The Effectiveness of Facility Assembly Devices Concerning the Wayfinding of People with Visual Impairments

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Abstract
The study of more effective methods in terms of environmental cognition to assist visually impaired people in moving about in a space is the primary objective concerning the accessibility of disabled people. Mobility aids supplemented by hearing and echo-location cues have proven to be the most difficult concerning the improvement of mobility in finding a safe path through the immediate environment. How to develop facilities without auditory aids and carriers and to overcome the functional limitation of a single component for blind pedestrians is a necessary issue.

A school with continuous space and a simple route and an office composed of open space and a complex route were selected as examples. The procedure of the experiment consisted of four phases; first, wayfinding was processed to evaluate the original environment; second, a tactile map was located at the start of the route; third, handrails were added along the test route, and finally, door signs were placed on doors. Fifteen visually impaired persons were selected for each phase. The results showed that both the tactile map and handrails with Braille landmarks were more effective in regard to wayfinding than were door signs. Handrails and door signs improved upon the limitations of a tactile map, raised the accuracy ratio of wayfinding close to 100%, and were more effective in a complex environment than in a simple environment.

Keyword: effectiveness; assembly devices; wayfinding; visual impairment

1. Introduction
Many wayfinding issues in architectural design have been explored, but most discussions focused on the movement experiences of sighted people. An increasing number of virtual reality studies have been conducted to predict how people move through spaces and form memories of those places. Nevertheless, the technology would be difficult to apply to the improvement of mobility for people with visual impairments because virtual theory relies on visual perception. Wayfinding and mobility refer to one's ability to know where one is in the pedestrian environment and to locate waypoints and destinations. A major problem for a blind pedestrian is to know exactly where they are, where their destination is located, and how to get there from where they are. In matters of wayfinding and mobility, most researchers analyzed the orientation abilities and wayfinding schemes of blind people, as well as the legibility of the built environment.

"Orientation" devices, however, offer potential technology for the traveler to support his/her mobility skills. Although visually impaired people may find it difficult to achieve a spatial representation from their direct experience, they may be able to compensate with spatial information gained from indirect sources. Hirtle and Hudson (1992) have indicated that effective learning about a space was highly related to the method used and information support in the environment. Hence, the study of more effective methods, in terms of environmental cognition to assist the visually impaired in moving about in a space, is the primary objective concerning the accessibility of disabled persons. Orientation training places great importance on the wayfinding ability of people with visual impairments. It assists them in learning routes through the environment by making use of their perceptual cues, such as auditory, tactile, and olfactory landmarks (Spencer et al., 1989), and mentally linking a series of recognizable features to form a route. Experimental evidence has shown that blind people perform mobility as well as do sighted people requiring estimates of the direction and distance (Rieser et al., 1986). Making an accurate estimation of direction and distance on a route is the most important mobility skill for visually impaired people.

The knowledge of direction and distance between...
two places can be gained from the direct experience of walking in the environment or from indirect sources of information, such as verbal instructions (auditory aid), the use of a scale map, handrail with signage or door signs. Thorndyke and Hayes (1982) pointed out that people were better able to coordinate the resulting spatial schemes by using a map to learn about a space than from a sequence of verbal descriptions. Mobility aids supplemented by hearing and echo-location cues have proven to be the most difficult for improving upon the mobility of finding and following a safe path through the immediate environment (Brabyn, 1997). Ungar and Blades (1997) have also indicated that visually impaired people could gain information about the spatial relationships between places much more rapidly from a tactile map than from direct experience within the environment. The tactile map, being recognized as an effective source of information about both immediate and distant places in the environment contributes to successful wayfinding (Passini et al., 1986).

Although blind people can perceive the spatial layout of the represented area by reading and memorizing a tactile map, they generally read it more slowly and understand it less than do sighted people who see a visual print of the same map (Ungar et al., 1995a), especially, when a tactile map represents a large environment or an environment with complex circulation. Therefore, more effective methods have been taken into account in regard to minimizing the time and effort that it takes for people with visual impairments to learn the unknown environments. In past years, many studies have focused on the designing of tactile maps and the way in which they were used. However, more recent efforts have focused on assembly devices and systems to provide support tools for the mobility of visually impaired people. Brabyn (1997) indicated that remotely readable signs, dead reckoning systems and the global positioning system were new technologies; however, the inconvenience to blind individual in carrying a handheld receiver or sensor and the high cost of such devises still needed to be overcome.

