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A new primary mobility tool for the visually impaired: A white cane—adaptive mobility device hybrid

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Abstract

This article describes pilot testing of an adaptive mobility device-hybrid (AMD-H) combining properties of two primary mobility tools for people who are blind: the long cane and adaptive mobility devices (AMDs). The long cane is the primary mobility tool used by people who are blind and visually impaired for independent and safe mobility and AMDs are adaptive devices that are often lightweight frames approximately body width in lateral dimension that are simply pushed forward to clear the space in front of a person. The prototype cane built for this study had a wing apparatus that could be folded around the shaft of a cane but when unfolded, deployed two wheeled wings 25 cm (9.8 in) to each side of the canetip. This project explored drop-off and obstacle detection for 6 adults with visual impairment using the deployed AMD-H and a standard long cane. The AMD-H improved obstacle detection overall, and was most effective for the smallest obstacles (2 and 6 inch diameter). The AMD-H cut the average drop off threshold from 1.79 inches (4.55 cm) to .96 inches (2.44 cm). All participants showed a decrease in drop off detection threshold and an increase in detection rate (13.9% overall). For drop offs of 1 in (2.54 cm) and 3 in (7.62 cm), all participants showed large improvements with the AMD-H, ranging from 8.4 to 50%. The larger drop offs of 5 in (12.7 cm) and 7 in (17.8 cm) were well detected by both types of canes.

Keywords

adaptive cane; blind; cane; mobility

Introduction

Nearly 285 million people worldwide are visually impaired (World Health Organization, 2010): a condition that can result in a myriad of social, emotional, and health problems, often due to difficulties with mobility (Court, McLean, Guthrie, Mercer, & Smith, 2014; Evans, Fletcher, & Wormald, 2007; Varma, Wu, Chong, Azen, & Hays, 2006). Vision loss significantly increases morbidity and mortality, thus making it a growing health crisis (Crewe et al., 2013; Zhang, Jiang, Song, & Zhang, 2016). People with a severe visual impairment are more prone to falls (Klein, Klein, Lee, & Cruickshanks, 1998), especially in older people (Coleman et al., 2004; Lord, Smith, & Menant, 2010;). In general, these falls are due to people with a visual impairment not seeing an obstacle or level change or over-correcting when navigating around a hazard (La Grow, Robertson, Campbell, Clarke, & Kerse, 2006).

For nearly a century, the white cane has been the primary mobility tool used to promote independence and increase safety in mobility for people who are blind and visually impaired (Strong, 2009). The cane is typically held at body midline and swung back and forward slightly more than body width in phase with the gait cycle; the swings are synchronized to the rear leg during walking, allowing the cane user to increase his or her reaction time to hazards while clearing the immediate path of the foot (Hoover, 1962; LaGrow & Long, 2011). However, the white cane has limitations. The white cane has difficulty with edge and obstacle detection (Kim, Moncada-Torres, Furrer, Riesch, & Gassert, 2016; Kim & Wall Emerson, 2014; Kim, Wall Emerson, & Curtis, 2009, 2010), neuromusculoskeletal overuse injuries (Gitlin, Mount, Lucas, Weirich, & Gramberg, 1997; Mount et al., 2001), training requirements (Virgili & Rubin, 2010), and cognitive burden, particularly in older adults (Zijstra, Ballemans, & Kempen, 2013). While the simplicity of the long cane has made it the most generally useful mobility tool for people who are blind, a single point contacting the walking surface, no matter how it is moved about, is not able to warn a cane user of all potential trip and fall hazards.

