum.

elderly visually impaired individuals in a supervised care facility. **Figure 8** shows a flowchart listing the different components of the study. Subjects were tested on a 36.6 m obstacle course using the Guido, their own device (if they used one), and the AMD.

The AMD is a cane-based assistive mobility device (**Figure 9**), designed at the Atlanta VAMC. It is lightweight and equipped with wheels on the end to allow for easy maneuverability by elderly individuals. It has no autonomous navigation or obstacle-avoidance capabilities. It requires very little training to master and can be used almost anywhere. This device was chosen to be compared with the Guido because it is a low-tech device, which would allow any possible advantages provided by the navigation and obstacle-avoidance algorithm of the Guido to emerge when compared with the AMD. The AMD was used instead of a traditional walker or rollator because none of the participants had prior experience with the AMD.

Subjects

A total of 45 subjects were recruited for this study through VA health care centers in Atlanta, Georgia; Salisbury, North Carolina; and Tucson, Arizona. All the subjects resided in a supportive living facility or nursing home and were ambulatory with limited assistance to the extent that they could walk at least 20 minutes over a 90-minute period. Demographic data collected from the subjects included age, level of schooling, and information about visual impairment. Approval to perform trials with human subjects was obtained from the VA institutional review board.

Baseline Data Collection

Baseline data collection was conducted after each subject was screened and signed the relevant informed consent forms. Subjects were first given a pretest Independent Mobility Questionnaire (**Appendix 1**, available online only at http://www.rehab.research.va.gov/jour/08/45/9/pdf/contents.pdf). This survey was intended to determine how the subjects rated themselves on mobility and how comfortable they were with their current mobility situation.

Subjects then completed a series of 36.6 m walks with their own mobility device (if they had one) or without a device (if they did not normally use one). Subjects were first asked to walk at their normal walking speed over a distance of 36.6 m while accompanied by a human

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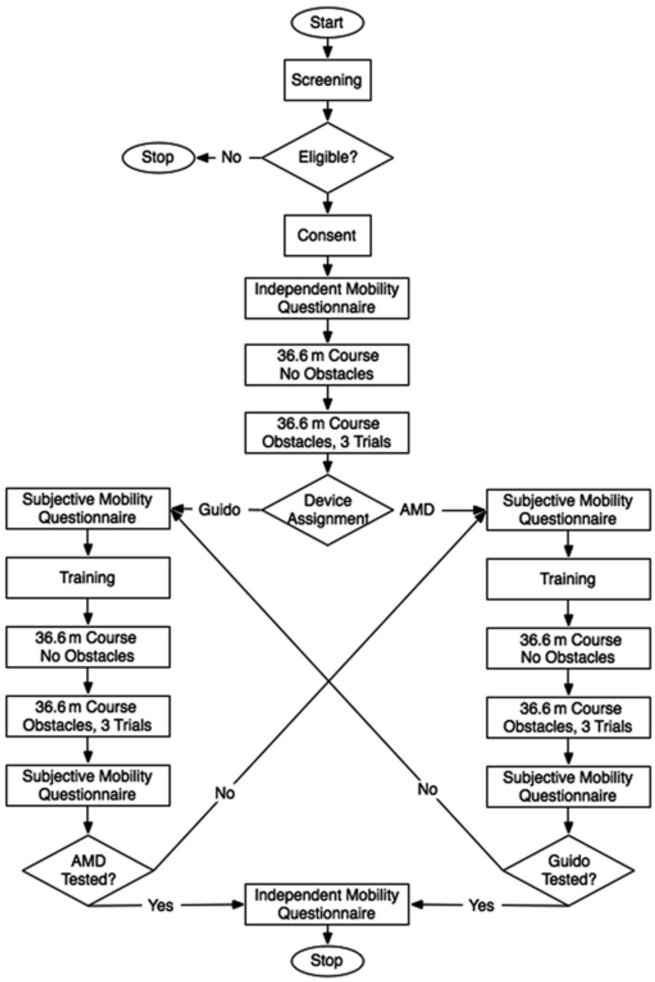

Figure 8.
Clinical study flowchart. AMD = Assistive Mobility Device.

guide. The time was recorded and the subject's preferred walking speed (PWS) was calculated as

PWS = Time (s)/36.6 m.