Taiwan has approximately fifty thousand blind people (Ministry of Interior, 2008), and the blind population continues to increase year by year. There

![Fig.1. Floor Plan of the Simple Environment (Case 1)](image1)

![Fig.2. Floor Plan of the Complex Environment (Case 2)](image2)
is a mandate within the building code to provide designing methods for public buildings to fulfill the objective of offering accessibility for the disabled. Determining how to develop assembly devices in buildings by the facilities, such as tactile maps, handrails with Braille and door signs without auditory aids and carriers, to overcome the functional limitation of single component use, and to form a sequence of cues for blind pedestrians is an absolutely necessary issue, so the purpose of this research was to test the effectiveness of assembly devices on the wayfinding of people with visual impairments.

2. Methods

2.1 Participants and Locations

Sixty visually impaired persons from the Association of People with Visual Impairments, with one-year training in orientation and mobility, participated in this research. The blind individuals had experiences in using Braille and reading tactile maps. The experiment included four phases, with 15 persons for each phase. A special education school with continuous space (Fig.1.) and a construction and administration office composed of open space and a complex route (see Fig.2.) were selected as examples of simple environments (case 1) and complex environments (case 2). Both locations were popular public buildings for visually impaired people in Taipei city.

2.2 Assembly Device

The ground floor plan of each building was made as a tactile map with a scale of 45 × 60 centimeters and consisted of a raised print wall-line and Chinese characters with Braille (see Fig.3. and 4.). A tactile map fixed on the wall was located at the start of the route. Handrails with Braille coded landmarks at the end of handrails to identify the locations were fixed on the wall at about 80 centimeters above the ground (see Fig.5. and 6.). Door signs were fixed on the right side wall of the door at about 135 centimeters above the ground to show the location of space by Chinese characters and Braille (see Fig.7. and 8.).

2.3 Procedure and Survey

This experiment consisted of setting a route...
composed of various spaces, such as washroom, storage, classroom, audio-video room, meeting room, library, staircase and elevator. Each route, including 8 objects in the environment (see Fig. 9. and 10.), was set for participants to identify the space sequentially.

The procedure included four phases: in the first phase, wayfinding was processed to evaluate the original environment in terms of the accurate ratio of test objects and how long participants spent in navigating the environment. As for the second phase, a tactile map was fixed at the start of the route in the original environment for participants to perceive the spatial layout of the route. Wayfinding was processed to evaluate the accurate ratio of test objects and how long participants took. In the third phase, handrails were added to the wall along the test route to assist participants in identifying their locations, in addition to an existing tactile map; wayfinding was then processed. Finally, signs were placed on doors along the test route for participants to judge their locations in the spaces, in addition to the existing tactile map and handrails; wayfinding was then processed. Photographs recording the simple environment (see Fig. 11., 12., 13. and 14.) and the complex environment (see Fig. 15., 16., 17. and 18.) are shown as follows.
2.4 Description and Analysis

Effectiveness was measured by predetermined objective factors of performance, such as how long it took to complete a trip or how many errors participants made. As for travel errors, these were defined as veering, stopping and other disorienting effects when walking (Ungar et al., 1997). On the other hand, the situation of the participants being unable to point out the correct location of the test object was also recognized as "error". The description of this measurement included the accurate number of test objects and how long participants took to complete the entire journey.

Descriptive and analytical statistics were performed with the SPSS computer program. A one-way analysis of variance was applied to compare the difference in the accuracy ratio of test objects between different phases of the experiment. The significance was established by using the Paired-Sample t test criterion. Another analysis was applied to compare the difference in the accuracy ratio of testing objects between the simple and complex environments by using Independent Samples t test criterion.

3. Results

The characteristics of participants, including gender, age, education and type of handicap, were analyzed as follows from the first phase to the fourth phase (see Table 1).

