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Infant Sensitivity to Figural Coherence in Biomechanical Motions

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Two experiments assessed infant sensitivity to figural coherence in point-light displays moving as if attached to the major joints of a walking person. Experiment 1 tested whether 3- and 5-month-old infants could discriminate between upright and inverted versions of the walker in both moving and static displays. Using an infant-control habituation paradigm, it was found that both ages discriminated the moving but not the static displays. Experiment 2 was designed to clarify whether or not structural invariants were extracted from these displays. The results revealed that (1) moving point-light displays with equivalent motions but different topographic relations were discriminated while (2) static versions were not, and (3) arrays that varied in the amount of motion present in different portions of the display were also not discriminated. These results are interpreted as indicating that young infants are sensitive to figural coherence in displays of biomechanical motion.

One might suppose that the extraction of form from a continuously changing object would be more difficult than the extraction of form from a stationary object. In the former case, the spatial relations of the edges and surfaces of the object are continuously changing while in the latter case these relations remain constant. Yet, recent research from the adult

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literature suggests that this intuition may not always be true (cf. Gibson, 1979; Johansson, von Hofsten, & Jansson, 1980). Adults perceive many of the persistent properties of their environment by observing events transforming proximal stimulation over time (e.g., Braunstein, 1976; Cutting & Proffitt, 1981; Johansson, 1975; Ullman, 1978). Either by observing moving objects or through self locomotion, adults extract invariant relations from a changing flow of optical structure. It is suggested by some theorists (e.g., Johansson, 1975) that this process is so fundamental that its origins must be rooted in early development.

To date, there is little consensus about infant sensitivity to motion carried information except that movement serves to recruit attention (Haith, 1966; Volkman & Dobson, 1976; Milewski, 1980). This situation arises, in part, from a less than complete appreciation by infant researchers that there are transformations manifested in motion that specify different persistent and changing properties of the environment. The following is but a partial listing of the varieties of motion carried information: Relative depth is unambiguously specified (Braunstein, 1962; Gibson, Kaplan, Reynolds, & Wheeler, 1969); an object can be seen moving relative to a stationary observer (Johansson, 1950), or the centrifugal expansion of texture in a stationary environment can specify movement of the observer (Gibson, Olum, & Rosenblatt, 1955); objects can be seen to undergo form changes (Gibson, Owsley, & Johnston, 1978; Shaw, McIntyre, & Mace, 1974); and dynamic causes can be seen in moving events (Michotte, 1963). One of the most basic aspects of the environment revealed through motion is figural coherence, and infant sensitivity to this property is the focus of the present paper.

Figural Coherence

Wertheimer (1923/1938), when proposing his principle of "Common Fate," stated that elements moving together are seen as forming a perceptual grouping. Subsequent research, notably that of Johansson (1950), demonstrated that movement is analyzed by the perceptual system into two components called relative and common motions. The relative motions of elements within an event serve to specify the form or figural coherence of the object involved. The common motion of these elements specifies the object's displacement relative to the observer. Point-lights attached to the rim of a rotating wheel, for example, are seen as having circular relative motions coinciding with the wheel's form, and a linear common motion describing its displacement relative to the observer (Wallach, 1965/1976). Relative motions, which are analyzable into rotations or rotary oscillations, can also specify the form of three-dimensional objects. The two best known examples of this phenomenon are the kinetic depth effect (Wallach & O'Connell, 1953/1976) and the perception of human walkers from dynamic point-light displays (Johansson, 1973).

In the kinetic depth effect, a two-dimensional shadow of a three-dimensional form is cast onto a screen. When viewed without motion the shadow appears as a two-dimensional shape; however, when it undergoes rotation, a rigid, three-dimensional form is immediately perceived. The same effect can also be produced with an array of unconnected point-lights (Green, 1961). These findings are particularly striking since the only available information is the continuously changing spatial relations between point-lights or edges. It thus appears that form is specified by invariants that remain constant over the perspective transformations of the object. One example of such an invariant is the cross-ratios of any four collinear points which according to the principles of projective geometry remain constant during the rotation of a rigid object (Johansson et al., 1980).

