Spatial Cognition of the Visually Handicapped: Case Study of Geometric Model Spaces with a Center Core

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Abstract
Our team previously carried out a series of studies1-4) on the spatial cognition of the visually handicapped. From these studies we ascertained that the visually handicapped are able to navigate space by walking across it – in effect, by "taking a shortcut" – to reach their destination. However, under conditions where the visually handicapped are unable to navigate space in this way – because their path has been obstructed by an "obstacle" – it is not so clear how they recognize this space, their position in it, nor what clues to aid their recognition.

In this study, in order to clarify the characteristics of their spatial cognition and search behavior in such spaces, experiments are carried out in 12 kinds of geometric model spaces with a center core. The behavior of the visually handicapped is analyzed by walking locus and observation; and the spatial cognition, by sketch map and interview.

Keywords: the visually handicapped; spatial cognition; walking environments; model spaces

1. Introduction
It is essential that the characteristics of spatial cognition in the visually handicapped are further explored and clarified so that they can reach their destination safely when walking alone, and that they can utilize "public" spaces more freely. In time, these kinds of experiments may serve to help designers and city planners create space to suit the special needs of the visually handicapped, rather than the visually handicapped having to adapt to the space around them.

In our previous studies1-4) on the spatial cognition of the visually handicapped, a number of factors were explored and clarified: for example, we looked at the various forms of search behavior exhibited by the subjects in navigating space; in addition, we analyzed the criteria applied by the subjects when analyzing/"recognizing" this space and, thus, deciding on a walking route.

It is particularly worthy of notice that the visually handicapped are able to take shortcuts across open space just as those with unimpaired sight do. However, in cases where they are unable to perform this task due to there being a core or obstacle in the space, it has not yet been proved satisfactorily how the visually handicapped recognize the spaces, how they ascertain their position in it, and what "clues" aid this recognition.

In this study, in order to clarify the characteristics of their spatial cognition and search behavior in such spaces, experiments are carried out by setting up 12 kinds of model spaces with a center "core"-positioned in accordance with the changes in 'the outside form' and 'the shape and form of the core itself'.

2. Theoretical Approach
A large amount of research has been conducted on the cognitive and "wayfinding" processes of the visually handicapped. R.Passini5, 6) set up courses in building and carried out experiments. R.L.Hollyfield7) studied representation of quiet outside walking. J.F.Fletcher8) advocated theories of 'deficiency, inefficiency and difference'. T.Yamamoto9) analyzed development process of spatial moving in children with or without visual experience. However, since their experiments were also carried out in "public" space where much of the data was complicated, it was difficult to show the causal relation between the cognitive processes and the information clearly. Therefore, a strict theoretical approach is also needed.

In our previous studies1-4) carried out under laboratory conditions, the characteristics of spatial cognition were clarified in 'square and corridor model spaces'. Furthermore, the 'relation between spatial cognition and basic space forms' was shown. As a supplement to, and development of, these studies, this paper also intends to explain the subjects' behavioral and cognitive processes when navigating model spaces.
Table 1. Attribution of the Subjects (The Blind)