Next, subjects repeated the course three times without a sighted guide. Before each trial, six different objects common to the living environment (such as chairs, trash cans, and wheelchairs) were randomly placed along the 36.6 m path. In each trial, the time, number of obstacle/wall contacts, and number of reorientations were recorded. Elapsed time was defined as the time it took the subject to traverse the obstacle course from start to finish. Obstacle/wall collisions refer to the number of times a subject contacted an obstacle or wall with his or her device or body. Reorientations were defined as the number of times that the subject had to be reoriented in order to finish the course.

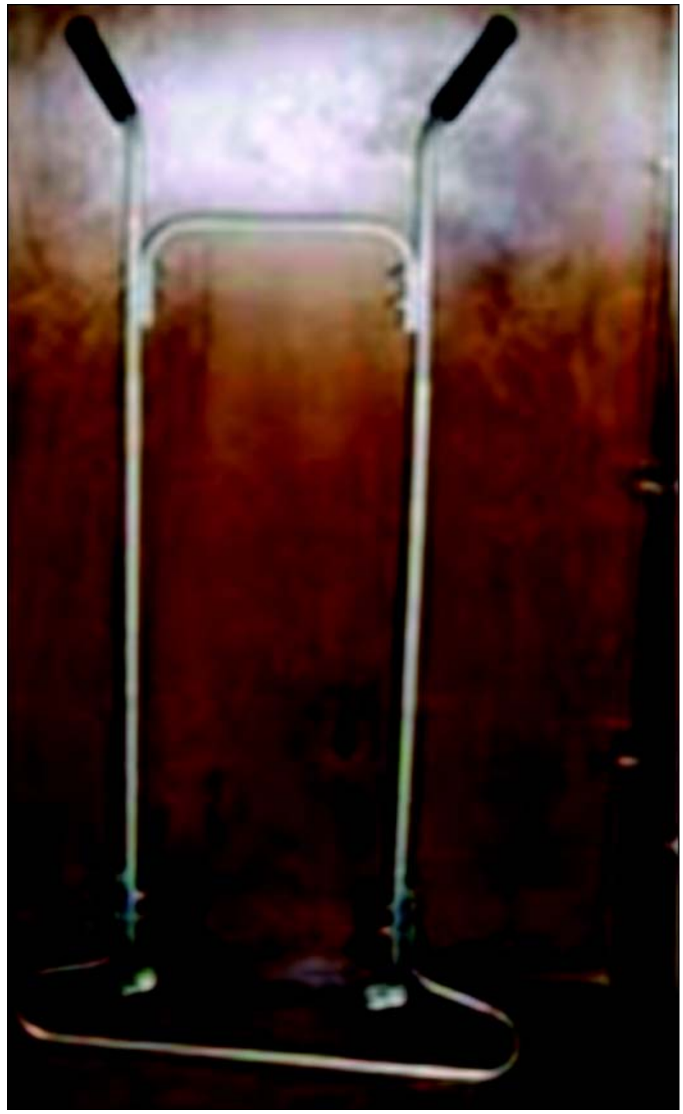

Figure 9.
Assistive Mobility Device.

Empirical Comparison Between Guido and AMD

The testing order for the Guido and AMD was randomly assigned for each subject. A pretest Subjective Mobility Questionnaire (**Appendix 2**, available online only at http://www.rehab.research.va.gov/jour/08/45/9/pdf/contents.pdf) was completed before training was provided. The survey was intended to determine how the subjects initially felt about the devices without actually having used them. The PWS was determined by having the subjects walk the 36.6 m obstacle-free path using the device. Each subject then used the device to traverse the

36.6 m obstacle course three different times. The time, number of obstacle/wall contacts, and number of reorientations were once again recorded. Finally, the posttest Subjective Mobility Questionnaire was administered. The subjects then completed the same tests and questionnaires for the second device. When all of the testing was completed for both devices, the posttest Independent Mobility Questionnaire was administered.

