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Direction judgment in a corridor containing a single turn

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Abstract

This experiment investigated direction judgment in a corridor containing a single turn. The turn degree of the corridor ranged from 0° to 90° with 15° intervals. A direction was presented to subjects at the entrance of the corridor and subjects were asked to point this direction at the exit of the corridor. Considering the fact that subjects had to judge directions in the featureless corridor, two hypotheses were proposed: (a) subjects tend to judge directions by eight categories of egocentric directions (front, back, left, right, and four diagonals); (b) subjects tend to estimate angular distance from their front to the direction which they try to judge. The result supported both hypotheses. The effects of vestibular and kinesthetic information as well as visual information obtained by subjects are discussed.

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The objective of this study is to experimentally investigate direction judgment in a corridor which has a single turn. Stated a little more explicitly, subjects in our experiment are firstly presented a direction at the entrance of a corridor; they secondly walk through the corridor to the exit; they are finally asked to point the target direction which was presented at the entrance (see Figure 1). The corridor is a featureless space except for a turn, and so subjects rely on an egocentric reference system to judge direction. That is, they judge direction with respect to their own body (e.g., now that I take a right turn in the corridor, the target direction comes to the front of my body).

Given this experimental environment, our first hypothesis is that subjects tend to judge direction by eight categories of egocentric directions (i.e., front, back, left, right, and four diagonals). An underlying model of our first hypothesis is that subjects use eight-direction reference axes in the eight egocentric directions (see the left panel of Figure 2) for judging direction. Subjects judge that the target direction belongs to which of eight directional categories by estimating the closest reference axis to the target direction. We call this model the *eight-direction* model.

Our second hypothesis is that subjects tend to make a judgment on which reference axis is the closest to the target direction by estimating angular distance from their front

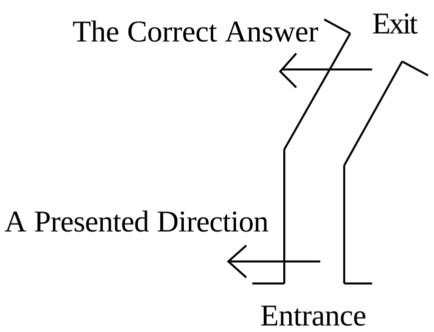

Figure 1. An example of a presented direction at the entrance of the corridor and the correct answer for the presented direction.

reference axis to the target direction. Because the front reference axis has the greatest saliency among reference axes, subjects use only their front axis as the basis of their judgment. This hypothesis is based on a model that the front axis predominates over the other axes.

Many experimental studies have been conducted concerning reference axes. Most of these studies focused on two topics. First topic is the existence of diagonal axes; the second topic is predominance of the front axis over the other axes. Rosch (1975) conducted two experiments in which subjects judged the angular orientation of lines. One experiment used a linguistic hedge task and the other experiment used a spatial task in which subjects estimated the psychological distance between two stimuli. Data from the linguistic hedge task supported the eight-direction model. On the other hand, data from the spatial task were against the existence of diagonal axes. In other words, the data supported the *four-direction* model that subjects' reference axes consist of four orthogonal axes (front, back, left, and right), as is shown in the right panel of Figure 2.