| Subjects | blind 1 | blind 2 | blind 3 | blind 4 | blind 5 | blind 6 | blind 7 |
|----------|---------|---------|---------|---------|---------|---------|---------|
| age/sex  | 21years/ male | 21years/ male | 25years/ female | 21years/ female | 19years/ male | 21years/ male | 21years/ male |
| occupation | self-employed business man | university student | domestic helper | university student | university student | office worker | technical college teacher |
| level of handicap | 1st class, acquired blindness | 1st class, acquired blindness | 1st class, acquired blindness | 1st class, acquired blindness | 1st class, acquired blindness | 1st class, acquired blindness | 1st class, acquired blindness |
| age became blind | 13 years | 0 years | 4 years | 13 years | 5 years | 7 years | 21 years |
| disease | glaucoma, cataract | nymhem, retinal detachment | detachment of the retina | nymhem, retinal detachment | nymhem, retinal detachment | nymhem, retinal detachment | nymhem, retinal detachment |
| eyesight 1: right | light perception | light perception | 0.01 | 0 | 0 | 0 | 0.01 |
| view | nothing | nothing | angle of 30 degrees | nothing | nothing | angle of 5 degrees | nothing |
| eyesight 2: left | normal | normal | normal | normal | normal | normal | normal |
| color shape | normal | normal | normal | normal | normal | normal | normal |
| hearing | normal | normal | normal | normal | normal | normal | normal |
| training: age | 17 years | 10-12 years | 11-12 years | 11-12 years | 13-14 years | 13-14 years | 13-14 years |
| contents | walking training, daily life training, braille training, personal computer | walking training, daily life training, braille training, personal computer | walking training, daily life training, braille training, personal computer | walking training, daily life training, braille training, personal computer | walking training, daily life training, braille training, personal computer | walking training, daily life training, braille training, personal computer | walking training, daily life training, braille training, personal computer |
| braille reading | all the time | all the time | all the time | all the time | all the time | all the time | all the time |
| walking cane | all the time | all the time | all the time | all the time | all the time | all the time | all the time |
| education/primary university | general course, junior high school | general course, junior high school | general course, junior high school | general course, junior high school | general course, junior high school | general course, junior high school | general course, junior high school |
| destination | hospital, bank, customer, school | station, super market, school | university, Namie Osaka, Umeda Osaka, school | university, university, super market, station | university, university, super market, station | university, university, super market, station | university, university, super market, station |
| frequency | once or 2 days/week | every day | every day | every day | every day | every day | every day |
| care giver | with a care giver | alone | alone | alone | alone | alone | alone |
| accommodation place | with a care giver | alone | alone | alone | alone | alone | alone |
| transportation | train, bus, taxi | train, bus, taxi | train, bus, taxi | train, bus, taxi | train, bus, taxi | train, bus, taxi | train, bus, taxi |
| dwelling style | with family | without family | with family | without family | without family | without family | without family |
| health condition | good | good | good | good | good | good | good |

Table 2. Attribution of the Subjects (The Eye-Masked)

| Subjects in eyemasked | eyemasked | eyemasked | eyemasked | eyemasked | eyemasked | eyemasked | eyemasked |
|-----------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| age/sex  | 21years/ female | 21years/ female | 21years/ female | 21years/ female | 21years/ female | 21years/ female | 21years/ female |
| occupation | university student | graduate student | doctor | university student | graduate student | research student | university student |
| level of handicap | normal | normal | normal | normal | normal | normal | normal |
| eyesight 1: right | 1.2 | 1.2 | 1.0 | 1.5 | 1.0 | 1.5 | 0.7 |
| eyesight 2: left | 1.2 | 1.2 | 1.0 | 1.5 | 1.0 | 1.5 | 0.7 |
| hearing | normal | normal | normal | normal | normal | normal | normal |
| housing type | apartment house | apartment house | apartment house | apartment house | apartment house | apartment house | apartment house |
| dwelling style | with family | with family | with family | with family | with family | with family | with family |
| health condition | good | good | good | good | good | good | good |

THE SQUARE TYPE

SQUARE (I) 6.000 x 6.000
SQUARE (II) 4.000 x 4.000
SQUARE (III) 2.000 x 2.000
SQUARE (IV) 1.000 x 1.000

THE TRIANGULAR TYPE

TRIANGLE (I) 10.400
TRIANGLE (II) 7.400
TRIANGLE (III) 4.400

THE RECTANGULAR TYPE

RECTANGLE (I) 12.000 x 5.000
RECTANGLE (II) 3.000 x 3.000
RECTANGLE (III) 1.500 x 1.500

Fig.1. Experimental Spaces

Starting point
Starting direction

Each starting points is 500mm forward from a center of the wall behind the subject.
which have an "obstacle" in them.

