Gait and Long Cane Kinematics: A Comparison of Sighted and Visually Impaired Subjects

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Although visually impaired individuals have used the long cane to increase mobility for many years, few empirical studies have examined the effectiveness of this tool. The purposes of this research were to determine if these cane procedures provide adequate protection for visually impaired individuals and to compare sighted and visually impaired gait mechanics. Seven sighted (four females, three males) and five visually impaired subjects (two females, three males) were videotaped at 60 Hz by two cameras situated at opposite 45° angles to the subjects' frontal plane so that three-dimensional coordinates could be calculated via direct linear transformation. One-way analyses of variance were calculated on 17 variables to determine if there was a significant biomechanical difference between sighted and visually impaired gait at an adjusted $\alpha = .003$. The results showed that for both groups the cane tip touched outside where the foot landed and that the only variable significantly different between the two groups was resultant cane velocity. The major conclusion of this research was that present cane techniques may not provide adequate protection for visually impaired individuals since the purpose of mobility training is to have the person touch the ground with the cane tip at the foot contact positions.

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Ambulation is an essential part of the everyday lives of most people. The great majority of the human population is able to travel with little concern for obstacles in their path because they are capable of visually observing and, therefore, avoiding any such obstacles present. Individuals with a visual impairment do not have this feedback mechanism and, as a result, must rely upon other means of detecting obstacles that impede their path. Several devices and techniques have been developed for assisting the mobility of individuals with a visual impairment. The two most prevalent devices used by individuals with a visual impairment are the dog guide and the long cane, with the long cane being most commonly used.

Very little biomechanical research has been performed on the gait mechanics of individuals with a visual impairment, including motions of the body and the long cane. Before reviewing this literature, it is important to understand the process of using the long cane as an increased mobility tool. The most common technique, and the technique used by all subjects in this study, is the touch technique. The cane should be grasped in the dominant hand in a "shake hands" grip with the index finger extended down the shaft toward the tip and the thumb positioned diagonally across the top of the grip (4,5). LaGrow and Weessies (5) also state that the top of the grip should rest in the palm of the hand with the upper arm flexed so that the hand is waist high. The lower arm is slightly flexed with the hand positioned at the center of the body to allow for a symmetrical arc, equal coverage to both sides of the body, and maximal frontal protection. The wrist is alternately flexed, extended, hyperextended, and flexed again to make one full sweep. This movement should be such that the cane tip touches the ground where the foot will land and is 1 inch above the ground at the center of each half sweep (4,5). The motion of the cane should correspond with the stride rate such that when the left foot touches down, the cane tip is touching down on the right side of the body and vice versa.

A study by Hamill et al (3) investigated the kinetics involved in walking gait for sighted and visually impaired subjects. These investigators tested whether there was symmetry between the lower limbs for selected force and impulse variables during one gait cycle for the two groups. It was shown that both the sighted and visually impaired subjects were consistent from the right to left side.

Another study investigated selected kinematic factors of walking gait of sighted and visually impaired children. MacGowan (6) found differences between the sighted and visually impaired children on such variables as stride length, total body velocity, total support time, and selected joint angles at different positions in the gait cycle. Nakata et al (7) studied the electromyographic (EMG) signals of several muscle groups and other kinematic variables for sighted and visually impaired subjects. This study reported differences in the EMG activation patterns between the groups. Interestingly, when blindfolded, the sighted subjects showed similar EMG patterns to individuals with a visual impairment (7). No other variables proved to be significant, although the sighted subjects did show a higher mean walking velocity.

Clark-Carter et al (1) performed a study that investigated the effectiveness of a Sonic Pathfinder that was designed to detect obstacles in the path of a visually impaired individual. The results from this study indicated the subjects walked faster when the preview was increased. The increased preview meant the subjects were able to distinguish objects in their path far before their long canes would have detected these objects. Another study by these authors investigated how route difficulty affected the walking speed of individuals with a visual impairment (2). The results indicated that the subjects' walking speed decreased as the difficulty of the route increased. Another result was that individuals with a visual impairment who used dog guides had a faster normal walking velocity than those using a long cane (2). Although no empirical data exist on the incidence of injury due to improper cane coverage, conversations with visually impaired individuals and mobility specialists indicate that there are problems. Anecdotal evidence from these individuals indicates that obstacles such as curbs and manholes are often undetected and can cause staggering or falling.

Purpose

Although sighted vs. visually impaired gait has been studied to some degree, no data have been collected comparing/contrasting sighted and visually impaired gait while using the long cane. Since sighted mobility instructors are teaching the visually impaired how to use the long cane as a mobility tool, it is important to study how both groups approach gait while using the long cane. The purpose of this study was two-fold. First, because very little research has been performed on biomechanical issues related to cane techniques, one purpose was to examine whether the cane procedures were actually reducing injury potential and increasing mobility. Second, because sighted individuals are often utilized to simulate the gait and cane techniques of visually impaired individuals in a variety of clinical and/or research settings, it was also a purpose of this research to determine whether sighted subjects can accurately replicate the biomechanics displayed by individuals with a visual impairment with regard to both body and cane biomechanics.