When using the Guido, subjects experienced both the manual and automatic modes. The first two trials were performed using the device in manual and automatic mode, respectively. The third trial was completed using the mode chosen by the subject.

RESULTS

Subject characteristics are shown in **Table 2**. The results for the pre- and posttest Independent Mobility Questionnaire are shown in **Table 3**. McNemar's test for correlated proportions (exact method) was used to compare nonparametric pre- and posttest responses, and a related-samples *t*-test was used to compare parametric pre- and posttest responses. A Bonferroni correction (p = 0.05/23 = 0.002) was used to correct for multiple comparisons. No statistically significant differences were identified.

Table 2.
Subject characteristics (n = 17).

Variable	Mean ± SD or *n*
Age (yr)	85.3 ± 7.0
Initial Cause of Visual Impairment	
Age-Related Macular Degeneration	13
Cataract	1
Other	2
Secondary Cause of Visual Impairment	
Glaucoma	2
Cataract	1
Other	4
Time Since Onset of Visual Impairment (yr)	20.4 ± 13.0
Education	
8th-Grade Diploma	1
High School Diploma	3
Technology Diploma	2
Some College	5
4-Year College Degree	2
Additional College	2

SD = standard deviation.

Tables 4 and **5** list the results for the pre- and posttest Subjective Mobility Questionnaire for the Guido and AMD, respectively. A paired-samples *t*-test was used to compare pre- and posttest answers for each device. A Bonferroni correction (p = 0.05/4 = 0.0125) was used to correct for multiple comparisons within each device. No statistically significant differences were found, although ease of use for the AMD was close at $p = 0.04$.

The average scores for subjects on the 36.6 m obstacle course (averaged over the three trials in which obstacles were present on the course) are listed in **Table 6**. Differences in the number of obstacle/wall contacts and reorientations on the 36.6 m obstacle course were determined by using a repeated measures analysis of variance (ANOVA) ($p < 0.05$). No significant differences were identified between the devices for any of these variables.

The intention of this study was to determine whether the Guido could provide mobility and navigational assistance to elderly visually impaired individuals. It is possible that certain subjects were able to effectively navigate the test path without the assistance of the Guido. There would then be little difference between the results of the different conditions. This may not necessarily mean that the Guido was ineffective, but rather that those subjects may not benefit from assistance. In order to account for such subjects, the distribution of the subjects' times to complete the test path without the use of either device was examined. The subjects with the longest times (>60 seconds), implying that they had the most difficulty with ambulation, were identified. Additional repeated measures ANOVAs ($p < 0.05$) were then run to determine differences in time, obstacle/wall contacts, and reorientations. The models were identical to those run for the entire subject pool. **Table 7** shows the average scores for the subset of subjects with the longest times (>60 seconds).

Each subject traversed the obstacle course using the Guido during three separate trials. The first two trials were performed using the device in manual and automatic mode. The third trial was completed using the mode chosen by the subject. Differences were tested for between the selected mode and the nonselected mode. For instance, if the subject chose automatic mode for the third trial, then the results were compared with the first or second trial using manual mode. A paired *t*-test ($p < 0.05$) was used to determine differences in time, obstacle/wall

Table 3.
Pre- and posttest Independent Mobility Questionnaire responses.

Question	Pre	Post
Problems walking around due to vision?	8/17	7/17
Problems walking around due to other health issues?	9/17	4/17
Feel safe walking by yourself?	14/17	8/17
Each situation below was rated on scale of 1–5*		
Walking in familiar areas	1.18	1.25
Walking in unfamiliar areas	3.13	2.73
Moving about in crowded situations	2.69	2.69
Walking through doorways	1.47	1.56
Walking in high-glare areas	3.18	2.94
Walking in dimly lit indoor areas	2.41	2.20
Being aware of another person's presence	1.50	2.29
Avoiding bumping into—		
People	1.76	1.56
Walls	1.41	1.63
Head-height objects	1.67	1.58
Shoulder-height objects	1.19	1.36
Waist-height objects	1.24	1.31
Knee-height objects	1.94	1.81
Low-lying objects	2.75	2.43
Avoiding tripping over uneven travel surfaces	2.80	2.25
Moving around in social gatherings	1.44	1.62
Have you fallen in the last year?	6/17	5/17
If yes, how many times?	8	9
Are you satisfied with your present level of travel?	12/17	13/17
Have you had mobility training?	7/17	4/17
Do you use a mobility aid?	12/17	9/17

*1 signifies no difficulty and 5 extreme difficulty.

