Cognitive Studies, **15**(1), 134-143. (March 2008)

■ **Feature — The Models of Spatial Perception and Spatial Cognition Research Paper**

Phenomenal Awareness of the Surrounding Space: An Ecological Perspective

Makoto Inagami [1], Ryuzo Ohno [1], and Rieko Tsujiuchi [2]

This study investigates the extent to which humans are aware of the space surrounding their bodies during daily locomotion. To capture this awareness in its natural state, our experiment adopted an indirect method that uses feelings of oppression and release caused by the surrounding environment. Participants continuously rated their feelings by turning a dial while walking along an outdoor route. The physical environment along this route was described in terms of the visible areas of buildings, trees, ground, and sky. Each area was measured from four different widths of view angles ranging from a limited view in front to a full 360° view. Analysis of the relationship between the ratings and measurements reveals that the feelings have the highest correlation with the 360° measurements. This result supports our hypothesis that humans are aware not only of the limited visual field but also of the entire surrounding space, including the space behind their bodies. Based on this finding, we discuss the traditional concept of spatial perception from an ecological perspective.

Keywords: phenomenal awareness, surrounding space, locomotion, spatial perception, ecological approach

1. Introduction

1.1 Background and purpose of this study

The overall purpose of our study is to explore how the human visual system, which includes the body as a whole, works under natural conditions in daily life, rather than under artificial conditions in laboratories. In the long history of vision science, many theorists and philosophers have criticized the field's overly simplistic theoretical framework of vision as a snapshot (e.g., Churchland, Ramachandran, & Sejnowski, 1994) and its artificial experimental conditions such as impoverished stimuli and restricted movement (e.g., Neisser, 1976). One of the most serious attempts to solve these problems includes the ecological approach by J. J. Gibson (1979), which emphasized the natural situation wherein humans actively perceive the surrounding environment while moving. This emphasis, with the criticism of the traditional approach, has been inherited and developed by recent theoretical studies (e.g., Noë, 2004). Our study, which also adopts the ecological perspective, attempts an empirical investigation of the natural workings of vision in order to contribute to a more profound understanding of the nature of spatial perception.

In particular, this article investigates the extent to which humans are aware of the space surrounding their bodies during locomotion. Our concern is with the phenomenal awareness generated by the natural workings of vision, which can extend beyond the visual field, as Gibson (1979) and Koffka (1935) have pointed out. Such awareness is difficult to capture in its natural state

1 Interdisciplinary Graduate School of Science and Engineering, Tokyo Institute of Technology, 2 Central Japan Railway Company.

for the following reasons. First, when participants introspect about their own visual experience, their natural awareness is lost. If they are asked a direct question such as what they are aware of at a particular moment, their answer will be limited to the objects seen in the visual field. Second, most experimental paradigms for studying visual perception, which use various visual tasks, are also too direct to capture natural awareness. These paradigms can investigate not the natural workings but the processing performances of vision, because the stimulated attitude in performing the visual tasks is, in itself, an unnatural state. Due to these reasons, the natural awareness with which we are concerned must be investigated so that participants focus their attention neither on their visual experience nor on any visual task.

To overcome these difficulties, we made an attempt to capture the natural awareness indirectly, using participants' ratings of feelings of oppression and release caused by the surrounding environment. In this article, we use the words "environment" and "space" without clear distinction. However, the former indicates the visual world surrounding the body, while the latter connotes its configuration of surfaces. In addition, we define the feelings of oppression and release as inversely-correlated feelings that change in accordance with the extent to which the surrounding environment is physically enclosed or open. The two feelings, although subjective, do not contain any evaluative meanings such as amenity and comfort, that is, they are considered to be a direct response to the spatial layout. This suggests the possibility that the feelings can be used as a medium for capturing the awareness of the surrounding space.

In our experiment, the participants continuously rated their feelings caused by the surrounding environment while walking along an outdoor route. The continuously changing feelings were outputted directly by turning a dial in their hands. This rating method allowed the participants to rate their feelings intuitively, without the intervention of any intellectual processes such as estimating the amount of buildings in the visual field. This intuitive rating did not require the participants to focus their attention on their visual experience or on any visual task, as mentioned above. Accordingly, during their ratings, they could maintain their natural state of awareness of the surrounding space (although they could not maintain the completely natural state because of the rating task). In our previous article (Ohno, Tsujiuchi, & Inagami, 2003), we discussed the validity of the continuous rating method by analyzing part of the rating data obtained from this experiment. The present article, on the other hand, is intended as an investigation of spatial awareness during natural locomotion by a further analysis of the entire rating data.

