Obstacle Detection with the Long Cane: Effect of Cane Tip Design and Technique Modification on Performance

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Structured abstract: *Introduction:* The purpose of this study was to investigate the effect of cane tip design and cane technique modification on obstacle detection performance as they interact with the size, height, and position of obstacles. *Methods:* A repeated-measures design with block randomization was used for the study. In experiment one, participants attempted to detect obstacles with either a marshmallow tip or a bundu basher tip. In experiment two, participants were asked to detect obstacles using either the constant-contact technique or a modified constant-contact technique. *Results:* As predicted, the obstacle detection rate with the bundu basher tip (M = 66.1%, SD = 7.4%) was significantly higher than that with the marshmallow tip (M = 54.6%, SD = 6.8%), $F(1, 11) = 24.19$, $p < .001$, $r = .83$. However, contrary to our hypothesis, the obstacle detection rate with the modified constant-contact technique (M = 56.0%, SD = 7.4%) was significantly lower than that with the constant-contact technique (M = 61.3%, SD = 5.2%), $F(1, 13) = 6.49$, $p = .024$, $r = .58$. In addition, participants detected the obstacles that were positioned at the center of their walking path (M = 61.9%, SD = 6.6%) at a significantly higher rate than those positioned slightly off to the side (M = 55.4%, SD = 7.3%), $F(1, 13) = 10.73$, $p = .006$, $r = .67$. *Discussion:* A bundu basher tip was more advantageous than the marshmallow tip for detecting obstacles. *Implications for practitioners:* Given the findings of the study, cane users and orientation and mobility (O&M) specialists should consider using or recommending a bundu basher tip (or a similar tip that has an increased contact area with the walking surface), particularly when the traveling environment often presents unexpected obstacles that may trip the cane user.

Modern long cane design and techniques have changed little since their development in the 1940s. The two-point touch technique—swinging the cane from side to side and tapping the edges of one's walking path in an arc slightly wider than the widest part of one's body—has been the standard long cane technique in its history (LaGrow & Long, 2011). The constant-contact technique—sweeping the cane from side to side, keeping the cane tip in constant contact with the walking

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surface—is also widely used among cane users (De Bruin, 1981). Regardless of which cane design or technique is used, obstacle detection, a key component of preview offered by a long cane (Blasch, LaGrow, & De l'Aune, 1996), is crucial for the safety of travelers who are visually impaired (that is, those who are blind or have low vision). Obstacles such as construction cones or toys left on the sidewalk, when undetected, may trip the cane user, resulting in falls and consequent fall-induced injuries.

Key functions of a long cane include detection of drop-offs and obstacles (Blasch et al., 1996). Several recent studies have examined how different biomechanical and ergonomic factors affect drop-off detection with the long cane. Cane users detected drop-offs more reliably when they used the constant-contact technique than when they used the two-point touch technique, particularly if they were inexperienced cane users (Kim, Wall Emerson, & Curtis, 2009, 2010). Cane users also detected drop-offs better when they limited the cane arc width to approximately one inch beyond the widest part of the body compared to when they swung it a foot wider on both sides (Kim, Wall Emerson, & Naghshineh, 2017). In addition, cane users detected drop-offs at a higher percentage with a heavier cane than with a lighter cane (Kim, Wall Emerson, Naghshineh, & Auer, 2017) and with a standard-length cane—determined by the sternum method as outlined in LaGrow and Long (2011)—than with an extended-length cane, which was 16 inches longer than the standard length (Kim et al., 2017).

With respect to the biomechanical factors affecting obstacle detection, LaGrow, Blasch, and De l'Aune (1997a) reported that participants achieved the greatest detection distance for foot-level objects when their cane-holding hand was held at the midline and was positioned below the waist. In another study, LaGrow, Blasch, and De l'Aune (1997b) also documented that the two-point touch technique did not provide consistent surface preview for four of seven participants. Wall and Ashmead (2002) found that pivoting the wrist when swinging the cane resulted in better body coverage than moving the whole arm. More recently, Kim and Wall Emerson (2014) reported that the constant-contact technique was better than the two-point touch technique for detecting shorter obstacles, but there was no significant difference in obstacle detection performance between the two techniques for taller obstacles.