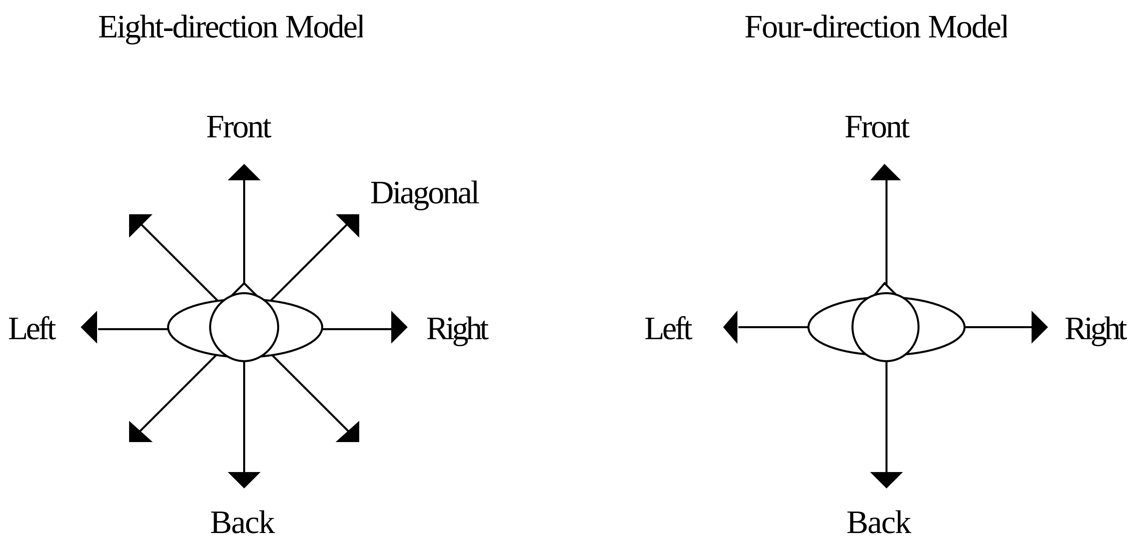

Figure 2. Eight-direction model and four-direction model of reference axes for direction judgment.

While Rosch (1975) used the linguistic hedges and the psychological distance between stimuli, some studies used reaction time for the analysis of reference axes. Loftus (1978) examined subjects' comprehension of compass directions. Reaction time supported the four-direction model, and showed that subjects used four reference axes equally for direction judgment. This result suggested that there was no predominance among reference axes. Franklin and Tversky (1990) also used reaction time to investigate predominance of the front axis. In their experiment, objects in front of subjects were judged most quickly, followed by objects in back, in left or in right. From this result, Franklin and Tversky concluded that the front axis predominated over the other axes.

Franklin, Henkel, and Zangas (1995) used errors in judgment for the analysis of reference axes. The errors showed that directions which were close to the front axis were recalled most accurately. On the other hand, directions which were close to the diagonal axes were recalled most inaccurately. This result supported the four-direction model. Montello, Richardson, Hegarty, and Provenza (1999) also used errors in judgment for the analysis of reference axes. In case that subjects used a manual pointer to judge direction, their data supported the four-direction model and showed that there was no predominance among reference axes.

While the experiments of the above studies were conducted on the subjects who stood at a point or took their seats, Sadalla and Montello (1989) conducted an experiment which required subjects to traverse pathways, each of which had a single turn. The subjects judged the angular size of the pathway turn by pointing the original direction of traverse at the end of the pathway. The errors in the judgment became the greatest when the turn degree was 45° and 135°. This result supported the four-direction model. Montello and Frank (1996) extended the analysis of Sadalla and Montello by computer simulation.

Montello and Frank hypothesized not only the four-direction model but also the eight-direction model. The result of the simulation showed that the eight-direction model accounted for the pattern of the data of Sadalla and Montello better than the four-direction model.

In summary, many previous studies supported the four-direction model, but some studies supported the eight-direction model. Many previous studies supported the predominance of the front axis, but some studies showed that there was no predominance among reference axes. Thus, it is still an open question that reference axes for direction judgment consist of either four or eight directions. Predominance of the front axis is also controversial. Because there is room for further discussion on these matters, the present study is designed to examine the existence of diagonal axes and predominance of the front axis.

By integrating our two hypotheses mentioned above, we expected the variation of absolute errors in judgment as is shown in Figure 3. By the first hypothesis, we expected that absolute errors in judgment would increase as a function of angular distance from every reference axes. In particular, we were concerned with absolute errors for the direction of 45° and 135°. If subjects used eight-direction reference axes, absolute errors for the directions would be small, as is shown in the left panel of Figure 3. On the other hand, if subjects used four-direction reference axes, absolute errors for the directions would be large, as is shown in the right panel of Figure 3. By the second hypothesis, we expected that absolute errors in judgment would increase as a function of angular distance from the front axis to the target direction that subjects tried to judge. If the front axis predominated over the other axes, that is, if subjects estimated an angular distance to the target direction from their front axis, absolute errors would become larger in proportion to the angular distance extended, as is shown by the broken line of Figure 3.