Although the long cane is the most widely used and most effective mobility tool for people who are blind, attempts have been made to compensate for its shortcomings by developing additional tools. In just the last few years, there are examples of bracelets (e.g., Bhatlawande, Sunkari, et al., 2014), long cane attachments (e.g., O'Brien, Mohtar, Diment, & Reynolds, 2014; Pyun, Kim, Wespe, Schneller, & Gassert, 2013), sensors (e.g., Wang & Kuchenbecher, 2012), and assorted electronic "smart" canes (e.g., Bhatlawande, Mahadevappa, et al., 2014; Bouhamed, Kallel, & Masmoudi, 2013; Jeslin, Vaishnavi, & Nivedha, 2015; Kim & Cho, 2013) that hope to address the needs of people who are blind. Many of these projects are similar to devices developed since the 1960s such as the Hand Guide, the Lindsay Russell Pathsounder, the Binaural Sensory Aid, the SonicGuide, the Trisensor, the Kasper, the "K" Sonar device, the Laser Cane, the Ultracane, the Mowat Sensor, the Polaron, the Sensory 6, the Sonic Pathfinder, and the Miniguide (Smith & Penrod, 2010). Most of these devices are no longer produced, having not been shown to be effective or not having been embraced by people who are blind.

An adaptive mobility device (AMD) is a primary mobility tool that can be used in place of a long cane; it is a lightweight frame approximately body width in lateral dimension that is simply pushed forward to clear one's immediate, forward-facing, peri-personal space (Sauerburger, n.d.; Smith & Penrod, 2010). It could be likened to a rolling walker without the mechanical support, clearing the near path with a preview window of several feet. While clearly advantageous, given its low cognitive burden, the AMD has difficulty with a lack of portability or compactness, a lack of easy foldability, and poor maneuverability in cluttered environments. The latter is particularly problematic because it requires the user to lift, pivot, and manipulate a large and unwieldy device, and generally relegates its use to a pre-cane training tool. One alternative device that has sought to combine additional feedback with aspects of an AMD is the GuideCane, which has a sensor array atop motorized wheels attached to the end of a long cane. A cane user directs the motion of the GuideCane with a joystick or button on the handle of the cane. Servo motors drive the wheels and the sensors alter the device's movements in response to environmental obstacles (Borenstein & Ulrich, 1997). Introduced in 1997, the GuideCane has not been widely adopted, perhaps due to the technology necessary to make it function.

Our goal was to create a composite instrument, the AMD-hybrid (AMD-H), that maximizes the beneficial properties of primary mobility tools such as the long cane and AMDs, while minimizing their respective flaws. The objective of this pilot project was to explore differences in drop-off and obstacle detection using the AMD-H, as compared to a standard white cane, using the constant contact primary cane technique. The constant contact cane technique is where a user's cane tip is moved left to right as the person walks, with the tip always on the ground. This cane technique is the most reliable for detecting drop offs, but the swinging of the cane left and right can allow it to miss obstacles (Blasch & De l'Aune, 1992).

Methods

Apparatus

The prototype cane built for this study had a multi-segment collapsible shaft and folding wing apparatus that could be deployed or "opened" and retracted or "closed," depending on user preference. The cane could also be folded, given the segmentation. Unfolded, the cane was 147-cm (57.9-in) long and the wing assembly was 56-cm (22-in) wide. The total weight was 658 g (23.2 oz). When folded and closed, the wing assembly measured 15 cm × 13 cm × 33 cm (5.9 in × 5.1 in × 13.0 in). The hybrid cane with wing apparatus unfolded is shown beside a standard long cane in Figure 1.

The cane shaft segments were built from unidirectional pultruded carbon fiber tubing (Rock West Composites), each with computer numerical control (CNC)-machined aluminum ferrules that deployed a taper fit to connect to each other and interlocking splines to prevent relative rotation between segments. Bungee cord (Paracord Planet 1/8-in Shock Cord) was channeled through the segments to provide tension, ensuring that the segments auto-aligned when unfolded. Each segment was approximately 25-cm (9.8-in) long. The distal segment to be placed on the ground had a cylindrical cane tip (40 g [1.4 oz] Ambutech Slip-on Roller Marshmallow Tip) that was pressure-fit onto an aluminum segment glued in to the adjacent

piece of carbon fiber. The segment to be held had a golf handle (25 g [0.9 oz] Winn Dri-Tac Midsize) glued to the length of the most proximal segment. Each segment was wrapped in reflective tape.

