An Attempt to Explain Way-Finding Activity by Cognitive Tasks

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ABSTRACT

We attempted to clarify how performance shaping factors and visual cognitive tasks affected the time taken to perform a way-finding activity in a maze.

We performed way-finding experiments on humans subjects in an underground maze, and found that the use of a visual guiding system halved the time required for way-finding. The experiments were performed under dim conditions. The luminance at floor level during the experiments was 1-9 lx. Without an escape-guiding system, some subjects mistook dim corners of the maze for dead ends, and turned back the way they had come. With the aid of a visual guiding system, no subject lost his or her way.

By considering the visual cognitive tasks needed to negotiate the maze, we developed a relationship between PSFs and way-finding activity in a dim environment, and proposed a possibility of PSF-based assessment for way-finding difficulty. Poor 'quality of interface' and poor 'environment' increased the number of visual cognitive tasks required to negotiate the maze and simply extended the 'time to perform'. Only when the best information assistance was given in the environment did the number of visual cognitive tasks required ('procedure required') decrease.

KEYWORDS: Way-finding, Performance Shaping Factor, Cognitive Task, Illuminance, Luminance

INTRODUCTION

We performed way-finding experiments on humans subjects in an underground maze, and found that the use of a visual guiding system halved the time required for way-finding. The experiments were performed under dim conditions. The luminance at floor level during the experiments was 1-9 lx. Without an escape-guiding system, some subjects mistook dim corners of the maze for dead ends, and turned back the way they had come. With the aid of a visual guiding system, no subject lost his or her way.

These results showed that there was a relationship between the visual cognitive tasks performed by the subjects and the time required for way-finding. We considered that it would be possible to explore this relationship in more detail by assessing cognitive tasks. We therefore devised a model of way-finding behavior, using the tasks that had to be performed to negotiate the maze and the concept of performance shaping factors (PSFs) that would affect the completion of the tasks. PSFs are concepts used in the field of human reliability engineering. In the control of a processing plant, for example, workers are required to perform tasks by responding to specific feedback in the form of qualitative or quantitative signs of control panels. The operators have to choose their responding activity among the clearly listed tasks. In the field, PSFs are factors that facilitate or hinder successful task completion under given conditions. In way-finding behavior, feedback can be regarded as the change of view the subject receives when traveling. Subjects get nonspecific information (for example, visual, auditory, smell, touch) and have to choose their responding activity among uncertainties or the clearly listed tasks taught by drills.

We related the results of our way-finding experiments to PSFs and visual cognitive tasks, and discussed a possibility of PSF-based assessment for way-finding difficulty.

WAY-FINDING EXPERIMENTS

Outline of Method and Results

The maze in which we conducted the way-finding experiments was located in our 20-m diameter underground experimental site; it had corridors and intersections arranged in symmetric lines. Subjects could travel a minimum distance of 70.8 m in the maze if they avoided corridors with obstacles and chose the right way at intersections. An escape-guiding system was placed along the right course: a weak, green blinking light from a twisted leaky optical fiber cable system showed the correct path. The illuminance at floor level was 1-9 lx.

The right course had 21 intersections. To minimize the effects on the traveling time of individuals' habits of turning right or left, the route had a nearly even number of right and left turns and crossings: the 21 intersections consisted of 8 right turns, 6 left turns and 7 crossings.

We obtained the following results[1] (**TABLE 1**);

(A) When the escape-guiding system was provided, the average traveling time was about 90 s.

(B) When two intersections were filled with smoke and the guiding system was provided, the average traveling time was prolonged by 60 s to about 150 s.

(C) When the escape-guiding system was not provided, the average traveling time was about 180 s. The difference between (C) and (A) – the time taken for way-finding – was therefore about 90 s.

(D) When two intersections were filled with smoke and the escape-guiding system was not provided, the average traveling time was about 250 s.

TABLE 1 The results of way-finding experiments

Condition	A	B	C	D
Escape-guiding system	○	○	×	×
Smoke	×	○	×	○
Time taken to negotiate maze (s)				
Subject	1:27	2:13		6:29
A				
B		3:21		2:19
C		1:48		2:41
D	1:38	2:12		3:13
E		1:50		7:33
F	1:13	1:55		2:35
G		2:54		
H		1:25		
I		1:51		
J	1:35	3:13	2:42	
K	1:57	3:36	2:02	
L	1:18	2:40	1:53	
M	1:44	3:59	2:44	
N			6:03	
O			2:07	
P			3:04	
Average traveling time	1:33	2:32	2:56	4:08

The result of about 250 s for (D) (smoke-affected unguided traveling time) roughly agreed with the sum of (A) (guided traveling time: 90 s), the effect of smoke in (B) (60 s) and (C) (time taken for way-finding: 90 s) = 240 s.