Method

Subjects

Seventy subjects consisted of 12 females and 58 males, ranging from 20 years to 33 years (mean age = 21.9 years). Subjects were undergraduates at the University of Tokyo, who attended an introductory urban analysis class and participated in partial fulfillment of a course requirement.

Materials

The experiment took place in a corridor which was temporarily constructed in a hall for this experiment. The walls of the corridor were made of plain white plates, which were 2 m high. The corridor was 1.5 m in width and 6 m in length. A blue sheet with no texture covered the floor of the hall in order to provide the subjects with no directional cues. A partition was placed around the corridor in order to prevent subjects from looking the

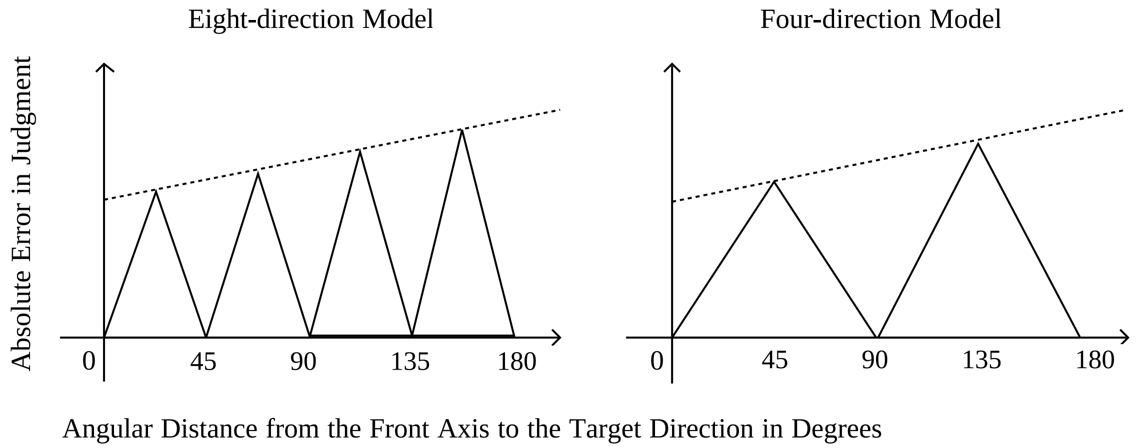

Figure 3. Eight-direction model and four-direction model of the expected variation of absolute errors in subjects' judgment.

corridor from the outside.

An angular turn was in the middle of the corridor, i.e., 3 m from the entrance (see Figure 4). The degrees of the turn ranged from 0° to 90° with 15° intervals. The corridor was used from both ends, and so the angular turn became both a left-hand turn and a right-hand turn. We considered that the difference between left and right would not affect direction judgment, because some previous studies (Franklin et al., 1995; Franklin & Tversky, 1990; Sadalla & Montello, 1989) found no significant difference between left and right in regard to direction judgment with an egocentric reference system.

A circular measuring device, an 18 cm diameter circle with a rotating pointer, was used for both presenting a direction to subjects at the entrance of the corridor and subjects' making direction judgment at the exit. The device was mounted horizontally on a stand 70 cm high.

Procedure

The experiment was administered individually. After receiving a brief instruction concerning the tasks to be performed, a subject was led to the entrance of the corridor. One of five directions (see Figure 5) was presented to the subject at the entrance. After memo-

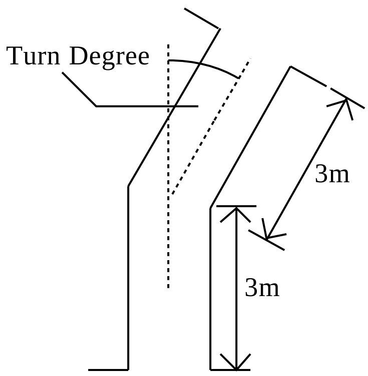

Figure 4. A bird's-eye view of the corridor for the experiment.

rizing the presented direction, the subject proceeded to walk along the corridor. The subject was asked to walk as usual. The subject was also asked not to look back and track back. On arriving at the exit of the corridor, the subject turned the pointer of the circular measuring device to make the pointer point the direction which was presented at the entrance (see Figure 1). Unlimited time was provided for this task. When this task was done, an experimenter turned the pointer randomly so that the subject could not utilize her/his previous answer for direction judgment.

