

Visuo-motor development which causes detection of visual depth from motion and density cues¹

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This study examines the effectiveness of cues of visual depth and distance in the course of development and how this process depends on visuo-motor development. In the visual pitfall situation, i.e. a modification of Gibson's visual cliff, eight Japanese monkeys (*macaca fuscata*) were observed with respect to their depth avoidance and visuo-motor activity. The tests were run once a week from the first until the sixteenth week after birth. Binocular parallax, motion parallax and texture density rates were manipulated to examine their effectiveness as cues. It was shown that for the first two months depth perception depended exclusively on motion parallax, whereas in the third month cues of motion and texture were added. Binocular cues did not have any effect in this age range. Three items of behaviour, i.e. visual regard of depth, head movement, and body movement, were checked and measured to obtain information which could explain the process of development of the cue function. The three items showed different developmental curves. During the first month, visual regard closely concurred with head and body movements, then visual activity suppressed motor behaviour and, after the end of the second month, the two became almost independent of each other.

These analyses demonstrated that at a later stage pictorial cues produced an effect additional to the primary motion cues and that the effective cue function was based on the development of visuo-motor activity.

Key words: Perceptual development, depth from motion, texture perception, visual development, motor development

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In textbooks on perception, a number of possible cues for visual depth and distance are listed. These cues may be grouped into ocular, pictorial, and parallax cues (Tsuji, Hayashibe & Hara, 1973). The ocular cue includes convergence and accommodation. The pictorial cue is a constellation of retinal stimulus, like texture gradient, perspective, superposition, relative size, nearness to horizontal line, etc. The parallax cue depends on the disparity of the input information picked up simultaneously and includes both binocular parallax and motion parallax.

However, those cues have as yet to be defined as a reference system to explain their interrelation and the developmental process of cue function. In order to investigate this interrelation we have attempted to rearrange a set of those cues in a consistent framework. The ocular cue was excluded, since this cue depends on the structure of the visual system which varies with the species. For this reason, the present study concentrates on the analysis of the potential effect of the pictorial and parallax cues.

It has remained as open question how these cues are related to each other in the developmental process and how they are based on the visuo-motor function at the respective stages. In this study we attempt to answer these questions by experiments with the Japanese monkeys.

Our approach is based on the view that visual space has the psychological meaning of a "field" in which the relationship between self and objects is brought into psychological existence, and that visual space perception guides such behaviour as exploration, locomotion, and manipulation in order to set the self in relation to the external world (Gibson, 1958; Held & Hein, 1963; Tsuji, 1984). In this sense, it may be called a behavioural or – on the lines of J.J. Gibson (1979) – an ecological approach to perception.

Our approach emphasizes the importance of the surfaces existing in the environment and the depth information picked up from these surfaces. It regards movement as a normal state of animals and considers motion parallax to be a crucial cue for visual depth perception, as has previously been demonstrated (Tsuji, Hayashibe & Hara, 1972, 1974). It assumes the developmental process of perception to be an "enrichment" of the cue efficiency and it attempts to investigate the ontogeny of human visual depth perception by inter-species comparison and simulation. Finally, it views perception in relation to visual emotion which occurs concurrently with perception and motivates spatial behaviour. This point has been discussed elsewhere (Tsuji, 1984).

Set-up of the observational situation

As Bollnow (1963) pointed out, it is necessary to set up a situation in which space perception strongly urges behavioural coping, in order to break down the psychological "naturalness" of the perceived world. Therefore, for our observational situation we chose a space extending downward, instead of the ordinary space extending forward.

The "visual cliff" could be a good example of this. We set up an optical depth situation which we called "visual pitfall". While it is basically similar to the visual cliff, it has some advantages over the cliff: It allows the subjects to move about more freely and thereby permits visual perception during spontaneous locomotion to be tested more accurately. In addition, the relative difficulty of the task can easily be varied with different arrangements of pitfalls on the basal surface (Hayashibe, Tsuji & Hara, 1975; Tsuji, Hayashibe & Hara, 1981). In the test, we placed an animal on the basal surface and observed instances of pitfall avoidance and other types of behaviour.

