JVIB

October 2005 • Volume 99 • Number 10

Human Factor Analysis of Long Cane Design: Weight and Length

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Abstract: In a series of experiments, canes of different lengths, weights, and weight distributions were assessed to determine the effect of these characteristics on various performance measures. The results indicate that the overall weight of a cane and the distribution of weight along a cane's shaft do not affect a person's performance, but accuracy does decline with the amount of time a person wields the cane, so a heavier cane may exacerbate this fatigue.

The authors would like to acknowledge the late Emerson Foulke, of the University of Louisville in Kentucky, for his role in the conceptualization and performance of the original research leading to this article. Dr. Foulke was a leader in the study of perceptual factors in non-visual mobility and is sorely missed.

The basic design of the modern long cane has changed little since the long cane was introduced by Richard Hoover in the 1940s (see Hoover, 1946, 1962) and continues to be the most effective mobility device (Foulke, 1975), despite demonstration that cane techniques do not provide total protection (Blasch & De l'Aune, 1992). Research has called into question the reliability of cane techniques that ostensibly place the cane tip on the ground where the following footfall will be placed (Blasch & De l'Aune, 1992; Blasch, LaGrow, & De l'Aune, 1996; Jacobson & Ehresman, 1983; LaGrow, Blasch, & De l'Aune, 1997; Potter, 1997; Uslan & Manning, 1974; Uslan & Schriebman, 1980; Wall, 2002; Wall & Ashmead, 2002). In light of such research on orientation and mobility (O&M) practices and techniques, it is reasonable to analyze the characteristics of long canes to determine how they affect individuals' performance with the canes.

The first wooden canes were found to be too unwieldy, short, and heavy and did not conduct information well (Hoover, 1946, 1962), so Hoover constructed a trial set of aluminum long canes using tubes of drawn aluminum. Specifications for the length, grip, tip, and weight were devised in collaboration with Russell Williams of the Veterans Administration (Hill & Ponder, 1976). Each original cane was 46 inches long, but it was noted that the length should be individualized so the tip would touch the ground where the next foot fell (Hoover, 1946). This ambiguous description of the desirable length of a cane led to an ongoing debate regarding the proper length (Loutfy & Baker, 1949), with one modern specification (the sternum method) requiring that a long cane be long enough to reach a point 1.5 inches above the xiphoid process (the pointed part of the sternum at the lower end) (Hill & Ponder, 1976; LaGrow & Weessies, 1994; Tooze, 1981).

An important function of the cane is to preview environmental information. Longer canes offer more-advanced warning of environmental hazards, since they contact environmental features before a shorter cane would. However, research has shown that the length of the cane is not as important as the angle at which the cane contacts the ground (see, for example, Burton, 1992, 1994). Schellingerhout, Bongers, van Grinsven, Smitsman, and van Galen (2001) showed that by bending a cane so that the length was not appreciably changed, but the angle of contact with the ground altered significantly, the detection of obstacles, but not of dropoffs, was changed.

Hoover (1946) intuitively observed that the weight of a cane could affect the performance of a cane user, reasoning that a heavier cane would logically increase fatigue over time. Aluminum was used for the new canes to lower the weight to less than 7 ounces (Hoover, 1946) yet maintain their durability and the conductivity of vibrations (Ball, 1964). The motion of the cane tip over a surface transmits vibration from its tip to the hand that is holding the grip. If a cane is made heavier without increasing its size, by constructing the cane from denser material, the inertia that must be overcome to impart motion to it will increase. Other characteristics being equal, the heavier of two canes should transmit less vibration than the lighter cane. Foulke (1967) found limited evidence of this point in a pilot study that reported a significant effect of a cane's weight on the ability to detect differences in the roughness of surfaces. This finding was supported by Walraven (1982), who noted that the lighter and more rigid a cane was, the better it was at transferring information to the user.

How weight is distributed along the shaft may also affect the use of a cane. To give the shaft of the long cane balance, Hoover tapered the aluminum tube from the crook to the tip (Loutfy & Baker, 1949). Moving from the large to the small end of a tapered shaft, each inch of it weighs less than the preceding inch, and its center of gravity is closer to the large end. Burton (1992, 1994) found that altering the distribution of mass along the cane shaft did not affect the detection of gaps in the walking surface. Note that the inclusion of a cane tip that is heavier than others would change the weight distribution of a cane. Such a tip would be most beneficial, all other parameters aside, if a counterbalancing weight was added on the other end of the cane, so that although the cane would be heavier overall, the user would not be taxed by wielding a cane with a center of gravity that was too far from the grip.