Point-light walker displays (see Fig. 1A) are created by attaching lights to the major joints and head of a person and filming their locomotion in a darkened room. Alternatively, this phenomenon can be created by

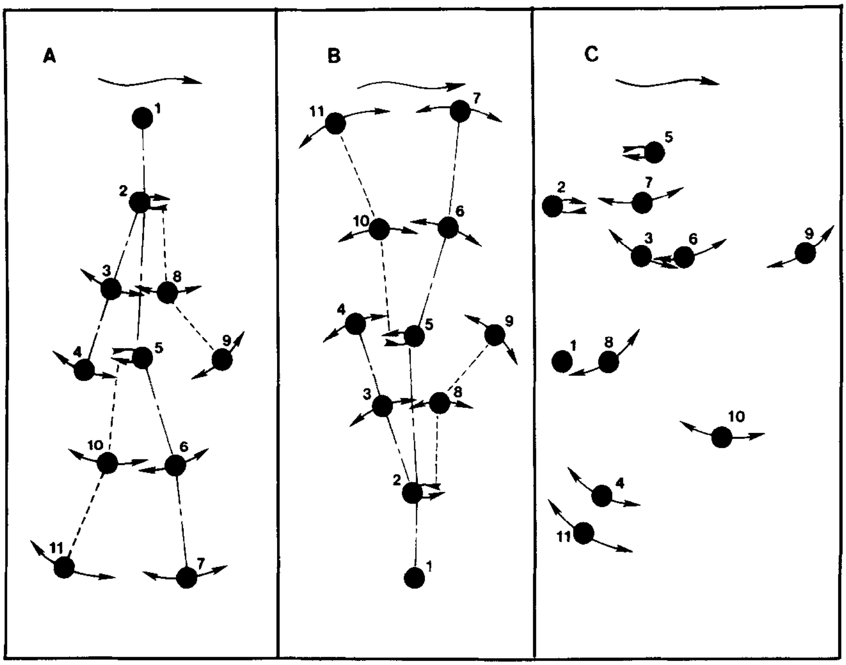

FIG. 1. Depicted in A is the array of 11 point-lights attached to the head and joints of a walking person: The head and right side of the body are numbered 1 through 7, and numbers 8 through 11 mark those of the body's left side. The motion vectors drawn through each point-light represent the perceived relative motions within the figure, and that drawn above the walker depicts its perceived observer-relative displacement. Depicted in B is the inverted, mirror image version of the walker in A. The anomalous walker depicted in C is identical to A except that the relative locations of the point-lights have been scrambled as shown. (Correspondingly numbered point-lights have the same absolute motions.)

mimicking the pattern of moving point-lights through computer synthesis (Cutting, 1978a). Any static frame from these sequences appears as a meaningless arrangement of dots; however, recognition of a walking human is immediately perceived in the moving displays. As with the kinetic depth effect, figural coherence is specified by the invariant relations extracted from the transformations of the elements.

In sum, figural coherence can be defined as a perceptual grouping of elements having a particular set of spatial relations. This grouping can be specified by invariant relations that are extracted exclusively from the relative motions among elements.

Infant Sensitivity to Figural Coherence

The extraction of figural coherence or form is certainly a fundamental process in the perception of the visual world. When one also considers the ubiquitous and salient nature of motion, it would seem highly adaptive for even young infants to be sensitive to figural coherence revealed through motion. Interestingly, a number of recent reviews of infant visual perception (Ruff, 1980; Yonas & Granrud, in press) suggest that sensitivity to motion-carried information is either innate or develops very early. Although the scant empirical evidence relating to figural coherence supports this position, much work still needs to be done. In particular, there are many different sources of kinematic information, including relative motions, disruption of texture, and occlusion; thus, a complete understanding of infant sensitivity to figural coherence depends upon establishing the particular forms of information that are available to the infant at different ages. In this paper, we are specifically concerned with whether or not relative motions alone are sufficient for specifying figural coherence.