The folding wing apparatus was made up of 10 pieces of 30% glass-filled Nylon 66. The elements included: two sleeves that traversed the length of the shaft, and whose relative position defined the open angle of the two wings, a series of four linkages (two per side) that connected the sleeves to the wings, two runners, and two wheels. The runners were casings that held the wheels, which were CNC-machined from Delrin; the runners were configured in a lateral position relative to the width of the wing. The wings were closed by bringing the sleeves closer together and opened by separating them as far as the linkages allowed—this was accomplished by deploying a spring-loaded, lever-action clasp with teeth that was pushed inward to disengage and released to re-engage, allowing the wings to open when pushed inward and combined with a gentle sliding of the sleeves proximally for closing or distally for opening. The wheels pivoted about a hinge in the wing to minimize the amount of space taken up by the folded prototype. Connections between parts of the wing assembly were secured with screws and metal pins.

Participants

Six adults with visual impairment were recruited to represent a cross-section of cane users for this pilot study. Due to limitations on location, participants were recruited from an established database of previous participants who are cane users as well as groups serving people who are visually impaired in the area where the study was to be conducted. To create as diverse a sample as possible in a small sample, a range of ages and amounts of cane use were a focus of the recruitment process. Potential participants were contacted with general information about the study and their questions answered when they contacted the researchers about possibly being involved. Informed consent was obtained from each participant, according to the Declaration of Helsinki, before taking part in the study. The participants were three females and three males aged 33 to 67 (mean age = 51.8). Participants were familiar with standard long cane techniques and cane use experience ranged from 3 to 47 years (mean = 26.8) with daily use ranging from 20 minutes to 4 hours. Demographic information for each of the six participants is shown in Table 1.

General study procedures

The study used a repeated-measures design with randomized introduction of conditions. Each participant used a typical long cane and the hybrid cane to detect obstacles and drop offs. Participants only used the hybrid cane with the wings unfolded and pushed it in front of them as they walked; there was no prior instruction or training. When using the conventional long cane, participants moved the cane from side to side with the tip on the ground, in an arc slightly wider than shoulder width. Headphones (RadioShack Full-Size Stereo Headphone 33-1225) connected to an MP3 player (Apple iPod 5th Generation) were worn by all participants during all trials. Through the headphones, rhythmic beats (90 to 110 beats per minute) over a white noise background were played to the participants. The speed of the rhythmic beats was set in accordance with each participant's relaxed stepping speed and participants synchronized their steps to the beats. This was aimed at helping participants

walk at an unchanging pace throughout the trials, thus limiting the potential confounding effect of walking speed on drop-off detection. For each trial, participants had small infra-red marker lights attached to their shoulders, torso, elbow, wrist, finger, toes, and cane that were followed in three dimensions by an Optotrak Certus motion analysis system (Northern Digital).

Obstacle detection apparatus and procedure

Circular objects with diameters of 5.1 cm (2 in), 15.2 cm (6 in), 25.4 cm (10 in), and 35.6 cm (14 in), and all 17.8-cm (7-in) high were made from Styrofoam with internal weights to give all obstacles similar resistance. Objects were placed on a participant's walking path at midline or slightly off to the side following a randomized schedule. Participants trailed a 6-m-long (19.7-ft), 90-cm (35.4-in) high rail, built of PVC pipe, with their free hand so participants walked consistently along the intended walking path and encountered obstacles at the intended relative position from the sagittal plane of the participant's body (see Figure 2).

Each participant was aligned at the midline of the obstacle detection walking path before the beginning of each trial. To prevent participants from anticipating obstacles, the distance between the participant and the obstacle was randomly varied from 3 to 6 m (9.8 to 19.7 ft). At a signal from the experimenter, the participant approached the obstacle on the walking path using either a rigid graphite long cane (Ambutech UltraLite Graphite Rigid Cane) with a marshmallow tip (Ambutech MT4080 High Mileage Tip) or the hybrid cane. Each participant was given a cane that was as long as the vertical distance from the ground to 5 cm (2 in) above the participant's xiphoid process (LaGrow & Weessies, 1994).