3. Outline of Experiments

3.1 Subjects

The subjects are seven visually handicapped people between 19 and 28 years old, and ten eye-masked people with ordinary vision who are aged between 22 and 25 years old. There is also a team of ten staff. Attribution of the subjects is shown in Tables 1 and 2.

3.2 Experimental spaces

Experimental spaces are created in a model laboratory situated in Kansai University (The lab measures 13m×18m, its CH=3m, and the floor is carpeted. Illumination is fluorescent light). Individual experimental spaces are made of corrugated cardboard panels (1800×900, in vertical usage). Experimental spaces are shown in Fig.1. There is a core in the center of the space and experimental spaces are composed of outside (shell) walls and core walls. Both the outside and core plans are geometrical.

There are three types of experimental space: square type, rectangular type and triangular type. In each type, there are sub-types I, II, III and IV.

Type I: Both the outside and core plans are the same, with each side being parallel. Type II: Outside and core plans are the same but each side is diagonally adjacent to the others. Type III: Outside and core plan surfaces are dissimilar. Type IV indicates the core plan as a circle, its relation to the outside walls being more complex.

3.3 Experimental period

The experimental period is from 31st October to 3rd November, 2004.

3.4 Experimental methods

First, the subjects receive directions from staff members at the starting point in each experimental space, and in an attempt to recognize the form and size of the experimental space, they walk around it for 2 minutes (searching walk). If this walk ends within the time limit, the subject signals to the staff member; otherwise, once the 2 minutes have elapsed, the staff member gives a signal to the subject.

Next, the subjects walk from the end point of the searching walk to the position that they think was the starting point (orientating walk). For this, there are no time limits. Their final position after the orientating walk is recorded in relation to their starting point.

Furthermore, at the end of the orientating walk, the subjects are asked to turn and face the direction that they thought they started from. This "direction angle" is the angle between the direction the subjects are facing at the starting point (starting direction), and the direction, which they actually turn to face. The angle is shown in terms of a scale, -180 ~180 degrees.

All the subjects walk with the aid of a cane.

After this experiment, the subjects come out of the experimental space, sit down in a chair and draw a sketch map at a desk near the experimental space. The instruction for drawing the sketch map is "Please draw how you felt the space." The eye-masked subjects should draw two sketch maps; the first with eye-mask, the second, without. There is no time limit for drawing a sketch map. After drawing is over, a member of staff asks the subject what form and size the space was, what criteria were used for deciding the direction of return to the starting point. Further queries include which direction they started to walk in when setting off from the starting point, and what features they noticed when returning to the starting point.

4. Results and Considerations

4.1 Distance from the starting point

The distance from the starting point is the length of straight line drawn from the starting point to the subject's position at the end of the orientating walk.

The distance from the starting point is shown in Fig.2.

In all the spaces, the distance from the starting point of the eye-masked is longer than that of the blind. From this, the blind are seen to be superior to the eye-masked in recognizing their position.

In the case of both the blind and the eye-masked, the distance from the starting point tends to be short in the rectangular type, while long in the triangular type. Particularly, in the case of the blind, it is short in the rectangular type, and the differences among these spaces tend to be small.

In the case of the blind, the distance of the starting point of the type I is the shortest in each type for both the square and triangular spaces.

In the rectangle (II), the distance from the starting point of both the blind and eye-masked marked the shortest of all the spaces, while it tends to be long in both the square (II) and triangle (II).

Comparing the results of the blind with those of the eye-masked, the difference between the two is large in the rectangular type (IV). This suggests that the blind subjects' method of recognizing their position differs from that of the eye-masked in this type of space. On the other hand, in the triangular model (IV), the difference is small – indicating that the blind and eye-masked use similar means to recognize their position.

![Fig.2. Distance from the Starting Point](image-url)
4.2 Angle of direction

Using the data of the "angle of direction" after the orientating walk, "difference of the angle" and "correct answer rate" are analyzed for each type of space. We have set up -22.5~22.5 as the correct answer of the "angle of direction". Based on this scale, we have analyzed the correct answer rate for each type of space.

