Development of a Visual Simulation System Synchronized with Walking Motion- An application for a study of distance perception

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ABSTRACT

Conventional visual simulators allow observers to move in the simulated space by using a mouse or a joy-stick without the kinesthetic feeling of motion. However, the link between visual image and body motion is important to perceive the environment, especially when people are walking. In this paper, a visual simulation system was designed to synchronize the subject's walking motion on a treadmill with the video image shown on a HMD. In order to detect the walking motion, sensors were attached to both subject's ankles. According to the detected motion, the treadmill rotates and a CCD camera moves in a model space. Because of the sensors' low sensitivity and the time lag between the detected motion and treadmill rotation, the subjects couldn't walk smoothly. Therefore, the walking speed which synchronizes with the video image was kept constant for each subject and the experimenter started up and stopped the simulator. The validity of this simulation system was examined by comparing the accuracy of distance estimation using the new simulator with that using the conventional system without walking motion. The "distance reproduction" method was applied to measure the perceived distance: subjects walked 25 meter in a real setting without being told the distance, and were asked to move the same distance in different conditions. Since the distance estimation became accurate in the condition with the walking motion, the validity of this simulator was secured. The following experiment was intended to investigate the influence of physical environmental features on perceived distance by using the simulation system. We operated some features using a scale model of a route and examined their influences. Subjects were asked to "walk" through a path consisted of two spaces with different physical features, and to respond by showing the proportion of the length of those two spaces. The result

revealed that the distance of a narrower and lower ceiling path where people perceive clearer line perspective and faster optical flow tends to be perceived longer.

INTRODUCTION

People perceive their environment by integrating information from their senses, corresponding to different situations. The link between visual image and body motion is important to perceive the environment especially when people are walking. Some researchers have been mentioned the importance of motion for the perception of the environment. For example, Gibson (1979) said “not only does locomotion depend on perception but perception depends on locomotion inasmuch as a moving point of observation is necessary for any adequate acquaintance with the environment.” However, conventional visual simulators allow observers to move in the simulated space by using a mouse or a joy-stick instead of real walking. This simulated walking state without kinesthetic feeling of motion is not a normal situation. Therefore, a new visual simulation system was designed to synchronize a subject's walking motion on a treadmill with the video image shown on a HMD. An experiment

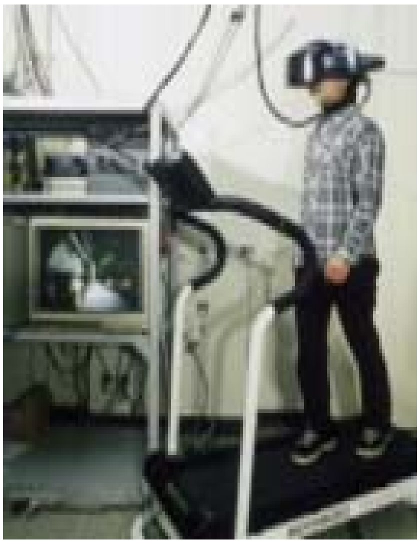


Fig 1: A CCD Camera in a model space and a subject under the experiment

was conducted to test the validity of the simulation system by comparing the accuracy of distance estimation with the conventional video image without walking motion. Then, another experiment was carried out to investigate the influence of physical environmental features on perceived distance.

DEVELOPMENT OF A VISUAL SIMULATION SYSTEM

The visual simulation system which synchronizes a video image with walking motion was designed by improving an existing simulator in our laboratory (Fig. 1, 2). The former one was designed to allow a subject, wearing a HMD, to virtually see and move through a scale model by controlling a joy-stick. In the simulator, a CCD color TV camera inserted into the scale model space moves according to subjects' head motion of "look around". The CCD camera's horizontal and vertical angles are 112 degrees and 88 degrees respectively. The focal distance is 15cm, and the depth of focus in which the subjects can see images clearly is 7Å`23cm (this correspond to 3.5Å`11.5m in scale 1/50).