Table 4.
Pre- and posttest Subjective Mobility Questionnaire for Guido robotic walker.

Question*	Pre	Post
How attractive do you find this device?	2.0	2.41
How easy did you think it would be to use this device?	2.29	2.41
How useful do you think it will be to move about in this living environment with this device?	2.65	2.47
How comfortable do you think you will feel when using this device in front of other people?	1.94	1.71

*Answered on 1–5 scale, where 1 is good and 5 is poor.

Table 5.
Pre- and posttest Subjective Mobility Questionnaire for Assistive Mobility Device.

Question*	Pre	Post
How attractive do you find this device?	2.38	2.23
How easy did you think it would be to use this device?	2.31	1.69
How useful do you think it will be to move about in this living environment with this device?	3.15	2.92
How comfortable do you think you will feel when using this device in front of other people?	1.54	1.62

*Answered on 1–5 scale, where 1 is good and 5 is poor.

Table 6.
Mean ± standard deviation scores for 36.6 m obstacle course (all subjects, $n = 17$). For "Own Device," participants completed course either with their own mobility device (if they had one) or without device (if they did not normally use one). Elapsed time was defined as time it took subject to traverse obstacle course from start to finish. Wall/obstacle collisions refer to number of times each subject contacted obstacle/wall with his or her device or body. Reorientations were defined as number of times subject had to be reoriented in order to finish course.

Variable	Own Device	Guido	AMD
Elapsed Time (s)	86.1 ± 69.3	98.5 ± 65.2	76.3 ± 61.1
Obstacle Collisions	0.81 ± 3.1	0.73 ± 1.47	1.0 ± 2.1
Wall Collisions	0.44 ± 2.27	0.31 ± 1.45	2.26 ± 0.39
Reorientations	0.27 ± 0.63	0.3 ± 0.74	0.18 ± 0.39

AMD = Assistive Mobility Device.

Table 7.
Mean ± standard deviation scores for 36.6 m obstacle course (subset of $n = 5$ subjects, time >60 s). For "Own Device," participants completed course either with their own mobility device (if they had one) or without device (if they did not normally use one). Elapsed time was defined as time it took subject to traverse obstacle course from start to finish. Wall/obstacle collisions refer to number of times each subject contacted obstacle/wall with his or her device or body. Reorientations were defined as number of times subject had to be reoriented in order to finish course.

Variable	Own Device	Guido	AMD
Elapsed Time (s)	136 ± 85.1	120.6 ± 83.2	120.7 ± 80.7
Obstacle Collisions	2.1 ± 4.9	0.6 ± 1.5	2.2 ± 3.0
Wall Collisions	1.2 ± 3.9	0.14 ± 0.48	5.7 ± 8.35
Reorientations	0.33 ± 0.66	0.52 ± 1.03	0.2 ± 0.41

AMD = Assistive Mobility Device.

contacts, and reorientations. The results for the paired *t*-tests for manual versus automatic mode for the Guido identified no significant differences.

DISCUSSION

No significant differences were found among the times taken to complete the test course. This includes the trials conducted on the 36.6 m course with no obstacles as well as the 36.6 m obstacle course. The AMD had the lowest average times on both courses for all of the conditions. For the subset of slower subjects, the Guido had lower average times than the subjects' own devices on the obstacle-free course and on the obstacle course.

On average, the Guido contacted less obstacles/walls than the AMD and the subjects' devices, but the differences were not significant. The subjects had to reorient themselves fewer numbers of times with the AMD, but again, the difference was not significant. Also, no significant differences were found between the automatic and manual modes with the Guido for any of the test variables.

The Guido failed to outperform the other devices during the obstacle testing. It did not significantly reduce the travel time, obstacle/wall contacts, or reorientations. Based on the results of this study, the Guido provides no significant advantages over the other devices with respect to travel time and safety. However, certain advantages are provided by the Guido that were not highlighted by this study.