As for the ergonomic factors that affect obstacle detection, Bongers et al. (2002) documented that the longer the cane, the better the body coverage, while Kim et al. (2017) reported that a 16-inch difference in cane length did not have a significant effect on obstacle detection performance. In addition, several researchers in computer science and engineering disciplines recently tested the effectiveness of prototype electronic canes or wearable devices for detecting obstacles. Most of these devices have been designed as a secondary device, complementing a traditional long cane as an attachment to the cane (Gallo et al., 2010; Kim & Cho, 2013; O'Brien, Mohtar, Diment, & Reynolds, 2014; Pyun, Kim, Wespe, Schneller, & Gassert, 2013; Tahat, 2009; Wang & Kuchenbecher, 2012). The majority of these studies reported a modest improvement in the object detection rate, largely

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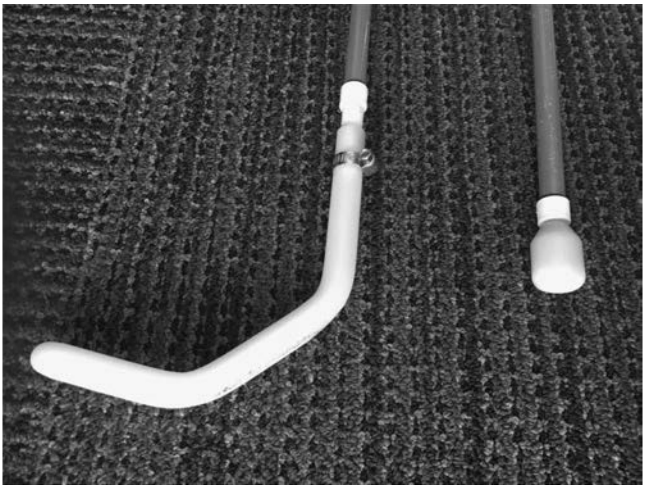

Figure 1. Bundu basher tip (left) and marshmallow tip (right).

as a result of detecting above-waist-level overhanging obstacles, which are inherently undetectable by the traditional use of a long cane. Although a few standalone electronic devices designed for replacing a long cane have also been tested (Bhatlawande et al., 2014a, 2014b; Bouhamed, Kallel, & Masmoudi, 2013; Jeslin, Vaishnavi, & Nivedha, 2015), none of these devices demonstrated the ability to reliably detect even large drop-offs, which limits the practical implications of these devices in their current forms for enhancing the safety of blind travelers.

Cane tip design appears to be an important factor in obstacle detection because the tip is the part of the cane that frequently makes contact with encountered obstacles. Schellingerhout, Bongers, van Grinsven, Smitsman, and van Galen (2001) reported that a long cane with a shaft bent on the cane tip end with an aim to increase the contact area with the walking surface resulted in a significantly higher rate of obstacle detection than a traditional long cane with a straight shaft. Although not widely used in the United States, a bundu basher tip (see Figure 1), originally developed in the bush country in Africa with the apparent aim of reducing the cane's tendency to stick on rough surfaces, provides an increased contact area with the walking surface somewhat similar to the way Schellingerhout et al.'s (2001) bent cane did. Given that replacing a cane tip is an easier and more practical way to increase the cane's contact area with the walking surface than bending the cane shaft in specified angles—some shaft materials such as graphite or carbon fiber are not amenable to angular bending—we examined whether a bundu basher tip would allow the participants to more reliably detect obstacles of different sizes and heights.

In respect to cane techniques, although the constant-contact technique was found to be better than the two-point touch technique for detecting shorter obstacles, it is important to note that the overall obstacle detection rate was only 56% even when the constant-contact technique was used (Kim & Wall Emerson, 2014). In addition, tall obstacles (five-inch- and seven-inch-tall obstacles), which pose a serious risk of tripping if missed, were still undetected by the participants a third of the time (Kim & Wall Emerson, 2014). Interestingly, four decades ago Uslan (1978) reported that by modifying the two-point touch technique—having the cane user swing the cane, pivoting from the elbow as well as from the wrist, keeping the orientation of the cane parallel to the cane user's line of travel at all times—the coverage rate increased from 69% to 100% (full path coverage). Although Uslan (1978) calculated the coverage rate based on the coordinates he generated by having the participants walk on a portable pathway with an electrical ladder network (rather than using actual obstacles), accomplishing a full path coverage was clearly noteworthy. Given that, we designed a study to determine whether similar results would be obtained when the participants are presented with actual obstacles of different sizes on their walking path. The purpose of the present study was to investigate the effect of the cane tip design and cane technique modification on obstacle detection performance as they interact with the size (diameter), height, and position of the obstacles.

