The Effect of Cane Material on Length Perception with Long Canes by Visually Impaired, Sighted-Blindfolded, and Sighted Participants

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Structured abstract: *Introduction:* Individuals with visual impairments may use long canes for estimating distances and detecting gaps, obstacles, and texture patterns. The study presented here investigated whether length perception with canes is influenced by cane material. *Methods:* Visually impaired, sighted-blindfolded, and sighted individuals ($n = 30$ for each group) participated in this study. Each group was divided into three subgroups (with 5 females and 5 males each) according to cane material. The canes (length = 80 cm, diameter = 1.5 cm) were made of wood, polyethene plastic, or aluminum. The participants were required to judge whether comparison stimuli were shorter than, equal to, or longer than the standard stimulus. Two sessions (for horizontal or vertical lines) were carried out on consecutive days. *Results:* Cane material was not a significant factor influencing accuracy, $F(2, 79) = 2.47$, $p = .091$, and difference threshold, $F(2, 79) = 2.01$, $p = .14$, in length perception for the three groups of participants, but cane material interacted with orientation of stimuli, $F(2, 79) = 3.24$, $p = .044$. There were significant group differences for accuracy, $F(2, 79) = 9.6$, $p < .001$, and difference threshold, $F(2, 79) = 8.8$, $p < .001$, revealing that participants with visual impairments were better at discriminating length than sighted-blindfolded participants. *Discussion:* Our results provide evidence that length perception with canes is not significantly influenced by cane material. The significant group differences for accuracy and difference threshold indicate that assessing visually impaired participants may be more adequate in studies aimed at investigating aspects related to long canes. *Implications for practitioners:* Orientation and mobility (O&M) instructors can report that there is experimental evidence that cane material is not a significant factor in conveying spatial (length) information, although some evidence suggests that it is a significant factor in conveying tactile information such as the roughness of surface textures.

Mobility is a fundamental aspect of everyday life. For individuals to move through the environment safely, several types of information should be detected and interpreted; for example, the characteristics of the ground and its gaps and obstacles. In general, vision is the primary sense for perceiving such information, and visually impaired individuals face limitations and challenges to safe navigation. They may use additional tools such as the long cane to explore objects or ground characteristics in their immediate environment (LaGrow & Weessies, 1994).

Although several high-tech travel devices have been developed, the long cane remains one of the most commonly used mobility tools by visually impaired individuals (Cyr & Burton, 2008; Hersh, 2015; Kim, Moncada-Torres, Furrer, Riesch, & Gassert, 2016). When touch is mediated by a tool, the individual's haptic space is extended from the extremity of the hands to the extremity of the tool (Burton, 1993; Hanley & Goff, 1974; Morioka & Maeda, 1998). The distal tip of the tool taps the surfaces of objects or the ground, causing vibrational waves that travel up to the proximal tip of the tool, which is in contact with the hand (Rodgers & Wall Emerson, 2005b). The information transmitted by vibrational waves may be influenced by the physical characteristics of the cane, such as its material, length, weight, density, and flexibility or rigidity (Rodgers & Wall Emerson, 2005a, 2005b). Thus, it is necessary to investigate the effects of specific characteristics of canes on haptic perception and mobility to understand which factors are significant and to allow for the canes to be improved (Cyr & Burton, 2008; Rodgers & Wall Emerson, 2005b; Sidaway et al., 2004).

Rodgers and Wall Emerson (2005a) investigated the effects of canes' overall weight and weight distribution (that is, balanced or unbalanced along the shaft) on the accuracy of tapping a target by blindfolded participants, and the results showed that performance was not influenced by such variables but only declined as a function of time due to fatigue. The lack of a significant effect of canes' weight was further observed in a discrimination task in which the participants were required to examine two surfaces with the cane and to indicate which one was the rougher of the two based only on vibratory stimulation (the participants were blindfolded and were hearing a white noise). A final experiment investigated the influence of canes' length on the accuracy of individuals who are blind in detecting drop-offs in a walk test. The results showed that performance declined when canes were shorter or longer than the personalized length for each participant (Rodgers & Wall Emerson, 2005a). Such results were in contrast with other findings; for example, Burton (1992) indicated that the judgment of crossability of gaps by blindfolded participants was not influenced by cane length. In addition, accuracy in gap-crossing decisions by visually impaired and blindfolded participants was not affected significantly by cane length (Burton & Cyr, 2004), nor

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was the detection of drop-offs by blindfolded participants in a walk test (Kim & Wall Emerson, 2012). However, there is evidence that cane length might be a relevant factor, since participants were more accurate in judging the height of blocks with shorter canes than with longer ones (Huang, Leung, & Wang, 2010; Sidaway et al., 2004).