It is not at all clear whether infants are sensitive to figural coherence revealed through the relative motions within an object. There is some evidence that 3- to 4-month-old infants are sensitive to the form and unity of objects undergoing continuous perspective transformations (Gibson, Owsley, Walker, & Megaw-Nyce, 1979; Ruff, 1982; Kellman & Spelke, 1981; Owsley, 1980). Still, the importance of relative motions alone remains uncertain in these studies since solid objects were used in all of them. When viewing a solid object undergoing a perspective transformation, the form of the object is specified not only by the relative motions but also by additional kinematic variables, such as foreshortening of texture as the object rotates out of the picture plane, as well as self-occlusion. A direct test of sensitivity to relative motions must use a more reduced stimulus display.

Such a test was conducted by Lasky and Gogel (1978). The stimulus display involved three moving dots: Two moved together horizontally back and forth in parallel trajectories while the third moved up and down between the other two. Although the absolute motion path of the third dot follows an up and down trajectory, it is seen as moving at a slant when the three dots are perceptually grouped. Since the slant occurs to the right or left of midline depending upon the phase relations of the three dots, it is possible to produce two discriminable displays that share the same absolute motions. Five-month-old infants were found to discriminate these two versions of the same display. The authors thus concluded that infants were sensitive to the relative rather than to the absolute motions in this display.

This conclusion cannot be accepted unequivocably, however, since it was also possible that the infants simply detected the phase changes between the absolute motions of the dots. In one of the two displays, the third dot is positioned at its highest vertical excursion when the two other dots are located at the extreme left of the display, while in the other display the third dot is high when the other two are at the extreme right. Accordingly, infants could have discriminated the two displays as a function of detecting these correlative differences among the absolute motions rather than as a function of grouping the elements and perceiving the movement of the third dot slanting to the right or left. Moreover, Lasky and Gogel were concerned with relative motions, per se, and did not examine the use of relative motion in perceiving figural coherence. Our research goes further in this direction.

Statement of the Problem

The purpose of the present research was to provide a more definitive test for infant sensitivity to figural coherence as revealed exclusively by relative motions. The following experiments involved biomechanical motions using displays of point-lights moving as if attached to the joints of a person walking. In contrast to the earlier described research where the extraction of invariants from a moving rigid object was examined, this research was designed to investigate infant sensitivity to invariant relations in a moving semirigid object (Cutting & Proffitt, 1981). These displays are extremely complex since each joint allows for directional change and thus spatial relations among various joints are continuously changing. In spite of this apparent complexity, these displays are recognized by adult observers as a person walking in less than 200 msec (Johansson, 1976).

Although infants may also see these displays as consistent with the form of a human walker, our objective in this initial set of experiments was to simply demonstrate whether or not infants are sensitive to figural coherence in these displays. This distinction between figural coherence and the form of a person walking is necessary since a point-light display affords many different interpretations depending upon the specific set of relative motions extracted. Consider, for example, the problem presented by a point-light display of a person on a bicycle. Observers might see this display as one unique form since all the point-lights are moving together, or they might separately extract the form of a person and the form of a bicycle. What is seen depends upon the relative motions extracted together as a perceptual grouping. In the case of a point-light walker, an observer may not group all of the relative motions together but rather may perceive coherence, for example, among only the lights of the upper torso or of the arm. Although the form of a person will not be seen unless all of the point-lights are perceptually grouped together, figural coherence of a more limited portion of the display is still possible as long as the appropriate relative motions are extracted.

Thus, the principle purpose of these initial experiments was to assess whether or not infants were sensitive to configural relations provided by relative motions among point-lights. Of course, infants might not be sensitive to figural coherence in these displays, in which case there are two alternatives. Either infants perceive a display of moving point-lights as an unrelated swarm of randomly moving dots or they detect the motion paths of individual point-lights. Two experiments were conducted to clarify the nature of infant sensitivity to these displays. Experiment 1 evaluated whether these displays were seen as an undifferentiated cluster of lights or as a set of individual or relative motions. Experiment 2 tested whether infants detected individual motions or configural relations in these displays.

EXPERIMENT 1: UPRIGHT AND INVERTED WALKER DISPLAYS

This experiment tested whether 3- and 5-month-old infants could discriminate between upright and inverted versions of a walker in both moving and static displays. If infants were responding only to an undifferentiated swarm of point-lights then no discrimination was expected since both displays contained the same number of point-lights moving in the same direction and at the same speed. Alternatively, we predicted discrimination if infants were sensitive to any of the more differentiable forms of motion information, e.g., figural coherence, contained within these displays. The inclusion of a test for discrimination between static displays controlled for the possibility that discrimination was simply a function of detecting changes in the spatial relations of the point-lights in the upright and inverted walkers.