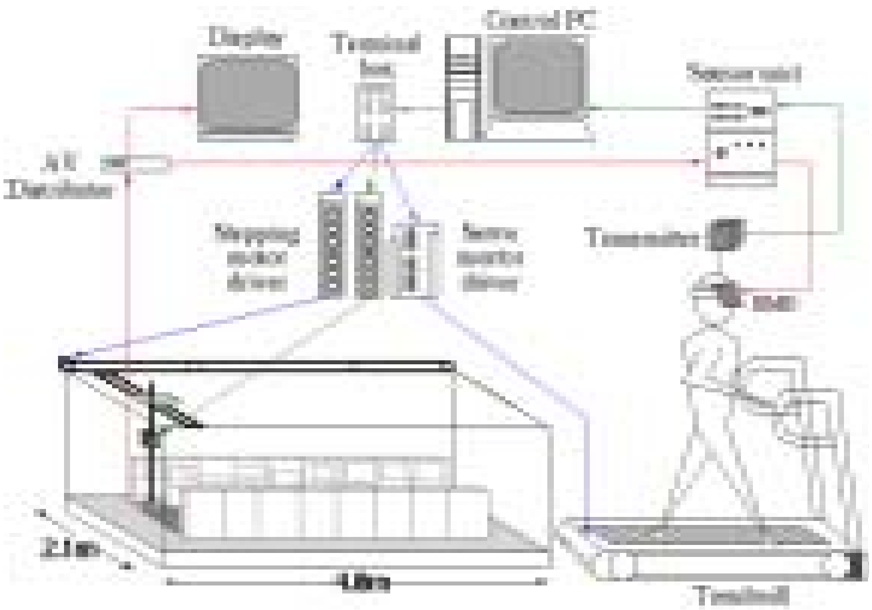


Fig 2: The model of a visual simulation system developed in this study

As an initial attempt, the treadmill's rotation and CCD camera's motion in a model space were tried to be synchronized with a subject's walking motion which was detected by Polhemus sensors. Because the sensors' sensitivity was low and there was a time lag between detected motion and the treadmill's rotation, however, subjects could not walk smoothly. Owing to these problems, the walking speed which synchronizes with a video image was held constant for each subject without Polhemus sensors. Thus, subjects cannot stop on the way, and the experimenter started up and stopped the simulator with a voice signal.

TESTING THE VALIDITY OF THE NEW SYSTEM

Method

This experiment aims at examining the validity of the simulation system by comparing with the system without walking motion in terms of the accuracy of distance estimation. 29 graduate students (20 males and 9 females) were employed as subjects. The "reproduction" method (Montello, 1991) was applied to measure the perceived distance: subjects walked for a distance without being told the distance (experience walk), and were asked to rewalk the same distance (distance reproduction) in each of three different modes.

