Published in final edited form as:

Hum Factors. 2010 June ; 52(3): 456–465.

Ergonomic Factors Related to Drop-Off Detection With the Long Cane: Effects of Cane Tips and Techniques

Dae Shik Kim, Robert S. Wall Emerson, and Amy B. Curtis

Western Michigan University, Kalamazoo

Abstract

Objective—This study examined the effect of cane tips and cane techniques on drop-off detection with the long cane.

Background—Blind pedestrians depend on a long cane to detect drop-offs. Missing a drop-off may result in falls or collision with moving vehicles in the street. Although cane tips appear to affect a cane user's ability to detect drop-offs, few experimental studies have examined such effect.

Method—A repeated-measures design with block randomization was used for the study. Participants were 17 adults who were legally blind and had no other disabilities. Participants attempted to detect the drop-offs of varied depths using different cane tips and cane techniques.

Results—Drop-off detection rates were similar between the marshmallow tip (77.0%) and the marshmallow roller tip (79.4%) when both tips were used with the constant contact technique, $p = .294$. However, participants detected drop-offs at a significantly higher percentage when they used the constant contact technique with the marshmallow roller tip (79.4%) than when they used the two-point touch technique with the marshmallow tip (63.2%), $p < .001$.

Conclusion—The constant contact technique used with a marshmallow roller tip (perceived as a less advantageous tip) was more effective than the two-point touch technique used with a marshmallow tip (perceived as a more advantageous tip) in detecting drop-offs.

Application—The findings of the study may help cane users and orientation and mobility specialists select appropriate cane techniques and cane tips in accordance with the cane user's characteristics and the nature of the travel environment.

Keywords

blind mobility; two-point touch; constant contact; marshmallow tip; roller tip; visually impaired

INTRODUCTION

The use of a stick, staff, or cane by persons who are blind to help them travel independently has been documented since ancient times (Hoover, 1962). However, modern long cane design did not emerge until World War II, when Dr. R. E. Hoover developed the systematic long cane techniques at Valley Forge General Hospital (Hoover, 1962). Type of cane tip, as

Copyright © 2010, Human Factors and Ergonomics Society.

Address correspondence to Dae Shik Kim, Western Michigan University, Department of Blindness and Low Vision Studies, 1903 W. Michigan Avenue, Kalamazoo, MI 49002-5218; dae.kim@wmich.edu.

Reprints: <http://www.sagepub.com/journalsReprints.nav>

well as the type of cane technique (Kim, Wall Emerson, & Curtis, 2009), may affect how well a cane user can detect drop-offs.

Armstrong (1975) attempted to create a framework for objectively measuring mobility performance. He divided mobility performance into two main components: safety (ability to walk from one place to another safely) and efficiency (ability to walk as quickly and smoothly as possible from one place to another). Armstrong indicated drop-off detection as one of the main measures of safety in this framework. In the 1990s, Blasch and his colleagues (Blasch & De l'Aune, 1992; Blasch, LaGrow, & De l'Aune, 1996; LaGrow, Blasch, & De l'Aune, 1997) developed a theoretical framework that describes how the long cane provides environmental information by creating a three-dimensional spatial window. In other words, as a cane user swings a cane side to side while walking forward, the user creates a three-dimensional window through which he or she previews his or her environment. This conceptualization was adopted as a theoretical framework by several long cane studies (Bongers, Schellingerhout, van Grinsven, & Smitsman, 2002; Kim et al., 2009; LaGrow et al., 1997; Rodgers & Wall Emerson, 2005a; Schellingerhout, Bongers, Grinsven, Smitsman, & van Galen, 2001; Wall & Ashmead, 2002). Blasch et al. (1996) made distinctions between three types of environmental preview: object preview (detection of obstacles on one's walking path), surface preview (detection of changes in elevation of one's walking surface), and foot placement "preview (whether the cane tip has touched the surface area where the cane user's foot will be placed). Drop-off detection, which was indicated as a key component of the surface preview (Blasch et al., 1996), is crucial for the safety of blind travelers, because missing a drop-off may result in falls or collision with moving vehicles in the street. Failure to detect a chuckhole or depressed slab on the sidewalk may also result in falls and consequent fall-induced injuries, possibly causing serious fracture-related complications, particularly for older adults (McClure et al., 2005; Rose & Maffulli, 1999).