4.2.1 Difference of the angle

The difference of the angle is shown in Fig. 3.

The difference of the angle of the eye-masked is larger than that of the blind in all the spaces. This "difference of angle" result, as with others in the same experiments, is mirrored by the results from the "distance from the starting point".

In the case of both the blind and the eye-masked, the difference of the angle is small in the rectangular type, and large in the triangular type. Significantly, in the case of the blind, the difference of the angle is small in the rectangular type, and the differences among these spaces are small. Moreover, the difference of the angle of the type I is the smallest in each type for both the square and triangular type.

Comparing the results of the blind with those of the eye-masked, difference between the two tends to be large in the type I configurations. This shows that the methods employed by the blind in "recognizing" their direction in these types of spaces are different to that of the eye-masked. On the other hand, in the triangle (III), the difference is small. This indicates that both the blind and the eye-masked use similar methods to ascertain their direction.

4.2.2 Correct answer rate for the angle of direction

The correct answer rate for the angle of direction is shown in Fig. 4.

The correct answer rate of the blind is higher than that of the eye-masked in all the spaces except triangle (III).

In the case of both the blind and the eye-masked, the correct answer rate is generally high in the rectangular type, followed by the square type, and then the triangular type. The blind score consistently high in the rectangular types, and notch up 100% for the square (I) and rectangle (IV). In the case of both the blind and the eye-masked, the correct answer rate for the triangle (IV) is the lowest out of all the spaces.

4.3 Recognition of the space

4.3.1 Correct answer rate for the outside space

The correct answer rate for recognition of the outside space is shown in Figs. 5. and 6.

In the case of the blind, the correct answer rate for recognition of 'both form and size' is high in the square type, and low in the triangular type. In the rectangle (II) and triangle (IV), the correct answer rate for 'both form and size' is low. Generally, the rate for 'incorrect' recognition is high in the case of the triangular type.

In the square type models (I to IV), the correct answer rate for 'both form and size' and 'incorrect' are predominant in the case of the eye-masked. Both factors achieve a rate in the vicinity of 40% to 60%. In the rectangular type, the rate for 'both form and size' is relatively low. In the rectangle (I) and triangle (I), the correct rate for 'both form and size' is lowest, while the rate for 'incorrect' is highest. On the other hand, for the rectangle (III) and triangle (III), the rate of 'incorrect' answer is lowest.

For both the blind and the eye-masked, there is no correct answer rate for 'only form' in the square (II).

In the rectangle (I), the rate for 'incorrect' of the blind is lowest, while the eye-masked is highest. On the other hand, in the triangle (III), a high number of 'incorrect' answer is recorded by the blind, whereas the eye-masked recorded a lowest rate.

The rate for 'incorrect' of the blind tends to be lower than that of the eye-masked. The average rate for 'incorrect' of the blind is 37.7%, while that of the eye-masked is 44.0%. Moreover, the average correct rate for recognition of 'both form and size' of the blind is 41.7%, with the eye-masked recording a rate of 35.0%.

4.3.2 Correct answer rate for the core space

The correct answer rate for recognition of the core space is shown in Figs. 7. and 8.

In the case of the blind, the correct answer rate for 'both form and size' is highest in the rectangle (III). In the square (III), rectangle (I), and triangle (I) and (IV), the rate for 'both form and size' is 0%, and the rate for 'incorrect' tends to be high. The rate for 'incorrect' is relatively low in the rectangular type, and the rate for 'incorrect' is 0% in the square (IV).

In the case of the eye-masked, correct answer rates
can be seen for 'both form and size' in all the square spaces, while the rate for 'incorrect' is also high. The rate for 'incorrect' of the blind tends to be lower than that of the eye-masked. The average rate for 'incorrect' of the blind is 27.3%, with the eye-masked recording 52.7%. The average correct rate for 'both form and size' of the blind is 17.9% and that of the eye-masked is 13.3%.