METHOD

Subjects

The final sample consisted of 24 twelve-week-old (X = 12.6 weeks, SD = 7.4 days) and 40 twenty-week-old infants (X = 19.4 weeks, SD = 8.0 days). An additional 12 twelve-week-old and 9 twenty-week-old babies failed to complete testing due to distress or fussiness. The babies constituted a relatively homogeneous sample with almost all coming from middle class homes. Babies were recruited from birth announcements in the local newspaper.

Stimuli

All stimuli depicted either static or moving versions of a human walker created through computer synthesis (e.g., Cutting, 1978b). In essence, these programs generated moving clusters of 11 phosphor dots mimicking the movements of a human walker. As depicted in Fig. 1A, it is as if the lights were mounted on the major joints and head of an individual walking across a dark background. Stimuli were displayed on a Hewlett–Packard (HP) 1350A display system driven by an HP 1000L computer and videotaped for presentation on a video monitor. Individual point-lights subtended a visual angle of 0.5° and the maximum vertical height of the walker and horizontal distance traversed were 3.5° and 7.0° of visual angle, respectively.

Four different stimuli were used in this experiment. The first, depicted in Fig. 1A, consisted of an array of point-lights moving as if attached to the joints of a person walking from left to right (three steps in 3 sec), immediately reappearing at the left of the screen after it vanished from the right. The second stimulus, depicted in Fig. 1B, was an inverted, mirror image of the first. Thus, although being an upside down version of the first event, this stimulus traversed the screen in the same left-to-right direction. The latter two stimuli consisted of single static images appearing in the middle of the video monitor. One was of the upright while the second was of the inverted. These frozen images from the step cycle were selected to maximize the distance between ankle point-lights.

Design

A partial lag design (Bertenthal, Haith, & Campos, 1983) was used for testing infant discrimination of the stimuli. This design is similar to the standard infant–control habituation paradigm (Cohen, 1972) but controls more directly for artifactual increases in looking times on test trials. In this procedure, infants are presented repeatedly with the same stimulus display over a series of trials until criterion is reached. The duration of the trial is under the infant's control and begins when the baby starts looking at the stimulus and ends when the baby looks away. Criterion is defined as the point when total looking on three consecutive trials sums to no more than 50% of the total looking on the first three trials. In cases ($N = 4$) where total fixation on the first three trials is less than 12 sec, an absolute criterion of 6 sec or less is used. Once criterion is reached, half of the infants in each group are presented with a novel stimulus on the next two trials while the other half continue to see the familiar stimulus for two additional trials (lag trials) before observing the novel stimulus. A significant increase in looking time on novel trials relative to the looking on the preceding two familiar trials is used to indicate discrimination.

Infants at both ages (Age manipulation) were randomly assigned to one of four groups, with the constraint that all groups contain an equal number of babies. Two groups were shown the two kinematic displays while the other two were shown the two static displays (Condition manipulation). The groups were further defined by the presentation order of the two stimuli (Order manipulation). Thus, two groups saw the upright version of the walker as the familiar stimulus and the inverted version as the novel stimulus while the other two groups were presented with the reverse sequence.

Apparatus

The apparatus was similar to one used previously (Bertenthal, Campos, & Haith, 1980) and thus will be described here only briefly. It consisted of an L-shaped cabinet that housed a half-silvered mirror (86 × 47.5 cm) at the intersection of the two chambers. A Dage 650SN video camera with an infrared sensitive tube was located at the end of one chamber and a 700-line video monitor with a 30.5-cm CRT (Panasonic WV-5400) was located at the end of the other chamber. The mirror was slanted at a 45° angle between the camera and the monitor so that it was possible to display the stimulus on the mirror and to simultaneously record the ocular behavior of the infant. Illumination of the baby's eye was provided by a red light source (which was filtered via light diffusing plastic) located below the viewing chamber and directed at the face. This light produced a corneal reflection in the infant's eyes when he or she was looking directly at the stimulus. All other lights in the room were turned off to maximize the infant's attentiveness to the stimulus display.