Experiment one (cane tip design)

Methods

Study design and participants

A repeated-measures design with block randomization was used for the study. Twelve students (seven female and five male) aged 22 to 37 years (median age = 25 years) from Western Michigan University's (WMU) orientation and mobility (O&M) program participated in the study. Two were visually impaired (visual acuities ranged from 20/50 to no light perception), and the remaining participants had typical vision. The participants were familiar with basic cane techniques, including the constant-contact technique. Cane-use experience of the visually impaired participants ranged from 3 to 11 years (median = 7 years), and that of the sighted participants (blindfold training) ranged from 1 month to 4 months (median = 4 months).

Apparatus

Each participant used a graphite rigid long cane (Ambutech UltraLite Graphite Rigid Cane) with a marshmallow tip (Ambutech MT4080 High Mileage Tip) or a bundu basher tip (Bevria) (see Figure 1). A proper length of the cane was determined for each participant according to his or her height, as outlined in LaGrow and Long (2011). Circular objects of different sizes (diameters of two, six, 10, and 14 inches) and heights (one, three, five, and seven inches) constructed with Styrofoam and linoleum were used for the study. These objects were presented on a participant's walking path either at the midline or slightly off to the side of the walking path (six inches off either to the left or right from the midline) following a randomized schedule. A 20-foot-long rail (3 feet high), built with PVC pipes, was placed next to the walking path for participants to trail with the free hand, enabling them to walk consistently along the midline of the intended walking path (see Figure 2). This measure was designed to ensure that the participants encountered the obstacles at the intended relative positions from the sagittal plane of their body (see Kim et al., in press,

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Figure 2. Participant approaching the obstacle on the obstacle detection path along the 20-foot-long guide rail.

and Kim & Wall Emerson, 2014 for further details of the study apparatus and procedure).

Research procedure

Upon arriving at the study site, each participant signed the informed consent form approved by WMU's Human Subjects Institutional Review Board. During all trials, all participants wore sleep shades and a full-size headphone set (Sony MDR-ZX770BT) that was wirelessly connected to a digital audio (MP3) player (iPod Touch 5th Generation), through which they heard regular beats over white noise (recorded by Sounds for Life). Background white noise was utilized to prevent the participants from using auditory cues for detecting obstacles, while the regular beats (90 to 110 beats per minute) helped them walk at a consistent pace through the trials. Each participant was positioned on the midline of the obstacle detection walking path and properly aligned with the path before the beginning of each trial. To prevent them from anticipating the obstacle at a predictable distance, the distance between the participant and the obstacle was randomly varied from 10 to 20 feet. At a signal from the experimenter, the participant approached the obstacle on the indicated walking path using the constant-contact technique.

In half of the trials, the participants used a marshmallow tip, and they used a bundu basher tip in the other half. Each participant completed six trials for each of the 16 size-height combinations (four sizes × four heights) for each of the two cane tip conditions (a total of 192 trials per participant). Each participant was instructed to stop immediately and say "obstacle" upon detecting an obstacle with the cane. 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; interrater reliability was 98%.

Variables and analyses

The obstacle detection rate was calculated by dividing the total number of detections by the total number of trials. Type of cane tip, obstacle size (diameter), and obstacle height were the independent variables. Upon completion of descriptive statistical procedures, we used a three-way repeated-measures ANOVA to answer our research questions. Given that the variability of proportions is not constant across the range of 0 and 1 (that is, variability peaks at .5 and declines to zero at 0 and 1), raw

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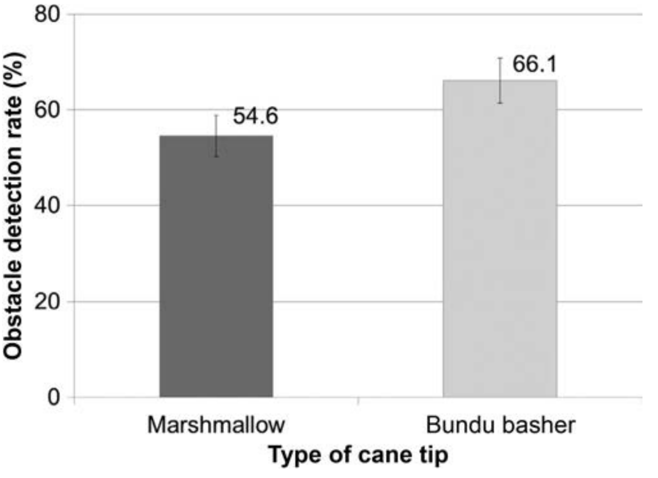