The mediolateral displacement of the cane tip was substantially higher in the visually impaired group than the sighted group.

Subjects

A total of 12 subjects participated in this study. Seven were sighted (four females, three males) and five were individuals with a visual impairment (two females, three males). Each subject had received orientation and mobility training in using the long cane as a tool for increased mobility. The purpose of mobility training is to teach the visually impaired individual how to use the cane as a mobility tool. An experienced mobility instructor concluded that each subject included in this research was efficient in using the long cane as a mobility tool. All sighted subjects were mobility instructors and all subjects in this study were right-handed. Although the ages of the subjects were not collected, visual observation of the subjects indicated the mean ages and age ranges of the groups were similar. Both younger and older subjects were included in the study to obtain a cross-section of ages. All visually impaired subjects were classified as fully blind.

Procedures

The data collection was conducted in an indoor setting. A large conference room with level, short-pile carpeted floors was selected due to its proximity to the subject population. Each subject was asked to walk along a straight line bisecting the calibrated space at a normal pace through a range of approximately 8 m while utilizing the long cane. Each subject was asked to perform five trials, and the mobility instructors were asked to walk with their eyes closed in order to compare the gait and cane mechanics of the two groups. All data were collected on the same day in the same room. They were informed that no obstacles were in their path. All subjects were asked to follow the sound of an advisor guiding them to make sure they stayed on line. All subjects were videotaped at 60 Hz by two cameras situated at opposite 45° angles to the frontal plane of the body. The cameras were synchronized to allow each to record at the same time.

The trial deemed most consistent, natural, and through the calibrated space by the research team was selected for analysis. The criteria for selection of the digitized trial was that one full stride was in the calibrated space and the subject was walking directly toward the audible source target. The performance of each subject from each videotape was digitized. Two-dimensional spatial coordinates from each view were determined for the left and right toes, right elbow, right wrist, and cane tip utilizing a Peak Performance Technologies Motion Analysis System (Peak Performance Technologies, Inc., Englewood, CO). Any missing data points were digitized manually. All data were smoothed using a Butterworth filter at a cut-off frequency of 2 Hz. The individual body landmarks used for joint identification were the lateral epicondyle of the right humerus, the junction of the radius, ulna, and first row of carpals for the right wrist, the distal phalanges of the fifth digit of each foot, and the cane tip. One researcher was responsible for marker placement. One visually impaired subject was digitized using a full body model for presentation purposes.

A three-dimensional calibration frame in the shape of a sphere measuring 1 m in radius was utilized to establish the geometry of the data collection space so these landmarks could be tracked in three dimensions. Three-dimensional coordinates were calculated from the two-dimensional spatial coordinates computed from each camera by utilizing the direct linear transformation technique. The direct linear transformation technique transforms the two independent two-dimensional spatial coordinates for each landmark into a single three-dimensional coordinate in each picture of the synchronized video records. This mathematical technique utilizes the known three-dimensional coordinates of the 24 points in the calibration sphere and the two sets of two-dimensional coordinates from the respective video records to transform the two-dimensional coordinates into three-dimensional coordinates. The transformations are accurate, however, only within the confines of the calibration sphere. Therefore, it was imperative the video records be reduced only during the time when the subject was within the confines of this space.

Variable	Visually Impaired $\bar{X}$	Visually Impaired SD	Sighted $\bar{X}$	Sighted SD	F Ratio	F Probability
Anteroposterior cane displacement per stride (meters)	.50	.19	.72	.11	6.37	.0302
Vertical cane displacement per stride (meters)	.06	.05	.04	.03	.62	.4493
Mediolateral cane displacement per stride (meters)	.97	.24	.71	.09	7.13	.0235
Maximum lateral cane position vs. left foot placement (meters)	.42	.23	.21	.07	5.44	.0419
Maximum lateral cane position vs. right foot placement (meters)	.30	.14	.37	.06	1.26	.2887

TABLE 1. *Means, standard deviations, and ANOVA results for cane-related displacements.*

Statistical Procedures

The subjects were classified as either visually impaired or sighted and the means and standard deviations were calculated for each of the following variables: anteroposterior cane displacement, vertical cane displacement, mediolateral cane displacement, maximal cane velocity in each of the three dimensions, maximal resultant cane velocity, mediolateral distance from the foot to where the cane tip touched, stride length, stride rate, and walking velocity. One-way analyses of variance (ANOVA) were calculated to test whether there was a statistical difference between the groups on these variables at an α of .05. Because of multiple comparisons, the Bonferroni procedure was used to generate a corrected α of .003 for the individual tests.