Previous choices for alterations of the long cane have been guided, for the most part, by hunches, rather than experimental results, with the basic design of the long cane changing little (see, for example, National Academy of Sciences, 1972). More recently, there has been an increase in interest in developing quantifiable improvements in the design of long canes (see, for example, Schellingerhout et al., 2001). The goals of the experiments reported in this article were to illustrate how the basic characteristics of the long cane (such as weight, length, and balance) affect the cane's performance and to point toward optimal characteristics for canes.

Experiment 1: Effect of weight on accuracy and fatigue

Method

Apparatus

For this task, the participants maintained a consistent side-to-side arc with canes of different weights. Canes were prepared by fitting five pieces of Series 6006/T-6 aluminum tubing (wall thickness = .028 inches) with standard cane grips and tips and then taping lead weights to the shafts. Small lead weights totaling 54 grams (about 2 ounces) were placed evenly along the shafts. Each cane was 55 inches long, and the total weights of the individual canes plus the lead weights were 175 grams (about 6 ounces), 219 grams (about 8 ounces), 263 grams (about 9 ounces), 307 grams (about 11 ounces), and 351 grams (about 12 ounces).

The accuracy of the cane arcing was automatically measured by a specially constructed device. A nail was inserted through a hole in the center of the nylon tip, so that it protruded $^{1}/_{8}$ inch beyond the end. A conductive wire ran from the nail, along the cane shaft, to a low-voltage power supply. The other side of the power supply was connected to each of 14 electromechanical counters. Each counter was also connected to an electrically conductive metal strip that was 1.27 centimeters (about 0.5 inches) wide and 25.4 centimeters (about 10 inches) long. Seven of these strips were mounted side by side, with 0.195 centimeter (about .08 of an inch) between the adjacent strips, on each of two boards that were aligned on the floor in front of the participant (see Figure 1).

The distance between the participant and the boards was adjusted, so that when the cane touched the ground at the end of an arc equal to the participant's shoulder breadth, plus 6 inches (3 inches on either side), the cane tip made contact with the center metal strip on the board on that side. When the cane tip touched any metal strip, a circuit was completed that activated the counter for that strip. If the center, target, strip was hit, a red pilot lamp also turned on, giving the participant immediate knowledge of the results. The participants tapped in unison with an electronic metronome set to 80 ticks per minute.

Procedure

Throughout the experiments reported in this article, sighted college students were used in situations that did not require experience with the long cane or nonsighted ambulation. This use of these subjects was valid, since the intent was to study the characteristics of canes across different canes or conditions; the means of wielding, as long as it was consistent, was not under consideration. In this study, the participants were 50 sighted undergraduate psychology students, 25 female and 25 male, who performed the task using their vision. Five male and 5 female students were randomly assigned to each of five groups, with each group assigned one of the five weighted canes.

After the participants were familiarized with the apparatus and the task, the experimental session consisted of nine 5-minute intervals (trials). Pilot data indicated that 45 minutes was long enough for fatigue to become evident, but not long enough to cause participants to stop using the cane. Reaching the point of fatigue was desired to ensure that a point was reached at which the participants' performance would begin to decline, thus illustrating the differential effects of the different weight conditions. Fatigue should increase with time and accuracy, indicated by the frequency of contacts with the target strips, and the variability of deviations from the targets should decrease. Counts were recorded of how many contacts, per trial, the cane made with each metal strip on each side of the participant.

Results and discussion

The strips on each pad were assigned values of -3 to 3, with the center strip having a value of 0. Positive values indicated "overshoots" (a wide arc), and negative values indicated "undershoots" (a narrow arc). Each deviation from the target during a trial was squared, the squares were summed, and the result was divided by the total number of contacts during the trial. The square root of this quotient is the root mean square (RMS). The estimate of accuracy that is calculated by this procedure can range from 0 (if a participant hit the target on every attempt) to 3 (if a participant hit the strip farthest from the target on every attempt). The participants kept time with the metronome, tapping 400 times in each 5-minute trial, but they occasionally missed taps. The pause after a missed tap might allow a more accurate tap on the next beat, so the RMS was corrected by multiplying it by the ratio of the maximum number of taps (400) over the actual number of taps.