With regard to the core space, for both the blind and the eye-masked, the correct answer rate for 'both form and size' is low in all the spaces. These findings suggest that it is more difficult for the subjects to recognize the core space than it is to "visualize" the outside space.

4.3.3 Correct answer rate for the positional relation between the outside and the core

Using the correct answer data for "both form and size", the positional relation between the outside and the core is analyzed for each type of space. If the subject gives a correct answer regarding its position in relation to the surroundings, then it is considered that they recognize the "whole space" correctly.

The correct answer rate for the positional relation is shown in Figs. 9 and 10.

In the case of the blind, there is no correct answer for 'both form and size', of both the outside and core in the triangular type. The rate for 'whole space' is high in the square (IV) and rectangular (III).

In the case of the eye-masked, rates for 'whole space' can be seen in all the types. The average rate for 'whole space' of the blind is 11.9%, and that of the eye-masked is 5.0%. These results confirm that recognition of the space for the eye-masked is more difficult than it is for the blind. However, the rate for 'whole space' of the blind is modest rather than high.
4.4 Searching order

The order of searching spaces can be classified into six types.
1) From outside to core: first, the subjects search more than the half of the outside, then they search the core.
2) From the core to outside: first, they search more than the half of the core, then search the outside.
3) Alternation (From outside): they search the outside and the core alternately, starting from the outside first.
4) Alternation (From core): they search the outside and the core alternately, but starting from the core first.
5) Only outside: they search only the outside, or they search only the outside since they are unable to recognize the core.
6) Only core side: they search only the core, or they search only the core since they cannot recognize the outside.

The searching order is shown in Fig.11.

For both the blind and the eye-masked, the space is most often searched from the outside first. This suggests that the search of the outside is easier than that of the core. It is therefore assumed that it is easier to mentally "visualize" the whole space by recognizing the outside first. From the results of the interviews, we have gained from the subjects’ descriptions that if they search the space from the outside to the core, it will be easy for them to recognize the whole space, and this gives them a sense of comfort. Significantly, the blind tend to search the outside and the core in an alternate fashion more so than the eye-masked.

For the recognition of the space for 'only outside' or 'only core', the result for the blind is 17.9% and for the eye-masked, 35.8%. In the case of the eye-masked, they often recognize only "one" of the sides; either outside or core side. This suggests a difficulty in recognizing the whole space. With regard to the recognition of only one side, the eye-masked predominantly recognize the outside, while the blind recognize the core side.

4.5 Walking behavior

4.5.1 Walking along the wall and walking across the space

The walking behavior in the experimental spaces can be classified into two types; (i) walking along the wall and (ii) walking across the space.

(1) In the searching walk: the rates for walking along the wall and walking across the space are shown in Figs.12 and 13.

Throughout the different model types, there is generally very little difference with regards to the performance of the blind, and of the eye-masked when "walking across the space". The fluctuations in their own performances (walking rate) are minimal for all the configuration types. Given this fact, it is therefore assumed that the outside and core walls do not greatly influence the two subjects. The average rate for walking across the space of the blind is 19.8%, and that of the eye-masked is 10.8%. In all the spaces, the rate of the blind is higher than that of the eye-masked.

(2) In the orientating walk: the rates for walking along the wall and walking across the space are shown in Figs.14 and 15.

In the case of the blind, the rate for walking across the space is high in the rectangular type, followed by the square, and then the triangle. A particularly high rate can be seen in relation to the rectangle (I), while the lowest is the triangle (I). In the case of the eye-masked, the rate for walking across the space is relatively low compared to the blind, and the differences between each space are small. However, in
rectangle (III) and triangle (I), it shows minimum rate for walking across the space. In all the spaces except triangle (III) and (IV), the rate for walking across the space of the blind is higher than that of the eye-masked.