Two primary cane techniques that are most commonly used by blind travelers are the two-point touch technique—swinging the cane side to side, tapping either side in an arc approximately 5 cm wider than the widest part of the body (Hill & Ponder, 1976; LaGrow & Weessies, 1994; Miller & Hoover, 1946)—and the constant contact technique—sweeping the cane side to side while keeping the cane tip in constant contact with the walking surface in an arc slightly wider than one's shoulders (De Bruin, 1981).

A large body of literature supports the advantage of continuous stimuli (or stimuli with shorter intervals) versus the stimuli separated by longer intervals in forced-choice discrimination tasks across different sensory modalities, including proprioceptive-kinesthetic and vibrotactile senses (Gescheider, Bolanowski, Verrillo, Arpajian, & Ryan, 1990; Kaplan, Nixon, Reitz, Rindfleish, & Tucker, 1985; Wickelgren, 1966). Drop-off detection with the constant contact technique requires discrimination of two stimuli (i.e., intensity of pressure on the cane-holding hand immediately before the cane tip passes the drop-off edge and the pressure at the moment the cane tip lands on the depressed surface) that are presented consecutively with little or no interval between them. In contrast, drop-off detection with the two-point touch technique involves comparison of two stimuli that are separated temporally. In other words, the cane user needs to determine whether the pressure on his or her cane-holding hand at the instant the cane tip lands on the depressed surface is different from a series of pressures the user had intermittently felt on his or her hand at the moments he or she tapped the walking surface during approach to the drop-off. A preliminary study's finding (Kim et al., 2009) that the constant contact technique has an advantage compared with the two-point touch technique in drop-off detection is consistent with the findings of previous studies that compared continuous stimuli with intermittent

stimuli in proprioceptive-kinesthetic or vibrotactile stimulus discrimination tasks (Gescheider et al., 1990; Kaplan et al., 1985; Wickelgren, 1966).

Cane tips are important because they are the part of the long cane that makes contact with the walking surface (Veterans Administration, 1964). A handheld probe's moment of inertia—resistance to angular acceleration—plays a critical role in haptic exteroception (Fitzpatrick, Carello, & Turvey, 1994; Solomon & Turvey, 1988; Solomon, Turvey, & Burton, 1989), including perception of vertical distance of a surface with a handheld probe (Chan & Turvey, 1991). The moment of inertia of a given long cane with respect to a fixed horizontal axis of rotation—related to lifting or lowering the cane tip by holding the other end of the cane along the sagittal plane—remains invariant regardless of the level of torque applied to rotate the cane with respect to a vertical axis of rotation (e.g., swinging the cane parallel to the transverse plane; Newman, 2008; Tipler, 1982). Required torque to sweep a long cane on a given surface is different between the cane tips of different coefficients of friction. Yet limited evidence exists in respect to whether the same vertical momentum created by the cane tip's vertical movement (from the walking surface to the depressed surface) can be psychophysically perceived as the same irrespective of the level of torque applied to the cane with respect to the vertical axis of rotation (Leung & Ciocca, 2004; Pagano & Cabe, 2003).

When examining the effect of different cane tips on drop-off detection performance, it is important to investigate such an effect in conjunction with the type of cane technique used in drop-off detection. This investigation is important because many cane tips have been designed to be used with specific cane techniques, and the cane techniques have a significant effect on drop-off detection performance (Kim et al., 2009).

Despite the importance of cane tips, only a small number of experimentally designed studies have examined how cane tips and other ergonomic factors affect cane performance. Rodgers and Wall Emerson (2005a) found that a cane shaft that is less flexible and lighter tends to help surface texture discrimination. Rodgers and Wall Emerson (2005b) also suggested that weight distribution of a cane does not affect texture discrimination, but a cane length that extends from the floor to 4 cm above the cane user's xiphoid process is optimal for drop-off detection.

In a single-subject study in which he performed all tasks as the sole participant, Rodgers (1991) reported that the standard (pencil) tip caused the most incidences of sticking, which was followed, in decreasing order of sticking, by marshmallow, scallop, metal glide, and curved tips. A few unpublished studies have also investigated the effects of different cane tips on frequency of sticking. Pietrowicz (1987) and Robertson (1987) found significantly fewer instances of sticking when using the marshmallow tip compared with using the pencil tip on a rural road and residential sidewalk, respectively. Wang (1991) found the ball tip to be superior to the marshmallow or metal glide tip in reducing the frequency of sticking in a rural area, and Lillie (1987) found significantly less sticking when a marshmallow roller tip was used than when a marshmallow tip was used in a semibusiness environment.