Determining the basic or primary cue by a test with chicks

A major purpose of our study was to examine the developmental process of the cue function and to answer the question of how depth cues are enriched. At the start, we assumed that irrespective of anatomical variability the cue function has a basic component which is common to widely different species whose behaviour is dependent on vision. Taking into account Heckel's recapitulation theory, we adopted a strategy of simulating the early stage of human ontogeny by an early stage of animal phylogeny.

To start with, chicks were tested in order to determine the basic or primary cue. As this species is precocial, the chicks' behaviour is visually guided immediately after they hatch. In precocial animals of *aves*, the young do not depend on their mother for their food, thus any maternal effects can be excluded.

With chicks we have found that motion parallax was the only effective cue, while other cues did not play any role at any stage of maturation (Tallarico, 1962; Tsuji et al., 1972, 1974; Hara, Tsuji & Hayashibe, 1974; Hayashibe, Tsuji & Hara, 1975).

Previous findings of visual and motor development in monkeys

As a next step, we attempted to observe monkeys' responses to the visual pitfalls, in order to obtain findings on the developmental process of cue function. The visual sensitivity and acuity of Macaques are basically similar those of humans (Cowey, Parkinson & Warnick, 1975; Teller, Regal, Videen & Pulo, 1978). In the Japanese monkey, vision rapidly develops during the first month after birth, approaches the adult level around the third month, and actually reaches the adult level at the age of six months. The fact that a two-day old monkey can visually follow a moving object shows the maturity of the level of visual ability at birth. By contrast, during the first month motor ability grows more slowly than visual ability, then accelerates in the course of the following two months, and reaches the adult level by the age of six months to one year (Matsuzawa, 1981).

Method

Subjects

The experiments were conducted with eight Japanese monkeys (*Macaca fuscata*). They were separated from their mothers immediately after birth, isolated and artificially nursed. The test was run in the visual pitfall situation (Type-III) shown in Figure 1. The animals were observed once a week from birth to 15 weeks of age.

Manipulation of the visual depth cues

We manipulated three possible cues, i.e. binocular parallax, motion parallax, and texture-density ratio. The effect of the binocular parallax was examined by comparing the responses in the binocular condition with those in a temporarily monocularized condition. Monocularization was achieved by attaching a specially devised occluder to either eye.

The effect of the texture-density ratio was tested by comparing the responses obtained in three conditions in which the size of the checkerboard patterns on the lower surface was changed while the size of those on the basal surface was kept constant. For Condition Lo (low), the retinal size of the patterns on the lower surface (19 degrees) was approximated to those on the basal surface (18 degrees). The density ratio of the lower to the basal surface was 1.06. Analogously, the ratio value was 0.71 for Condition Me (medium) and 0.38 for Condition Hi (high).

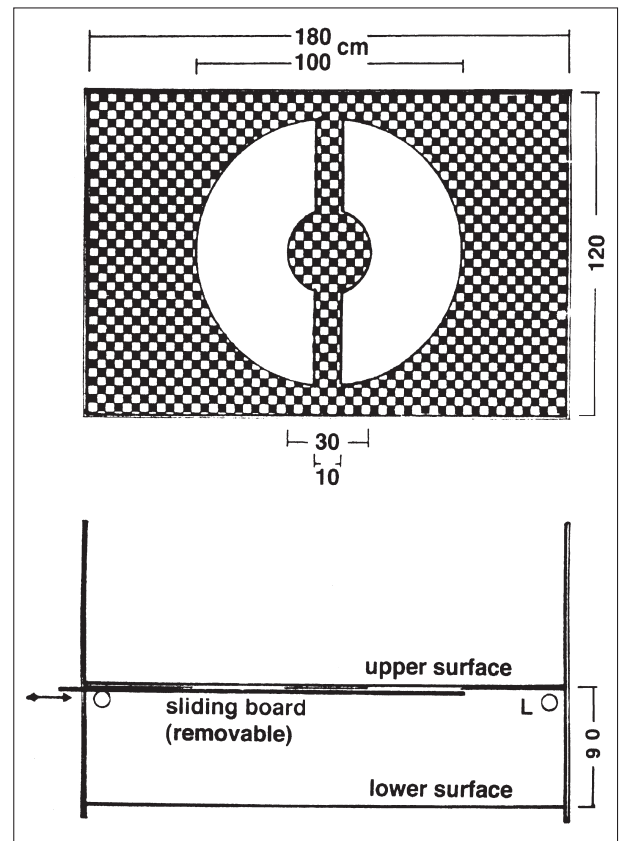


Figure 1: Visual pitfall apparatus: Type III.