After completing this task, the subject went out the corridor once. The experimenter asked to the subject whether or not she/he could maintain sense of orientation during the task.

After a short interval, the subject was asked to reenter the corridor. At this time, the subject traversed the corridor to the opposite direction. One of the other directions, as is also shown in Figure 5, was presented to the subject at the entrance, and then the subject performed the task in the same manner. This procedure was repeated five times to complete the tasks for all directions shown in Figure 5. After five tasks were finished, the turn degree of the corridor was changed to another one, and the same tasks were performed in the same manner. Every subject traversed four out of seven angles: half of the subjects walked the corridor which had an angular turn of 0°, 15°, 45°, and 75°; the other half

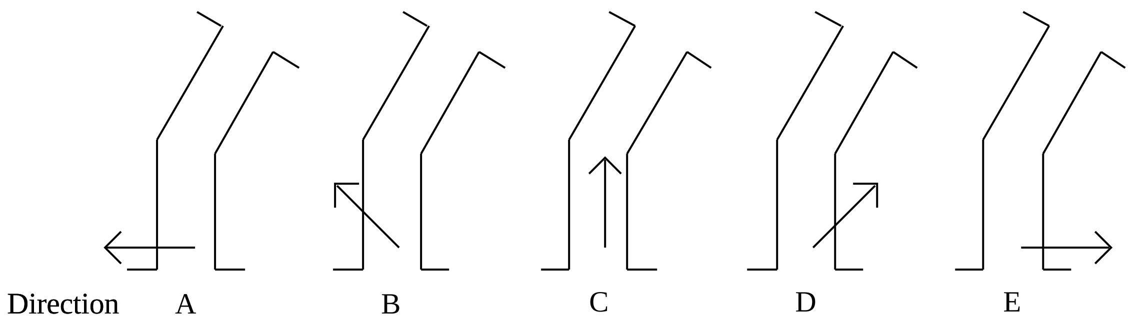

Figure 5. Directions which were presented to the subjects at the entrance of the corridor.

walked the corridor which had an angular turn of 0°, 30°, 60°, and 90°. The experiment took approximately 30 minutes for a subject. The order of the presented directions and the turn degrees was randomized for each subject.

Results

The answers of the subjects were examined both as absolute errors and as signed errors. Note that in signed errors, overestimation of the angular distance from the front reference axis to the target direction was defined as positive value, and underestimation of the angular distance was defined as negative value.

We eliminated 86 data points, because the subjects reported that they lost sense of orientation and gave up answering in these trials. These eliminated data points were approximately 6 % of the whole data. In addition, two data points were lost because of the experimenter's error.

To test our model of the variation of absolute errors in judgment (see Figure 3), we primarily examine the answers of the subjects as absolute error in three steps. First, we investigate subjects' perception of the direction that was presented to subjects at the entrance of the corridor. Second, we investigate subjects' perception of the turn degree of the corridor. Third, we test both the four-direction model and the eight-direction model to account for the variation of absolute errors by using the results obtained in the former two steps.

Perception of the Direction That Was Presented to Subjects at the Entrance

Errors for the 0° turn was examined in order to investigate perception of the direction that was presented at the entrance. Because the corridor became complete straightaway when the turn degree was 0°, the errors showed how subjects perceived the presented direction at the entrance. The mean errors are plotted in Figure 6.

If subjects perceived the presented directions accurately, all the mean errors for each presented direction would be approximately equal to 0. The errors were analyzed by a repeated-measures ANOVA with the presented direction (direction A, B, C, D, and E; see Figure 5) as within-subjects factor. The result of the ANOVA revealed that all the presented directions were not perceived equally (F (4, 268) = 8.46, p < .001). To find the presented directions which were not perceived accurately, we applied a two-sided t test to the errors under the null hypothesis that the mean error for each presented direction was equal to 0. The result of the t test showed that the errors for the direction B and D were significantly less than 0 (for the direction B, t (69) = -2.93, p < .01; for direction D, t (68)