Figure 3. Obstacle detection performance by different cane tips. Error bars indicate 95% confidence intervals.

percentages were converted to rationalized arcsine units (RAU) before ANOVA was performed (Studebaker, 1985). RAU scores were converted back to percentages for reporting descriptive results (for example, means and standard deviations for given conditions). In case of the violation of the sphericity assumption, adjustments were made to the ANOVA results by using the Greenhouse-Geisser degree of freedom correction. We used a significance level of .05 for all statistical tests (two-tailed). The statistical power of the main-effect F-tests was .71 or higher when a large effect size ($f = .4$) was assumed (Cohen, 1988; Erdfelder, Faul, & Buchner, 1996). All statistical analyses, except for power analyses (G*Power version 3.1), were conducted with SPSS version 24.

Results

Overall, participants were able to detect the obstacles 60.3% (SD = 5.9%) of the time. The obstacle detection rate with the bundu basher tip (M = 66.1%, SD = 7.4%) was statistically significantly higher than that with the marshmallow tip: M = 54.6%, SD = 6.8%, $F(1, 11) = 24.19$, $p < .001$, $r = .83$ (see Figure 3). Obstacle detection performance improved as the size (diameter) of the obstacle increased, $F(3, 33) = 95.44$, $p < .001$. Similarly, the taller the obstacle, the higher the detection rate, $F(3, 33) = 35.92$, $p < .001$. None of the two-way interactions were statistically significant: cane tip × obstacle size, $F(3, 33) = .40$, $p = .756$; cane tip × obstacle height, $F(2.1, 23.4) = .33$, $p = .805$; and obstacle size × obstacle height, $F(9, 99) = 1.00$, $p = .446$. The three-way interaction was not statistically significant either, $F(9, 99) = 1.53$, $p = .149$.

When examined purely descriptively within the sample, the obstacle detection rate of the visually impaired participants (M = 67.4%, SD = 1.1%, $n = 2$) was somewhat higher than that of the sighted participants (M = 58.9%, SD = 5.4%, $n = 10$). However, the groups benefited from the bundu basher tip similarly—from 63.0% to 71.9% for the visually

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Figure 4. Modified constant-contact technique—wrist, elbow, and shoulder joints move in conjunction with one another to keep the orientation of the cane parallel to the cane user's line of travel at all times.

impaired group; from 52.9% to 64.9% for the sighted group.

Experiment two (cane technique modification)

Methods

Study design and participants

A repeated-measures design with block randomization was used for the study. We recruited 14 sighted students (10 female and 4 male) aged 24 to 51 years (median age = 32 years) from WMU's O&M program. The participants were familiar with basic cane techniques, including the constant-contact technique, and their cane use experience ranged from one month to four months (median experience = one month).

Apparatus

The apparatus used for experiment two was the same as described in experiment one except that only the seven-inch-high obstacles of three different sizes (diameters of 2, 6, and 10 inches) were used for the study. Being 7 inches tall, these obstacles posed a greater risk of tripping the cane user if missed than the shorter ones. Unlike in experiment one, only the marshmallow tip was used in experiment two.

Research procedure

The research procedure used for experiment two was the same as described in experiment one, except that in half of the trials the participants used the constant-contact technique, while in the other half they used the modified constant-contact technique similar to the modified two-point touch technique Uslan (1978) described in his study. That is, the participants swung their arm across the body, engaging the shoulder, elbow, and wrist joints concurrently, so that the orientation of the cane was kept parallel to the line of travel at all times (see Figure 4). This method is in contrast to the traditional constant-contact technique, which involves