The multiple levels of the cane variables in these studies increased the likelihood of violating the sphericity assumption or homogeneity-of-variance-of-differences assumption (Keppel, 1991). A multivariate analysis of variance (MANOVA) was used instead of a univariate analysis of variance, since it does not require the assumption of sphericity (Morrison, 1990). The MANOVA evaluates the mean difference scores between n_i and n_j groups, as well as the linear combination of these difference scores (Green, Salkind, & Akey, 1999). For all the experiments that are discussed in this article, Pillai's Trace was used to report *F*-values for MANOVAs, and standard *F*-values were used for between-subject measures. Pillai's Trace is one of the statistics that is the most immune to violations of assumptions underlying a MANOVA and preserves power (Hair, Anderson, Tatham, & Black, 1998).

In this study, the nine rate-corrected RMS of deviations from the target that were calculated for each participant were the dependent variable in a mixed-model MANOVA. Between-subjects factors were the participant's gender and weight of the cane, and the repeated-measures factor was time. The MANOVA indicated a significant main effect of time (Pillai's Trace = .45, $F(8,33) = 3.53$, $p = .006$), showing the planned effects of fatigue. There was also a significant main effect of gender, $F(1,40) = 14.82$, $p < .001$, but not of cane weight, $F(4,40) = 1.36$, $p = .265$. There were no significant interactions among the three independent variables.

More fatigue and therefore less accuracy should result from the manipulation of heavier canes, but the weight-by-trial interaction was not significant, indicating that increasingly heavier canes did not make the participants' performance decrease more sharply. The female participants performed less accurately than did the male participants, regardless of the weight of the cane or time on task, perhaps because of the differences in strength between men and women.

Experiment 2: Effect of the distribution of weight on accuracy

Method

Apparatus

In addition to the total weight, a cane's center of gravity may influence accuracy. A cane with a tapered shaft has a center of gravity that is closer to the grip than does a cane with weight that is distributed evenly along the shaft. Four canes were constructed for this experiment. Cane construction began with four shafts of aluminum tubing (Series 6006/T-6) with a wall thickness of .028 inches with similar grips and 54 grams (about 2 ounces) of lead weights taped to each shaft, so that the shafts balanced at their midpoints. An additional 54 grams of weight were then added to each cane to create different weight distributions. The first cane had the extra weight evenly distributed along the shaft. The second cane was weighted like a cane with a tapered shaft by adding the extra weights to the shaft at intervals that decreased nearer the grip. The third cane had a center of gravity near its tip, so the additional weight was attached near the tip. The fourth cane was counterbalanced; a short wooden dowel was inserted in the grip end of the shaft, and the additional weight was attached to the dowel. All four canes were fitted with electrically conductive tips as in the previous experiment. The experimental task and apparatus described in the previous experiment was used in this experiment as well.

Procedure

The participants were 24 sighted psychology students (12 males and 12 females) who were were randomly assigned to four groups, so each group had 3 males and 3 females. Each group used one of the weighted canes. Each participant performed the experimental task continuously for 45 minutes, so that the effects of fatigue could become evident. The 45-minute period was divided into nine 5-minute intervals, and the accuracy of performance during each interval was measured the same way as in the previous experiment.

Results and discussion

A mixed-model MANOVA was calculated, with RMS deviations from the target as the dependent measure, the distribution of the cane weight as a between-subjects factor, and time on task as a repeated-measures factor. The only significant finding was a main effect of time on task, Pillai's Trace = .70, $F(8,13) = 3.85$, $p = .015$. This finding indicates that accuracy decreased over time, without regard to which distribution of weight a cane had (see Table 1). The lack of significant effects in this experiment, coupled with the findings from the previous experiment, indicate that neither overall weight nor the distribution of weight has a significant effect on fatigue and accuracy.