Two video recorders, one for controlling the stimulus display (Sony SLO-323) and one for recording the infant's ocular behavior (Sony AV-3600), and two video monitors, one for displaying the stimulus seen by the child (Panasonic WV-5400) and one for displaying the infant's ocular behavior (Sony CVM-950) were located in an adjacent control room. Also located in this room was a programmable calculator (HP-67) used for making all on-line computations and indicating when criterion was reached (see Haith & Bertenthal, 1979, for a more detailed description).

Procedure

Infants were seated on their mother's laps and faced the mirror. Mothers were instructed to avoid interacting with their babies and also to avoid looking at the stimulus displays. (The camera operator located behind the half-silvered mirror was able to ensure that the mother followed these instructions.) As soon as the infant appeared comfortable and attentive, the experimenter in the control room switched the video recorder to the play mode and the stimulus began to appear on the mirror. A trial began when the infant was observed by the experimenter to orient to the stimulus display and ended when the baby looked away. Judgments concerning ocular orientation were facilitated by the presence of the corneal reflection from the red filtered light. (The relative location of the corneal reflection when looking at the stimulus display was calibrated prior to the experiment using five adult observers.) At the end of each trial, the video recorder was stopped. After a 5-sec interstimulus interval, the stimulus display was again presented.

Once criterion was reached, the videotape was advanced to the novel stimulus display which was presented for two trials. Infants in the lag condition were not shown the novel stimulus display until two trials later.

Reliability

The observer who scored duration of looking during the experiment was aware of which display the infant was seeing, but was uninformed as to the hypotheses of the study. A second observer scored 20 of the babies from the videotape for the purpose of computing reliability. All auditory information identifying trial offset was eliminated prior to these assessments. The correlation coefficient computed between the scores of the two observers was $r(19) = .94$. The mean absolute difference between these scores was 1.10 sec.

RESULTS AND DISCUSSION

Discrimination between the stimuli was assessed by comparing mean duration of looking on the two test trials with mean duration of looking on the last two trials showing the familiar stimulus. For those infants shown the novel stimulus on the first two postcriterion trials, a regression procedure using the lag infants' data was employed to partial out the contribution of spontaneous regression to looking scores on the two test trials (Bertenthal et al., 1983).[1] A multivariate analysis of variance was

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[1] Since spontaneous regression contributes to ostcriterion looking scores (Bertenthal et al., 1983; Dannemiller, 1983), it was necessary to assess the magnitude of this artifact and partial it out of the looking scores. The technique for accomplishing these objectives is described in detail by Bertenthal et al. (1983). In brief, a linear regression analysis was computed between looking scores on the last two habituation and first two postcriterion trials for infants (lag infants) continuing to see the familiar stimulus on the first two postcriterion trials. The results of this analysis were used in a regression equation to provide an assessment of the relative contribution of spontaneous regression to each nonlag baby's looking scores on postcriterion trials. This contribution was then partialed from the looking scores of nonlag infants shown the test stimulus on the first two postcriterion trials. Additional tests revealed that the artifactual increase in looking times was limited to the first two postcriterion trials. Accordingly, the looking times for the lag infants were used without any correction.

used to test whether or not infants showed response recovery. The between-subjects variables included Age (3 or 5 months), Condition (kinematic or static), and Order (upright–inverted or vice versa) and the repeated measure was Response Recovery (familiar vs novel stimulus).

As can be observed in Fig. 2, infants showed a significant amount of response recovery to the novel stimulus $F(1, 56) = 5.76$, $p = .02$, but this recovery also showed a marginally significant interaction with condition, $F(1, 56) = 3.45$, $p = .07$. An analysis of the simple effects revealed that infants shown the two kinematic displays demonstrated significant response recovery, $F(1, 56) = 10.41$, $p = .002$, while infants shown the two static displays did not, $F(1, 56) = .11$, $p = .73$. Response recovery was not found to interact with age or order.