However, LaGrow, Kjeldstad, and Lewandowski (1988) found no significant difference in the frequency of sticking between the pencil, marshmallow, and curved tips. Yet it should be noted that the participants in the Rodgers (1991), Robertson (1987), Wang (1991), and Lillie (1987) studies used the constant contact technique, whereas those in the LaGrow et al. study used the two-point touch technique. Given the reported tendency of the two-point touch technique to stick less frequently than the constant contact technique (Fisk, 1986), the discrepancy between the findings of LaGrow et al. and the others may be at least partly a result of the use of different cane techniques.

Only one published experimental design study examined the effect of cane tips on drop-off detection. LaGrow et al. (1988) found no statistically significant difference in drop-off detection rate between the pencil, marshmallow, and curved tips; however, the participants in the LaGrow et al. study used only the two-point touch technique for all drop-off detection trials.

Currently, more than a dozen different types of cane tips with various dimensions and materials are commercially available. However, they tend to fall into the following five categories: standard (pencil), marshmallow (teardrop), ball, roller, and metal (or ceramic) glide. In a survey conducted with 98 cane users in 2005, marshmallow tip was rated as the most preferred cane tip in three of six functional categories, which include durability, resiliency, and strength (Ambrose-Zaken, 2005). Although roller tips were not rated high in this survey, personal communications with one of the major cane tip vendors (T. Russell, personal communication, September 23, 2008) and orientation and mobility (O&M) specialists (A. Kaufman, personal communication, February 2, 2009; M. J. Weessies, personal communication, February 4, 2009; S. Williams-Riseng, personal communication, February 5, 2009) indicated that its popularity has been growing in recent years.

One of the obstacles to more widespread use of the constant contact technique has been its propensity for sticking on walking surfaces (Fisk, 1986). Some of the cane users who preferred the constant contact technique in light of its ability to more reliably detect drop-offs (Kim et al., 2009) started using the constant contact technique with a roller tip to lessen the frequency of sticking (R. Saccoia, personal communication, March 30, 2008; S. Williams-Riseng, personal communication, January 31, 2009). Although roller tips appear to have ameliorated the sticking problem (Lillie, 1987), some cane users have stated that the use of a roller tip somewhat compromised their ability to detect drop-offs (D. Davis, personal communication, April 5, 2008; M. McCubbin, personal communication, March 16, 2008). Given such, one of the logical next steps is to examine whether the constant contact technique's advantage compared with the two-point touch technique in drop-off detection (Kim et al., 2009) can be maintained even when the constant contact technique is used with a tip that has a perceived disadvantage in drop-off detection (e.g., roller tip) and when the two-point touch technique is used with a tip that is perceived to be more advantageous in detecting drop-offs (e.g., marshmallow).

The Present Study

The four possible combinations that can be created by the two types of cane techniques and two types of cane tips included in this study are (a) two-point touch with marshmallow tip, (b) two-point touch with marshmallow roller tip, (c) constant contact with marshmallow tip, and (d) constant contact with marshmallow roller tip. However, marshmallow roller tips were not designed to be used with the two-point touch technique, primarily because of weight; therefore, we excluded the combination of the two-point touch technique with the marshmallow roller tip from the present study. Among the remaining three combinations, three possible comparisons can be made: (a) versus (c), (a) versus (d), and (c) versus (d). However, Kim et al. (2009) showed that the constant contact technique is better than the two-point touch technique in drop-off detection when both techniques were used with the marshmallow tip. Given such, this study aimed to answer the following two primary research questions: First, is the marshmallow tip better than the marshmallow roller tip in drop-off detection when both tips are used with the constant contact technique, and second, is the constant contact technique used with the marshmallow roller tip better than the two-point touch technique used with the marshmallow tip in drop-off detection? As a secondary research question, this study also examined the interactions between drop-off depth and the conditions included in the primary research questions.

METHOD

Study Design and Recruitment Criteria

This study was conducted in 2009 as part of a larger study on factors related to drop-off detection. A repeated-measures design with block randomization was used for the study. We recruited 17 adults who were legally blind and had no other disabilities. At least 1 month of cane training as well as familiarity with and current use of both two-point touch and constant contact techniques was also required.

Apparatus

A 9.8-m-long walkway with six carpeted plywood platforms (2.4 m long, 1.2 m wide, 20.3 cm high) was used for the study (see Figure 1). The walkway was 1.2 m wide for the first 4.9 m and 2.4 m wide for the latter 4.9 m. We placed two plywood boards (0.6 m long, 1.2 m wide) laid on top of braced rectangular frames (0.6 m long, 1.2 m wide, 5.1 cm high) against the lengthwise end of the walkway to vary the drop-off depth from trial to trial. We used carpeting on the plywood boards that is identical to that on the walkway to prevent the participants from using tactile and/or auditory cues for drop-off detection.

