Effects of change of spatial distance between moving dots on their apparent linkage

AKIRA ISHIGUCHI

Department of Psychology, Ochanomizu University, Bunkyo-ku, Tokyo 112

The aim of this study was to tackle empirically a problem of competing apparent linkages between moving dots. The problem is brought up in a situation in which the visual system recovers a local structure (i.e., a pair-wise structure) from its moving elements, in particular, a structure from the "biological motion". An experiment was performed to examine the effects of changes of spatial distance between moving dots on perceived strength of linkage between the moving dots, using the methods of clarity rating of perceived linkage between two pairs of moving dots. The results indicated that the proximity of the spatial distance between the dots in a 2-D projection plane did not always have dominant effects on the perceived strength of the linkage, and that the change of the spatial distance between the dots during their motion had crucial effects. These results were applied to a human gait perception with point-light display.

Key words: motion perception, biological motion, human gait, proximity principle, apparent linkage.

The human visual system has an ability to recover a structure from motion of its elements (Ullman, 1979, 1983, 1984). A vivid demonstration for this ability of the human visual system is a perceptual phenomenon of the "biological motion" (Johansson, 1973; Cutting, 1978a, 1981; Cutting & Proffitt, 1981; Cutting, Moore, & Morrison, 1988). The demonstration showed that the visual system has the ability to utilize two dimensional motions of elemental points to construct unique descriptions of the underlying multi-limbed objects.

There seem three main problems to be solved concerning a process of perceiving the "biological motion".

The first is a "linkage problem", which is translated into a following informal expression: Which is his partner? When some dot elements are stationary, they are perceived to be a random dot pattern. As the dots commence to move, however, an original structure consisting of the dots is constructed instantaneously. In this recovering process, a spatial configuration of the moving dots (i.e., a set of some pair-

ings of the dot elements) is determined uniquely. How does the human visual system find out the neighboring pairs with efficiency and without errors?

The second is a problem about an interpolation process, which may operate as the correct two-dimensional links are obtained. The third is a problem about a top-down process, or utilization of "knowledge data base". These problems are discussed later.

The aim of this research is to probe empirically a local mechanism determining apparent linkage between moving dots.

Meanwhile, theoretical approach to this problem has been made (Hoffman & Flinchbaugh, 1982). This theoretical research, however, had some problems when applied to perception of the "biological motion". First, the theoretical research could not elucidate an empirical phenomenon that a linkage between two moving dots corresponding to two end-points of a non-rigid rod is observed. In a human gait perception from the motion of point-lights, for example, the point-lights corresponding to a shoulder and a wrist

are perceived to be linked when a point-light corresponding to an elbow is turned off (Cutting, 1981). Even when a local structure between a shoulder and a wrist is non-rigid, the human visual system constructs a pair-wise (i.e., a shoulder-wrist) structure. Secondly, the theoretical research ignored possibility of competing linkages. In a human gait perception, for example, a point-light corresponding to a wrist is linked not only to a point-light corresponding to an elbow, but also to a point-light corresponding to a hip or a head. There exists a three dimensional plane on which two point-lights (e.g., point-lights corresponding to a wrist and a head) move with a local rigidity of the pair-wise structure held. Thus, the theoretical approach is insufficient to explain the linkage process in the "biological motion".

So far, some psychological researches have dealt with a problem similar to the linkage problem (Wertheimer, 1923; Johansson, 1950; Gogel, 1978). The main problem they were concerned with was an organization or grouping of moving points. With the gestalt ideas combined with Johansson's vector analysis about the organization of moving points, Restle (1979) proposed coding theory to fit the simple motions of Johansson's 1950 experiments. Recently, Cutting (1981) adapted the coding theory to gait perception, and proposed a revised theory for a hierarchical organization of moving points which correspond to major joints constructing a human body. In contrast, the present study intended to identify the information input into a visual process obtaining apparent links, not a simple grouping, between moving dots, and to propose a feasible mechanism operating in the process.