In (A), with the escape-guiding system in place, no subject lost his or her way. In (C), some subjects mistook dim corners in the maze for dead ends, and turned back the way they had come many times. In (D), some subjects thought that smoke was pouring out from several locations.

Although the results of state and

trait anxiety (STAI) testing showed that some subjects had higher anxiety scores than others, on covariance analysis there was no correlation between the anxiety-state score and the traveling time.

Our results suggested that, in a dimly lit maze, the total traveling time was merely the sum of the time taken to travel and the time taken to pursue the options of way-finding and avoiding an obstacle (smoke).

We assumed that easy recognition of 3-dimensional geometric structures would help subjects to travel easily, and that the ease of recognition could be evaluated by the total traveling time. From that point of view, several observations had been made about the relation between traveling speed and dim illuminance of floor level of escape space[2 3 4 5 6 7 8 9]. Those observations clarified the tendency of decrease in traveling speed in dimly lit environment. However, the relationship between way-finding, traveling time and the effects of required tasks has not been determined. Therefore, we analyzed the influence of PSFs and required visual cognitive tasks on the time taken to perform a way-finding activity.

ANALYSIS OF PSFS AND TASKS IN WAY-FINDING

During way-finding in a maze the subject receives information from the surrounding environment, including the arrangement of crossings and corridors, and the presence of signs, obstacles and smoke. The activities that must be accomplished are the interpretation of information and traveling to the exit. These are repetitive activities of perception of space arrangement, choice of way and travel. Applying PSFs and cognitive tasks in the field of human reliability engineering has the advantage of enabling the researcher to affect human behavior. PSFs are considered to have either a preventive or helping effect on task completion. We chose 4 categories of PSF from definition of PSF[10] that would relate to way-finding behavior (**TABLE 2**).

In the 'time' PSF category, ‘time available’ indicated that a task required an immediate response or activity. However, ‘time available’ and ‘time to perform’ were also terms used in evaluating the successful completion of tasks.
In the 'information' PSF category we placed ‘quality of interface’ and ‘feedback to action’ factors. In way-finding behavior, ‘quality of interface’ can be regarded as the quality if interface presented by the ambient space, that is, the quality of visual, auditory, smell, touch stimuli. These factors were considered as PSFs if the information presented by the ambient environment had the effect of guiding the subject to a safe place.

TABLE 2 PSFs those relate to way-finding behavior

Category	Performance shaping factors	Note
Time	Time to perform Time available	
Information	Quality of interface Feedback to action	
Ambient environment	Environment Procedure required	Arrangement, obstacles, smoke
Personal attribute	Procedure understood Procedure practiced Exercise capacity Eye sight Stress	

In the ‘ambient environment' PSF category there was ‘environment.’ The ‘environment’ factor included space arrangement, obstacles, and smoke. These elements determined the other factor, 'procedure required'. The ‘procedure required’ factor related to the difficulty of way-finding and the efficiency of way-finding. It was impossible to treat ‘procedure required’ as an independent factor, as it was greatly affected by information presented by the ambient space and environment elements. However, ‘procedure required’ could be regarded as a combination of information and environmental PSFs. The ‘procedure required’ changed in accordance with the number of tasks that needed to be conducted. If the number of tasks was minimized by an effective guiding system, the ‘procedure required’ would be simple.
'Personal attributes’ PSFs also affected the efficiency of way-finding. These attributes included whether subjects understood the procedures and options of the activity, and whether they had experience. The subjects' exercise capacity and stress levels also would affect the efficiency of their way-finding.

Procedure Required

The procedure that subjects used in way-finding experiments was repeating their choosing behavior at each intersection. Therefore, for the purposes of our experiment, it was adequate to consider the cognitive tasks of interpreting visual information as applying to the whole maze. A cognitive event tree is a tool for cognitive task analysis (**FIGURE 1**). Each node represents a cognitive task. The lines to the left and right represent success and failure, respectively. Each line has a probability of choice: that is, in the case of a junction of 3 corridors, the probability of choosing the right way is 1/3.