Mobility support is one of the main factors that the Guido addresses. The other devices in the study provide no physical support for the users. Measures of physical exertion (e.g., heart rate) might be useful for distinguishing the Guido from other devices.

The Guido is also capable of providing information about the surrounding environment, such as recognizing open doorways and T-junctions. This capability was of limited utility for most of the subjects in this study because they had some limited vision. They had to depend less on the ability of the walker to detect and avoid obstacles because they could identify them without assistance. Additional testing that makes use of measures of cognitive load or a participant's awareness of his or her surroundings may identify advantages that the Guido provides that were not evident in this study.

Testing subjects with severe visual impairments may also produce different results. However, we had difficulty recruiting severely visually impaired elderly individuals for this study. The requirement that the subjects reside in a nursing home or assisted living center hampered recruitment. Investigators may want to consider different subject requirements for future research. For instance, visually impaired subjects with no mobility problems would be easier to recruit. Useful information could be gathered involving the effectiveness of the navigational and avoidance software and the overall performance of the device.

Although no significant differences were found for collisions with obstacles/walls, the subjects collided with an average of <1 object per trial using the Guido. The Guido performed in a safe manner during the clinical trials. The results demonstrate that its performance is equivalent to the current device of the subjects as well as the AMD.

The results of the mobility surveys also provide useful information concerning what potential users of the Guido like and dislike about the device. After participating in the study, the subjects responded more positively to questions concerning the walker. They expressed more confidence in their abilities to use the device (2.15 compared with 2.46), felt it would be useful in their living environments (2.42 compared with 3.08), and were more comfortable using the device in front of other people (1.77 compared with 2.23). Again, it should be stressed that people with complete blindness may find the Guido more helpful and would rate questions concerning the device more favorably.

CONCLUSIONS

Overall, the results of the clinical testing showed that the Guido performed at a similar level to the AMD and the subjects' own devices. Possible advantages in navigation and obstacle avoidance were not evident when compared with the other devices. Travel time, obstacle/wall contacts, and reorientations did not significantly decrease. Additional testing that includes more obstacles and a longer course and that is limited to severely visually impaired individuals may produce different results.

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REFERENCES

1. Freid V, Prager K, MacKay A, Xia H. Chartbook on trends in the health of Americans. Health United States. Hyattsville (MD): National Center for Health Statistics; 2003.
2. Biomedical innovations, Baby Boomers and aging. Pfizer J. 1999;3(1).
3. Kramarow E, Lentzner H, Rooks R, Weeks J, Saydah S. Health and aging chartbook. Health, United States, 1999. Hyattsville (MD): National Center for Health Statistics; 1999.
4. Sayhoun NR, Pratt LA, Lentzner H, Dey A, Robinson KN. The changing profile of nursing home residents: 1985–1997. Aging trends. No. 4. Hyattsville (MD): National Center for Health Statistics; 2001.
5. Bedsine RW, Rubenstein LZ, Snyder L. Medical care of the nursing home resident: What physicians need to know. Philadelphia (PA): American College of Physicians; 1996.
6. Rubenstein LZ, Josephson KR, Robbins AS. Falls in the nursing home. Ann Intern Med. 1994;121(6):442–51. [PMID: 8053619]
7. Boyce PR. Lighting for the elderly. Technol Disabil. 2003; 15(3):165–80.
8. Pleis JR, Lethbridge-Cejku M. Summary health statistics for U.S. adults: National Health Interview Survey, 2005. Hyattsville (MD): National Center for Health Statistics; 2006.
9. Keysor JJ, Jette AM. Have we oversold the benefit of late-life exercise? J Gerontol A Biol Sci Med Sci. 2001;56(7): M412–23. [PMID: 11445600]
10. Melzer I, Benjuya N, Kaplanski J. Effects of regular walking on postural stability in the elderly. Gerontology. 2003; 49(4):240–45. [PMID: 12792159]
11. Barnes PM, Schoenborn CA. Physical activity among adults: United States, 2000. Hyattsville (MD): U.S. Department of Health and Human Services; 2003.
12. Dobrin L. Origin and evolution of the walkerette. Mt Sinai J Med. 1980;47(2):172–74. [PMID: 6993922]
13. Brandt A, Iwarsson S, Stahl A. Satisfaction with rollators among community-living users: A follow-up study. Disabil Rehabil. 2003;25(7):343–53. [PMID: 12745958]
14. Nabizadeh SA, Hardee TB, Towler MA, Chen VT, Edlich RF. Technical considerations in the selection and performance of walkers. J Burn Care Rehabil. 1993;14(2 Pt 1): 182–88. [PMID: 8501107]
15. Kaye HS, Kang T, LaPlante MP. Mobility device use in the United States. Washington (DC): National Institute on Disability and Rehabilitation Research, U.S. Department of Education; 2000.
16. Kraditor K, Dollard KJ, Hodlewsky RT, Kyllo D, Sabo S. Facts and trends: The assisted living sourcebook. Washington (DC): National Center for Assisted Living; 2001.