To deal with the linkage problem, we must devise a spatial arrangement and motion of dots. When we present many moving dots like a normal "biological motion" display, we will be troubled by

the possibility that many complicate factors is incorporated. Since the aim of this study was to elucidate a fundamental process for perception of linkage between moving dots, fewer dots were necessary for finding out some crucial factors incorporated in this process. However, usage of only two moving dots was afiel from the point of linkage problem how the visual system finds out pairs of dots. Thus, three moving dots were presented in this experiment, and relative strength between two pairs of dots was compared.

These three dots were arranged vertically as shown in Fig. 1, following the "biological motion" display. That is, the arrangement borne in mind was that of major joints constructing a human body. As a result, the dots motion used in the present study was transverse motion or pendular oscillation which is the fundamental motion element of the biological gait motion. Using the fundamental arrangement and motion of three dots, I conducted the following experiment in a condition that caused competing linkage between the moving dots, in order to identify some crucial information used by the human visual system for solving out the linkage problem.

Experiment

Method

Subjects. Eleven undergraduates in the department of psychology at Ochanomizu University participated as subjects in this experiment. All were naive to psychological experiments, and had not seen the moving dot display as used in this experiment.

Apparatus. Stimulus patterns were generated by a microcomputer (NEC PC-9801vm21) and displayed on a random-scanning CRT (Kikusui COS1711 with a P31 phosphor). The CRT was placed 57.5 cm from the eyes of the subject, who sat in a chair with a chinrest and viewed

the pattern binocularly in a dimly lit room.

Stimuli. Three moving dots (D1, D2 and D4) were presented in the CRT. The D1 and D2 moved in a fashion of horizontal single oscillation. Another dot, D4, moved as an end-point of a pendulum moving around D1, D2 or a middle point (D3) between D1 and D2. That is, the motion of D4 consisted of both the horizontal single oscillation and the pendular oscillation. A sample display is illustrated in Fig. 1. Closed circles indicate the dots at the first stage of motion; and open circles, dots in the course of motion. In an actual display, the middle dot (D3) between D1 and D2 and the measure at rightmost in Fig. 1 were not presented. The frequency of the motion was kept constant at 1.0 Hz, and the motion lasted for five seconds. The amplitude of the pendular oscillation was set at 30 arcdeg around the point D1, D2 or D3. The amplitude of the horizontal simple oscillation was varied and is described below.

A set of 48 displays was presented in random order. Each display was presented three times. The 48 displays resulted from a combination of following three factors.

1. Center of pendular motion: As described before, D1, D2 or D3 was selected as the center (i.e., pivot) around which D4 moved pendulously in a display. This variation resulted in the variation of the radius of the pendular motion of D4.

2. Size of display: Both large and small displays were made. In the "large display", the distance between D1 and D4 at the initial stage of motion (closed circles in Fig. 1) was 4.8 deg in visual angle (hereafter, all degrees are likewise in visual angle). In the "small display", the distance was 2.4 deg. Furthermore, the amplitude of the horizontal simple oscillation was set at 2.4 deg in the "large display", and 1.2 deg in the "small display".

3. Distance between D1 and D2: The

distance between D1 and D2 was varied from 0.96 to 4.32 deg by 0.48 deg steps in the "large display", and 0.48 to 2.16 deg by 0.24 deg steps in the "small display".

Fig. 1. (a) An arrangement of three moving dots used in Experiment 1. This consists of both (b) a horizontal simple oscillation (i.e., the motion of D1, D2 and D4) and (c) a pendulum oscillation (i.e., the motion of D4 around D1). Closed circles indicate the three dots at the first stage of motion, and open circles indicate positions of the three dots at one point in the course of their motion. Dotted circles indicate the positions of D3 which was not presented in an actual display. The distance between D1 and D2 was varied by steps shown in the measure at the right-most part of the figure (c). The measure was not shown in an actual display. $\overline{D1D4}$ and/or $\overline{D2D4}$ are possible links between moving dots.