Identical canes (Ambutech UltraLite Graphite Rigid Cane) were used for all trials. Definition of proper cane length outlined in LaGrow and Weessies (1994)—vertical distance from the ground to 5.1 cm above the cane user's xiphoid process—was used to determine the appropriate cane length for each participant. The marshmallow roller tip (Ambutech MT4090 Marshmallow Roller Tip; 4.6 mm in length, 3.2 mm in diameter, 40 g) and the marshmallow tip (Ambutech MT4080 High Mileage Tip; 3.5 mm in length, 2.5 mm in diameter, 16 g) were used in this study (see Figure 2). Each trial was recorded with a digital camcorder (Panasonic SDR-S10P1). Further details of the apparatus and research procedure are available in Kim et al. (2009).

Experimental Procedure

All experiments were conducted in a 2.4-m-wide concrete hallway in Western Michigan University's (WMU) College of Health and Human Services building basement (see Figure 1). After arriving at the study site, each participant signed the informed consent form approved by WMU's Human Subjects Institutional Review Board. Sleep shades and a full-size headphone set (RadioShack Full-Size Stereo Headphone 33-1225) connected to an MP3 player (Apple iPod 5th Generation) were worn by each participant during all trials. Through the headphone set, participants heard rhythmic beats (90 to 110 beats per minute) over a white noise background (recorded by Sound for Life). The experimenter (a certified O&M specialist) set the speed of the rhythmic beats per each participant's relaxed stepping speed and instructed the participant to synchronize his or her steps to the beats. Such instruction was designed to help the participant walk at an unchanging pace throughout the trials, limiting the potential confounding effect of walking speed on drop-off detection performance.

We varied the starting points randomly (4.3 m to 9.1 m from the drop-off) from trial to trial to prevent the participants from estimating the distance to the drop-off. Participants walked toward the drop-off using either the two-point touch technique or the constant contact technique upon a tap on the shoulder by the experimenter. Participants stopped instantly upon detecting the drop-off and said, "Drop-off." When a participant failed to detect the drop-off, the experimenter, if needed, intervened to keep the participant from tumbling off the drop-off in a similar manner as is used when teaching mobility skills.

Each participant completed eight trials for each drop-off depth (2.5 cm, 7.6 cm, 12.7 cm, 17.8 cm) for the following three conditions: (a) constant contact technique used with a marshmallow tip, (b) constant contact technique used with a marshmallow roller tip, and (c) two-point touch technique used with a marshmallow tip. That is, each participant completed a total of 96 trials. We used the block randomization method to vary the drop-off depth from trial to trial. We also used a Latin square design to control for possible order effects. We recorded a trial as a miss if the participant fell off the drop-off or would have fallen off the drop-off had it not been for the experimenter's intervention. In other words, a trial was recorded as either a "miss" or "detected." An independent rater scored a random selection of one third of the trials by watching a video that had been prerecorded; interrater reliability was 97%. On-site records were used when there was a discrepancy.

Variables

Absolute drop-off detection threshold (50%) and drop-off detection rates were used as the measures of drop-off detection performance (dependent variables). We calculated the 50% absolute drop-off detection threshold for each of the three conditions stated above using the psychometric function outlined in Gescheider (1997, pp. 45–48). That is, a normal cumulative distribution curve was fitted to the data points for extrapolating the drop-off depth detected 50% of the time (threshold). We computed drop-off detection rates 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).

The type of cane tip used in drop-off detection trial, which is a within-group variable with two categories (marshmallow, marshmallow roller), and the type of cane technique used in drop-off detection trial, which is also a within-group variable with two categories (two-point touch, constant contact), were the independent variables of the study.

Analyses

After completion of descriptive statistical procedures, a two-way repeated-measures ANOVA and within-subjects *t* tests were used to test the hypotheses. Wilcoxon signed-ranks tests were used when the assumption of normality was violated. We used a significance level of .05 for all statistical tests (two tailed). Statistical powers of *F* tests and *t* tests were .82 or higher when a large effect size ($f = .4$ or $d = .8$) was assumed (Cohen, 1988; Erdfelder, Faul, & Buchner, 1996). All statistical analyses, except for power analyses (G*Power Version 3.0.10), were conducted with SPSS Version 16.0.