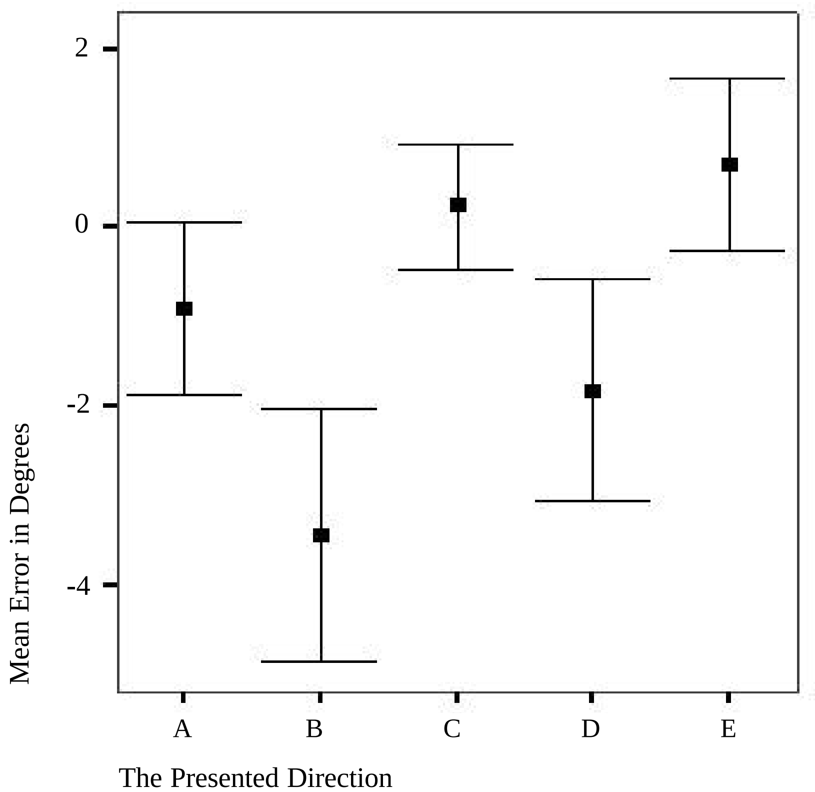

Figure 6. Mean errors and 95 % confidence intervals for the presented direction when the turn degree was 0°.

= -4.82, $p < .001$). The errors for the direction A, C, and E were not significantly different from 0.

Perception of the Turn Degrees of the Corridor

Figure 7 shows the mean errors for each turn degree when the direction C (see Figure 5) was presented at the entrance. In these cases, subjects tried to estimate angular distances from their front axis to the target direction so that the angular distances became equal to the turn degrees of the corridor. Thus the mean errors plotted in Figure 7 shows how subjects perceived the turn degrees of the corridor.

The mean errors indicated that turn degrees between 0° and 45° were all overesti-