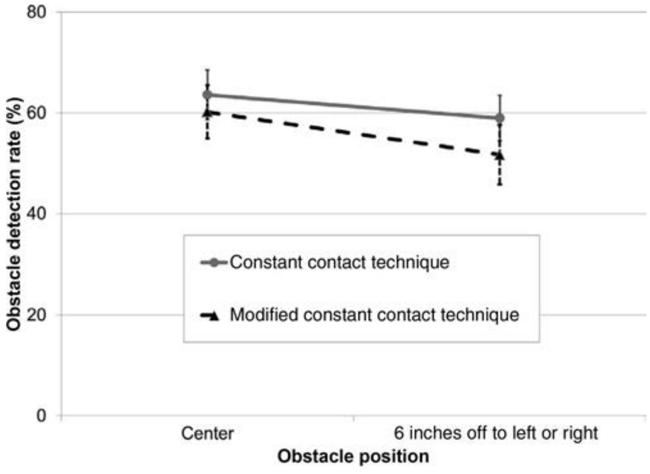

Figure 5. Obstacle detection performance by obstacle position. Error bars indicate 95% confidence intervals.

arcing the cane with a hinge-like pivoting motion of the wrist while keeping the elbow and shoulder joints motionless. The width of the lateral cane tip movement in the modified constant-contact technique was kept at approximately an inch wider than the widest part of the cane user's body.

A research assistant changed the size and position of the obstacle for each trial following a randomized schedule. Each participant completed 10 trials for each of the nine size-position combinations (three sizes × three positions—left, midline, or right) for each of the two cane techniques—constant-contact and modified constant-contact techniques (a total of 180 trials per participant).

Variables and analyses

Type of cane technique, obstacle size, and obstacle position were the independent variables. Analyses for experiment two were the same as described in experiment one except that the statistical power of the main effect *F*-tests was .79 or higher when a large effect size ($f = .4$) was assumed (Cohen, 1988; Erdfelder et al., 1996).

Results

Overall, participants were able to detect a little more than half of the obstacles on their walking path ($M = 58.6\%$, $SD = 5.2\%$). Contrary to our hypothesis, the obstacle detection rate with the modified constant-contact technique ($M = 56.0\%$, $SD = 7.4\%$) was statistically significantly lower than that with the constant-contact technique: $M = 61.3\%$, $SD = 5.2\%$, $F(1, 13) = 6.49$, $p = .024$, $r = .58$ (see Figure 5). Obstacle detection performance improved as the size of the obstacle increased, $F(2, 26) = 119.46$, $p < .001$. In addition, participants detected the obstacles that were positioned at the center of their walking path ($M = 61.9\%$, $SD = 6.6\%$) at a statistically significantly higher rate than those positioned slightly off to the side: $M = 55.4\%$, $SD = 7.3\%$, $F(1, 13) = 10.73$, $p = .006$, $r = .67$. None of the two-way interactions were statistically significant: technique × obstacle size, $F(2, 26) = .62$, $p = .546.460$; technique × obstacle position, $F(1, 13) = .42$, $p = .528$; and obstacle size × obstacle

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position, $F(2, 26) = 2.12$, $p = .140$. The three-way interaction was not statistically significant either, $F(2, 26) = .62$, $p = .547$.

Discussion

Interpretation of the findings

As predicted, a bundu basher tip was better than the marshmallow tip for detecting obstacles. However, contrary to our hypothesis, the constant-contact technique allowed a higher rate of obstacle detection than the modified constant-contact technique. The bundu basher tip's larger contact area with the walking surface appears to have contributed to its advantage over the marshmallow tip. In other words, the bundu basher tip covered a larger surface area than the marshmallow tip when the cane was swung back and forth, resulting in making contact with more obstacles than the marshmallow tip did.

The modified constant-contact technique's poor performance (overall detection rate of 56%), despite the claim of perfect coverage by Uslan (1978), may be attributable to several factors.

First, when Uslan calculated coverage rate, he assumed all obstacles to be at least as high as the cane-holding hand (for instance, poles, pillars, and the like). In our study, to better simulate real-world obstacles such as bricks, driveway toys, and construction cones, we used obstacles of different diameters (2 to 14 inches) and heights (1 to 7 inches). One of our observations was that many obstacles were missed as the cane was swung over them. For example, when an individual who is five feet, seven inches tall uses a long cane, as prescribed in LaGrow and Long (2011), his cane-holding hand is positioned at approximately 28 inches from the ground, forming an angle of about 40 degrees between the cane and the walking surface. That is, regardless of which technique was used, only the first 11 inches of the cane shaft from the cane tip were useful for detecting even the tallest obstacles used in our study. Partly as a result of the heights of the obstacles used in our study, the modified constant-contact technique produced an obstacle detection rate far lower than what was claimed by Uslan (1978).