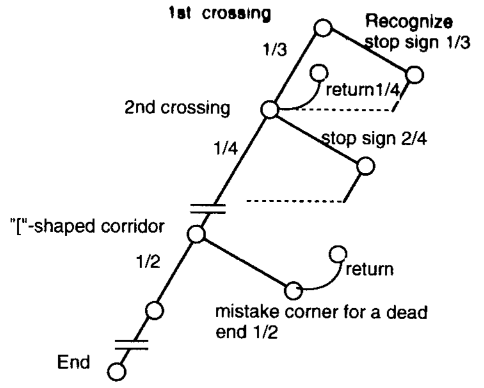

FIGURE 1 A part of cognitive event tree of way-finding experiment

The "["-shaped corridor was a corridor with 2 corners at each end. In this corridor some subjects mistook the dim corners for dead ends, and turned back the way they had come.

The cognitive event tree developed for this experiment had 21 nodes as right choices in the straight line of left side. Each node had a few branches. The total number of nodes on the left side branches was 24. So, if the subject chose the right way at each intersection, completing the course would require a minimum of 21 tasks of judgement of visual information. If the wrong way were chosen at every intersection, the course would require a minimum number of 45 tasks of judgement of visual information. If the subject turned back the way he or she had come, the number of tasks of judgement of visual information would have increased further.

A comparison of the results of (A) and (C) suggests that subjects took an average of 90 s extra to find their way using 45 tasks of judgement of visual information.

Visual Cognition in Dim Corridors

At the "["-shaped corridor (FIGURE 1) some subjects mistook dim corners of the maze for dead ends, and repeatedly turned back the way they had come. We examined the relationship between these visual perceptive difficulties, the ambient lighting conditions and the visual angles of the entrances to these branch corridors.

We used a model of a combination of corridors and intersections (**FIGURE 2**).

We assumed that the vertical luminance of the walls was even. The observed distribution of luminance of the walls was expected to change with the observer's location.

The visual angle of the entrance of crossing corridor, $\theta = (\theta'' - \theta')$ becomes:

$$\theta = \theta'' - \theta' = \tan^{-1}(\frac{w/2}{\ell}) - \tan^{-1}(\frac{w/2}{\ell + w'}) \qquad (1)$$

Considering the visual angle θ in relation to the observing distance and the width of the corridor, as the traveling corridor narrows, θ becomes smaller. It is also obvious that as the observing distance lengthens the θ becomes smaller.

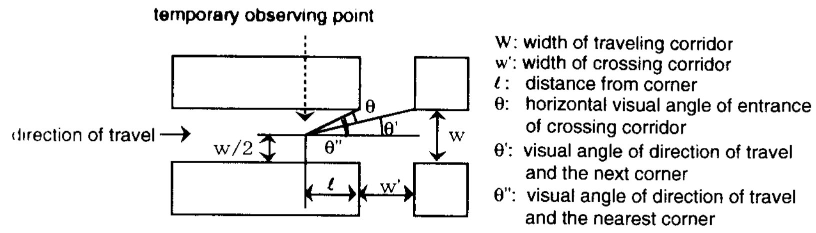

FIGURE 2 Intersection model (floor plan)

On the other hand, if all the walls have a luminance (cd/m^2) of even a normal vector of luminance, the apparent luminance of the walls changes in accordance with the horizontal visual angle with direction of travel Θ:

Wall parallel to observer's line of sight: proportional to $\cos(\pi / 2 - \Theta)$ (2)
Wall perpendicular to observer's line of sight: proportional to $\cos(\Theta)$ (3)

We conducted a luminance simulation in order to determine the subjects' perception of the corner of a dimly lit corridor. We determined the horizontal luminance distribution from several observing points (FIGURE 3). In this simulation, w = w' = 1 m, the observing distance ℓ varied from 1–10 m, and the walls had an even vertical luminance distribution. The horizontal and vertical axes represent the horizontal visual angle (0° is direction of travel) and the apparent luminance distribution, respectively. The wall of the corridor crossing at right angles produced a discontinuity in luminance distribution. At the luminance discontinuity point, the rate of apparent luminance distribution varied about 2 to 50 range in these cases.

Recent cognitive research indicates that humans recognize depth of view by difference in luminance. However, both the wavelength of the stimulant and difference in luminance affect recognition of shape of objects. Human perception of depth of view is different from human perception of shape of objects, and does not require color information. Recent research has concluded that when a small luminance contrast is present, human perception of both movement and depth is quantitatively reduced, and movement perception is greatly reduced[11].

The small luminance discontinuity present in our study (2 to 50 by rate) prevented early perception of branch corridors, especially in dim conditions. These problems arose when subjects were aware of the existence of branches in dim conditions but did not have a visual escape-guiding system.