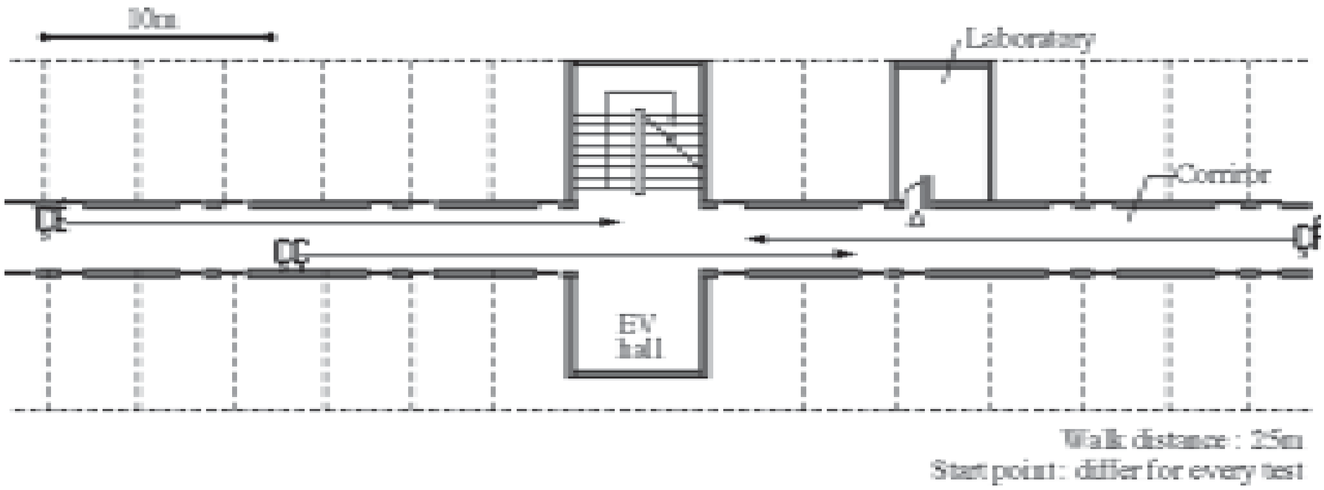


Fig 3: A corridor and a room in which the experiment was carried out

Table 1: Experiment mode

	Mode	Experience	Reproduction
a	Visual Image mode	Corridor	Video image
b	Walking Motion mode	Corridor	Video image + Walking motion
c	Real mode	Corridor	Corridor

The three types of mode were:
(1) Visual Image mode, in which only the video image of a model space is shown
(2) Walking Motion mode, in which the video image is shown with walking motion
(3) Real mode, which subjects rewalk in the same place where the experience walk is done
Figure 3 shows the plan of a corridor and a simulation room. In order to avoid the influence of the order of the experimental modes on distance estimation, subjects were divided into two groups in different order of the modes (Table 2). A scale model (1/10) of corridor (2 m width, 70 m length, 2,5 m ceiling height) was made of styrene boards on which photographs of a wall and a floor were stuck. Doors in the model were placed at random. Since the distance estimation was expected to be based partially or completely on time or effort (Montello, 1991), the walking time was measured in each walking.

Procedure

At first, each subject chooses the appropriate walking speed which he/she can walk on the treadmill safely. Then, he/she walks 25 meter in the corridor and rewalk the same distance in a certain mode

Table 2: Subject groups

Subject groups	Order of modes
1	Visual Image mode → Walking Motion mode → Real mode
2	Walking Motion mode → Visual Image mode → Real mode

Mode /Groups		Reproduced distance						Difference of speed (Reproduction - Experience)						Difference of Time (Reproduction - Experience)					
Mode /Groups	Groups	Mean [m]		σ^2	A	B	C	Mean [km/h]		σ^2	A	B	C	Mean [s]		σ^2	A	B	C
Visual image	1	13.8	15.3	18.6	\	**	**	-1.6	-1.3	0.68	\	-	**	6.7	5.7	34.2	\	**	*
	2	14.8	[0.64]					-1.3						3.7					
Walking motion	1	19.8	19.4	38.6	**	\	**	-1.6	-1.3	0.53	-	\	**	14.1	14.5	123	**	\	**
	2	19.1	[0.81]					-1.2						13.8					
Real	1	23.8	23.9	14.3	**	**	\	-0.2	-0.1	0.25	**	**	\	1.2	-0.2	16.6	*	**	\
	2	23.8	[1.00]					-0.1						-1.6					

[ ] : Rate with Test C *: p < 0.05 **: p < 0.01

Table 3: Result of each mode

according to the order of Table 2. The start points were different on each of walking. The subjects are told that the position of doors in the model space will not be a clue for distance estimation.

Results and Discussions

Since there was not the significant difference in the reproduced distance between two groups, results of those groups were analyzed together. Table 3 shows the average of reproduced distances, differences in walking time, and speed which were taken at the experience walk and the distance reproduction. The reproduced distances in both Visual Image mode and Walking Motion mode were quite shorter than the actual distances. It might be caused by subject's slower walking speed (the average was 2.16 km/h) on the treadmill. Because the subject's eyes were covered by the HMD and their steps on the treadmill were not visible to them, they chose slower speed. From this result, it is concluded that the subjects used the sense of time for the distance reproduction in this situation

Figure 4 and Figure 5 show the differences in distance and the differences in time which were taken at the experience walk and the distance reproduction. Comparing two figures, the reproduced distances were more accurate in Walking Motion mode although there were large differences in time. Analysis of this result indicates that the subjects used the kinesthetic feeling as a clue for the distance estimation. Therefore, the visual simulator with the walking motion is more suitable than the conventional visual simulator which shows only a video image.