Since infants may look longer at moving displays than at static displays (e.g., Volkman & Dobson, 1976), it was necessary to evaluate this possibility for the present study; otherwise it could be argued that differential effects in response recovery were a function of differences in encoding time rather than differences in discriminability. This issue was tested by examining whether Age, Condition, or Order varied systematically with either number of trials to criterion or total duration of looking during

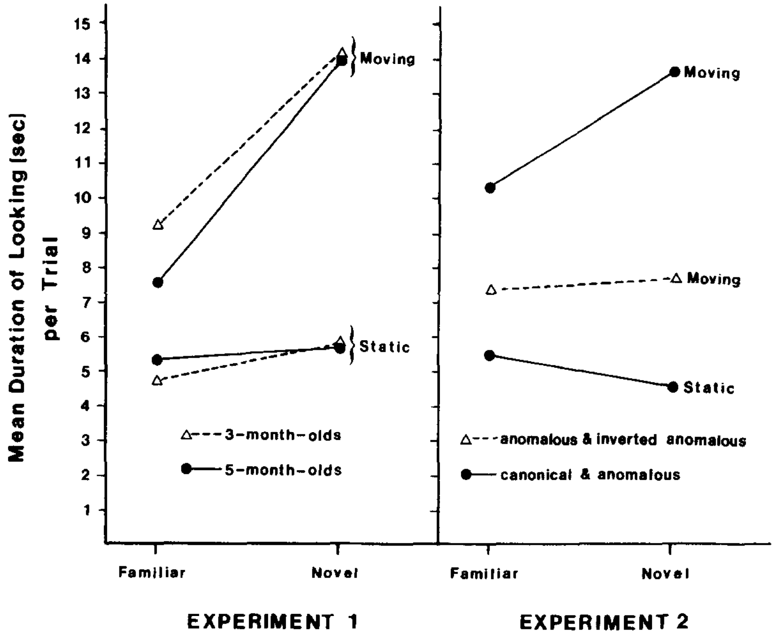

FIG. 2. Mean duration of looking at the novel stimulus on the two test trials and at the familiar stimulus on the preceding two trials as a function of age and condition.

habituation trials in two separate analyses of variance. Neither of these analyses, however, revealed any significant effects.[2]

The preceding results are noteworthy for a number of reasons. First, they demonstrate that point-light displays involving biomechanical motion can be used for successfully probing the visual competence of babies. Second, the finding that the kinematic displays were discriminated supports the notion that these displays were not viewed as merely unrelated swarms of randomly moving point-lights. Third, the failure of infants to discriminate the static displays indicates that the basis for discrimination in the moving displays was not due to a sensitivity to discontinuous changes in the topographic relations of these complex arrays of point-lights. Interestingly, infants have shown such sensitivity to much simpler static point-light arrangements (Haith, Goodman, Goodwyn, & Montgomery, 1982; Milewski, 1979). Finally, and most importantly, these results provide preliminary support for the possibility that infants are sensitive to configural relations revealed through motion.

EXPERIMENT 2: CANONICAL AND ANOMALOUS WALKER DISPLAYS

Although the preceding results are consistent with the idea that infants are sensitive to structure revealed through motion, they are far from definitive since these findings are also consistent with a number of other possible interpretations. One possibility is that infants detected the different absolute movements (180° phase and tilt differences) in the two moving displays. A second is that infants noticed that the absolute amount of motion in different portions of the upright vs inverted walker displays was different. If, for example, the babies attended to only the bottom third of the display, then different amounts of motion would be observed in the two moving conditions. A third possibility derives from our decision to use only one static image from the step cycle for testing discrimination of the static stimuli. It could be argued that this test seriously underestimates the amount of information available in a walker translating across the monitor. The second experiment tested these alternatives by assessing infants' sensitivity to various combinations of a "treadmill" and an "anomalous" walker.

METHOD

Subjects

The final sample consisted of 36 twenty-week-old infants (X = 19.7 weeks, SD = 8.9 days) selected in the same fashion as babies used in

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[2] Since it is somewhat surprising that there was no difference between static and moving displays, we present here the relevant means and statistical tests. A comparison between the two conditions on total duration of looking during habituation revealed a modest difference (X's = 123.6 and 95.6 sec for moving and static displays, respectively) that was not significant, $F(1, 60) = 1.80$, $p = .19$. The second comparison involving number of trials to criterion revealed absolutely no difference between the conditions (X's = 8.6 and 8.6 trials for moving and static displays, respectively).