The subsequent study by Rodgers and Wall Emerson (2005b) investigated the influence of cane shaft material on the discrimination of surface roughness by blindfolded participants. The materials tested were vinyl, fiberglass, aluminum, and carbon fiber (in descending order of flexibility). The results showed that the flexibility of the shaft influenced the number of correct discriminations significantly, with an increase in accuracy following a decrease in flexibility, indicating that less flexible shafts are better at transmitting information by vibrations. Physical tests revealed that the frequencies at which the canes resonated were associated with the canes' weight and flexibility, with the less flexible cane (carbon fiber) transmitting more vibrational information than more flexible canes (Rodgers & Wall Emerson, 2005b).

Recently, several studies addressed ergonomic aspects of long cane use such as cane length, weight, and rigidity, as well as the type of cane tapping technique and users' characteristics (Kim & Wall Emerson, 2012; Kim, Wall Emerson, & Curtis, 2009, 2010a, 2010b, 2010c; Kim, Wall Emerson, Naghshineh, & Auer, 2017). However, it remains unclear whether differences in material influence the perception of length. In the daily life of the cane user, stereotyped movements with the cane are used for estimating distances and detecting gaps, obstacles, and texture patterns of the ground. The exploration of the immediate environment with long canes requires the evaluation of lengths in both the horizontal and vertical planes; for example, by measuring the width of a stairway and the height of its steps. Although some research evaluated the perception of length along the vertical axis (for example, the height of cubes or cylindrical obstacles; Chan & Turvey, 1991; Huang et al., 2010; Kim & Wall Emerson, 2014; Sidaway et al., 2004; Sunanto & Nakata, 1998) or the horizontal axis (for example, the size of a gap on the floor; Burton, 1992, 1994; Burton & Cyr, 2004), to the best of our knowledge no study directly investigated the perception of length in both vertical and horizontal axes with canes or probes made of different materials.

In the present study, we investigated the perception of vertical and horizontal lengths with canes made of wood, aluminum, and polyethene by visually impaired, sighted-blindfolded, and sighted participants. We employed the traditional psychophysical method of constant stimuli to calculate the percentage of correct responses and the difference threshold, which is the magnitude of the difference between two stimuli necessary to make them just discriminable. As this method requires a large number of trials, cane material was manipulated as a between-subjects factor, whereas the vertical and horizontal orientation of stimuli was a within-subjects factor.

Our experimental approach required the standardization of the testing session across the participants. We constructed an apparatus for the standardization of lengths and to ensure a straight path for the cane tip to move through. The apparatus was placed on a table with 75 cm of height, and the participants were positioned at about 80 cm from the apparatus and were required to perform the experiment holding a cane with the right hand at waist level. Our experiment manipulated cane material and controlled for cane length, so that the difference between the canes concerned only the material they were made of. We constructed three canes with rounded distal and proximal tips, each measuring 80 cm in length and 1.5 cm in diameter. The alternative of personalizing cane length according to each participant's height was discarded due to the possible confounding effect of varying both cane length and material, as well as the distance between the apparatus and the participants. The alternative of using commercial canes was discarded to better control for the difference in material while keeping other characteristics fixed. For example, canes available on the market differ not only in material, but also in type of shaft (such as rigid, telescoping, or foldable), tips (such as marshmallow, pencil, rolling, or glide tips), and handles (such as straight, crook, palm, or derby handles). Finally, the alternative of using canes measuring 135 cm (as some commercial, standard canes) was tested in a pilot study, but it was discarded due to the possible confounding effect of fatigue because they required more effort to be handled during our extensive testing sessions (two sessions of approximately 50 minutes each).