1.2 Previous related studies

Much literature in environmental and architectural psychology (e.g., Hayward & Franklin, 1974; Takei & Ohara, 1977; for a review see Stamps, 2005a) has shown that participants' ratings for such spatial feelings as oppression and release correlate with the size of wall surfaces, indicating that the feelings accurately reflect the awareness of the physical environment, particularly its spatial layout. However, most of the previous studies have dealt with directionally restricted scenes through pictures or drawings. According to Gärling (1969), ratings for the entire surrounding environment correlated with the average ratings for each scene in four orthogonal directions. This suggests that humans may feel oppression and release beyond their current visual field, that is, they are extensively aware of their surrounding space.

This extensive awareness is closely related, but not identical, to what has been generally studied as "ambient vision" or "spatial vision." Early anatomical and physiological studies (e.g., Trevarthen, 1968) have found the existence of two visual systems, which consist of "focal" or "ob-

ject" vision and "ambient" or "spatial" vision. The former obtains detailed information from the central visual field to recognize objects, whereas the latter receives global information from the entire visual field to localize objects. Recently, the function of the latter has been reinterpreted as the guidance of motor actions toward objects (e.g., Milner & Goodale, 1995). It is highly probable that this wide-field visual system contributes to the generation of the phenomenal awareness of the surrounding space. However, the wide-field vision and the spatial awareness are critically different in that the awareness is not necessarily based on retinal stimulation and, therefore, not limited to the visual field.

The spatial awareness considered in this study can include what has been generally studied as a mental image or internal representation of the surrounding space. Early studies on the memory of the location of out-of-sight objects have reported that participants can accurately imagine the space behind them as if seen through "eyes in the back of the head" (Attneave & Farrar, 1977; see also Kato & Matsui, 1998) and that the imagined space behind them is functionally continuous with the perceived space in front of them (Attneave & Pierce, 1978). Following this, many experiments based on the "spatial updating" paradigm have shown that humans can update the internal representation of their surrounding space even while walking blindfolded (e.g., Loomis, Da Silva, Fujita, & Fukusima, 1992; Rieser, Guth, & Hill, 1986; Thomson, 1980), and that this updating is done automatically while walking (e.g., Farrel & Thomson, 1998; Rieser, 1989; Walter, Montello, Richardson, & Hegarty, 2002). Blindfolded humans can update the representation of the space behind them as accurately as they can update that in front of them (Horn & Loomis, 2004). In addition, Beer (1993) has reported that participants can update the representation of off-screen space by using on-screen visual flow with movement of viewpoint. Wang and Spelke (2000) have argued that the dynamically updated internal representation of the surrounding space supports human navigation in the environment. In our view, the internal representation and above-mentioned wide-field vision are both component parts of the phenomenal awareness of the surrounding space.

2. Experiment

2.1 Outline of our experiment

As mentioned earlier, the participants in our experiment continuously rated their feelings of oppression and release while walking along an outdoor route. These ratings are expected to reflect their awareness of the surrounding space, which keeps changing along the route. To describe the physical environment quantitatively, we measured the visible areas of buildings, trees, ground, and sky along the route. These areas were measured from four different widths of view angles ranging from a limited view in front to a full 360° view. By examining which of the four measurements are best correlated with the ratings, we test the hypothesis that humans are aware of the entire surrounding space, including the space behind their bodies.

2.2 Method

Participants

Fourteen graduate students (7 females and 7 males) participated in our experiment. All were compensated for their time, except those who volunteered to participate without compensation.

Experimental site

The experimental site was an outdoor route in the Suzukakedai campus of the Tokyo Institute of Technology. This route is 425 meters long and contains various characteristic spaces such as a tunnel, a hill, and areas surrounded by tall buildings. The ratings were conducted in both directions, namely, leaving and returning. We did not regulate the flow of traffic during the experiment because pedestrian and vehicular traffic were suf-

Figure 1 Rating device and rating experiment.