17. Lacey G, MacNamara S. User involvement in the design and evaluation of a smart mobility aid. J Rehabil Res Dev. 2000;37(6):709–23. [PMID: 11321007]
18. Rentschler AJ, Cooper RA, Blasch B, Boninger ML. Intelligent walkers for the elderly: Performance and safety testing of VA-PAMAID robotic walker. J Rehabil Res Dev. 2003; 40(5):423–31. [PMID: 15080227]
19. International Organization for Standardization. Walking aids manipulated by both arms: Requirements and test methods. Part 2: Rollators. Geneva (Switzerland): International Organization for Standardization; 1999.
20. RESNA, American National Standards Institute. Wheelchair standards. Washington (DC): RESNA; 1998.
21. Blasch B, Long R, Griffin S. Results of a national survey of electronic travel aid use. J Vis Impair Blind. 1989;33(9): 449–53.
22. Spenko M, Yu H, Dubowsky S. Robotic personal aids for mobility and monitoring for the elderly. IEEE Trans Neural Syst Rehabil Eng. 2006;14(3):344–51. [PMID: 17009494]
23. Wasson G, Gunderson J, Graves S, Felder R. An assistive robotic agent for pedestrian mobility. In: Proceedings of the 5th International Conference on Autonomous Agents; 2001; Montreal, Canada. p. 169–73.
24. Wasson G, Gunderson J, Graves S, Felder R. Effective shared control in cooperative mobility aids. In: Proceedings of the 14th International Florida Artificial Intelligence Research Society Conference; 2001 May 21–23; Key West, Florida. Menlo Park (CA): AAAI Press; p. 509–13.
25. Graf B, Hans M, Schraft RD. Mobile robot assistants. IEEE Rob Autom Mag. 2004;11(2):67–77.
26. Matthews JT, Thrun S, Dunbar-Jacob J. Robotic assistive technology for community-residing older adults and persons with disabilities: An inter-institutional initiative for students in the health and technology fields. In: Proceedings of the International Conference on Engineering Education; 2002 Aug 18–21; Manchester, England.
27. Morris A, Donamukkala R, Kapuria A, Steinfeld A, Matthews JT, Dunbar-Jacob J, Thrun S. A robotic walker that provides guidance. In: Proceedings of the IEEE International Conference on Robotics and Automation, Vol. 1; 2003 Sep 14–19; Taipei, Taiwan. New York: IEEE Press; 2003. p. 25–30.
28. Glover J, Thrun S, Matthews JT. Learning user models of mobility-related activities through instrumented walking aids. In: Proceedings of the IEEE International Conference on Robotics and Automation, Vol. 4; 2004 Apr 26–May 1; New Orleans, Louisiana. New York: IEEE Press; 2004. p. 3306–3312.
29. Rodriguez-Losada D, Matia F, Jimenez A, Galan R, Lacey G. Implementing map based navigation in Guido, the robotic smartwalker. In: Proceedings of the IEEE International Conference on Robotics and Automation; 2005 Apr 18–22; Barcelona, Spain. New York: IEEE Press; 2005. p. 3390–3395.

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