Methods

Participants

This study was approved by the Research Ethics Committee of our institution (Process 542/2010-2010.1.2163.59.6), and all the participants signed consent forms. We formed three groups of participants: namely, visually impaired individuals, sighted-blindfolded individuals, and sighted individuals, with each group comprising three subgroups according to cane material (wood, aluminum, and polyethene). Sample size was defined prior to data collection for including 10 right-handed individuals (five females and five males) within each subgroup. We generated two randomized lists for distributing the visually impaired females and males across the subgroups, and we generated two randomized tables for distributing the females and males without visual impairments across the groups and subgroups.

A total of 90 participants who were right-handed (45 females and 45 males) volunteered for this study. Thirty visually impaired individuals (15 females and 15 males) aged 18 to 56 years were recruited from a local association for visually impaired people, all of whom were habitual cane users. The participants who reported some level of residual sight performed the experiment using a blindfold. Sixty sighted individuals aged 18 to 43 years, with no experience or training with long canes, were recruited from the university campus, half of the sighted participants were in the sighted-blindfolded group and the other half in the sighted group.

Materials

We devised an apparatus to investigate length perception with canes that allowed the standardization of lengths, with a smooth surface and a perpendicular wooden divider both to support the tip of the cane and to ensure a straight path for the cane tip to move through. The apparatus

Figure 1. The apparatus constructed for investigating length perception with canes as observed from the experimenter's side. To the left side of the apparatus, there is a ruler of acrylic with openings for adjusting each one of the nine stimuli lengths, from one (35 cm) to nine (51 cm). The moveable support is set at the standard stimulus of five (43 cm).

consisted of a base made of acrylic that was 56 cm in length, 13 cm in width, and 2 cm in height. There was a ruler with nine openings with a moveable support to adjust different lengths, and a perpendicular wooden divider to hide the ruler from the sighted participants' view, that was 56 cm in length and 13 cm in width (see Figure 1). The standard stimulus was a line of 43 cm and there were nine comparison stimuli lines (in cm): 35, 37, 39, 41, 43, 45, 47, 49, and 51. The apparatus was placed over a table measuring 58 × 58 × 75 cm, and a bracket was used to maintain the equipment in the vertical position when necessary.

We used three canes that were 80 cm in length and 1.5 cm in diameter (volume = 141.3 cm^3), with rounded distal and proximal tips: one cane made of sanded and polished pine (weight = 45 g, density = 0.318 g/cm^3), one cane made of polyethene plastic (weight = 185 g, density = 1.309 g/cm^3), and one made of polished aluminum (weight = 245 g, density = 1.734 g/cm^3).

Procedure

Each participant was tested individually in two sessions of approximately 50 minutes each, carried out on two consecutive days. One session was for horizontal stimuli lines and the other session was for vertical stimuli lines, with the order of stimuli orientation being counterbalanced across participants. The first session started with the signing of the consent form by the participant and the presentation of standardized instructions by the experimenter. The participant was then blindfolded (if he or she belonged to the sighted-blindfolded group or had residual sight) and conducted to the front of the table with the line-perception equipment, at approximately 80 cm from the equipment, with slight variations only to ensure a similar arm position across participants. One of the cane types was given to the participant and the experimenter positioned the distal tip of the cane on the central sulcus of the equipment and instructed the participant how to perform straight horizontal or vertical lines. The participant was instructed to perform the experiment holding the cane with the right hand at waist level. The participants of the sighted group were able to see the equipment and the length being explored while performing the task, however, they were not able to see the ruler or the length being adjusted by the experimenter.

The experiment followed the psychophysics method of constant stimuli, in which a standard stimulus is held constant during the experiment and the set of comparison stimuli are presented at random in a series of trials. The participant was first presented to the standard stimulus, and then was presented to a comparison stimulus, the task being to judge whether the comparison stimulus was shorter than, equal to, or longer than the standard stimulus. Specifically, each trial started with the presentation of the standard stimulus and the participant was required to explore its length with the cane. The participant then was required to position the tip of the cane to the left of the line (for horizontal lines) or to the bottom of the line (for vertical lines), and the experimenter adjusted the length of the comparison stimulus. The participant was required to explore the length of the comparison stimulus and to answer whether it was shorter than, equal to, or longer than the standard stimulus. No feedback about judgments were provided to participants. The nine comparison stimuli were presented at random in a series of nine trials, and this procedure was repeated 15 times, resulting in a total of 135 trials per session and 270 trials in the whole experiment.