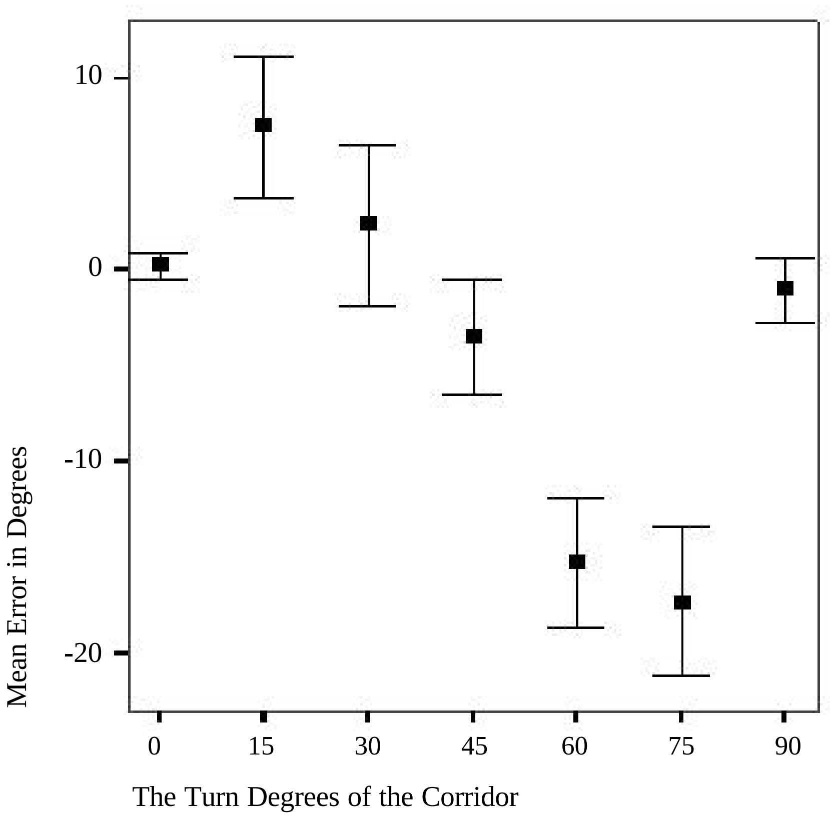

Figure 7. Mean errors and 95 % confidence intervals for the turn degrees of the corridor when the direction C was presented.

mated, while turn degrees between 45° and 90° were all underestimated. The mean errors also indicated that turns of 0°, 45°, and 90° were accurately perceived. This fact was confirmed statistically by a two-sided *t* test under the null hypothesis that the mean error for each group of the presented directions was equal to 0: for the turn degrees less than 45°, t (67) = 3.47, $p < .01$; for the turn degrees greater than 45°, t (64) = -12.9, $p < .001$. Thus, all turn degrees were distorted in the direction of 45°.

Variation of Absolute Errors

The mean absolute errors are shown in Figure 8. This figure illustrates that the abso-

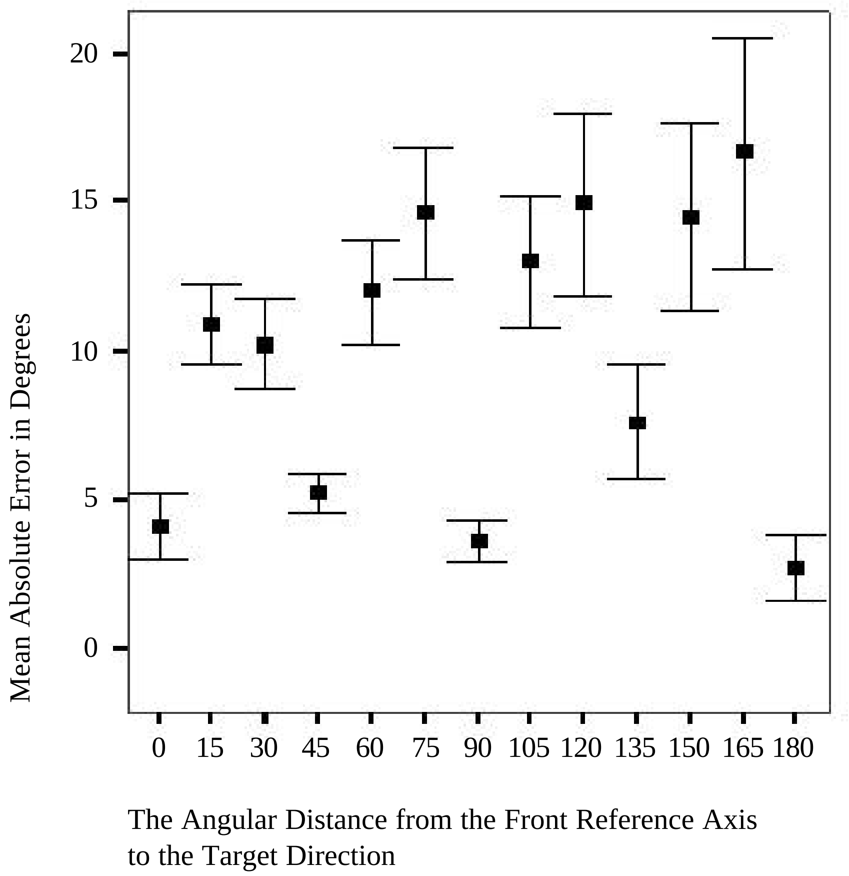

Figure 8. Mean absolute errors and 95 % confidence intervals for the angular distance from the front axis to the target direction.