We predicted that the percent of avoidance for Lo, Me, Hi would increase in that order.

Added to those three conditions was Condition No in which the lower patterned surface was replaced with a homogeneous surface so as to eliminate the effect of motion parallax. The effect of that cue was determined by comparing the responses in the patterned conditions with those in the homogeneous condition.

Results

Analysis I: Effectiveness of the three cues in the course of development

Figure 2 shows the avoidance percent for Condition Lo in which the motion parallax was the only cue available. Throughout the sessions, avoidance remained at nearly same level of 80 to 90% without a significant difference between binocular and monocular conditions. The result confirmed the primacy of the motion parallax as well as the inefficiency of the binocular parallax.

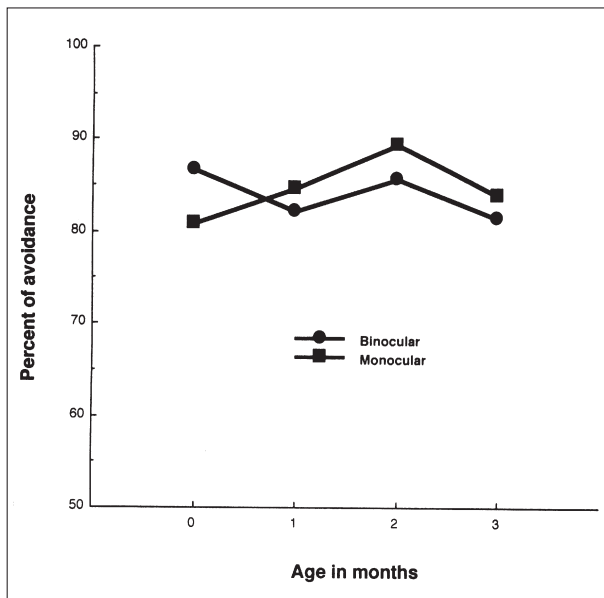


Figure 2: Percentage of avoidance responses in binocular and monocular conditions.

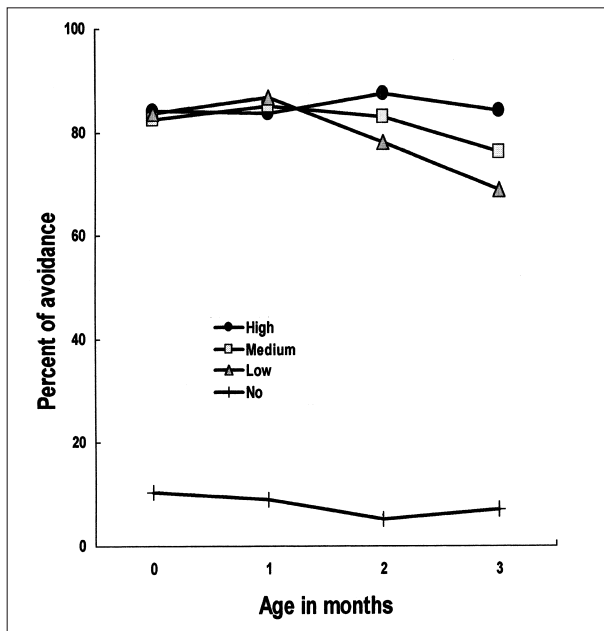


Figure 3: Percentage of avoidance responses for four density-ratio conditions.

Figure 3 presents the comparison of avoidance between the three conditions of density ratio. There was no difference in the avoidance for the first two months. However, the percent of avoidance started to differ at the age of two months, and was remarkably diverse at the age of three months. This pattern of results is in accordance with our prediction.

As these results demonstrate, in the initial stage depth perception depends exclusively on motion parallax, and in the third month it shifts to a stage in which it additionally depends on the effects of motion and density cues. The observations in all sessions revealed clearly that the binocular parallax did not enhance depth perception.

Analysis II: Developmental process of visuo-motor function

On the basis of the above finding, we focused on the animals' visual and motor activities in the test situation. For this purpose, the duration of each of the following three items was checked and measured: visual regard of the pitfall, head movement (head rotation and looking around at the edge of the pitfall), and body movement (gross movement of the whole body like swinging and rocking at the edge of the pitfall).