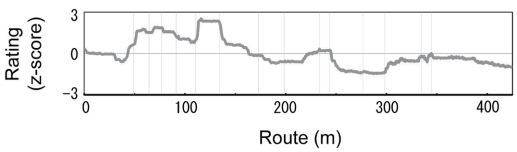


Figure 2 An example of the ratings along the route: feeling of oppression when walking in the leaving direction.

ficiently light so as not to disrupt the ratings.

Apparatus

We have developed an experimental apparatus with a rating device and a position-marking device (Ohno, Tsujiuchi, & Inagami, 2003). Participants continuously rate their feelings of oppression or release by turning a dial on the rating device in their hands (see Fig. 1). The ratings are recorded on a laptop (IBM ThinkPad 560), which is placed in a backpack worn by the participants. The laptop is equipped with a data-collecting PC card (KEYENCE NR110), which continuously captures the data 5 times per second. At the same time, an experimenter walks behind the participants and operates the position-marking device (see Fig. 1), from which data are recorded in the same way as the rating data are. When the participants reach predetermined checkpoints along the route, the experimenter marks the rating data by pushing a button on the position-marking device. Using these marks, the temporally recorded rating data can be converted into data representing points along the route. In this experiment, we chose 850pieces of the rating data in such a way that each piece approximately corresponds to 850 points at 0.5-meter intervals along the route (for an example, see Fig. 2).

Procedure

The experiment was conducted on either sunny or cloudy afternoons between October and December. All participants provided their informed consent in advance and were tested individually. The experimenter explained the route and rating task to them before the experiment, which consisted of four sessions. In the first session, the participants rated their feelings of oppression while walking in the leaving direction; in the second, they rated it while walking in the returning direction. In the third and fourth sessions, they rated their feelings of release in the leaving and returning directions. They were instructed to walk at their own pace and rate their intuitive feelings toward the surrounding environment.

2.3 Description of the environment

The physical environment along the route was quantitatively described by a method developed by Ohno (1991). This method views the environment around a viewpoint as a spherical surface consisting of four environmental components (buildings, trees, ground, and sky) and measures each visible area as a ratio of solid angle. The continuous changes in the surrounding environment due to locomotion are described as variations in the visible areas along the route. These variations were calculated by our original

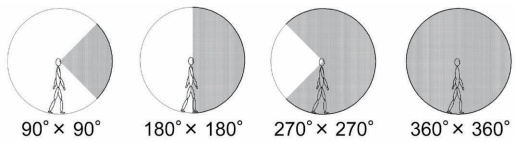


Figure 3 Four widths of measuring view angles.

computer program from computer-aided design (CAD) data of the environment along the route, which were created based on our actual survey and a site plan of the campus. The measurement was conducted at 850 points at 0.5-meter intervals along the route, corresponding to the positions of the rating data. At each measuring point, the program divides the spherical environment into 1944 cells (72 parts horizontally and 27 parts vertically) and classifies each cell as one of the four environmental components. The measurement is limited to within a 72-meter radius of each measuring point, the outside of which is classified as "sky." The "buildings" include the tunnel, walls, and steep hills of approximately over 30°. In this experiment, we systematically varied the measuring area to four different widths of view angles: 90°, 180°, 270°, and 360°, vertically and horizontally, around the traveling directions (see Fig. 3). The visible areas were calculated for each view angle (see Fig. 4 for examples).

Benedikt (1979) developed an alternative method — the isovist method — for obtaining a quantitative description of the physical environment. The isovist of a particular point is defined as the planar (horizontal) shape of the surrounding space that is visible from that point, which is quantified through various measures such as its area and the length of its visible boundary. Recent studies (e.g., Stamps, 2005b; Wiener et al., 2007) have investigated the relationships between the isovist measures and human behavior as well as subjective impressions. As argued in Benedikt and Burnham (1985), the isovist method was inspired by the concept of

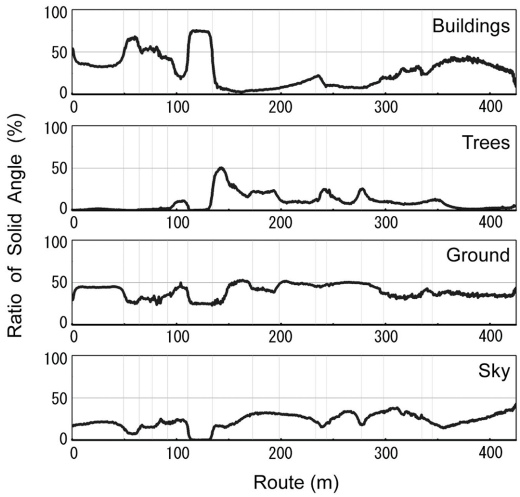


Figure 4 Examples of environmental measurements along the route: visible areas of buildings, trees, ground, and sky as measured from the 360° view angle.