Upon detecting the obstacle, the participant stopped immediately and said "obstacle." Upon completion of each trial, the experimenter guided the participant to the next starting point. A research assistant changed the size and location of the obstacle for the next trial following a randomized schedule. Each participant completed six trials for each of the four sizes of obstacles with each of the canes (conventional and hybrid). A trial was recorded as a miss if the participant failed to detect the obstacle with the cane before contacting it with the foot or other part of the body. Two experimenters scored the trials independently and interrater reliability was 98%. After completing all trials, each participant answered a series of questions regarding their impressions of the two canes they used.

Drop-off detection apparatus and procedure

Six carpeted plywood platforms were used to form a 32-ft-long (9.8-m) and 8-ft-wide (2.4-m) walkway (see Figure 3). Two carpeted plywood boards laid on top of braced rectangular wooden frames were placed against the lengthwise end of the walkway to vary the drop-off depth from trial to trial. Drop-off depths ranged from 1 in (2.5 cm) to 7 in (17.8 cm) in 2-in (5.1-cm) increments. Carpeting on these plywood boards was identical to that on the walkway, which was aimed at preventing participants from using texture and auditory cues for detecting drop-offs. Each trial was also recorded with a digital camcorder (Canon Vixia HF R300 HD).

Each participant was positioned at the center of the walkway, squarely facing the drop-off. Randomly selected starting points were chosen for different trials to prevent participants from anticipating the drop-off. Participants walked toward the drop-off using the conventional long cane or the hybrid cane, following a randomized schedule of trials. Participants stopped upon detecting the drop-off and verbally indicated detection of the drop-off. An experimenter walked behind the participant to help in case of stumbling off the walkway. After each trial, the experimenter guided the participant to the next starting point, walking in an irregular pattern to prevent the participant from knowing how far the next starting point was from the drop-off. Each participant completed four trials for each of the four drop-off depths with each of the cane conditions.

A trial was recorded as either a “miss” or “detected.” It was recorded as a miss if the participant stepped off the drop-off or would have stepped off the drop-off had it not been for the experimenter’s intervention. Such intervention was necessary to prevent injuries when large drop-offs were presented. Two experimenters scored the trials independently; interrater reliability was 98%. After completing all trials, each participant answered a series of questions regarding their impressions of the two canes they used.

Results

Obstacle detection data

Biomechanical data on how participants used the conventional long cane was gathered to ensure that the cane was being used in an appropriate manner. The participants had 10 cm to 20 cm (3.9 in to 7.9 in) of lateral offset in their cane hand and all lateral deviation was to the right. Four participants shifted their cane arcs to the right of midline (1, 3, 4, and 6), but all participants had high measures of body coverage (a measure of how much, in percentage, of the space through which a participant’s body moved that was previously previewed or occupied by the cane). There was no difference in obstacle detection as a function of how the cane was being wielded.

Table 2 shows the percent of obstacles detected by each participant when using both the conventional and the hybrid cane for each obstacle size. Averaged across participants, the hybrid cane improved obstacle detection for all obstacle sizes. For the 2-in (5.1-cm) diameter obstacles, the hybrid cane was more effective for all participants. For the 6-in (15.2-cm) diameter obstacles, two participants performed less well with the hybrid cane, but only by 17%. Two other participants improved substantially with the hybrid cane (34% to 50%). For the two larger obstacles, participants did very well with both canes leaving little room for improvement.

Drop-off detection data

Biomechanical data were collected for drop-off trials, as it was for obstacle trials. As in the obstacle trials, participants had 10 cm to 20 cm (3.9 cm to 7.9 in) rightward offset to their cane hand. Participants 1 and 3 shifted their cane arcs to the right of midline, but participants 2 and 5 shifted their cane arcs to the left. All participants had high body coverage measures,

with more variation shown across individual trials than in the obstacle trials. There was no effect on drop-off detection as a function of how the cane was wielded.