RESULTS

Participant Demographics

For this study, 9 female and 8 male adults who were visually impaired participated. Visual acuities ranged from 20/200 to no light perception. Causes of visual impairment included retinopathy of prematurity ($n = 3$), diabetic retinopathy ($n = 2$), retinitis pigmentosa ($n = 2$), microphthalmia ($n = 2$), and others ($n = 8$). Visual impairment occurred at age 4 or younger for 7 participants, and it occurred beyond age 4 for the remainder. Participants' preferred cane tip included metal glide ($n = 8$), marshmallow roller ($n = 4$), pencil ($n = 3$), marshmallow ($n = 1$), and ball roller ($n = 1$).

Participants' age varied from 23 years to 75 years (median = 37). Of the sample, 9 participants used the two-point touch technique more frequently (60% to 90% of the time; median = 75%), and the remainder used the constant contact technique more often (60% to 90%; median = 75%). Half of the older participants (older than 50 years) preferred the two-point touch technique ($n = 2$), and the other 2 preferred the constant contact technique.

Similarly, approximately half of the younger participants preferred the two-point touch technique ($n = 7$), whereas the remaining 6 preferred the constant contact technique.

Comparison of Marshmallow and Marshmallow Roller Tips

There was no statistically significant difference in drop-off detection threshold between the marshmallow ($M = 4.65$ cm, $SD = 2.62$ cm) and marshmallow roller tips ($M = 4.29$ cm, $SD = 2.29$ cm) when both tips were used with the constant contact technique, $t(16) = .871$, $p = .397$ (see Figure 3). The difference between the marshmallow ($M = 77.0\%$, $SD = 13.2\%$) and marshmallow roller tips ($M = 79.4\%$, $SD = 11.9\%$) was not statistically significant for the overall drop-off detection rate, either, $F(1, 16) = 1.178$, $p = .294$. A post hoc power analysis indicated that this sample size ($N = 17$), with two-tailed tests and $\alpha = .05$, yields statistical power of .29 for effect size of this magnitude ($f = .13$).

Drop-off detection performance improved as the depth of the drop-off increased, albeit with a declining rate (see Figure 4). In fact, the large drop-off (12.7 cm, 17.8 cm) detection rate was identical for the two cane tips ($M = 99.3\%$, $SD = 2.1\%$). There was no statistically significant interaction between the type of cane tip and drop-off depth, $F(1, 16) = .486$, $p = .496$.

The drop-off detection threshold of the constant contact technique used with the marshmallow roller tip ($M = 4.29$ cm, $SD = 2.29$ cm) was statistically significantly smaller than that of the two-point touch technique used with the marshmallow tip ($M = 7.39$ cm, $SD = 2.59$ cm), $t(16) = 6.300$, $p < .001$ (see Figure 5). In other words, participants could detect much smaller drop-offs when using the constant contact technique with the marshmallow roller tip than when using the two-point touch technique with the marshmallow tip.

The overall drop-off detection rate of the constant contact technique used with the marshmallow roller tip ($M = 79.4\%$, $SD = 11.9\%$) was statistically significantly higher than that of the two-point touch technique used with the marshmallow tip ($M = 63.2\%$, $SD = 12.6\%$), $F(1, 16) = 40.386$, $p < .001$. There was a significant interaction between drop-off depth and the method of drop-off detection (two-point touch technique with a marshmallow tip vs. constant contact technique with a marshmallow roller tip), $F(1, 16) = 21.942$, $p < .001$. Drop-off detection rate difference between these two drop-off detection methods gradually decreased as the drop-off depth increased, albeit with an exception of 7.6-cm drop-off detection rate (see Figure 6).

For large drop-offs (12.7 cm, 17.8 cm), the drop-off detection rate difference between the constant contact technique used with the marshmallow roller tip ($M = 99.3\%$, $SD = 2.1\%$) and the two-point touch technique used with the marshmallow tip ($M = 96.3\%$, $SD = 5.9\%$) was not statistically significant, $z = -1.930$, $p = .054$. However, it was worth noting that even for large drop-offs, which if missed may pose a serious risk of falling, participants still missed 1 in 27 drop-offs when they used the two-point touch technique with the marshmallow tip, whereas they missed less than 1 in 100 drop-offs when they used the constant contact technique with the marshmallow roller tip. Although not statistically significant ($U = 11.5$, $p = .064$), perhaps because of low statistical power, this difference was larger for the participants who were older than 50 ($M = 7.8\%$, $SD = 7.9\%$, $n = 4$) than for those who were younger ($M = 1.4\%$, $SD = 4.5\%$, $n = 13$).