the "ambient optic array" developed by Gibson (1979). In addition, Kadar and Shaw (2000) have attempted to apply the isovist method to an ecological theory of locomotion control. Although these studies are highly suggestive, our description method seems to differ from the isovist method in one major respect. A group of solid angles measured by our method is a feature of the ambient optic array itself, whereas the isovist is a feature of the spatial layout, which is perceived from the optic array. In this sense, our method describes the environment at a more primary level than the isovist method dose.

3. Results

To analyze the participants' ratings and environmental measurements, we developed a model of the relationship between a physical environment and the feelings of oppression and release caused by it. This model is based on the assumption that an environment is composed of only the ground and sky in its basic state and that the addition of buildings and trees would increase the feeling of oppression and decrease the feeling of

release. We described the model by using the following linear regression equations:

$$F_o = \alpha_0 + \alpha_1 Vb + \alpha_2 Vt + \varepsilon \qquad (1)$$

$$F_r = \beta_0 - \beta_1 Vb - \beta_2 Vt + \varepsilon, \qquad (2)$$

where F_o and F_r are the feelings of oppression and release, Vb and Vt are the visible areas of buildings and trees, α_0 and β_0 are the intercepts, α_1, α_2, β_1, and β_2 are the regression coefficients, and ε is the error term.

We performed multiple regression analyses using the model to obtain the prediction relations between the ratings for each participant and session and the visible areas of buildings and trees measured from each view angle. The resultant coefficients of determination (R^2s) were analyzed by a 4 (session) × 4 (measuring view angle) analysis of variance with repeated measures. An alpha level of .01 was used for all statistical tests. As a result, there were significant main effects of session[1)] and measuring view angle, $F(3, 39) = 10.22$, $p < .001$ and $F(3, 39) = 15.64$, $p < .001$, respectively. The interaction between the two factors was not significant, $F(9, 117) = 1.35$, $p = .22$. Figure 5 shows an overall tendency for the goodness of fit of the model to increase with the width of the measuring view angle. Furthermore, one-tailed paired t-tests with Bonferroni correction revealed significant differences between the R^2s for the 360° measuring view angle and those for the other measuring view angles (vs. 90°: $t[55] = -6.13$, $p < .001$; vs. 180°: $t[55] = -4.42$, $p < .001$; vs. 270°: $t[55] = -3.26$, $p < .01$). This indicates that the feelings of oppression and release are best predicted by the environmental measurements of the 360° view angle.

1) However, at this point, we are not concerned with the differences between the two feelings or between the two directions of travel because the experiment, in which all participants conducted the four sessions in the same order, did not annul the order effect.

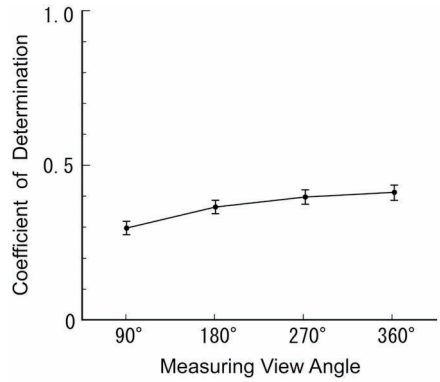


Figure 5 Goodness of fit of the regressions to the participants' ratings by the environmental measurements for each view angle. The plots and error bars indicate the mean R^2s across all participants and ±1 SEM, respectively.