RESULTS

Tables 1–3 present the means, standard deviations, and ANOVA results. Figure 1 presents a stick figure representation of the whole body of one subject at selected points during the gait cycle and the motion of the cane tip through the calibrated space.

DISCUSSION

The results clearly show the cane dynamics for the two groups differ. The mediolateral displacement of the cane tip was substantially higher (p = .0235) in the visually impaired group than the sighted group. Since the visually impaired group has no visual feedback even though they knew no obstacles were in their path, they would have a tendency to obtain more coverage side to side than the sighted group. The problem is this large mediolateral displacement causes the cane tip to land outside or wide of the point at which the foot will eventually land. This is a finding

Variable	Visually Impaired $\bar{X}$	Visually Impaired SD	Sighted $\bar{X}$	Sighted SD	F Ratio	F Probability
Anteroposterior cane velocity (m/sec)	2.28	.90	2.04	.20	.47	.5096
Vertical cane velocity (m/sec)	.28	.18	.32	.24	.11	.7452
Mediolateral cane velocity (m/sec)	2.90	.59	2.29	.27	5.89	.0356
Resultant cane velocity (m/sec)	3.61	.49	2.79	.23	15.35	.0029

TABLE 2. *Means, standard deviations, and ANOVA results for cane-related maximum velocities.*

Variable	Visually Impaired		Sighted		F Ratio	F Probability
	$\bar{X}$	SD	$\bar{X}$	SD		
Stride length (meters)	1.09	.40	1.42	.22	3.56	.0886
Stride rate (steps/minute)	94.08	3.24	103.56	5.52	11.64	.0066
Stride time (seconds)	1.28	.06	1.15	.06	14.93	.0031
Support time (seconds)	.82	.08	.70	.02	14.37	.0035
Double support time (seconds)	.22	.08	.15	.04	3.95	.0749
Time in support (%)	64.35	5.92	61.00	3.67	1.48	.2518
Time in double support (%)	16.95	6.00	13.10	2.80	2.25	.1642
Walking velocity (m/sec)	.85	.33	1.22	.18	6.27	.0312

TABLE 3. *Means, standard deviations, and ANOVA results for stride-related variables.*

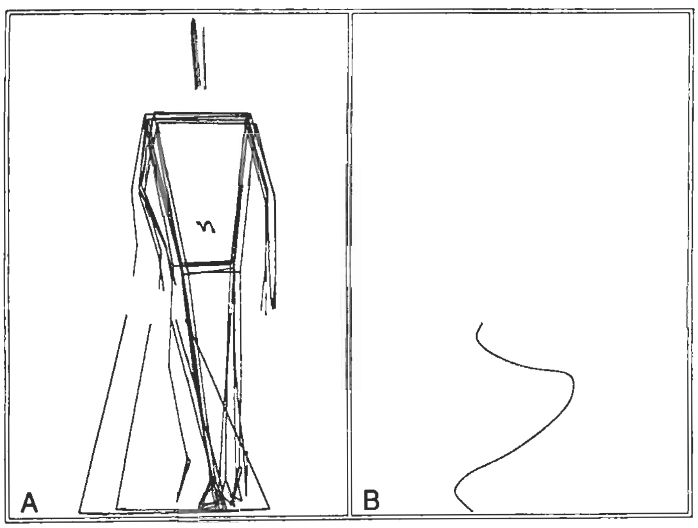

FIGURE 1. *A) Stick figure representation of visually impaired subject 1 (frontal view). B) Tracing of the cane tip of visually impaired subject 1 (overhead view).*

that is contrary to normal training of individuals with a visual impairment using a long cane, as they are instructed to touch the surface with the cane tip over which they are ambulating at a point at which the foot will ultimately touch down (5). A nonsignificant (p = .0419) mean mediolateral distance from the foot to the cane tip for the visually impaired and sighted groups on the left side of .4208 m and .2194 m, respectively, was observed. The mean mediolateral distance to the right side for the visually impaired subjects was .3062 m and a distance of .3657 m was calculated for the sighted subjects.

Graphically, Figures 2 and 3 show that the cane tip touchdown position for the sighted subjects tended to be more outside the right foot, while the visually impaired subjects tended to be more outside the left foot. Because there is more range of motion in flexion than in hyperextension, it is plausible that more displacement to the left would be expected. The wrist is also slightly hyperextended when at the midline of the body so the cane can be held straight out in front of the body which will also limit the range of motion to the right. It is possible the sighted subjects displaced more to the right because they could see during mobility training that more clearance was needed to this side to overcome the tendency not to hyperextend. Since it is clear the cane tip is not touching where the foot will land, holes and other objects in the foot path could cause problems for pedestrians with a visual impairment.