lute errors were small when the angular distance from the front axis to the target direction was 0°, 45°, 90°, 135°, and 180°. This fact was confirmed statistically, t (1310) = -18.1, p < .001. This result supported the eight-direction model of the variation of absolute errors, which is shown in the left panel of Figure 3. We hereby examined both the four-direction model and the eight-direction model by estimating two parameters of the model: a slope and an intercept of the broken line in Figure 3. These two parameters can determine the structure of the model, because our model considered that middle directions of two adjoining reference axes (e.g., the direction of 22.5° in the eight-direction model) gave the peaks of the graph. This meant that our model considered that egocentric space would be divided homogeneously into four or eight categories. On the other hand, Franklin et al. (1995) and Montello and Frank (1996) showed that egocentric space was divided heterogeneously (e.g., front category have wider range than the other categories). Further examination on this matter would be required in the future.

To estimate these two parameters, the true angular distance from the front axis to the target direction was transformed into subjective angular distance. To make this transformation, both the subjects' perception of the presented direction and the subjects' perception of the turn degrees was used in the following manner. When the direction B or D was presented at the entrance, the error for each direction was subtracted from the true angular distance. In a similar manner, the error for each turn degree was add to or subtracted from the true angular distance. Thus, the true angular distance was transformed to the subjective angular distance. We used this subjective angular distance hereafter.

The parameters were estimated by the least square method, and the results are tabulated in Table 1. Comparing the values of the determination coefficient in Table 1, the eight-direction model fitted to the data better than the four-direction model. This result showed that the eight-direction model accounted well for the variation of the absolute errors. Moreover, values of the slope were significantly greater than 0 (for the four-direction model, t (1310) = 6.54, $p < .001$; for the eight-direction model, t (1310) = 8.86, $p < .001$). This result showed that the subjects estimated the angular distance from their front reference axis.

Clockwise or Counterclockwise Error

As we have seen in the above examination, the eight-direction model could account for the variation of the absolute errors well. The absolute errors, however, do not have another important information; whether the answer of the subjects appeared on the clockwise side or counterclockwise side of the correct answer. We therefore examined both the four-direction model and the eight-direction model whether or not the answer predicted by the model and the answer made by the subjects was on the same side of the correct answer. The investigation was conducted by the following steps.

First, the mean direction of the subjects' answers for each trial was calculated by circular statistics (Fisher, 1993). Second, the subjects' judgment that the target direction belonged to which directional categories was predicted by the subjective angular distance. Third, the answer predicted by the model was fixed by the reference axis which was in the

Table 1
Values of Parameters and Determination Coefficient

Model	Intercept	Slope	Determination Coefficient
Four-direction model	8.50	0.0385	0.390
Eight-direction model	12.1	0.0530	0.661

directional category chosen by the former step. Fourth, the mean direction and the predicted value were examined with regard to whether or not these two directions were on the same side of the correct answer. Note that 15 trials in which the turn degree of the corridor was 0°, 45°, and 90° were excluded from the investigation, because it could not be determined that the predicted value was on which side of the correct answer in these trials.

The result of the above investigation also revealed that the eight-direction model was more advantageous to account for the data than the four-direction model. The eight-direction model explained well that the subjects' answer appeared on which side of the correct answer, $z = 3.35$, $p < .001$ (by a binomial test). The 18 predicted values from the eight-direction model and the corresponding mean directions of the subjects' answers were on the same side of the correct answer. On the other hand, the same test conducted on the predicted values from the four-direction model was not significant. The 8 predicted values from the four-direction model and the corresponding mean directions were on the same side of the correct answer.

Discussion

The present study tested two hypotheses regarding direction judgment with an egocentric reference system. The first hypothesis is that subjects tend to judge direction by eight categories of egocentric directions (i.e., front, back, left, right, and four diagonals). An underlying model of the first hypothesis is the eight-direction model in which subjects judge directions by using eight-direction reference axes. This model was compared with the four-direction model in which subjects' reference axes consist of only front, back, left, and right axis. The result of the present study supported the eight-direction model. The second hypothesis is that subjects tend to estimate angular distance from their front reference axis to the target direction in order to make a judgment on which reference axis is the closest to the target direction. The second hypothesis is based on the model that the front axis predominates over the other axes. The result of the present study also supported this model. Our results, however, were not always consistent with the results of the previous studies referred to in the introduction.