That is, the ratio of the distance D1-D2 to the distance D1-D4 at the initial stage of motion was varied from 0.2 to 0.9 by 0.1 steps in both display conditions.

Since the distance between D1 and D4 at the initial stage of motion was kept constant under any one display-size condition, an increase of distance between D1 and D2 resulted in a decrease of distance between D2 and D4.

Procedure. The subjects were required to allocate the appearance of the motion of D4 into the following four categories according to a perceived relative strength of linkage (i.e., relative clarity of subjective lines) between D4-D1 and D4-D2:

0: D4 appears to move separately with regard to other two dots.

1: D4 appears linked to D1 more strongly than to D2, and moves together with D1.

2: D4 appears linked to D2 more strongly than to D1, and moves together with D2.

3: D4 appears linked to both D1 and D2, and moves together with D1 and D2.

The category number 3 includes the following two observations. One observation is that D4 appears linked to D1, at the same time to D2. The other is that D4 appears linked to D1 and to D2 alternately in the same display.

When no interpolated lines were perceived between the moving dots, the subjects were instructed to report the category number 0.

The subjects performed twelve practice trials before test trials.

Results

All subjects reported subjective lines interpolated between moving dots in many cases of the motion display. This result reconfirmed the results of Ishiguchi (1988a, b) that a vivid line is perceived from the motion of dot elements of a pendulum. In addition, the subjects in this experiment frequently said that these lines (in particular, a line D2-D4) moved not only in

a frontal parallel plane under one condition, but also in a plane slanted in depth under other conditions.

Frequencies of the category numbers reported by the subjects were summarized with the following equation:

$$\text{FLD}(i) = (\text{frequency of category number } i) + 0.5 \cdot (\text{frequency of category number 3}) \quad (1-1)$$

FLD(*i*) (*i*=1, 2) is an abbreviation for the frequency of perceived linkage of D4 to D_{*i*}. The frequency of category number 3 was divided between FLD(1) and FLD(2) because the aim of this experiment was to make clear the distinction between a condition causing linkage of D1 to D4 and a condition causing linkage of D2 to D4.

Figure 2 shows proportions of FLD(*i*) for each D_{*i*} to total frequency as a function of the distance ratio of D1-D2 to D1-D4. In each figure, subtraction of both proportion of FLD(1) and that of FLD(2) from 1.0 gives the proportion of reported category number 0. Mean proportion of reported category number 0 was only 0.056. Figures 2-a, b and c show the results obtained under the condition that the center of pendular oscillation of D4 was D1, D3 and D2, respectively. Open circles in each figure indicate proportions of FLD(1) under the "large display" condition; closed circles, proportions of FLD(1) under the "small display" condition; open squares indicate proportions of FLD(2) under the "large display" condition; and closed squares, proportions of FLD(2) under the "small display" conditions.

As shown in these figures, the size of motion display had little effects on the perceived linkage between moving dots under any condition. A chi-square test reveals no significant differences between the large and small displays ($\chi^2 \approx 1.12$, 0.86, and 3.21 under three conditions, shown in Fig. 2-a, b and c, respectively, concerning the center of pendular oscilla-

tion of D4).

On the other hand, the length of distance between D1 and D2 at the initial stage of motion had strong effects, combined with the effects of the position of the center of the pendular motion, on the perceived linkage. The effects of the distance between D1 and D2 are equivalent to effects of the ratio of the distance of D1-D2 to the distance of D1-D4. This is because distance between D1 and D4 at the initial stage of motion was kept constant. The chi-square test was used to determine whether the proportion of FLD(1) was different significantly from the proportion of FLD(2) in each condition. Arrows in Figs. 2-a, b and c indicate the significant difference between the proportions of FLD(1) and FLD(2). Solid arrows indicate 0.01 significant level; and dotted arrows, 0.05 level with chi-square tests.

For this analysis, the data obtained under both the large and the small display conditions were pooled.