(3) Comparing the searching walk with the orientating walk: in the case of the blind, the rate for walking across the space of the orientating walk is higher than that of the searching walk in all the spaces except triangle (I) and (III). In the case of the eye-masked, the rate for walking across the space of the orientating walk is higher than that of the searching walk in all the spaces except rectangle (III) and triangle (I).

4.5.2 First behavior for confirming its position

In the beginning of the searching walk, two types of behavior are exhibited when the subject is confirming its position.

(1) The subjects attempt to confirm the position of the wall behind them (walking locus figure of Fig.16.):

First, the subjects walk along the wall behind them, from corner to other corner; after this, they try to ascertain both the length of the wall and the location of the center.

(2) The subjects attempt to confirm the distance from the front wall to the wall behind them (walking locus figure of Fig.17.):

First, the subjects walk straight across the space from front wall to the wall behind them, then they try to ascertain the distance between these walls, their starting point, and whether or not the walls are parallel.

4.6 Frequency of turn

The frequency of turn per a walking distance of 1 meter is shown in Fig.18.

In the case of the blind, the frequency of turn is higher in the square type and lower in the triangular type. The differences between each space are small in the rectangular type.

In the case of the eye-masked, the frequency of turn is highest in the three type II s. This shows that frequency of turn becomes higher in spaces where the outside and core surfaces have a diagonal relationship to each other.

4.7 Sketch map and spatial cognition

4.7.1 Sketch map of wrong recognition

Examples from the sketch map of wrong recognition are shown in Fig.19. The subjects often incorrectly recognize the square as a diamond or trapezoid, equilateral triangle as an isosceles triangle, straight line as a curve, circle as an oval, and so on. This shows that their recognition of the spaces can become distorted.

4.7.2 Unique example of wrong recognition

There are two types of unique recognition. One is "unification of the outside and the core", another is "confusion of the core". These unique examples of wrong recognition are shown in Figs.20. and 21. The unification of the outside and the core is caused by the subjects' inability to distinguish the outside walls from the core walls. The subjects' confusion surrounding the core is caused by their "mis"-recognition of the space, which is caused by the subject's inability to correctly...
recognize the relationship between those two forms. This is especially evident in the case of the rectangle (II). The subjects "mis"-recognize the rectangle as a trapezoid or parallelogram in the outside, or rectangle as a triangle in the core, since the rectangle of the core is placed diagonally.

5. Conclusions
(1) From the result of the distance from the starting point, it can be said that the blind are superior to the eye-masked in terms of recognizing their position. It is easy for both the blind and the eye-masked to recognize their position in the rectangular type, while it is more difficult in the triangular type.
(2) With regard to the subjects' sense of direction, the blind are superior to the eye-masked. However, in the rectangular type, the eye-masked can recognize the direction as well as the blind can.
(3) Both the blind and the eye-masked find it more difficult to recognize the core than to recognize the outside. Recognizing both the outside and the core proves to be the most difficult task for them. It is particularly difficult for the blind to recognize the triangular spaces, while for the eye-masked, it is difficult in all the model spaces.
(4) In most cases, the blind and the eye-masked search from the outside first. This behavior indicates that it is easier for them to recognize the "whole" space when they search from the outside to the core; this approach appears to be more comforting – or "safer" – for them.
With regards to geometric model spaces with a center core, it is found that most of the eye-masked are able to recognize only one of the sides; either outside or core side – the former of the two figuring more prominently.
(5) There are two types of walking in this experiment; one is walking "along the wall", another is walking "across the space". Neither the outside nor the core greatly influences the subjects' walking rate across the space. In this experiment, the rate of the blind tends to be higher compared to the eye-masked – in both the searching and orientating walks.
(6) Unique behavior can be first seen at the outset of the searching walk. The subjects have a tendency to continually make sure of their position in relation to the wall behind them, and constantly attempt to ascertain their distance from front wall to the wall behind them.
(7) Wrong recognition is made due to the fact that the subjects often have a distorted "picture" of their spatial surroundings. Unique examples are unification of the outside and the core, and confusion regarding the form and nature of the core.

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