As compared with the experiments of the previous studies, the present experiment had two distinctive features. The first feature was that there was no restriction on the subjects' vision; the second feature was that the subjects walked through the corridor. In contrast with the first feature of the present experiment, Montello et al. (1999) and Sadalla and Montello (1989) restricted subjects' vision partially or completely. This difference implies that the subjects of the present study obtained more visual information than the subjects of their studies. In contrast with the second feature of the present experiment, Franklin and Tversky (1990), Franklin et al. (1995), Loftus (1978), Montello et al., and Rosch (1975) conducted the experiment on subjects who stood at a point or took their seats. This difference implies that the subjects of the present study obtained more vestibular and kinesthetic information than the subjects of their studies. These two differences suggest that vestibular and kinesthetic information as well as visual information obtained by the subjects affected the results of the present study.

The first result of the present study was that the subjects used eight-direction reference axes, as mentioned previously. As compared with the subjects of the previous studies (Franklin & Tversky, 1990; Franklin et al., 1995; Loftus, 1978; Sadalla & Montello, 1989) who used four-direction reference axes, the subjects of the present study had four more categories in their egocentric space. Dividing egocentric space into eight categories would require more information than dividing it into four categories.

In the present study, the subjects were provided with more information than the previous studies. The subjects saw an angle made by the walls of the corridor and received an optic flow in the course of walking. Because these visual cues were sufficient to construct eight categories within egocentric space, the subjects of the present study could use eight-direction reference axes. This inference was evidenced from the fact that Sadalla and Montello (1989), which required subjects to walk pathways, supported the four-direction model. In their experiment, the subjects' forward vision was restricted to 0.5 m and their peripheral vision was completely restricted. Thus the subjects of their experiment had vestibular and kinesthetic information but had little visual information. The lack of visual information led to the result that subjects used four-direction reference axes.

Vestibular and kinesthetic information also affected the first result in conjunction with spatial updating. When locomotion involved rotational body movement, vestibular and kinesthetic information enhanced the accurate updating of self-position and traveling direction (Chance, Gaunet, Beall, & Loomis, 1998; Klatzky, Loomis, Beall, Chance, & Golledge, 1998; Presson & Montello, 1994). Differently from the experiments of the previous studies, the present experiment required subjects to walk through the corridor. Since walking through the corridor provided vestibular and kinesthetic information for perceiving change in the traveling direction, the subjects could update the perceived traveling direction more accurately. This allowed subjects to use eight-direction reference axes.

The second result of the present study was predominance of the front reference axis. Because egocentric directions typically serve for guiding travel, the front axis should intrinsically be predominant when people walk. Moreover, visual information in the environment of the present experiment helped the subjects perceive their traveling direction. Thus the fact that the subjects of the present study walked through the corridor with sufficient visual information elicited the intrinsic predominance of the front axis. This inference was supported by the fact that Sadalla and Montello (1989) found no predominance among reference axes. In their experiment, subjects received a partial optic flow due to a complete blockage of peripheral vision, and so it was difficult for them to perceive their traveling direction after taking a turn. This difficulty led to the result that there was no predominance among reference axes.

Lastly, we should note the possibility that the subjects of the present study did not completely rely on an egocentric reference system. Although the corridor for the experiment was a featureless space, the subjects might have formed representation of geometry of the corridor, and might have used this representation to judge directions (Shelton & McNamara, in press; Wang & Spelke, 2000). If we completely prevented the subjects from looking the corridor by asking them to wear a blindfold or a hood, we could have completely precluded this possibility. Nevertheless we did not use a blindfold or a hood, because we aimed to make our experimental environment as natural as possible. Walking without vision is not a natural experience for sighted people. On the contrary, walking through a featureless corridor with vision is a common behavior in our everyday lives. This was the very reason that we used the corridor for the experiment. Thus using the corridor was an appropriate method for the present study, although it might make possible that subjects used non-egocentric information for direction judgment.

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