Obviously, there was a critical point in the "ratio of distance" axis for whether D4 appeared linked more vividly to D1 or D2. When the ratio of the distance D1-D2 to the distance D1-D4 was less than a value of the critical point, D4 appeared linked more vividly to D2; and when the ratio was larger than a value of the critical point, D4 appeared linked more vividly to D1. As shown in Fig. 2, the value of the critical points depended on the position of the center of the pendular oscillation.

We must consider, then, what the critical points reflected. In Table 1, both the maximum and the minimum distances of D_i -D4 ($i=1, 2$) during motion of these dots in the "large display" condition are listed. As shown in Table 1, the distance

Fig. 2. Proportions of FLD(i) for each D_i to total frequency as a function of the distance ratio of D1-D2 to D1-D4. The center of pendular oscillation was (a) D1, (b) D3, and (c) D2. Circles indicate the proportions of FLD(1), and squares, the proportions of FLD(2). Open symbols indicate data under the "large display" condition; and closed symbols, data under the "small display" condition. Arrows indicate a significant difference between proportion of FLD(1) and that of FLD(2). Solid arrows indicate 0.01 significant level; and dotted arrows, 0.05 level.

Table 1

The maximum and minimum distance between a pair of moving dots (i.e., D1-D4 or D2-D4) and a ratio of the maximum to the minimum distance during motion under the "large display" condition

Pivot	Ratio 0	Distance of D1-D4			Distance of D2-D4		
		Max. 1 (deg)	Min. 1 (deg)	Ratio 1	Max. 2 (deg)	Min. 2 (deg)	Ratio 2
D1	0.2	4.80	4.80	1.00	4.00	3.84	1.04
D1	0.3	4.80	4.80	1.00	3.63	3.36	1.08
D1	0.4	4.30	4.80	1.00	3.28	2.88	1.14
D1	0.5	4.80	4.80	1.00	2.97	2.40	1.24
D1	0.6	4.80	4.80	1.00	2.72	1.92	1.42
D1	0.7	4.80	4.80	1.00	2.53	1.44	1.76
D1	0.8	4.80	4.80	1.00	2.42	0.96	2.52
D1	0.9	4.80	4.80	1.00	2.41	0.48	5.01
D3	0.2	4.80	4.74	1.01	3.91	3.84	1.02
D3	0.3	4.80	4.72	1.02	3.48	3.36	1.04
D3	0.4	4.80	4.70	1.02	3.05	2.88	1.06
D3	0.5	4.80	4.68	1.03	2.63	2.40	1.10
D3	0.6	4.80	4.66	1.03	2.23	1.92	1.16
D3	0.7	4.80	4.65	1.03	1.86	1.44	1.29
D3	0.8	4.80	4.64	1.03	1.55	0.96	1.61
D3	0.9	4.80	4.64	1.03	1.33	0.48	2.77
D2	0.2	4.80	4.70	1.02	3.84	3.84	1.00
D2	0.3	4.80	4.66	1.03	3.36	3.36	1.00
D2	0.4	4.80	4.64	1.03	2.88	2.88	1.00
D2	0.5	4.80	4.63	1.04	2.40	2.40	1.00
D2	0.6	4.80	4.64	1.03	1.92	1.92	1.00
D2	0.7	4.80	4.66	1.03	1.44	1.44	1.00
D2	0.8	4.80	4.70	1.02	0.96	0.96	1.00
D2	0.9	4.80	4.74	1.01	0.48	0.48	1.00

Note: Ratio 0=(Distance of D1-D2)/(Distance of D1-D4) at the initial stage of motion.