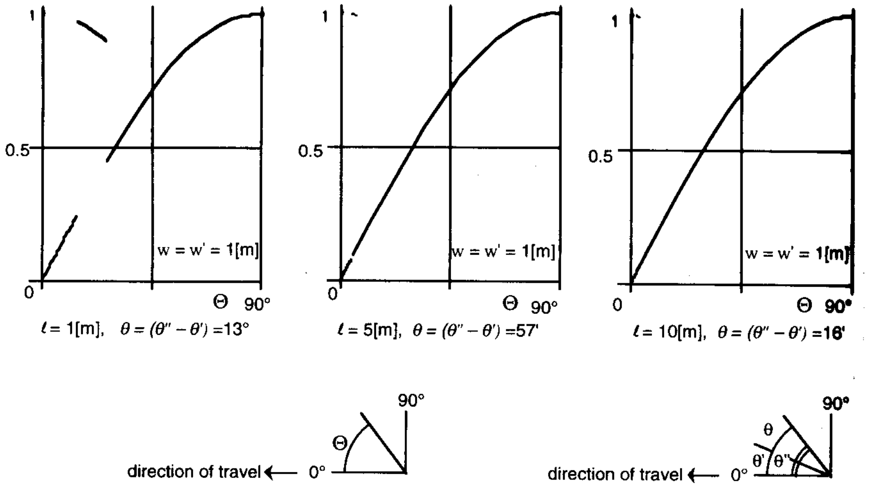

FIGURE 3 Simulation result of horizontal luminance distribution

Subjects also have problems with acuteness of vision in dim conditions.

Three kind of sense of vision are defined in accordance with adopted field luminance; photpic vision in daylight (about 10 cd/m^2 and more), twilight vision in twilight (greater than about 10^{-2} and less than 10 cd/m^2), and scotopic vision in dark (less equal about 10^{-2} cd/m^2). Sense of vision differs in these three conditions, because of two kind of optic nerve action.

In our way-finding experiments the floor-level illuminance was 1–9 lx. If the illuminance is converted to luminance, it can be seen to vary 10^{-1}–10^{0} order range, under ideal complete-reflection conditions. The real luminance of our experimental conditions should have been smaller, as the floor and wall material never totally reflected the light. Our experiment conditions corresponded to twilight vision.

By the definition of acuteness of vision, the simulated 16' visual angle of entrance of the crossing corridor from 10 m distance is sufficient for cognition, even for people with 0.1 acuteness of vision, if the field luminance is daylight level and if the subject gazes at a standstill.

In practice, under conditions of low-level field luminance, this angle would not be sufficient Acuteness of vision becomes low at low field-luminance levels. If a person has 2.0 acuteness in daylight conditions, this acuteness will decrease by about 0.5 in experimental field luminance condition. This means that if visual information is presented in monochrome (light-absorbing black and reflective white), the subject can distinguish 2' visual angle.

In our experiments the width of the corridor was 1 m and the observing distance was about 5 m or less when the subjects turned back. Every wall was the same color. The results of our simulation modeling indicated an observing angle of 57' from 5 m distance.

The luminance of the walls was estimated to be about 10^{-1}–10^{0} cd/m^2, using the luminance at floor level in accordance with the simulation. The difference in luminance between the walking corridor and a wall crossing at right angles would be about 2 to 50 in accordance with our simulation. Such conditions present a kind of border in the completion of visual cognitive tasks, because the time record in Table 1 (C) varies widely. When the escape-guiding system was used, the difference in luminance between the walls and the surface leaky fiber cable was of the order of 10^2 and more. In Table 1 (A), when the escape-guiding system was used, the dispersion of time was small.

DISCUSSION

Relationship between PSFs and way-finding activity

In the light of the results of our way-finding experiments, our analysis of visual cognitive tasks and our simulation, we rearranged the PSFs that affected way-finding (see TABLE 1) and developed relationships between them (**FIGURE 4**). 'Time to perform' was positioned on the right side as an index of condition of task completion affected by all the PSFs on the left side. Each node represented the effects of left-side elements by 1 of 5 types of operator: sum, product, maximum, minimum and independent.

Procedure required' and 'personal attributes' were directly connected to 'time to perform.' Poor 'quality of interface' and poor 'environment' increased the number of visual cognitive tasks and simply prolonged 'time to perform', so the operator sum was chosen.

'Visual information' and 'auditory information' were connected to 'quality of interface.' It was important that the given environment had clearly distinguishable visual information on the arrangement of space and the way out of the maze. At the 'quality of interface' node, the operator maximum was chosen, because only the best information assistance in the environment decreased the number of visual cognitive tasks required ('procedure required').