Experiment 3: Effect of weight on sensitivity

Method

Apparatus

Just as it was presupposed that a heavier cane would increase fatigue and decrease accuracy, it was thought that a lighter cane would allow for more sensitivity in assessing information that was transmitted along the cane shaft. The five weighted canes from the previous experiment were used in this experiment, except that the metal tips were replaced with standard nylon tips. A two-choice discrimination task was used in which the participants examined, with the canes, the surfaces of two plates that differed only in regard to roughness. The task was to identify the rougher of the two surfaces. To ensure that the participants based their judgments only on vibratory stimulation of their hands by the canes, each participant wore a sleep shade and a pair of mono-headphones (Foster RDF 208) connected to a Grason-Stadler white-noise generator (Model 455B) delivering 75 decibels of continuous white noise.

The surfaces were two aluminum plates, 9 inches by 6 inches by a half inch, whose surfaces were milled with parallel grooves that were perpendicular to the plates' long edges. Grooves covered an area 3 inches wide, centered on the plate to provide a smooth surface 3 inches wide on either side of the grooved surface. Pilot testing found that a 75% correct identification criterion was met if the grooves on each plate contained six grooves that were 1⁄4-inch wide, separated by islands that were 1⁄4-inch wide. One plate had grooves that were 0.0105-inch deep, and the other plate had grooves that were 0.0125-inch deep. This difference in depth produced the differential effect of roughness.

Procedure

The participants were 10 sighted volunteers who were drawn from an introductory psychology class. They were acquainted with the task in a brief practice session, put on the sleep shades and headphones, stood before the plates, scanned each surface with the cane tip, and indicated which of the two surfaces felt rougher. The participants were allowed to vary their scanning rate and force of the cane, but after examining both plates, they were not allowed to return to a plate for further examination. Each trial consisted of one attempted discrimination between the two plates. Each participant experienced three blocks of 50 trials, with each of the five canes used 10 times in each block, so each cane was used 30 times in all. The order in which the plates were examined was varied randomly from trial to trial, and in each block, half the participants used the five canes in one order, and the other half used them in a different order.

Results and discussion

Table 2 shows the mean number of correct identifications made with each cane. A MANOVA indicated that there was no overall effect of weight on detection ability, $F(4,36) = 1.69$, $p = .268$, so the distribution of weight does not appear to have a significant impact on the detection of differences in roughness.

Experiment 4: Effect of cane length on the detection of drop-offs

Method

Participants

Detecting drop-offs is a primary goal of the use of long canes, and the length of a cane may affect this ability. To control for the variability in having novice cane users uncertainly probe for changes in levels, we chose 10 adults with visual impairments who were experienced and competent cane travelers. All the participants had light perception only or were totally blind and wore blindfolds during the study.

Apparatus

A carpeted runway was built out of plywood to be 4 feet wide, 44 feet long, and 6 inches high. The task was to walk on the runway while using the touch technique and then locate and step off the end of the runway onto the floor. The effect of walking speed on preview was held constant by having the participants keep pace with a research assistant who walked alongside the platform carrying a small battery-powered device that regularly emitted clicks. The assistant regulated her walking speed by stepping, every 0.5 seconds, on regularly spaced marks that were placed on the path along which she walked. The click generator moved at approximately 2 miles per hour, a generally comfortable walking speed. The assistant always started 10 feet behind the participant and continued walking 10 feet beyond the end of the runway.

The participants used a long cane with a standard grip and tip and a telescoping shaft that allowed for adjustable cane lengths. Eight cane lengths were tested, from 85% to 120% of each participant's reference length, in increments of 5%. Each participant's reference length was determined by measuring from the ground to a point 1.5 inches above the participant's xiphoid process.

Procedure

The participants were familiarized with the task and how to keep pace with the moving sound source and then instructed to walk along the platform swinging the cane from side to side, touching the tip to the surface of the runway at the end of each arc. Test canes were randomly ordered, and each cane was used for six trials, twice at each of three starting points. Three starting points (20 feet, 30 feet, or 40 feet from the end of the runway) were randomly assigned before each trial to prevent the participants from memorizing the distance from the starting point to the end of the runway. Before each trial, the participants were guided in several large circles on one side of the runway and then guided to the runway at an angle to disorient them to the position of the end of the runway. Each participant was then centered on the runway at the appropriate starting point. As the participants walked along the runway, a sighted assistant walked along one side to help any participant who failed to detect the edge of the runway or stumbled.