Absolute drop-off detection threshold (50%) and drop-off detection rates were used as the measures of drop-off detection performance. We calculated the 50% absolute drop-off detection threshold for each of the four depths using a psychometric function outlined in Gescheider (1997). That is, a normal cumulative distribution curve was fit to the data for extrapolating the drop-off depth detected 50% of the time (threshold). Drop-off detection rates were computed by dividing the total number of detections by total number of trials for each drop-off depth (2.5 cm, 7.6 cm, 12.7 cm, 17.8 cm). Table 3 shows the drop-off detection threshold for each participant for both the conventional and the hybrid cane. Across participants, the hybrid cane cut the mean drop-off threshold almost in half from 4.55 cm (1.79 in) with the conventional cane to 2.44 cm (.96 in) with the hybrid cane. All participants showed a decrease in drop-off detection threshold.

Table 4 shows the percent of drop-offs detected by each participant when using both the conventional and the hybrid cane. Drop-off detection rates were computed by dividing the total number of detections by the total number of trials for each experimental condition. Detection rates improved for all participants, with an improvement of 13.9% overall.

Since the conventional cane has shown to be effective at detecting drop-offs of 5 inches (12.7 cm) and 7 inches (17.8 cm) at 80% or better (Kim et al., 2009), the relative difference of the hybrid cane and conventional canes for detecting only the two smaller sizes of drop-offs was investigated. Table 5 shows the percent of drop-offs detected by each participant for the two smaller drop-off heights when using both the conventional and the hybrid cane. For drop-offs of 1 in (2.54 cm) and 3 in (7.62 cm), all participants showed large improvements with the hybrid cane, ranging from 8.4% to 50%.

Discussion

The hybrid cane improved obstacle detection overall, and was most effective for the smallest obstacles (the 2-in and 6-in diameter obstacles). The hybrid cane cut the average drop off threshold from 1.79 inches (4.55 cm) to 0.96 inches (2.44 cm). All participants showed a decrease in drop-off detection threshold. In addition, detection rate improved for all participants (13.9% overall). For drop-offs of 1 in (2.54 cm) and 3 in (7.62 cm), all participants showed large improvements with the hybrid cane, ranging from 8.4% to 50%. As in obstacle detection, the more obvious drop-offs of 5 in (12.7 cm) and 7 in (17.8 cm) were well detected by both types of canes. Nonetheless, the hybrid cane showed an improvement over the conventional cane. Overall, the hybrid cane improved both obstacle and drop-off detection, most notably for smaller obstacles and drop offs (i.e., those that did not already have large detection rates with the conventional cane). Additionally, all obstacles were 7-in (17.8-cm) tall; we hypothesize that for lower heights, the hybrid cane would perform as well, but the conventional cane would have decreased performance. Lower obstacles are more problematic for detection and create a vulnerability window for cane users, given the angle with which the conventional cane meets the ground.

This iteration of the hybrid cane shows promise for being useful to travelers who are blind. The hybrid cane can be ergo-nomically opened and closed to be used as a typical long cane or as more of an AMD. The hybrid cane can be used to fit environmental constraints or user fatigue. The hybrid cane demonstrated improved obstacle and drop-off detection over the traditional long cane. However, it is possible for the current version of the hybrid cane to draw a traveler off of a straight line of travel. Additional training in usage might reduce this effect, as participants were naïve to the hybrid cane and received no prior training or instruction; in fact, instructions were intentionally limited in an effort to gauge the simplicity of the deployed apparatus. Additionally in the subject questionnaires following testing, some participants mentioned the weight of the hybrid cane as a drawback in their estimation of its usefulness. If a further iteration of the hybrid cane reduced weight and introduced wheels with more maneuverability to allow for veering corrections of with a feature set that reduced the veering potential, the hybrid cane has tremendous potential for detecting small ground perturbations and reducing the likelihood of trips and falls, especially as a result of small obstacles. As with any new device, it is critical that potential users of the hybrid cane receive training in its use. However, it is likely that this training will be substantially less than that required for the traditional long cane. Since the hybrid cane is not swung from side to side or have its movement synched to footfalls, there is less cognitive load associated with its use and a traveler is free to pay more attention to the environment. Less cognitive load and less swinging of the cane may also mean that a traveler will experience less wrist fatigue and be able to travel farther with less general fatigue.