Experiment 1. An additional 17 infants failed to complete testing due to distress or fussiness.

Stimuli

Two different configurations of point-lights were used in this experiment. The first corresponded to a treadmill (or canonical) walker, which was identical to the previously described translating walker except that most of the common motion was removed. Thus, this particular stimulus always remained in the middle of the screen. The second was an anomalous version of the treadmill walker and is depicted in Fig. 1C. As can be seen, the anomalous walker also consisted of 11 point-lights moving with exactly the same motions as the treadmill walker; however, the relative location of each point-light was scrambled such that the perception of this event to an adult suggests little more than a cyclically moving swarm of bees (Cutting, 1981).

Design

Infants were randomly assigned to six groups with the restriction that all groups contain an equal number of babies. Two groups were shown moving displays of the treadmill and anomalous walker with order of presentation counterbalanced. Here, the absolute motions of the two events are the same but figural coherence is much easier to extract from the treadmill version (Bertenthal & Proffitt, 1983). This comparison thus provides a direct test of infant sensitivity to structure revealed through motion while avoiding the previous confound of different absolute motions appearing in the two stimulus displays.

The second two groups were presented with two versions of the anomalous walker with order of presentation again counterbalanced. One stimulus was similar to the previously described anomalous walker while the second corresponded to a mirror inverted version of the first. Since these two stimuli did not differ significantly in figural coherence but did contain different distributions of absolute motion, they were well designed to test infant sensitivity to differential amounts of motion in delimited portions of the display.

The final two groups were presented with sets of three static images from each of the two stimuli used by the first two groups. A different static image was presented on each of three consecutive trials to better control for nonspecific static cues in the moving displays that may have been responsible for discrimination. Each static stimulus was chosen to show the walker in one of three consecutive phases of the two-step cycle and the order of presentation preserved the natural occurrence of this cycle. As with the groups viewing the moving displays, these last two groups were differentiated by whether they saw the treadmill walker as the familiar or as the novel stimulus.

A partial lag design was again used for testing infant discrimination of the stimulus displays. (An absolute criterion was required for five babies in this experiment.) The apparatus and procedure were the same as described in the first experiment. Reliability of the scoring procedure was again very high, $r(9) = .96$. The mean difference between the scores was .46 sec.

RESULTS AND DISCUSSION

The first analysis revealed that total duration of looking during habituation varied as a function of condition, $F(2, 30) = 7.10$, $p = .003$. Duration of looking in the static condition ($X = 46.7$ sec) was significantly shorter than the looking times in the moving canonical–anomalous condition ($X = 118.0$ sec), $F(1, 30) = 12.10$, $p = .002$, and the same was true for the comparison with the moving upright anomalous–inverted anomalous condition ($X = 108.7$ sec), $F(1, 30) = 9.14$, $p = .005$. Since the existence of these differences would confound response recovery with encoding time, all subsequent analyses were designed as analyses of covariance with total duration of looking during habituation as the covariate. The advantage of this particular analysis is that it partials out the contribution of differential looking time during habituation from the recovery scores.

Discrimination was again assessed by comparing mean duration of looking on the two test trials with mean duration of looking on the last two familiar trials. (As before, the contribution of spontaneous regression was partialed out of the recovery scores of those infants presented with the novel stimulus on the first two postcriterion trials). A multivariate analysis of variance was used to test response recovery. Condition (moving canonical–anomalous, moving upright anomalous–inverted anomalous, or static canonical–anomalous) and Order were the between-subjects variables while Response Recovery was the repeated measure and total duration of looking on habituation trials served as the covariate.