Videotaped trials were scored independently by two persons. The failure to detect the end of the runway and stepping off it unexpectedly was scored 0 for that trial, detecting the end of the runway and stepping off it smoothly and without hesitation was scored 2, and intermediate performance was scored 1. Behaviors indicating intermediate performance included having over half a foot hanging off the step, taking an overly large step, pausing at the end of the runway, hitting one's heel on the step, and sliding one's heel off the end of the runway. The raters were in agreement on 96.5% of the trials that they scored. In disagreements, the more lenient score was used.

Results and discussion

A one-way MANOVA was conducted, with cane length as the independent factor and performance scores as the dependent measure. The results indicated a significant main effect of cane length, Pillai's Trace = 1.0, $F(8, 2) = 1864.56$, $p = .001$. Performance scores as a function of cane length are shown in Figure 2.

Planned comparisons assessed the differences among the individual cane lengths. Three out of four presumptions were significant. The longest cane (120% of reference length) led to significantly worse performance than that afforded by the reference length (100%), $F(1,9) = 7.28$, $p \leq .02$). The shortest cane (85% of reference length) also led to significantly worse performance than that afforded by the reference cane, $F(1,9) = 53.63$, $p \leq .001$. The reference cane led to significantly better performance than the 95% length, $F(1,9) = 22.22$, $p \leq .001$, but was not significantly different from the 105% long cane, $F(1,9) = .73$, $p \leq .414$.

These results suggest that if a cane is either too short or too long, the ability to locate and negotiate features of the environment that require a change in walking behavior is diminished. If the cane is too long, a clear indication of a drop-off may not be afforded, whereas if a cane is too short, not enough time is given for the person holding the cane to react to the drop-off. Although the participants in this experiment used their canes in the prescribed manner, we acknowledge that canes are often used in modified ways. Some examples include changing the length of the stride or arc width and thus affecting whether the cane tip previews foot placement. For the task presented, however, the mean performances seem to indicate that the sternum method of determining cane length provides an optimum length. Decreasing the cane length led to a more-pronounced decrease in performance than did increasing the cane length.

General conclusions

While there is some evidence that, within the weight range that was examined, the ability to manipulate a cane accurately depends, in part, on the cane's weight, these effects were not significant. It was found, however, that the ability to manipulate a cane accurately declines rapidly as time on task increases and that the use of a cane that is more than 5% shorter or is 20% longer than the length prescribed by the sternum method results in decreased accuracy. These results differ somewhat from the findings of Burton (1992, 1994) that length and the distribution of mass do not impinge on the use of long canes in detecting changes in surfaces.

Several experiments have demonstrated the need for preview while performing perceptual motor tasks (Crossman, 1960; Poulton, 1954). Although it may seem that the ability to locate and negotiate steps down would be facilitated by greater preview than that provided by the long cane prescribed by O&M specialists, this contention is not supported by the results of this study. There is evidence that the performance of mobility tasks is affected by the length of a cane and that the optimal length is determined by the sternum method described by Hill and Ponder (1976). It may be that the proprioceptive information that is provided by the cane becomes less precise as the length is increased beyond the length that tests the part of the surface to be occupied by the foot on the next step. It may be that deficiencies in preview that are afforded by using a long cane are not the result of cane length, but the manner in which the cane is wielded.

The ability of a person who is visually impaired to travel independently and safely is determined, in no small measure, by the accuracy with which tools that are used for this purpose can be manipulated. For the majority of visually impaired pedestrians, the long cane is the primary tool. It is important to know, therefore, how accurately a cane can be used, how accuracy depends on the time the cane has been in use, and how accuracy is affected by the characteristics of the cane. The results of this study, together with those of other studies, have begun to chart the extent to which variables of long canes affect the performance of mobility tasks, but further research on the effects of weight and length on mobility performance are warranted. A major limitation in generalizing the results of this study was the use of sighted college students as participants. While the use of these participants does not limit the differential findings on the characteristics of canes, it may limit how the findings would affect the use of long canes by people who are blind, especially those who are older. For this reason, the experiments should be conducted with these populations to validate them with these other populations.

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