Second, anatomical or physical characteristics of some of the participants made it challenging for them to move the cane-holding hand and forearm laterally fully across the body, which is one of the required motions of the modified constant-contact technique. As a result, it was difficult for some of the participants to use the modified constant-contact technique exactly as prescribed, possibly causing inconsistencies in its use.

It was interesting to note that the participants were able to detect the obstacles placed at the center of their walking path at a higher percentage than those placed six inches off to the side, regardless of the technique. This difference in detection performance might have been partly because of the uneven coverage of the walking path by some of the participants resulting from swing arcs that often covered far beyond the boundary of the walking path on one side while not extending widely enough to cover the walking path on the other side. In fact, the detection rate for the obstacles on the cane-holding-hand side ($M = 56.9\%$, $SD = 12.0\%$) was slightly higher than that for the obstacles on the non-cane-holding-hand side ($M = 53.8\%$, $SD = 8.5\%$).

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Limitations

One of the limitations of the study (experiment two) was that the participants were less familiar with the modified constant-contact technique and did not have an extended period of time to practice it. Another limitation is related to the use of mostly sighted O&M students as participants. Use of such a sample limits the generalizability of the study findings. However, although examined purely descriptively, it is worth noting that the two visually impaired cane users included in experiment one—who were also far more experienced in cane use than the sighted O&M students (median cane use experience = seven years)—detected obstacles at a higher percentage (M = 81.3%, SD = 2.9% for seven-inch-tall obstacles when using the constant-contact technique) than did the sighted O&M students (M = 62.9%, SD = 6.6% for seven-inch-tall obstacles when using the constant-contact technique). In addition, the obstacle detection rate for the seven-inch-tall obstacles of the visually impaired cane users who participated in our previous study with the same protocol (Kim et al., 2017) (M = 78.0%, SD = 7.1%, median cane-use experience = 18 years, n = 15) was also similar to that of the visually impaired participants in this study. These results indicate that the overall obstacle detection performance of the experienced visually impaired cane users may be better than that of the less experienced sighted O&M students. Last, the statistical power for detecting interaction effects might not have been adequate.

Practical implications

The obtained effect size (the size of the impact produced by the treatment, Huck, 2008) that corresponds to the bundu basher tip's advantage over the marshmallow tip is large (r = .83) when measured against Cohen's (1988) operational definition of *effect size* in behavioral sciences. Although subjective, the actual difference in the detection rate of 11.5% (66.1% vs. 54.6%) also appears to be large enough to be practically meaningful for cane users. Furthermore, even for taller obstacles (five-inch and seven-inch obstacles), missing which poses a serious risk of causing one to lose one's balance or fall, the bundu basher tip's advantage over the marshmallow tip remained large (r = .77, 75.0% vs. 64.2%). Given that advantage, cane users and O&M specialists should consider using or recommending a bundu basher tip (or a similar tip that has an increased contact area with the walking surface), particularly when the traveling environment often presents unexpected obstacles that may trip the cane user or for older cane users who are more prone to falls. The findings of this study also suggest that the modified constant-contact technique may not have an advantage over the traditional constant-contact technique in detecting obstacles—at least ones that are not taller than seven inches—while requiring biomechanical movements that are anatomically challenging for some of the cane users. Given that finding, it is not recommended that O&M specialists advocate for this technique to their students with an aim of improving their ability to reliably detect obstacles. However, we do not interpret the findings to suggest that the bundu basher tip should be the cane tip recommended to all cane users in all situations, or that the traditional constant-contact technique should be the technique used in all cir-

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cumstances. Rather, a thoughtful consideration of the pros and cons of each cane tip and technique, as well as the cane user's abilities and situations, needs to be taken into account when deciding which cane tip or cane technique should be used in a given environment.

Recommendations for future studies

Obstacle detection is only one of the many outcome measures of long cane performance. A study that examines how reliably a bundu basher tip allows a cane user to detect drop-offs and changes in walking surface texture would be necessary to determine its overall effectiveness. In addition, an investigation into how different cane techniques and designs (for example, cane shaft, tip weight, and weight distribution) cause fatigue and consequent deterioration of cane performance would be helpful in determining the practical usability of a given technique or design. Moreover, conducting similar studies in real-world settings (for instance, an actual sidewalk with obstacles such as construction cones, driveway toys, and the like) and conditions (for instance, without occluding hearing) would allow us to further determine the practical applicability of the study findings. Last, inclusion of a sufficient number of experienced visually impaired cane users would improve the generalizability of the study findings.

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