Of the 'personal attributes', 'procedure understood' and 'procedure practiced' should have diminished 'time to perform', but this result was not clear in our experiments. The effects of 'exercise capacity' were also unclear. ('Exercise capacity' did not affect traveling time in the horizontal maze, unlike the situation with uphill travel [10].) As described above, we did not find

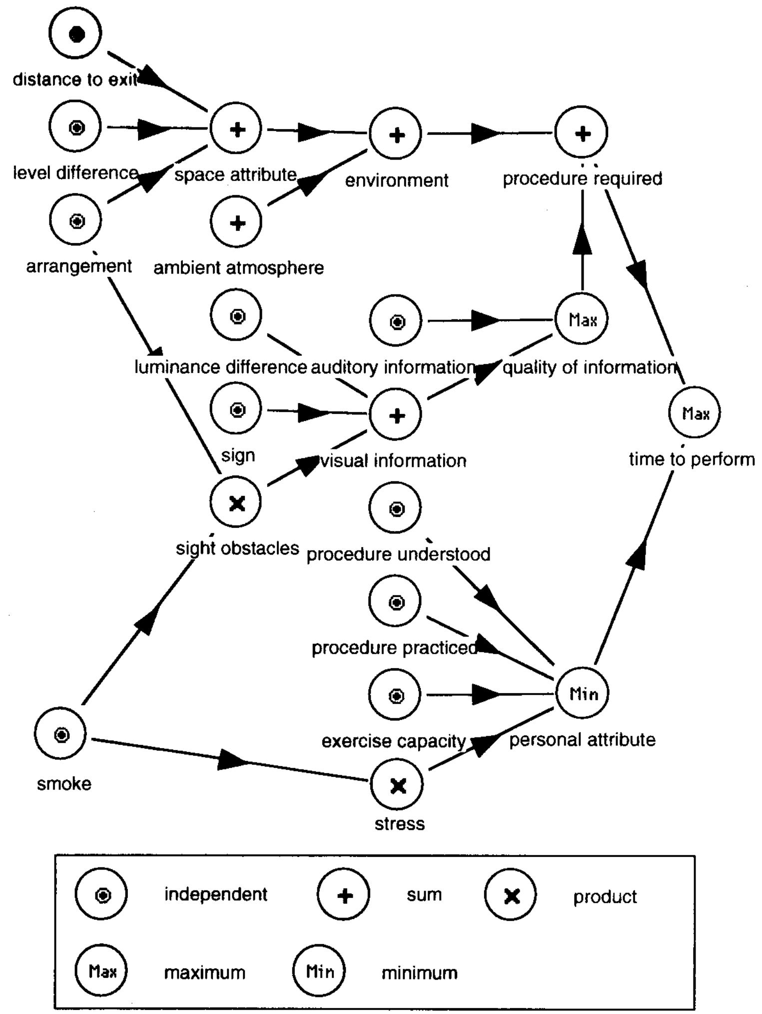

FIGURE 4 Relations between PSFs of way-finding behavior

a relationship between stress (anxiety state) and traveling time. It is generally observed that if there is no 'procedure practiced' then the 'time to perform' will expand, even if one has good ‘exercise capacity'; therefore we chose the operator minimum (worst element) for 'personal attributes.'

Possibility of PSF-based Way-Finding Difficulty Assessment

It is possible to utilize the relationship among the PSFs for assessing way-finding difficulty.

If the intersections without visually effective signs were counted, the results would reflect the number of visual cognitive tasks in the given environment and would be regarded as 'procedure required.'

If suitable semi-quantitative rank was settled to both of ‘environment’ and ‘quality of interface’ PSFs, the maximum could be another assessment tool for difficulty of way-finding. If the number of intersections were counted, the results would reflect the number of potential visual cognitive tasks in the given environment. Furthermore, the luminance difference of signs against the background was an index of quality of information. So, when introduce suitable rank to both PSFs, the maximum of both ranks could be regarded as an index of way-finding difficulty ('procedure required'), separate from traveling time (TABLE 3).

TABLE 3 Evaluation of procedure required

		Environment		
		Complicated	Medium	Simple
	Maximum	1	2	3
Quality of interface	Good 3	3	3	3
	Fair 2	2	2	3
	Poor 1	1	2	3

CONCLUSION

We attempted to clarify how performance shaping factors and visual cognitive tasks affected the time taken to perform a way-finding activity in a maze.

By considering the visual cognitive tasks needed to negotiate the maze, we developed a relationship between PSFs and way-finding activity in a dim environment, and proposed a possibility of PSF-based assessment for way-finding difficulty. Poor ‘quality of interface’ and poor ‘environment’ increased the number of visual cognitive tasks required to negotiate the maze and simply extended the 'time to perform'. Only when the best information assistance was given in the environment did the number of visual cognitive tasks required ('procedure required') decrease.

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