Statistical analyses

For each participant, the number of correct judgments for each comparison stimulus was computed, and then the overall percentage of correct answers for each orientation (horizontal and vertical) was calculated for statistical analyses. The difference threshold was also calculated, a measure that represented the amount of difference from the standard stimulus that was detected reliably; that is, in at least 50% of the trials. The data were analyzed by using a mixed ANOVA with group of participants and cane material as between-subjects factors, with repeated measures on stimuli orientation. The significance level was set at .05, the effect-size measure partial *eta*-squared (η^2_p) was computed, and post hoc tests using Bonferroni's correction were applied as necessary.

Results

Two participants belonging to the visually impaired group were not able to discriminate stimuli that were shorter than the standard stimulus reliably; that is, in at least 50% of the trials. One participant failed to discriminate the shorter vertical stimuli, including the shortest one with 35 cm (seven correct judgments "shorter than," six answers "equal to," and two answers "longer than"), and succeeded in discriminating only the shortest horizontal length (10 correct judgments "shorter than" and five answers "equal to"). The other participant failed to discriminate the shorter horizontal stimuli lengths, including the shortest one with 35 cm (seven correct judgments "shorter than," seven answers "equal to," and one answer "longer than"), and succeeded in discriminating only the shortest vertical length (10 correct judgments "shorter than," three answers "equal to," and two answers "longer than"). Due to the lack of discrimination, we could not obtain estimates of difference threshold for these

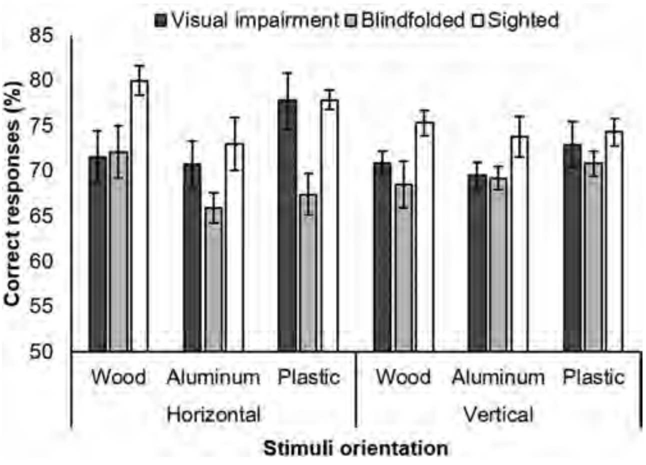

Figure 2. Mean percentage of responses in length comparison for horizontal and vertical stimuli by cane material and group of participants. Error bars represent standard errors of the mean.

two participants, and for this reason we decided not to consider their data in the analyses. Taking the whole sample into consideration, these two participants were the only ones displaying such a pattern of performance (lack of discrimination and very low performance), and for this reason they were considered as outliers within the visually impaired group, as well as with respect to the whole sample of participants.

Figure 2 shows the mean percentage of correct answers for horizontal and vertical judgments for each group of participants and cane material. The three group × three cane material × two orientation of stimuli mixed ANOVA revealed a significant main effect of group, $F(2, 79) = 9.6$, $p < .001$, $\eta^2_p = .195$, and the post hoc test revealed that the sighted group ($M = 75.7\%$, $SE = 1.09$) performed better ($p < .001$) than did the blindfolded group ($M = 68.9\%$, $SE = 1.09$), but not the visually impaired group ($M = 72.2\%$, $SE = 1.13$, $p = .077$); the difference between these two latter groups was not significant ($p = .14$). The main effect of cane material did not approach significance, $F(2, 79) = 2.47$, $p = .091$, $\eta^2_p = .059$, given the nonsignificant discrepancies in mean accuracy with aluminum ($M = 70.3\%$, $SE = 1.09$), wood ($M = 73\%$, $SE = 1.11$), and polyethene ($M = 73.5\%$, $SE = 1.11$). The interaction between the factors group and cane material was not significant, $F(4, 79) < 1$, $p = .58$, $\eta^2_p = .035$. The main effect of orientation of stimuli was not significant, $F(1, 79) = 3.64$, $p = .060$, $\eta^2_p = .044$, since the slight difference in accuracy between horizontal stimuli ($M = 72.9\%$, $SE = .81$) and vertical stimuli ($M = 71.7\%$, $SE = .61$) was not consistently significant. The interaction between orientation of stimuli and group approached significance, $F(2, 79) = 3.06$, $p = .053$, $\eta^2_p = .072$, and Figure 3A shows the mean percentage of correct responses for each group and orientation of stimuli, collapsing across cane materials. As can be observed there, the interaction resulted from the blindfolded group's low accuracy for horizontal stimuli in comparison with the other groups. The interaction