4. Discussion

4.1 Validity of our method

We first discuss the validity of the indirect method that uses feelings of oppression and release to investigate the awareness of the surrounding space. The validity mainly depends on how closely feelings and awareness are connected, and this closeness is supported from two viewpoints. First, feelings and awareness have a common function. According to recent studies (e.g., Damasio, 1994; LeDoux, 1996), emotions, which include feelings in a broad sense, are not merely epiphenomenal responses but important factors that control behavior, depending on the situation. In particular, such spatial feelings as oppression and release are related to affordances of the spatial layout such as the blocking of locomotion by wall surfaces (Stamps, 2005a, 2005b). Viewed in this light, it is reasonable that feelings of oppression and release as well as spatial awareness support various actions in the environment. Next, feelings are merged with awareness. To take a simple example, we cannot differentiate the awareness of a wall behind us from the feeling of oppression caused by it. Even if we

turn around and scrutinize the wall, it is difficult to separate the visual awareness from the feeling. Although it may be possible, such a task is never undertaken in daily life. To sum up, humans, especially under natural conditions, utilize their feelings of oppression and release to determine their actions in the environment, without distinguishing the feelings from their awareness of the spatial layout. This suggests that the feelings are closer to the awareness than we usually assume, thus supporting the validity of our method.

4.2 Awareness of the surrounding space and ecological perception

Given that our method is valid, our experimental results support the hypothesis that humans are aware of the entire surrounding space, including the space behind their bodies. According to the experimenter's observations of the participants' head movements during the process of their rating, the participants were facing the direction of travel most of the time. If their spatial awareness had been limited to the visual field, their feelings would have been best predicted by the environmental measurements of the 180° view angle, which approximately corresponds to the view captured by their visual field along the route. However, our results indicate that their feelings are best predicted by the environmental measurements of the 360° view angle. This suggests that humans are aware of the entire surrounding space, including the space behind their bodies. What they are aware of under natural conditions is not the "visual field" but the "visual world" that extends beyond it, as argued by Gibson (1950, 1979).

This extensive awareness seems to capture an aspect of spatial perception at the ecological level. Based on the traditional concept, visual perception is viewed as a snapshot obtaining tachistoscopic information from within the visual field. Consequently, the awareness that extends beyond the visual field is excluded from the spatial perception. In fact, the non-visual awareness of the surrounding space, such as spatial updating, has been studied as a mental image or an internal representation, as mentioned earlier. However, Pick (1993) has argued that such awareness is sometimes based on perceptual updating and other times based on configurational knowledge. In other words, humans can be aware of out-of-sight space, at least to some extent, at the perceptual level rather than at the higher-order cognitive level. This implies that the traditional concept of visual perception may be defective in the study of spatial perception. On the other hand, the ecological approach considers that perception is both spatially and temporally unbounded. According to the ecological concept, visual perception is not entirely based on retinal stimulation (Gibson, 1979). In addition, perception is inseparable from the memory component and is carried out over an interval of time (Johansson, 1979). It follows that visual perception can be panoramic, that is, it can extend beyond the visual field (Gibson, 1979; see also Heft, 1996). Accordingly, based on this concept, the extensive awareness revealed in this study can be compatibly classified as spatial perception.

Whether or not the extensive awareness is classified as spatial perception depends on how visual perception is conceptualized, although there is no doubt that the awareness is consistent with our phenomenal experience of the visual world in daily life. While humans can obtain detailed visual information only from the limited view in front of them, they are continuously aware of the environment behind their bodies, at least of its schematic spatial layout. This indefinite awareness seems to correspond to what William James (1890/1950) emphasized by comparing it to the abstraction of "free water" in the "stream of consciousness," as is evident in the following quotation:

> What must be admitted is that the definite images of traditional psychology form but the very smallest part of our minds as they actually live. The tra-

> ditional psychology talks like one who should say a river consists of nothing but pailsful, spoonsful, quartpotsful, barrelsful, and other moulded forms of water. Even were the pails and the pots all actually standing in the stream, still between them the free water would continue to flow. It is just this free water of consciousness that psychologists resolutely overlook. Every definite image in the mind is steeped and dyed in the free water that flows round it. (p.255)

Although this passage is about the human consciousness in general, we believe that the same is also true of spatial perception. Traditional psychology has dealt with only a fraction of spatial perception, that is, the acquisition of definite information from within the visual field. However, such perception, especially under natural conditions, is always embedded in the indefinite awareness of the entire surrounding space. It is necessary to recognize the importance of this awareness and reconsider the traditional concept of visual perception in order to elucidate the nature of spatial perception.