3.1 Descriptive Data of Accuracy Ratio and Travel Time

Table 2. shows that the mean accuracy ratio was 3.26 of 8 test objects when participants completed the route of the original environment in the case of the simple environment (case 1), and the mean accuracy

Table 1. Gender, Age, Education and Type of Handicap of Participants

| Phase of experiment | First phase No. (%) | Second phase No. (%) | Third phase No. (%) | Fourth phase No. (%) |
|---------------------|---------------------|----------------------|---------------------|---------------------|
| Gender              | Male                | 8 (53.3%)            | 8 (53.3%)           | 9 (60.0%)           | 8 (53.3%)           |
|                     | Female              | 7 (46.7%)            | 7 (46.7%)           | 6 (40.0%)           | 7 (46.7%)           |
| Age                 | Under 30 years old  | 7 (46.7%)            | 7 (46.7%)           | 5 (33.3%)           | 7 (46.7%)           |
|                     | 31-40 years old     | 4 (26.7%)            | 1 (6.7%)            | 1 (6.7%)            | 5 (33.3%)           |
|                     | 41-50 years old     | 4 (26.7%)            | 4 (26.7%)           | 7 (46.7%)           | 3 (20.0%)           |
|                     | Over 51 years old   | 0 (0.0%)             | 3 (20.0%)           | 2 (13.3%)           | 0 (0.0%)            |
|                     | Elementary school   | 0 (0.0%)             | 4 (26.7%)           | 1 (6.7%)            | 0 (0.0%)            |
|                     | Junior school       | 0 (0.0%)             | 1 (6.7%)            | 0 (0.0%)            | 0 (0.0%)            |
|                     | Senior high school  | 6 (40.0%)            | 4 (26.7%)           | 12 (80.0%)          | 5 (33.3%)           |
|                     | University          | 9 (60.0%)            | 6 (40.0%)           | 2 (13.3%)           | 10 (66.7%)          |
| Type of handicap    | Congenital impairment | 9 (60.0%)             | 8 (53.3%)           | 2 (13.3%)           | 8 (53.3%)           |
|                     | Acquired impairment | 6 (40.0%)            | 7 (46.7%)           | 13 (86.7%)          | 7 (46.7%)           |
ratio was 5.20 of 8 test objects when participants completed the route of the original environment with a tactile map. The difference in the accuracy ratio of test objects between the original environment and the original environment with a tactile map was significant ($t$=-2.430, $p$ <0.05). As for the participants completing the route of the original environment with a tactile map and handrails, the mean accuracy ratio was 7.00 of 8 test objects. The difference in the accuracy ratio of test objects between the original environment and the original environment with a tactile map and handrails in the case of the simple environment was also significant ($t$=-2.358, $p$ <0.05).

Table 3. shows that the accuracy ratio of test objects of each phase was significantly different from the other phase in the complex environment (case 2). The result of the mean accuracy ratio was 2.00 of 8 test objects when participants completed the route of the original environment in the case of the complex environment, and the mean accuracy ratio was 4.26 of 8 test objects when participants completed the route of the original environment with the aid of a tactile map. As for participants completing the route of the original environment with a tactile map and handrails, the mean accuracy ratio was 6.46 of 8 test objects. Furthermore, the mean accuracy ratio was 7.46 of 8 test objects when participants completed the route of the original environment with a tactile map, handrails and door signs.

Obviously, the difference in the accuracy ratio between the original environment and the original environment with a tactile map was significant ($t$=-3.407, $p$ <0.01), and the difference in the accuracy ratio between the original environment with a tactile map and the original environment with a tactile map and handrails was significant ($t$=-3.336, $p$ <0.01), as well. There was a significant difference in the accuracy ratio between the original environment with a tactile map and handrails and the original environment with a tactile map, handrails and door signs ($t$=-2.351, $p$ <0.05).