In a random sample of one third of the trials examined via prerecorded video, the experimenter had to provide manual assistance to prevent stumbling participants from falling each time they missed a large drop-off (12.7 cm, 17.8 cm). Participants stumbled and were provided assistance to prevent falling 77% of the time in the trials in which they missed a 7.6-cm drop-off. However, participants stumbled and thus needed the

experimenter's intervention in only 15% of the trials in which they missed a 2.5-cm drop-off.

DISCUSSION

The constant contact technique used with a marshmallow roller tip (perceived as a less advantageous tip) was more effective than the two-point touch technique used with a marshmallow tip (perceived as more advantageous tip) in detecting drop-offs. However, drop-off detection performance was similar between the marshmallow and marshmallow roller tips when the constant contact technique was used for both cane tips.

Similarity in drop-off detection performance between the marshmallow and marshmallow roller tips (see Figure 3) when both tips were used with the constant contact technique is contrary to some of the cane users' perceived advantage of the marshmallow tip versus the marshmallow roller tip. One hypothesis that could be proposed to explain this result is that the difference in coefficient of friction between the two cane tips and resulting difference in required torque to sweep the cane on the walking surface does not significantly affect drop-off detection performance; this explanation is consistent with the findings of Pagano and Cabe (2003) in that participants could differentiate the moment of inertia related to the probe length perception (or surface depth perception) from the torque required to wield the probe side to side. However, a counterargument could be made, given the carpeted walkway that was used in the study. In other words, it is possible that the experimental design of this study did not sufficiently allow a potentially important difference between the marshmallow and marshmallow roller tips—the amount of friction against the walking surface—to affect drop-off detection performance. Differences in diameter and weight between the two cane tips could also have confounded the result. However, LaGrow et al. (1988) reported that there was no statistically significant difference in drop-off detection performance between the cane tips with different diameters. In addition, adding a moderate extra weight (up to 105 g) at the end of a rod did not appear to have affected the accuracy of vertical distance estimation (Chan & Turvey, 1991).

The constant contact technique was superior to the two-point touch technique even when the former was used with a cane tip perceived to be disadvantageous for drop-off detection (marshmallow roller; see Figure 5). This result is consistent with the findings of previous studies that demonstrated the advantage of continuous stimuli compared with intermittent stimuli in proprioceptive-kinesthetic and vibrotactile stimulus discrimination tasks (Gescheider et al., 1990; Kaplan et al., 1985; Wickelgren, 1966). The fact that older cane users, who are more prone to falls, did not miss any large drop-offs (12.7 cm, 17.8 cm) when they used the constant contact technique with the marshmallow roller tip, whereas they missed 1 in 13 large drop-offs when they used the two-point touch technique with the marshmallow tip, suggests practical significance of the constant contact technique's advantage compared with the two-point touch technique.

Order effect was controlled for by the use of Latin square design. In addition, the within-subject design allowed each participant to serve as his or her own control for potential confounding by variables, such as age, experience, vision, preferred cane technique, and preferred cane tip. However, despite our efforts to include more older and less experienced cane users in our sample, only 4 participants who were older than 50 and 3 participants who had less than 2 years of cane use experience participated, which limits the generalizability of the findings to less experienced and older populations. In addition, we tested only two of the many widely used cane tips in this study. Furthermore, the smooth walking surface used in the study may not have adequately reflected the walking surface blind travelers encounter every day, which may include rough and uneven sidewalks as well as unpaved surfaces.

There are times O&M specialists recognize situations in which it would be more beneficial for the individual to use the constant contact technique than the two-point touch technique because of the need to detect drop-offs more reliably. Some cane users have shied away from using a roller tip (which appears to reduce the tendency to stick) in conjunction with the constant contact technique in fear of compromising their ability to detect drop-offs. Given the findings of this study, O&M specialists may consider suggesting the constant contact technique with a marshmallow roller tip without the worry of compromised ability to detect drop-offs. However, the readers should not interpret the findings of this study as a suggestion to teach and use only the constant contact technique. Benefits and drawbacks of each cane technique, characteristics of the cane user (physical abilities, cane use experience), and the environment the person travels need to be carefully evaluated before selecting a cane training strategy for an individual or an appropriate cane technique for a given environment.

Investigation of the cane tips other than the marshmallow and marshmallow roller tips may be needed, given the variety of cane tips currently used by blind travelers. Exploring other ergonomic factors, including flexibility, length, and weight of the cane shaft, would also be important for fuller understanding of how ergonomic factors affect drop-off detection performance. In addition, examining the findings of this study in a more ecologically valid environment, such as an actual sidewalk with surface irregularities, would be necessary to test the practical applicability of the study findings.