It is important that this study be replicated with a larger sample size, and that potential users receive more extended training with use in a variety of environments in order to more fully assess the potential benefits of the hybrid cane. In this pilot study, only six participants were evaluated due to the requirements for eligible participants in the location of the pilot study. A larger sample size would require multiple sites and an increased research budget. It is true that a smaller sample size might skew results by not adequately representing a valid cross-section of the target population. However, the six participants of the study did not represent a homogenous group, as there was an equal split along gender lines, there were a range of ages, there was a range of visual acuities, and there was a range of how long participants had been using the cane and how much participants used a cane on a daily basis. While a larger sample would better address the generalizability of the sample to the overall visually impaired population, the fact that each one of the pilot participants demonstrated an improvement on both obstacle and drop-off detection with the hybrid cane suggests that the effect is a strong one.

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Figure 1.
Hybrid cane with wing assembly unfolded and standard long cane.

Figure 2.
The guide rail.

Figure 3.
Walking platform for drop-off trials.

Table 1

Participant demographic information.

	P1	P2	P3	P4	P5	P6
Age	67	60	50	41	33	60
Gender	Male	Male	Female	Female	Male	Female
Acuity	NLP OU	NLP OU	LP OU	Unknown, no central vision	HM OD, 20/320 OS	LP OU
Etiology	ROP	Glaucoma	ROP	Fundus flavimaculitis	Optic neuropathy	RP
Onset	Birth	16 years	Birth	Birth (age 11)	26 years	Birth
Cane use	47 years	44 years	41 years	3 years	6 years	20 years
Cane use per day	20 min	30 min	2 hours	1 hour	2 hours	4 hours

Note. LP = light perception, NLP = no light perception, OU = left eye, OD = right eye, HM = hand movements, ROP = retinopathy of prematurity, RP = retinitis pigmentosa.

Table 2

Obstacle detection (% detected).

	Conventional cane				Hybrid cane			
	2" diameter	6"	10"	14"	2" diameter	6"	10"	14"
P1	25	91.7	100	91.7	66.7	83.3	100	100
P2	66.7	83.3	91.7	100	100	100	100	100
P3	58.3	100	100	100	66.7	83.3	100	100
P4	66.7	75	100	100	83.3	83.3	100	100
P5	50	66.7	100	100	83.3	100	83.3	100
P6	33.3	50	75	91.7	100	91.7	100	100
Avg	50	77.8	94.4	97.2	83.3	90.3	97.2	100

Note. 2" = 5.1 cm, 6" = 15.2 cm, 10" = 25.4 cm, 14" = 25.6 cm.

Table 3

Drop-off threshold in cm (inches in parentheses).

	Conventional cane	Hybrid cane
P1	2.24 (0.88)	1.93 (0.76)
P2	2.24 (0.88)	1.27 (0.5)
P3	3.76 (1.48)	2.54 (1)
P4	3.76 (1.48)	1.27 (0.5)
P5	5.08 (2)	2.54 (1)
P6	10.16 (4)	5.08 (2)
Avg	4.55 (1.79)	2.44 (0.96)

Table 4

Drop-off detection rate across all drop-off depths (%).

	Conventional cane	Hybrid cane
P1	91.7	95.8
P2	91.7	100
P3	79.2	87.5
P4	79.2	100
P5	75	87.5
P6	45.8	75
Avg	77.1	91

Table 5

Drop-off detection rate across small depth (%).

	Conventional cane	Hybrid cane
P1	83.3	91.7
P2	83.3	100
P3	58.3	75
P4	58.3	100
P5	50	75
P6	0	50
Avg	55.6	81.9