Ratio 1=Max. 1/Min. 1; Ratio 2=Max. 2/Min. 2

Max. *i* (or Min. *i*) means the maximum (or minimum) distance of *D_i*-D4 during motion (*i*=1, 2).

of D1-D4 changed little regardless of not only variation of the center of the pendular motion of D4, but also of the distance between D1 and D2. On the other hand, the distance of D2-D4 changed largely with variation of stimulus conditions. We must, thus, pay attention to the change of the distance between D2 and D4 during motion. When D1 was the center of the pendular oscillation, the critical point in Fig. 2-a corresponded to the Ratio 2 value 1.42 in Table 1 (Ratio 2 is the ratio of the maximum to the minimum distance be-

tween D2 and D4 during motion). In a similar way, when D3 was the center, the critical point in Fig. 2-b corresponded to the Ratio 2 value 1.61 or less. These data lead to a conclusion that when the Ratio 2 value exceeds about 1.5, D4 appears linked with D1 which takes the place of D2. With these results in mind, we may resolve the problem that critical points was not obtained when D2 was the center of the pendular oscillation. Under this condition, the distance between D2 and D4 was kept constant, and the Ratio 2 value

did not exceed the value of about 1.5.

Figure 2-c reveals another important characteristic of distance information for linkage between moving dots. Figure 2-c shows the results under the condition that D2 was the center of pendular motion of D4. Under this condition, the distance between D2 and D4 (i.e., the radius of pendular motion of D4) was decreased with increase of the ratio of the distance of D1-D2 to the distance of D1-D4 at the initial stage of motion. Although the distance between D2 and D4 was decreased, the relative strength of linkage between D2 and D4 did neither increase nor decrease, and was almost kept constant. This result indicated that the distance information for determination of linkage between moving dots is used qualitatively (i.e., "which is near?"), not quantitatively (i.e., "how much is it near?").

Discussion

The results in this experiment can be summarized as follows:

1. Competing linkage between different pairs of moving dots was produced. Otherwise, the proportion of $FLD(i)$ (i.e., frequency of perceived linkage of D4 to D_i) would have been 1.0 or 0.0 in the case that all subjects perceived only one link between D4 and D1 or D4 and D2. However, such results were not obtained. If all subjects had constantly perceived two links (i.e., D1-D4 and D2-D4) simultaneously, the proportion of $FLD(i)$ would have been 0.5 for each D_i . However, the fact is that $FLD(1)$ was significantly different from $FLD(2)$ in almost all conditions. Yet, these results does not mean that no observations corresponding to the category number 3 (i.e., D4 appears to link to both D1 and D2 simultaneously) were reported. In fact, mean proportion of reported category number 3 was 0.295. Many subjects reported that a 3-D triangle translated horizontally, and, at the same time, it moved around a vertical axis when D4 appeared linked with D1 and D2

simultaneously.

2. The size of stimulus motion displays had little effects on a variety of perceived linkage. Whereas, the distances between moving dots had strong effects. With these results combined, it can be concluded that it is the ratio, rather than the difference, between the two distances of D1-D4 and of D2-D4 that determined whether D4 appeared linked with D1 or D2. If the difference in the distances had some roles in the determination, the size of stimulus motion display, in turn, would have influenced differently on the competing linkage, but it did not.

3. The distance between moving dots seemed to have first-order effects on perceived strength of linkage. However, the present results showed that more adjacent pair was not always linked, as suggested by Hoffman and Flinchbaugh (1982). Though the distance between D1 and D4 was greater than the distance between D2 and D4 under every condition in Experiment 1, linkage between D1 and D4 was perceived stronger in some conditions. From a viewing point of a distance-change, the distance between D1 and D4 during motion was almost kept constant in a fixed condition, that is, the ratio of the maximum to the minimum of the distance during motion of dots was about 1.0 (see Table 1). On the other hand, for a pair of D2 and D4, the distance between D2 and D4 was varied during motion even within a condition except under the condition that D2 was the center of the pendular motion of D4. Furthermore, the ratio of the maximum to the minimum of the distance during motion for the pair, D2 and D4, increased as the distance between D1 and D2 increased (i.e., the distance between D2 and D4 decreased) under the condition that D1 or D3 was the center of the D4's pendular oscillation. As shown by the results, when the ratio exceeded about 1.5, the linkage between D2 and D4 was perceived to have less strength than the linkage between D1 and

D4. When the ratio was less, the linkage between D2 and D4 was perceived to be stronger than the linkage between D1 and D4.