KEY POINTS

- Drop-off detection rates were similar between the marshmallow tip (77.0%) and the marshmallow roller tip (79.4%) when both tips were used with the constant contact technique.
- However, participants detected drop-offs at a significantly higher rate when they used the constant contact technique with the marshmallow roller tip (79.4%) than when they used the two-point touch technique with the marshmallow tip (63.2%).
- The findings of the study may help cane users and O&M specialists select appropriate cane techniques and cane tips in accordance with the cane user's characteristics and the nature of the travel environment.

Acknowledgments

This project was supported by Grant No. 2R01 EY12894-07 from the National Eye Institute, National Institutes of Health. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the National Eye Institute.

REFERENCES

- Ambrose-Zaken G. Knowledge of and preferences for long cane components: A qualitative and quantitative study. *Journal of Visual Impairment & Blindness* 2005;99:633–645.
- Armstrong, JD. Evaluation of man-machine systems in the mobility of the visually handicapped. In: Pickett, RM.; Triggs, TJ., editors. *Human factors in health care*. Lexington, MA: Lexington Books; 1975. p. 331-343.
- Blasch BB, De l'Aune W. A computer profile of mobility coverage and a safe index. *Journal of Visual Impairment & Blindness* 1992;86:249–254.
- Blasch BB, LaGrow SJ, De l'Aune W. Three aspects of coverage provided by the long cane: Object, surface, and foot-placement preview. *Journal of Visual Impairment & Blindness* 1996;90:295–301.

- Bongers RM, Schellingerhout R, van Grinsven R, Smitsman AW. Variables in the touch technique that influence the safety of cane walkers. *Journal of Visual Impairment & Blindness* 2002;96:516–531.
- Chan T, Turvey MT. Perceiving the vertical distances of surfaces by means of a hand-held probe. *Journal of Experimental Psychology: Human Perception and Performance* 1991;17:347–358. [PubMed: 1830080]
- Cohen, J. Statistical power analysis for the behavioral sciences. 2nd ed.. Mahwah, NJ: Erlbaum; 1988.
- De Bruin D. The constant contact technique. *American Association of Workers for the Blind Newsletter*. 1981 June; n.p.
- Erdfelder E, Faul F, Buchner A. Gpower: A general power analysis program. *Behavior Research Methods, Instruments, & Computers* 1996;28:1–11.
- Fisk S. Constant-contact technique with a modified tip: A new alternative for long-cane mobility. *Journal of Visual Impairment & Blindness* 1986;80:999–1000.
- Fitzpatrick P, Carello C, Turvey MT. Eigenvalues of the inertia tensor and exteroception by the muscular sense. *Neuroscience* 1994;60:551–567. [PubMed: 8072695]
- Gescheider, GA. Psychophysics: The fundamentals. 3rd ed.. Mahwah, NJ: Erlbaum; 1997.
- Gescheider GA, Bolanowski SJ, Verrillo RT, Arpajian DJ, Ryan TF. Vibrotactile intensity discrimination measured by three methods. *Journal of the Acoustical Society of America* 1990;87:330–338. [PubMed: 2299043]
- Hill, EW.; Ponder, P. Orientation and mobility techniques: Guide for the practitioner. New York, NY: American Foundation for the Blind; 1976.
- Hoover, RE. The cane as a travel aid. In: Zahl, PA., editor. *Blindness: Modern approaches to the unseen environment*. New York, NY: Hafner; 1962. p. 353-365.
- Kaplan FS, Nixon JE, Reitz M, Rindfleish L, Tucker J. Age-related changes in proprioception and sensation of joint position. *Acta Orthopaedica* 1985;56:72–74.
- Kim D, Wall Emerson RS, Curtis AB. Drop-off detection with the long cane: Effects of different cane techniques on performance. *Journal of Visual Impairment & Blindness* 2009;103:519–530.
- LaGrow SJ, Blasch BB, De l'Aune W. Efficacy of the touch technique for surface and foot-placement preview. *Journal of Visual Impairment & Blindness* 1997;91:47–52.
- LaGrow SJ, Kjeldstad A, Lewandowski E. The effects of cane-tip design on three aspects of nonvisual travel. *Journal of Visual Impairment & Blindness* 1988;82:13–16.
- LaGrow, SJ.; Weessies, MJ. Orientation and mobility: Techniques for independence. Palmerston North, New Zealand: Dunmore Press; 1994.
- Leung M, Ciocca V. The effect of vertical tongue loading on position perception of the tongue. *Perception & Psychophysics* 2004;66:1115–1124. [PubMed: 15751470]
- Lillie, CA. The effects of cane tip design when using the constant contact cane technique. Kalamazoo: Western Michigan University; 1987. (Unpublished master's thesis)
- McClure R, Turner C, Peel N, Spinks A, Eakin E, Hughes K. Population-based interventions for the prevention of fall-related injuries in older people. *Cochrane Database of Systematic Reviews* 2005;1 Article No. CD004441. doi:10.1002/14651858.CD004441.pub2.
- Miller ME, Hoover RE. Foot travel without sight. *Outlook for the Blind* 1946;40:244–251.
- Newman, J. Physics of the life sciences. New York, NY: Springer Science+Business Media; 2008.
- Pagano CC, Cabe PA. Constancy in dynamic touch: Length perceived by dynamic touch is invariant over changes in media. *Ecological Psychology* 2003;15:1–17.
- Pietrowicz, D. The effect of the marshmallow tip on cane sticking rates on a group of visually impaired veterans in a rural travel setting. Kalamazoo: Western Michigan University; 1987. (Unpublished master's thesis)
- Robertson, LE. The effects of cane tip design and cane technique on sticking. Kalamazoo: Western Michigan University; 1987. (Unpublished master's thesis)
- Rodgers, MD. Dissertation Abstracts International. Vol. 53. 1991. A human factors analysis of the long cane. (UMI No. 746490191)
- Rodgers MD, Wall Emerson R. Human factor analysis of long cane design: Weight and length. *Journal of Visual Impairment & Blindness* 2005a;99:622–632.