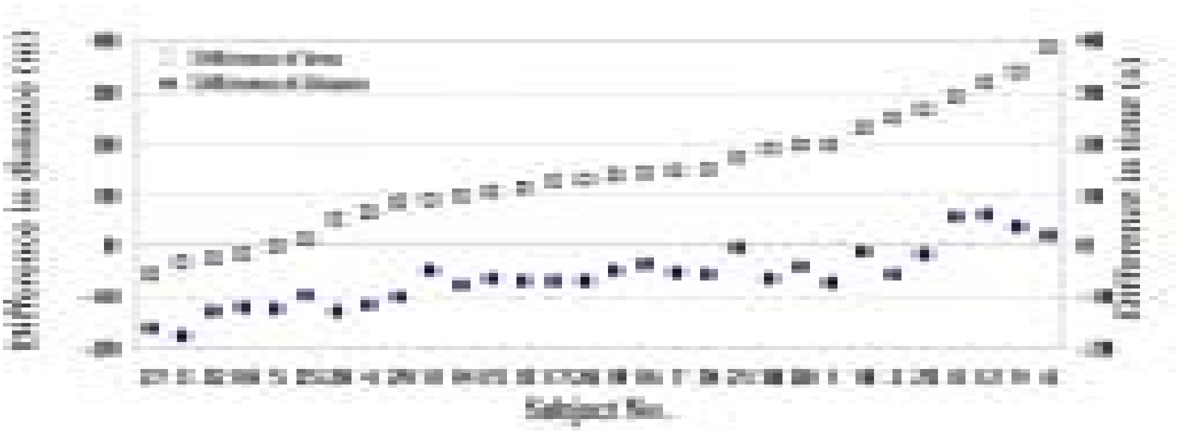


Fig 4: Differences in distanca and differences in time in Visual Image mode

THE INFLUENCE OF PHYSICAL FEATURES ON A PERCEIVED DISTANCE

Method

The following experiment was carried out to investigate the influence of physical environmental features on perceived distance by using the new visual simulation system. Subjects virtually walked along a route with which two model spaces were connected and they were asked to compare the distances of spaces.

The physical features dealt with were as follows:

(1) Complexity of elements' layout on the wall surface along the route

(2) Spaciousness of the route

The complexity of elements' layout on the wall surface was consisted of a facade of shopping streets and a corridor in a school (simple, middle and complicated) as shown in Table 4. The spaciousness was achieved by changing the route width (2 m, 8 m, 32 m), height (2.5 m, 6 m) and the existence of the ceiling. In this experiment, 6 routes were produced by connecting two of six model spaces with different complexity and spaciousness (Figure 9). Each route has a changing point of spaces in the middle of the route. The subjects were the same as the former experiment (20 males and 9 females).