5. Conclusion

In this article, we attempted to capture the natural state of the phenomenal awareness of the surrounding space. Through acute theoretical or phenomenological analyses, Gibson (1979) and Koffka (1935) have insisted that the awareness extends beyond the visual field. Our results provide empirical support for this insistence and defend the ecological concept of visual perception. Although such extensive awareness is most likely an essential part of daily spatial perception, it has not been studied empirically thus far. This is attributed to the fact that most experiments on spatial perception have been conducted under artificial conditions in faithful accordance with the traditional methods of vision science. Recently, some visual experiments have used pictures of natural scenes instead of simple geometric shapes as the stimuli, and their unexpected findings on the performance of human visual processing, as Braun (2003) has argued, may have "upset the applecart." However, we believe that what will truly upset the applecart will be future studies on the natural workings of the human visual system, since these will require the deconstruction of the traditional concept of visual perception.

Acknowledgement

We express appreciation to those who kindly volunteered to participate in the experiment, and also to Eriko Kawano for some suggestions in polishing this article.

References

Attneave, F. & Farrar, P. (1977). The visual world behind the head. *American Journal of Psychology*, **90** (4), 549–563.

Attneave, F. & Pierce, C. R. (1978). Accuracy of extrapolating a pointer into perceived and imagined space. *American Journal of Psychology*, **91** (3), 371–387.

Beer, J. M. (1993). Perceiving scene layout through an aperture during visually simulated self-motion. *Journal of Experimental Psychology*: *Human Perception and Performance*, **19** (5), 1066–1081.

Benedikt, M. L. (1979). To take hold of space: Isovists and isovist fields. *Environment and Planning B*, **6**, 47–65.

Benedikt, M. L. & Burnham, C. A. (1985). Perceiving architectural space: From optic arrays to isovists. In Warren, W.H. & Shaw, R.E. (Eds.), *Persistence and Change*, 103–114. London: Lawrence Erlbaum Associates.

Braun, J. (2003). Natural scenes upset the visual applecart. *Trends in Cognitive Sciences*, **7** (1), 7–9.

Churchland, P. S., Ramachandran, V. S., & Sejnowski, T. J. (1994). A critique of pure vision. In Koch, C. & Davis, J.L. (Eds.), *Large-scale neuronal theories of the brain*, 23–60. Cambridge: MIT Press.

Damasio, R. A. (1994). *Descartes' error*: *Emotion, reason, and the human brain*. New York: G.P. Putnam's Sons.

Farrel, M. J. & Thomson, J. A. (1998). Au-

tomatic spatial updating during locomotion without vision. *Quarterly Journal of Experimental Psychology*, **51A** (3), 637–654.

Gärling, T. (1969). Studies in visual perception of architectural spaces and rooms: Judgment scales of open and closed space. *Scandinavian Journal of Psychology*, **10**, 250–256.

Gibson, J. J. (1950). *The perception of the visual world*. Boston: Houghton Mifflin Company.

Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston: Houghton Mifflin Company.

Hayward, S. C. & Franklin, S. S. (1974). Perceived openness-enclosure of architectural space. *Environment and Behavior*, **6** (1), 37–52.

Heft, H. (1996). The ecological approach to navigation: A Gibsonian perspective. In Portugali, J. (Ed.), *The construction of cognitive maps*, 105–132. Boston: Kluwer Academic Publishers.

Horn, D. & Loomis, J. (2004). Spatial updating of targets in front and behind. *Paidéia*, **14** (27), 75–81.

James, W. (1890/1950). *The principles of psychology*: *Volume 1*. New York: Dover Publications.

Johansson, G. (1979). Memory functions in visual event perception. In Nilsson, L. (Ed.), *Perspectives on memory research*: *Essays in honor of Uppsala university's 500th anniversary*, 93–103. New Jersey: Lawrence Erlbaum Associates.

Kadar, E. E. & Shaw, R. E. (2000). Toward an ecological field theory of perceptual control of locomotion. *Ecological Psychology*, **12** (2), 141–180.

Kato, K. & Matsui, T. (1998). Recognizing the surrounding space. *Cognitive Studies*, **5** (3), 5–14. (In Japanese)

Koffka, K. (1935). *Principles of Gestalt psychology*. New York: Harcourt, Brace & World, inc.

LeDoux, J. (1996). *The emotional brain*. New York: Simon & Schuster.

Loomis, J. M., Da Silva, J. A., Fujita, N., & Fukusima, S. S. (1992). Visual space perception and visually directed action. *Journal of Experimental Psychology*: *Human Perception and Performance*, **18**, 906–922.