- Rodgers MD, Wall Emerson R. Materials testing in long cane design: Sensitivity, flexibility, and transmission of vibration. *Journal of Visual Impairment & Blindness* 2005b;99:696–706.
- Rose S, Maffulli N. Hip fractures. An epidemiological review. *Hospital for Joint Diseases Bulletin* 1999;58:197–201.
- Schellingerhout R, Bongers RM, Grinsven R, van, Smitsman AW, van Galen GP. Improving obstacle detection by redesign of walking canes for blind persons. *Ergonomics* 2001;44:513–526. [PubMed: 11345494]
- Solomon HY, Turvey MT. Haptically perceiving the distances reachable with hand-held objects. *Journal of Experimental Psychology: Human Perception and Performance* 1988;14:404–427. [PubMed: 2971770]
- Solomon HY, Turvey MT, Burton G. Gravitational and muscular variables in perceiving rod extent by wielding. *Ecological Psychology* 1989;1:265–300.
- Tipler, PA. *Physics*. 2nd ed.. New York, NY: Worth; 1982.
- Veterans Administration. Specifications for the long cane (Typhlocane). Washington, DC: Author; 1964.
- Wall RS, Ashmead DH. Changes in biomechanical features of the two-point touch technique as it is learned. *Journal of Visual Impairment & Blindness* 2002;96:829–841.
- Wang, W. The effects of cane-tip design on nonvisual travel in rural areas. Kalamazoo: Western Michigan University; 1991. (Unpublished master's thesis)
- Wickelgren WA. Consolidation and retroactive interference in short-term recognition memory for pitch. *Journal of Experimental Psychology* 1966;72:250–259. [PubMed: 5966625]

Biographies

Dae Shik Kim is an assistant professor in the Department of Blindness and Low Vision Studies at Western Michigan University in Kalamazoo. He received his PhD in interdisciplinary health sciences at Western Michigan University in 2009.

Robert S. Wall Emerson is an associate professor in the Department of Blindness and Low Vision Studies at Western Michigan University in Kalamazoo. He received his PhD in education and human development at Vanderbilt University in 1999.

Amy B. Curtis is an associate professor in the Interdisciplinary Health Sciences PhD Program at Western Michigan University in Kalamazoo. She received her PhD in epidemiologic science at the University of Michigan in 1997.

Figure 1.
Participant approaching the drop-off on the walkway.

Figure 2.
Marshmallow tip (left) and marshmallow roller tip (right).

Figure 3.
The 50% absolute drop-off detection thresholds of two cane tips when both tips were used with constant contact technique. Error bars indicate 95% confidence intervals.

Figure 4. Drop-off detection rates of different cane tips by drop-off depth (when both tips were used with constant contact technique).

Figure 5. The 50% absolute drop-off detection thresholds of two cane techniques when equipped with different cane tips. Error bars indicate 95% confidence intervals.

Figure 6. Drop-off detection rates by depth of combinations of type of cane technique and type of cane tip.