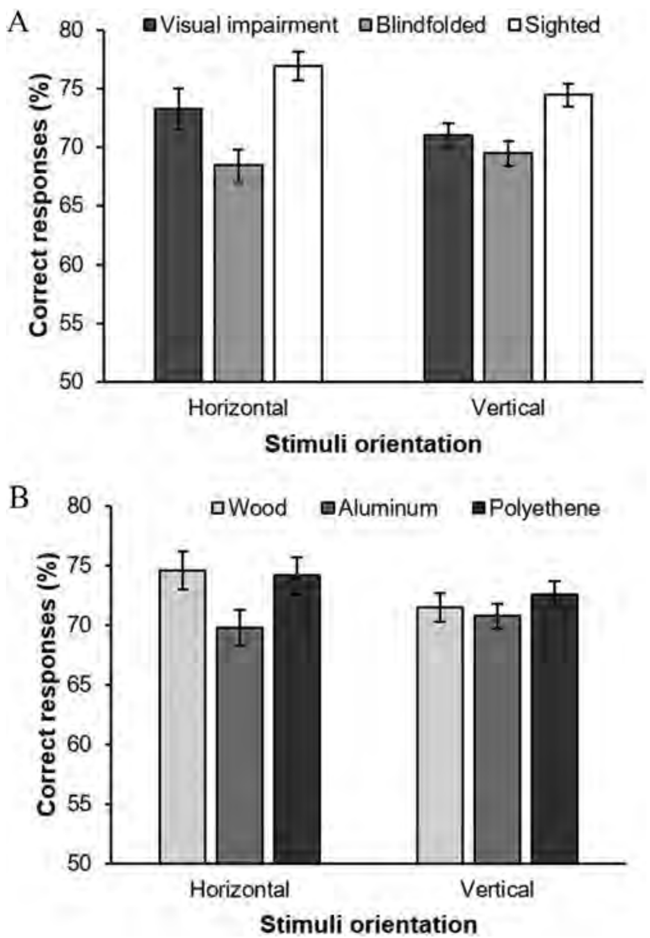

Figure 3. Mean percentage of correct responses in length comparison for horizontal and vertical stimuli by (A) group of participants collapsing across cane material, and (B) by cane material collapsing across group of participants. Error bars represent standard errors of the mean.

between orientation of stimuli and cane material was also significant, $F(2, 79) = 3.24$, $p = .044$, $\eta^2_p = .076$, but the post hoc test did not reveal significant differences in pairwise comparisons. Figure 3B shows the mean percentage of correct responses for each cane material and orientation of stimuli, collapsing across groups. As shown there, discrepancies between materials were smaller for vertical stimuli, whereas for horizontal stimuli a poor performance with the aluminum cane can be observed. Finally, the three-way interaction did not approach significance, $F(4, 79) = 2.2$, $p = .077$, $\eta^2_p = .10$.

Figure 4 shows the mean difference thresholds for each group of participants and cane material. The three group × three cane material × two orientation of stimuli mixed ANOVA revealed a significant main effect of group, $F(2, 79) = 8.8$, $p < .001$, $\eta^2_p = .182$, and the post hoc comparisons revealed that the blindfolded group's mean difference threshold was significantly higher ($M = 2.55$, $SE = .100$) than was that of both the visually impaired group ($M = 2.17$, $SE = .104$,