Regarding a comparison of the accuracy ratio of the simple environment with the complex environment, Table 4. shows that there was no significant difference between the simple environment and the complex environment. Table 5. shows the results of the travel time of the simple environment and complex environment. On the route of the simple environment, it took an average of 5 minutes and 10 seconds for the participants to complete the trip in the original environment, and 4 minutes and 32 seconds on average for them to complete the route of the original environment with a tactile map. When handrails were added to the wall along the testing route, it

Table 2. Accuracy Ratio of Test Objects of the Simple Environment (Paired-Sample t Test)

| Phase of experiment | Samples | Mean of accuracy ratio | SD of accuracy ratio | $t$   | $p$    |
|---------------------|---------|------------------------|---------------------|------|--------|
| Original environment of case 1 (simple) | 15 | 3.26 | 2.604 | -2.430 | 0.029* |
| Environment with tactile map of case 1 | 15 | 5.20 | 2.455 | -2.358 | 0.033* |
| Environment with tactile map of case 1 | 15 | 7.00 | 1.463 | -1.047 | 0.313 |

$p$ <0.05* $p$ <0.01** $p$ <0.001***

Table 3. Accuracy Ratio of Test Objects of the Complex Environment (Paired-Sample t Test)

| Phase of experiment | Samples | Mean of accuracy ratio | SD of accuracy ratio | $t$   | $p$    |
|---------------------|---------|------------------------|---------------------|------|--------|
| Original environment of case 2 (complex) | 15 | 2.00 | 1.309 | -3.407 | 0.004** |
| Environment with tactile map of case 2 | 15 | 4.26 | 2.631 | -3.336 | 0.009** |
| Environment with tactile map of case 2 | 15 | 6.46 | 2.199 | -2.351 | 0.034* |

$p$ <0.05* $p$ <0.01** $p$ <0.001***
took an average of 3 minutes and 33 seconds for the participants to complete the route. Only 2 minutes and 57 seconds on average were needed on the route of the environment with increased door signs along the test route.

On the route of the complex environment, it took on average 7 minutes and 4 seconds for the participants to complete the trip in the original environment (including travel time of the open space), and 5 minutes and 46 seconds (including travel time of the open space) on average on the route of the environment with a tactile map. When handrails were added to the wall along the test route, it took on average 4 minutes and 0 second (including travel time of the open space) for the participants to complete the trip. Only 3 minutes and 53 seconds (including travel time of the open space) on average were spent on the route of the environment with increased door signs along the test route.

4. Discussion

From the significant differences of the accuracy ratio of test objects between the original environment and the original environment with a tactile map both in the simple and complex environments, the finding was that the environment with a tactile map obviously assisted visually impaired people in perceiving the spatial layout of the route. On the other hand, it also had significant differences in the accuracy ratio of test objects between the original environment with a tactile map and the original environment with a tactile map and handrails both in the simple and complex environments. The authors found that handrails with coding landmarks in Braille signage added to the wall along the test route were effective in assisting visually impaired people in identifying the location.

Nevertheless, there was no significant difference between the original environment with a tactile map and handrails and the original environment with a tactile map, handrails and door signs in the case of the simple environment. The result showed that the door signs with Chinese characters and Braille on the doors were useful for people with visual impairments in judging the location of space but only in the complex environment.

As for travel time, the authors found that it took less time for people with visual impairments to complete the route when a tactile map, handrail or door sign was added to the route than was the case before the aid was offered in the simple environment. The result also showed that it took less time for people with visual impairments to complete the whole trip, including open space, with the facility devices along the route than without the cues in the complex environment. Hence, both the accuracy ratio of test objects and the travel time to complete the route correlated positively with the aid cues made by facilities because people with visual impairments had a higher accuracy ratio concerning the test objects and spent less time in completing the task with the aid devices.

This experiment demonstrated that assembly devices consisting of tactile maps, handrails and door signs were significantly effective in the wayfinding of

### Table 4. Comparison of Mean Accuracy Ratio of the Simple Environment with the Complex Environment (Independent Samples t Test)

| Type of environment          | Samples | Mean of accuracy ratio | SD of accuracy ratio | t      | p     |
|------------------------------|---------|------------------------|----------------------|--------|-------|
| Original environment of case 1 (simple) | 15      | 3.26                   | 2.604                | 1.683  | 0.107 |
| Original environment of case 2 (complex) | 15      | 2.00                   | 1.309                | 1.004  | 0.324 |
| Environment with a tactile map of case 1 | 15      | 5.20                   | 2.455                | 2.631  | 0.442 |
| Environment with a tactile map of case 2 | 15      | 4.26                   | 2.631                | 1.004  | 0.324 |
| Environment with handrails of case 1 | 15      | 7.00                   | 1.463                | 0.782  | 0.442 |
| Environment with handrails of case 2 | 15      | 6.46                   | 2.199                | 0.000  | 1.000 |