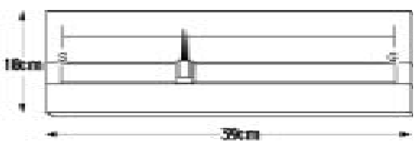


Fig 6: Division indicator

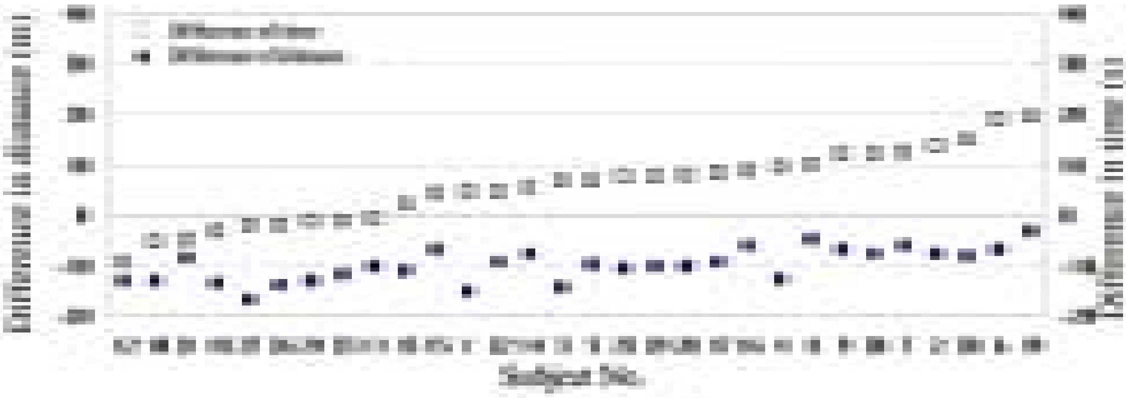


Fig 5: Differences in distance and differences in time in Walking Motion mode

Procedure

Each subject virtually walks through a route, and is asked to indicate the changing point on the division indicator (Figure 6). The experiments are carried out in going both up and down those six routes, and three dummy routes which have no changing point in the center (totally fifteen routes). The distances of these routes are any of 40m, 60m and 80m. The walking speed for each subject is the same as former experiment.

Results and Discussions

Table 4 shows the ratios of the perceived distances of two model spaces. These values were calculated from all the subjects' distance estimation in each route, adding some compensation. Route C-D was excluded from the analysis as almost no subjects noticed the change of the two model spaces. Then we calculated the ratio to see the relation among all the spaces. Figure 9 shows the perceived distance of each space on the basis of Space D. The ratio of the perceived distance between Space B and the others could be calculated through three routes (Route B-D, B-E and A-B), however, any large differences were not seen in those values. This result shows that a perceived distance can be determined by a space itself not by a combination of spaces.

Route	Rate of Cognitice distance	σ (Comparison with 1)	P
A-B	B/A= 0.848	0.287	++ 0.008
B-D	D/B= 0.956	0.239	– 0.320
B-E	E/B= 0.990	0.259	– 0.836
D-E	E/D= 1.085	0.253	– 0.081
D-F	F/D = 0.984	0.216	– 0.688

++ : $p < 0.01$

Table 4: Results of the distance comparsion in each route

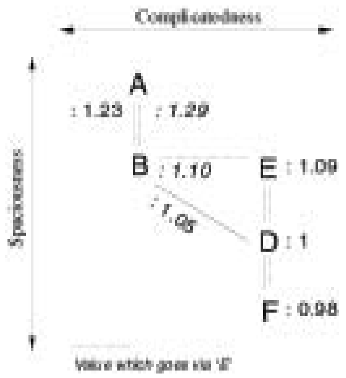
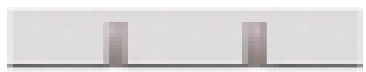


Fig 7 (above): Ratio of perceived distance on the basis of space D

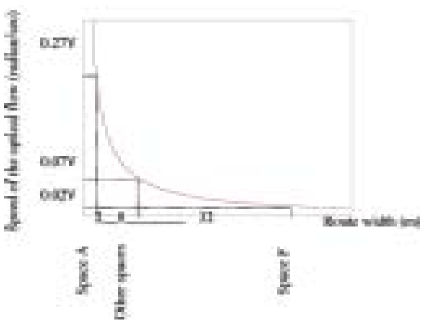
Fig 8 (down): Relation of the optical flow and the route width

Fig 9 (next page): Routes produced by connesting two of six model spaces

Table 5 (right): Complexity of elements‘ layout on the wall surface along a route