Figure 4 shows each of the three measures as a function of age in weeks. The values are the means calculated with the binocular and monocular conditions and the three density-ratio conditions combined. Data for Condition No were excluded.

Visual regard grew longer, reached a peak at the age of eight weeks, and abruptly shortened toward the age of 15 weeks. Gross movement of the whole body dominated for the first three or four weeks, and was reduced sharply after peaking at the age of three weeks. In the place of body movement, head movement increased, but it became shorter after peaking at the age of five weeks. Thus, the developmental curves of the three activities showed different temporal functions in the course of development.

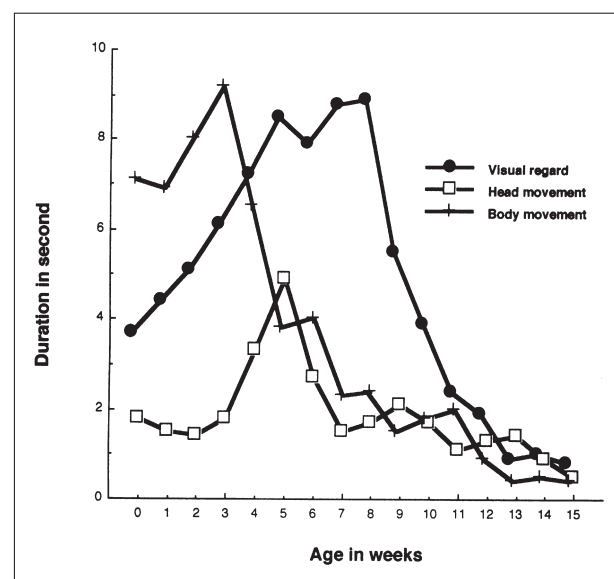


Figure 4: Visual and motor activities as a function of age.

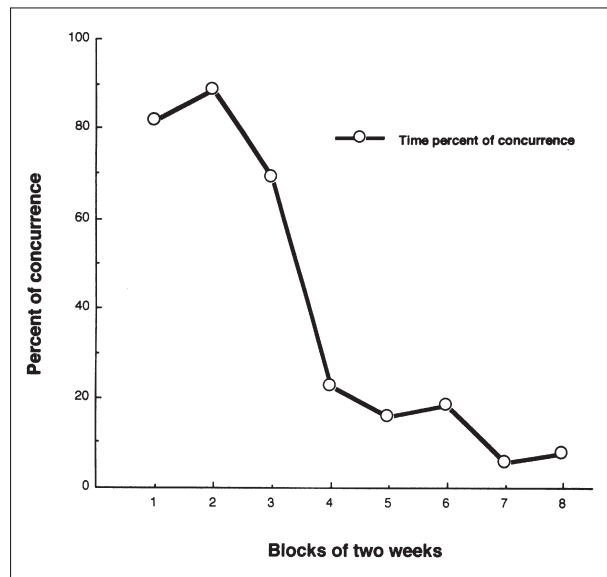


Figure 5: Percentage of concurrence of visual and motor activities as a function of age.

Figure 5 shows the time percent of concurrence of visual regard with movement. The value indicates the duration of body and head movements during visual regard divided by the total time of visual regard. Concurrence was more than 80% for the first month, and then dropped to less than 20% for ages after two months.

Clearly, visual regard concurrent with either body or head movement dominated during the first six weeks, and was replaced by longer visual regard with suppressed movement in the age ranging from seven to nine or ten weeks. Then, after 11 weeks, visual and motor activities became extremely brief and independent of each other. Visuo-motor activity was thus shown to have three phases.

Discussion

The results of the two analyses in the present study successfully demonstrated that the developmental process of the cue function proceeds with the concomitant development of visuo-motor activity which can be divided into three phases.

In the first phase, the monkeys fail to pick up the density cue because their own movement produces “optical flow” and spoils its possible effect even if the cue exists in the external environment.

However, in the second phase, body and head movements are remarkably suppressed during visual regard, that is, motor activity comes to be separated from visual activity, which makes the “stationary pattern” of the den-

sity cue effective. Finally in the third phase, visual activity becomes more efficient and more independent of motor activity than in the second phase. It might be concluded that visual depth perception develops as an enrichment of effective cues and that the development of the visuo-motor function underlies the cue function.

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