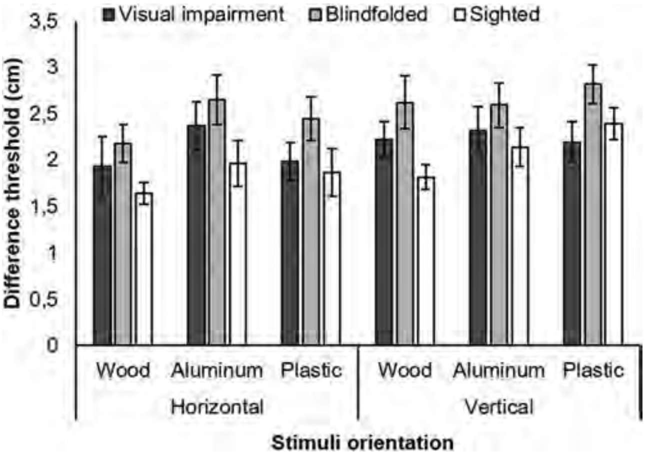

Figure 4. Mean difference thresholds for horizontal and vertical stimuli by cane material and group of participants. Error bars represent standard errors of the mean.

p = .030) and the sighted group (M = 1.97, SE = .100, $p < .001$); the difference between these two later groups was not significant (p = .48). The main effect of cane material was not significant, $F(2, 79) = 2.01$, p = .14, η^2_p = .048, given the nonsignificant discrepancies in mean difference thresholds with aluminum (M = 2.34, SE = .100), wood (M = 2.07, SE = .102), and polyethene (M = 2.28, SE = .102). The interaction between the factors group and cane material was not significant, $F(4, 79) < 1$, p = .82, η^2_p = .019. The main effect of orientation of stimuli was significant, $F(1, 79) = 5.45$, p = .022, η^2_p = .064, given the lower difference threshold for horizontal stimuli (M = 2.11, SE = .081) than for vertical stimuli (M = 2.35, SE = .072). The two-way interactions were not significant; that is, between orientation of stimuli and group, $F(2, 79) < 1$, p = .84, η^2_p = .004; orientation of stimuli and material, $F(2, 79) = 1.16$, p = .32, η^2_p = .028; or the three-way interaction, $F(4, 79) < 1$, p = .91, η^2_p = .012.

Discussion

To the best of our knowledge, no previous study has addressed the issue of eventual differences in length perception by using canes or probes made of different materials, highlighting the originality of the present study in comparing canes made of wood, aluminum, and polyethene. Here, length perception was assessed both for horizontal and vertical stimuli in two groups of participants; that is, visually impaired individuals who were habitual cane users and sighted individuals without cane training. This approach allowed a more complete view of the issue, since studies in the literature usually focused on either horizontal or vertical stimuli, in general assessing sighted-blindfolded participants rather than visually impaired individuals.

The results of the present study showed that cane material is not a significant factor in influencing accuracy (p = .091, η^2_p = .059) and difference threshold in length perception (p = .14, η^2_p = .048). Such results were consistent across the three groups of participants, given the nonsignificant interactions between group and cane material regarding both accuracy ($p = .58$, $\eta^2_p = .035$) and difference threshold ($p = .82$, $\eta^2_p = .019$). Cane material interacted significantly with orientation of stimuli ($p = .044$, $\eta^2_p = .076$), since discrepancies in accuracy between materials were less accentuated for vertical stimuli than for horizontal stimuli (see Figure 3B). However, such discrepancies were not reliable, since post hoc tests did not reveal significant differences between cane materials.

Thus, our results provide evidence that length perception with canes is not significantly influenced by cane material. Considering the literature, it is worth noting that cane material may be a significant factor when it comes to the perception of the roughness of surfaces (Rodgers & Wall Emerson, 2005b). In that case, it was shown that more rigid materials transmit more vibrational information than do flexible materials. Although cane material may be a relevant factor in conveying surface information, it does not seem to be relevant in conveying spatial (length) information.

An interesting output of the present research concerns significant group differences in accuracy ($p < .001$, $\eta^2_p = .195$) and difference threshold ($p < .001$, $\eta^2_p = .182$), especially regarding the comparison between sighted-blindfolded participants and visually impaired individuals (cane users). Although these groups did not differ in accuracy reliably, sighted-blindfolded participants had a higher difference threshold than did visually impaired participants, indicating a significant discrepancy in detecting length differences. In addition, concerning accuracy, the interaction between group and orientation of stimuli approached significance ($p = .053$, $\eta^2_p = .072$), since the blindfolded group was less accurate than the visually impaired and sighted groups for horizontal stimuli (see Figure 3A). Taken together, these results indicate that visually impaired participants were better at discriminating length with canes than were blindfolded participants, and that assessing visually impaired participants may be more adequate in studies aimed at investigating aspects related to long canes. In fact, some studies on haptic perception have shown that visually impaired individuals perform better than sighted-blindfolded individuals (Postma, Zuidhoek, Noordzij, & Kappers, 2007; Sunanto & Nakata, 1998). Visually impaired individuals seem to benefit from a richer somatosensory, proprioceptive experience in daily activities, such as braille reading and the use of a long cane, whereas sighted individuals depend heavily on visual information (Sunanto & Nakata, 1998).