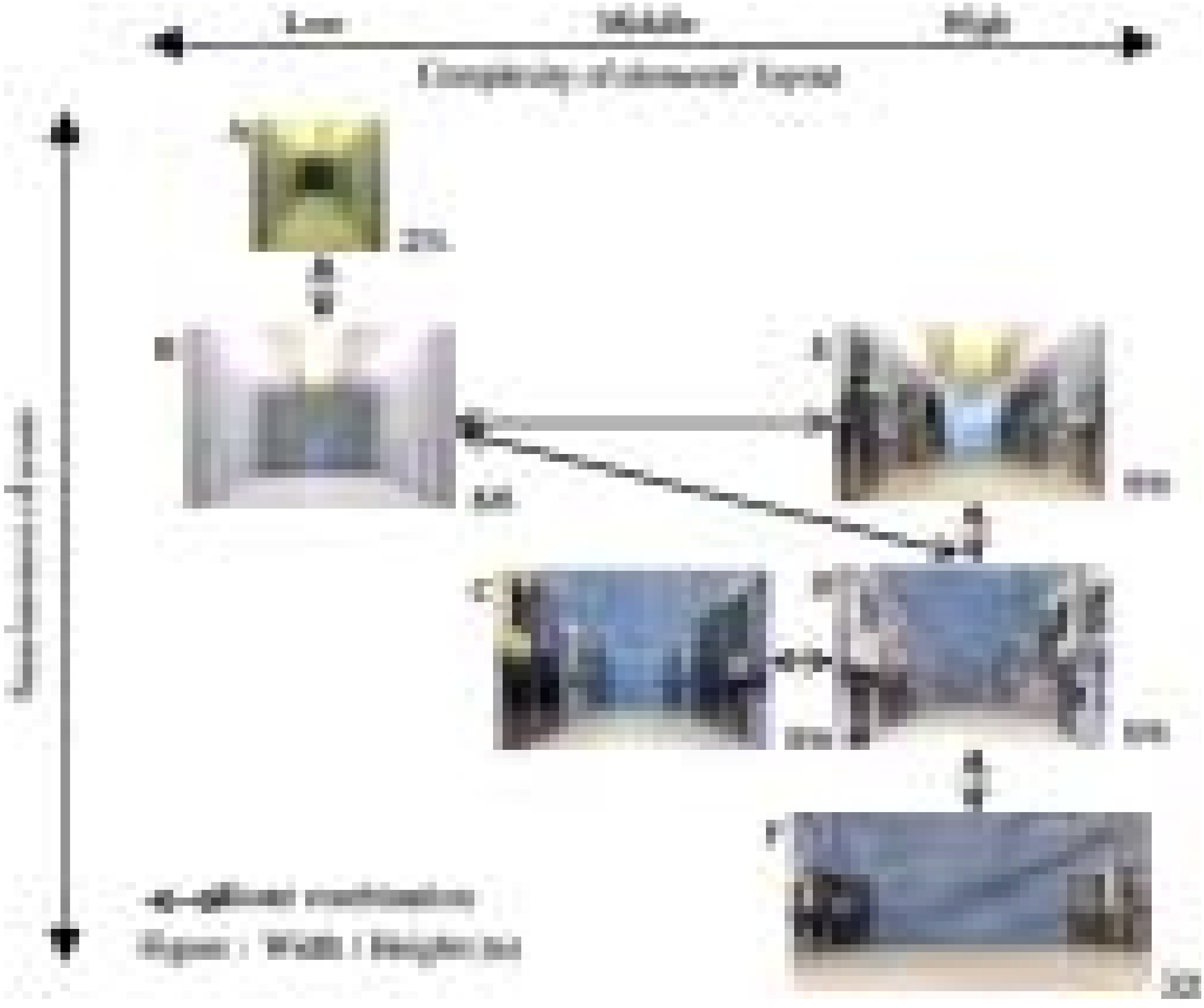
Simple: The gray door in a line with the white wall.	
Middle: The shopping street with the shutter closed.	
Complicated: The shopping street with the shutter opened. (There are overhangs and hollows)	

Although, only Space A was statistically significant, narrower or lower spaces tended to be perceived longer. The reason would be that the depth of the route is more emphasized by the line perspective, as the edges of the walls go to near the vanishing point. In addition, the optical flow of the texture that is faster in the narrower space strengthens the subjects’ feeling of movement (Figure 8). On the other hand, no tendency was found in the complexity of elements’ layout on the wall surface in this experiment.



CONCLUSION

The visual simulation system was designed to synchronize the subject's walking motion with video image shown on a HMD. Although the subject’s walking speed was kept constant, its validity was secured through the experiment that compared the accuracy of a perceived distance with conventional visual simulator without walking motion. Moreover, using the new simulation system, the influence of physical environmental features on perceived distance was investigated. It is found that the spaciousness of a route affected perceived distance, especially a narrower and a lower space where


Low
Middle
High

people see clearer perspective line and faster optical flow tended to be perceived longer.

The influence of walking speed which may vary according to an environment would be a future subject for a fully synthesized simulation system. Although it is required to improve this simulation system, it would be a useful tool to know the way people integrate their senses on environmental perception.

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