Here, we must consider implication of the value 1.5 to the human visual system. If a rigid pendulum moves in a plane slanted in depth, the ratio of the maximum to the minimum distance between two end-points of the pendulum in a frontal parallel plane (i.e., a projection plane) increases with the slant-angle of the motion plane. When the slant-angle is about 66 deg, the ratio becomes 1.5. These values were obtained simply with analytic geometry under the parallel projection. Though it is possible that this value of slant-angle is critical for the human visual system, the value seems to be applied only to the competing linkage situation. If only two dots were used, a simulated rigid pendulum, which moved in a plane slanted 80 deg in depth, was perceived from motion of the two dots corresponding to the two end-points of the pendulum (Ishiguchi, 1988a).

Strictly speaking, in this experiment, the trajectory of D4 around D2 was not the same as that of an end-point of a rigid pendulum moving in a plane slanted in depth. However, the change of distance between D2 and D4 during motion has little deviation from the change of distance between two end-points of a rigid pendulum moving in a plane slanted in depth. This comparison was performed under the experimental condition in which D1 was the center of D4's pendular oscillation, and the distance ratio of D1-D2 to D1-D4 was 0.6, which produced the ratio of 1.42 of the maximum to the minimum distances between D2 and D4 (Ratio 2 in Table 1); whereas under a simulated condition of a rigid pendulum with a radius of 4.3 deg in visual angle moving in a plane slanted about 63.5 deg in depth, the ratio of 1.42 of the maximum to the minimum distances between two end-points of the pendulum was produced. The deviation was at most

0.014 deg in visual angle. This comparison was also assured partly by the subjects' reports in this experiment that the linked line between D2 and D4 appeared to move in a plane slanted in depth.

In the above discussion, the focus is not on the difference but on the ratio of the distance between dots during motion. This is because, as mentioned above, the results in this experiment showed that the size of stimulus display has little effects on the competing linkage. Furthermore, both under "large display condition" and under "small display condition", the linkage between D1 and D4 had similar strength to the linkage between D2 and D4 at a critical point on the distance ratio axis of D1-D2 to D1-D4 at the initial stage of motion. At the critical point, the ratio of the maximum to the minimum distance between D2 and D4 during motion was about 1.5 both under the "large display condition" and under the "small display condition". On the other hand, the difference between the maximum and the minimum distances of D2-D4 under the "large display condition" was twice as large as that under the "small display condition".

Next, these results were applied to a human gait perception using moving point-light (Cutting & Proffitt, 1981). Calculation of both the 2-D distance and the ratio of the maximum to the minimum distance between moving point-lights was performed. Actually, the calculation was based on a program which Cutting (1978b) made to generate synthetic walkers using 13 point-lights. Thus, the ratio was calculated for 78 pairs. Based on this calculation, pair-wise structure was determined (Fig. 3-a). The determination was performed through a following procedure: Two point-lights (e.g., D1 and D2) are linked as a pair when following two conditions are held.

1. A critical ratio: The ratio of the maximum to the minimum distance is less than 1.5.

2. A proximity principle: The distance between the point-lights (D1 and D2) is shorter than that of any other pairs (D1 and D3, D1 and D4, etc.) which also hold the first condition.

When the proximity principle is applied, a mean distance between two moving point-lights is used as a distance.

The structure obtained through this procedure corresponds to the structure perceived from this point-light display. In this example, the point-light display simulates a human gait motion in a direction perpendicular to an observer's line of sight. Moreover, when the display simulates a human gait motion in depth, a structure

corresponding to perceived one is also obtained through the above procedure.