* p < 0.05  ** p < 0.01  *** p < 0.001

### Table 5. Comparison of Mean Travel Time of the Simple Environment with the Complex Environment

| Type of environment          | Mean of time on the route | Mean of time in open space | Total time  |
|------------------------------|---------------------------|----------------------------|-------------|
| Original environment of case 1 | 5 min. 10 sec.            | None                       | 5 min. 10 sec. |
| Environment with a tactile map of case 1 | 4 min. 32 sec. | None                       | 4 min. 32 sec. |
| Environment with handrails of case 1 | 3 min. 33 sec. | None                       | 3 min. 33 sec. |
| Environment with door signs of case 1 | 2 min. 57 sec. | None                       | 2 min. 57 sec. |
| Original environment of case 2 | 4 min. 46 sec.            | 2 min. 18 sec.             | 7 min. 4 sec. |
| Environment with a tactile map of case 2 | 3 min. 45 sec. | 2 min. 1 sec.             | 5 min. 46 sec. |
| Environment with handrails of case 2 | 2 min. 46 sec. | 1 min. 14 sec.             | 4 min. 0 sec. |
| Environment with door signs of case 2 | 2 min. 59 sec. | 54 sec.                   | 3 min. 53 sec. |
visually impaired people, with the mean accuracy ratio of 3.26 of 8 objects in the first phase being raised to the mean accuracy ratio of 7.46 of 8 objects at the final phase in the simple environment. At the same time, assembly devices were also successful in supporting visually impaired people in finding the location of each space, with the mean accuracy ratio of 2.00 of 8 objects at the first phase being raised to the mean accuracy ratio of 7.46 of 8 objects at the final phase in the complex environment.

Moreover, it seems that the facility assembly devices were more effective in wayfinding in the complex environment than in the simple environment, as attested to by the increase of the accuracy ratio.

Although Ungar et al. (1995a) pointed out that blind people generally read a tactile map more slowly and memorized it less than sighted people, assembly devices such as handrails and door signs (rather than a tactile map) successfully formed a sequence of cues to improve upon the limitations of a tactile map. In fact, this assembly device has overcome the functional limitation of a single component in wayfinding and has helped people with visual impairments to more easily find locations. Nevertheless, tactile maps and handrails were more effective in regard to wayfinding than door signs, because the increase of mean accuracy ratio was better at the second phase (when the tactile map was added) and at the third phase (when handrails were added) than that of the final phase (when door signs were added) both in the simple and complex environments.

As for the correlation between the characteristics of participants and the data of this test, there was no significant difference in gender, education and type of handicap in terms of comparison of the accuracy ratio of test objects by the Independent Samples t test. However, the difference in the accuracy ratio of test objects between the under 30 years old participants (the mean accuracy ratios were 4.80 in case1 and 6.20 in case 2) and over 51 years old participants (the mean accuracy ratios were 7.50 in case1 and 8.00 in case 2) was significant (t=-2.546, p=0.049 < 0.05) during the third phase. This may result from the fact that the growth of space cognition needs the experience of activity, and the younger participants have less experience of mobility than the elder participants.

5. Conclusion

Based on the results of the experiment, the four aspects of the conclusion in terms of the effectiveness of facility assembly devices on the wayfinding of people with visual impairments are as follows: (a) both the environment with a tactile map and handrails with Braille coded landmarks in the environment were more effective in regard to wayfinding than were environments with door signs, (b) assembly devices such as handrails and door signs (rather than a tactile map) successfully formed a sequence of cues to improve upon the limitations of a tactile map and to raise the accuracy ratio of wayfinding close to 100%, (c) both a single component and an assembly device were more effective in wayfinding in the complex environment than in the simple environment, and (d) an assembly device supported visually impaired people not only in improving the accuracy ratio of wayfinding but also in decreasing the travel time to complete a route.

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