In addition to a mediolateral displacement difference, there was also a substantial difference in the cane tip anteroposterior displacement between the groups. The visually impaired subjects moved their cane tip a mean of .50 m, while the sighted subjects moved a mean of .72 m. This indicates the sighted subjects were moving the cane tip .22 m more per stride than the visually impaired subjects. This displacement is probably due to a longer stride length demonstrated by the sighted subjects. Although not significant (p = .0881), a .3362 m greater stride length was displayed by the sighted subjects.

Overall, the subjects with a visual impairment moved their canes much faster than the sighted subjects. This is reflected in the significant resultant cane tip velocity (p = .0029), where the subjects with a visual impairment moved their cane tip an average of .8121 m/sec faster than the sighted subjects. The major contributor to this resultant difference was the mediolateral cane velocity. Although individuals with a visual impairment moved the cane faster in the anteroposterior direction as well, this finding was insignificant compared with the .6087 m/sec (p =

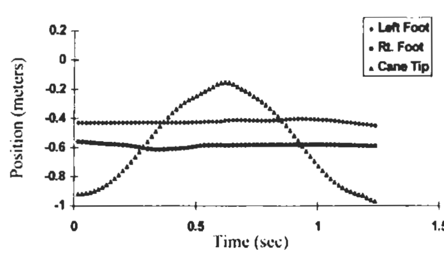

FIGURE 2. *Average mediolateral cane position vs. mediolateral foot placement (sighted subjects).*

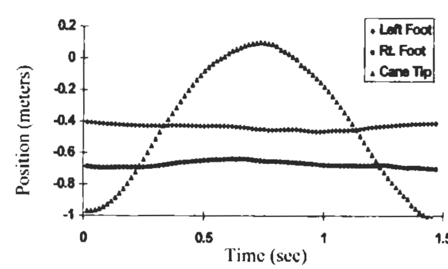

FIGURE 3. *Average mediolateral cane position vs. mediolateral foot placement (visually impaired subjects).*

.0356) difference in the mediolateral direction. The larger mediolateral displacement of the cane tip by the visually impaired subjects caused them to have a larger velocity in this direction also. Although the sighted subjects did have a slightly larger velocity in the vertical direction, the values were very close and therefore insignificant.

Although statistically insignificant, one of the largest discrepancies (p = .0066) observed between the groups was for stride rate. The stride rate of the subjects with a visual impairment was 94.08 steps per minute while the stride rate for the sighted subjects was 103.56 steps per minute. Even though the individuals with a visual impairment knew there were no objects in their path, they were still extremely careful and protective of how fast they would walk. This is also evident when examining walking velocity, calculated from stride rate and stride length. The one-way ANOVA produced a p value of .0312, and the means for individuals with a visual impairment and sighted subjects were .8598 m/sec and 1.2299 m/sec, respectively.

These values are consistent with some of the research done in this area. Nakata et al (7) reported values of approximately 1.125 m/sec and 1.00 m/sec for sighted and visually impaired subjects, while Clark-Carter et al (2) reported values ranging from 1.13 m/sec to 1.51 m/sec in two studies involving subjects with a visual impairment. Although these values are substantially larger than those found in this study, the values by Clark-Carter et al (2) were based on a percentage of preferred walking speed calculated by having the visually impaired subject walk at a comfortable pace guided by a sighted subject, which should give a faster pace. Values of 1.01 m/sec and .75 m/sec were reported for sighted and visually impaired children, mean age = 9 years, respectively, in a study by Hamill et al (3).

CONCLUSIONS

First, the data indicate the cane technique used by these subjects did not provide foot placement protection for either group since the cane touched down outside where the foot lands for both the sighted and visually impaired groups. This leaves the visually impaired subjects vulnerable to surface depressions or moderate elevations in the location at which the foot lands as the cane tip will likely miss each of these surface abnormalities. This could be an extremely important finding because it gives feedback to the mobility instructors that they may need to change their teaching methods to decrease the sweep or touch the ground where the foot will land and then continue the sweep to the side before sweeping to the other side of the body. Since no obstacles were presented to the subjects during this study, there is no conclusive evidence that the cane would not have detected these surface abnormalities, although the data seem to suggest that these environmental barriers may present a problem. The authors are presently exploring the response of visually impaired individuals to different obstacles, including surface depressions and elevations. Secondly, it is obvious the cane techniques and body movements of the subjects with a visual impairment were different than those of the trained sighted group. This conclusion is made based upon the large number of variables that were different at the .05 level even though only one variable was significant at the .003 level of significance. Thus, it would be improbable to obtain generalizable results to a visually impaired population from a sighted sample. Third, it is also clear the visually impaired subjects in this research walked at a much slower velocity than the sighted group so they can adjust more readily to any obstacles in their path or any other abnormal situations.

Since no obstacles were presented to the subjects during this study, there is no conclusive evidence that the cane would not have detected these abnormalities.

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