Finally, another relevant aspect concerned the orientation of stimuli, since the participants' overall accuracy for horizontal stimuli tended to be slightly better ($p = .060$, $\eta^2_p = .044$) than it was for vertical stimuli, and difference thresholds were significantly lower ($p = .022$, $\eta^2_p = .064$) for horizontal than they were for vertical stimuli. Furthermore, regarding accuracy, the factor orientation of stimuli interacted with group ($p = .053$, $\eta^2_p = .072$) and material ($p = .044$, $\eta^2_p = .076$), providing further support to the idea that a more complete view on the effects of specific characteristics of canes and cane use requires studies investigating samples of visually impaired individuals and sighted-blindfolded participants, as well as a display of stimuli in different orientations.

Limitations

In sum, the present study may be regarded as a first approach aimed at investigating length perception by using canes made of different materials. Even though our results indicated that length perception is not significantly influenced by cane material, our findings will need to be confirmed and extended because we adopted a restricted experimental approach aimed at standardizing the testing materials and the testing session. For this reason, our study had a number of limitations that would have to be carefully considered in future research. Fundamental limitations of this study include the experimental setting and the apparatus, since the participants were required to perform length comparison in a context that is substantially different from everyday life situations of cane users. Other limitations were the choice of constructing our own canes instead of using commercial canes available on the market, in addition to the fact that cane length was shorter than standard cane lengths. Furthermore, we investigated only three types of material, and long canes made of other materials are available on the market (such as fiberglass, carbon fiber, and graphite). Finally, we opted for manipulating cane material as a between-subjects factor in view of the extensive testing session with a large number of trials, and our study would have been stronger if cane material were a within-subjects factor; that is, if every participant had performed the task with each one of the canes.

Thus, future research may consider the development of experimental settings closer to the actual demands of cane users; for example, by investigating the detection of obstacles, gaps, or drop-offs (Kim & Wall Emerson, 2012, 2014; Kim et al., 2009, 2010a, 2010b, 2010c), the judgment of gap crossability (Burton, 1992, 1994; Burton & Cyr, 2004), and the evaluation of obstacles' height or width (Huang et al., 2010; Sidaway et al., 2004; Sunanto & Nakata, 1998), in addition to exploring eventual differences in performance that might be associated with canes' characteristics, such as cane shaft weight and rigidity (Kim et al., 2017; Rodgers & Wall Emerson, 2005a, 2005b), cane length (Huang et al., 2010; Kim & Wall Emerson, 2012; Rodgers & Wall Emerson, 2005a; Sidaway et al., 2004), and cane tips (Kim et al., 2010b).

Conclusion

The present study addressed one of the functions of the long cane—namely, a probe to get information as an extension of the individual's hand, a tool that mediates the tactile sense and extends the individual's haptic space (Burton, 1993; Hanley & Goff, 1974; Morioka & Maeda, 1998). We focused on the perception of length, since length estimation is implicated directly or indirectly in everyday life activities of cane users, and we compared canes made of different materials, since their physical characteristics impact on vibrational waves and the quality of the information being transmitted (Rodgers & Wall Emerson, 2005b). Despite previous evidence showing that cane material is a significant factor in conveying tactile information such as the roughness of surface textures (Rodgers & Wall Emerson, 2005b), the results of our study showed that cane material is not a significant factor in conveying spatial (length) information. Practitioners and instructors in the field of orientation and mobility (O&M) may use the experimental evidence from this study and other recent studies (Kim & Wall Emerson, 2012; Kim et al., 2010b, 2017) to explore the benefits and limitations of different types of long canes, depending on the personal needs of the cane user.

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