Milner, A. D. & Goodale, M. A. (1995). *The visual brain in action*. Oxford: Oxford University Press.

Neisser, U. (1976). *Cognition and reality*. San Francisco: W. H. Freeman and Company.

Noë, A. (2004). *Action in perception*. Cambridge: MIT Press.

Ohno, R. (1991). Ambient vision of the environmental perception: Describing ambient visual information. *Proceedings of the 22nd Annual Conference of the Environmental Design Research Association*, 237–252.

Ohno, R., Tsujiuchi, R., & Inagami, M. (2003). A method of continuous rating for psychological impact while moving through exterior space: A study on description method of ambient visual information and its application (Part 2). *Journal of Architecture and Planning*, **570**, 65–69. (In Japanese)

Pick, H.L. Jr. (1993). Organization of spatial knowledge in children. In Eilan, N., McCarthy, R., & Brewer, B. (Eds.), *Spatial Representation: Problems in Philosophy and Psychology*, 31–42. Oxford: Blackwell.

Rieser, J. J. (1989). Access to knowledge of spatial structure at novel points of observation. *Journal of Experimental Psychology*: *Learning, Memory, and Cognition*, **15** (6), 1157–1165.

Rieser, J. J., Guth, D. A., & Hill, E. W. (1986). Sensitivity to perspective structure while walking without vision. *Perception*, **15**, 173–188.

Stamps, A. E. (2005a). Enclosure and safety in urbanscapes. *Environment and Behavior*, **37** (1), 102–133.

Stamps, A. E. (2005b). Isovists, enclosure, and permeability theory. *Environmental and Planning B*, **32**, 732–762.

Takei, M. & Ohara, M. (1977). Experimental study on measurement of the sense of oppression by a building (Part 2): Selection process of the physical scale and proposal of the equation for estimating the sense of oppression caused by a building in housing area. *Transactions of the Architectural Institute of Japan*, **262**, 103–113. (In Japanese)

Thomson, J. A. (1980). How do we use visual information to control locomotion? *Trends in Neurosciences*, **3**, 247–250.

Trevarthen, C. B. (1968). Two mechanisms of vision in primates. *Psychologische Forschung*, **31**, 299–337.

Walter, D., Montello, D. R., Richardson, A. E., & Hegarty, M. (2002). Orientation specificity and spatial updating of memories for layouts. *Journal of Experimental Psychology*: *Learning, Memory, & Cognition*, **28** (6), 1051–1063.

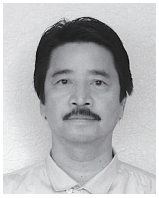
Wang, R. F. & Spelke, E. S. (2002). Human spatial representation: Insights from animals. *Trends in Cognitive Sciences*, **6** (9), 376–382.

Wiener, J. M., Franz, G., Rossmanith, N., Reichelt, A., Mallot, H. A., & Bülthoff, H. H. (2007). Isovist analysis captures properties of space relevant for locomotion and experience. *Perception*, **36** (7), 1066–1083.

(Received 20 Oct. 2007)
(Accepted 7 Jan. 2008)

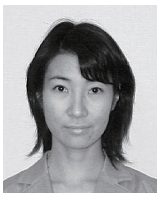
Makoto Inagami

Makoto Inagami is a doctoral student in the Department of Built Environment at Tokyo Institute of Technology, where he also earned his M. Eng. in 2004. His research empirically examines how humans perceive their surrounding environment during daily locomotion. He is also interested in the ecological and phenomenological approaches to perception.
E-mail: `inagami.m.aa@m.titech.ac.jp`



Ryuzo Ohno

Ryuzo Ohno is a Professor in the Department of Built Environment at Tokyo Institute of Technology where he teaches behavioral aspects of Urban and Architectural Design. He received his M. Arch. from Univ. Wisconsin-Milwaukee and D. Eng. from Tokyo Tech. His research interests include description/analysis of ambient visual information, development of simulation systems for investigating human-environment relations, and environmental design based on empirical data.
E-mail: `rohno@n.cc.titech.ac.jp`



Rieko Tsujiuchi

Rieko Tsujiuchi currently works for Central Japan Railway Company. She received her M. Eng. from Tokyo Institute of Technology in 1999. Her master thesis, which was supervised by Prof. Ohno, developed a rating method which allows participants to output their feelings continuously while walking and, in addition, discussed the validity of the method.