In addition, according to this procedure, a point-light corresponding to a wrist is linked to a point-light corresponding to an isolateral shoulder when a point-light corresponding to an elbow is turned off. This is explained in Fig. 3-b. This figure shows a rank of possible linkages between a point-light corresponding to a right wrist and other point-lights. This rank is obtained both through the "critical ratio" and through the "proximity principle". The first of this rank is a linkage between a right wrist and a right elbow, and the second is a linkage between a right wrist and a right shoulder. This is why the linkage between a right wrist and right shoulder is perceived when a point-light corresponding to a right elbow is turned off.

In comparison with these structures, a structure obtained through only the proximity principle is shown in Fig. 3-c. As shown in these figures, not only the proximity principle but also the critical ratio should be involved in determining the pair-wise frame structure from dynamic point-light displays.

Now we discuss a general problem about the "biological motion".

There seem three main problems to be solved concerning a process of perceiving the "biological motion".

The first is a "linkage problem". In a process of recovery of an original biological structure from motion of the elements, a spatial configuration of the moving elements (i.e., a set of some pair-wise structures) is determined uniquely. A mechanism solving this problem in the visual process is rather simpler than has ever been thought, as suggested by results of this research.

The second is a problem about an interpolation process, which may construct actually correct two-dimensional links. When a structure is recovered from motion of its elements, an interpolated line be-

Fig. 3. Linkage structure resulting from application of (a) (b) both a "critical ratio" and a "proximity principle", and (c) only a "proximity principle", to a human gait motion with a point-light display. Numbers in (b) indicate a rank of possible linkages between a point-light corresponding to a right wrist and other point-lights.

tween paired dots is perceived. How is this subjective line constructed by the human visual system? In this regard, Ishiguchi (1988b) hypothesized a dynamic interpolation mechanism based on his empirical data.

These two problems should not be considered to be both sides of only one problem. For the biological motion, when no lights are on elbows, the motion of bending arms are perceived (Cutting, 1981). The solution of the "linkage problem" does not result in making clear a process producing this perception of the bending structure from two moving lights.

The third is a problem about a top-down process, or utilization of "knowledge data base". In a recovery of structure from motion, there has been some circumstantial evidence that the top-down process is involved. Bertenthal, Proffitt, and Kramer (1987) showed that infants of 5-month-old discriminate a locally rigid point-light walker display from one in which local rigidity is perturbed, but that they cannot discriminate the inverted rigid display from the non-rigid display. The result suggested that the subjects used a knowledge about a biological form for their discrimination between a locally rigid- and nonrigid-structure. Furthermore, since subjects in this research were infants of 5-month-old, the results raised a new problem whether the knowledge data base that the subjects possibly used was constructed through learning or was innate. In addition to this example, a research demonstrated utilization of knowledge data base in the interpolation process of perceiving structure from motion (Ishiguchi, 1990).

The aim of the research reported here is to commence to probe into the information used by the human visual system for solution of "linkage problem" which seems one of three main problems concerning the process of perceiving the "biological motion". The present research intended to find out empirically informa-

tion which the human visual system utilize to get a pair of moving dots linked.

From the results obtained in this experiment, it was found that the visual system used multiple information about spatial distance between moving dots. Even though the distance between moving dots changed (i.e., a rigidity was not held in 2-D plane) during motion within a fixed range in a projection plane, a proximal pair of moving dots was perceived to link more strongly than a more distant pair. This linkage was produced partly because distance change of the proximal pair of moving dots was attributed to change of depth during motion for two end-points of rigid rod: a 3-D rigid rod was perceived preferentially from the proximal pair of moving dots. However, when the degree of the distance change between moving dots during motion exceeded a critical value, the linkage of even the proximal pair (not only in a 2-D but also in a 3-D space) was broken, and other possible linkage was produced. The critical value of the distance change during motion was translated into a slant-angle in depth of a plane where dots moved. The slant-angle was about 66 deg. However, the implication of the value, in particular, its ecological meaning was uncertain.

In addition to the spatial information, the human visual system possibly uses some temporal information for solving "linkage problem". Ishiguchi (in preparation) suggested that a phase difference between moving dots is used to solve the "linkage problem", but that the usage of the temporal information is auxiliary.

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