The right hand panel of Fig. 2 depicts the response recovery for each group. As evident from this figure, there was a significant effect for response recovery, $F(1, 29) = 8.73$, $p = .006$, that also interacted with condition, $F(2, 29) = 3.49$, $p = .04$. This interaction occurred because infants discriminated the moving canonical vs anomalous displays, $F(1, 29) = 10.90$, $p = .01$, but did not discriminate the static canonical vs anomalous displays, $F(1, 29) = 1.64$, $p = .21$, nor the moving upright vs inverted anomalous displays $F(1, 29) = 0.62$, $p = .44$. Planned comparisons indicated that the differences between the first condition and each of the latter two were statistically reliable $F(1, 29) = 12.25$, $p = .002$ and $\mathrm{F}(1, 29) = 18.06$, $p = .001$ for comparisons with the static condition and anomalous condition, respectively. Order of presentation of the stimulus displays did not interact with response recovery.

In sum, infants were not sensitive to differences in the absolute motions of individual or groups of point-lights; furthermore, they were not demonstrably sensitive to various forms of static information available in these moving displays. In regard to this latter point, it should be noted that this finding cannot be simply attributed to less encoding of the static displays since we attempted to eliminate any effect of differential encoding time on discrimination performance by partialing out of the relevant analyses duration of looking on precriterion trials. Furthermore, the correlation between response recovery and duration of looking showed a marginally negative trend, $r(35) = -.23, p = .09$, indicating that differences in encoding time could not have produced the observed pattern of results.

The most parsimonious interpretation for the preceding results is that infants can extract invariant structure from moving point-light displays of biomechanical motions. Significantly, this sensitivity to configural relations was manifested even though the stimulus displays did not include any common motion. It is therefore concluded that infants, like adults, are able to derive figural coherence from the relative motions alone.

GENERAL DISCUSSION

Considering the complexity of the moving point-light displays used in these experiments, the finding that infants detected structure is impressive. Still, the results from these experiments provide us with less than a complete picture of what structure was detected by the infant. As discussed in the introduction, figural coherence is not an all or none affair but instead depends upon which relative motions are extracted. Furthermore, even if all relative motions are extracted as a perceptual whole, these biomechanical displays may be interpreted in a number of different ways.

As a guide to our future research, we have delimited five levels of interpretation that could, in principle, be extracted from point-light walker displays. These levels are presented below in an order coinciding with the number of constraints specifying what could be seen in these displays. It must be stated that the purpose of this framework is not to suggest that the developing sensitivity to motion information progresses from one level to the next. Rather, the framework is a heuristic that we developed in order to guide our research toward a more precise assessment of what infants perceive in these displays. In essence, it seemed to us that future investigations of infant sensitivity to biomechanical motions should be guided by a specification of all of the interpretations that might be extracted from these events. In delimiting interpretations, we found that they could be classified into five levels. The first three levels consist of *kinematic* interpretations since the available information is defined exclusively in terms of the motions of the point-lights. The remaining two levels involve *kinetic* interpretations since the visual information is subject to additional constraints derived from the physical laws governing the motions of masses.

Levels of Interpretation

Individual motions. It is possible for the observer to perceive something more than arrays of unrelated and randomly moving dots, but still not perceive any figural connectivity between individual point-lights. Specifically, the orderly motions of the individual lights may be perceived, but not the relations among them. (This level is included for the purpose of completeness even though our results indicate that individual motions were not detected by the infants.) If point-light walker displays are so perceived, then the absolute motions of the individual dots specify the structure extracted from the event (cf. Cutting & Proffitt, 1982). Once figural coherence occurs, the discrimination of individual motions is obscured. Consider, for example, the phenomenon of point-lights attached to the rim of a rolling wheel. If no figural coherence is extracted from this event, then the cycloidal motions of each light are seen, whereas perceiving the event as a figural whole causes an analysis of these cycloidal motions into common linear and relative rotary motion components. Likewise, with point-light walker displays, the absolute motions of each point-light are detected if no figural organization is extracted. In this case, an ankle light, for example, is seen to have a very complex motion path rather than the simple pendular motion typically seen by adults.

Organization of figural coherence. As invariant, topographical relations between moving points are extracted from relative motions, figural coherence is achieved. In the phenomenon involving point-lights on a rolling wheel, the relative motions specify, in their radii of rotation, the wheel's configuration. In such complex phenomena as point-light walker displays, and even point-light rolling wheels, there are an indefinite number of possible configurations that could be perceived depending upon what relative motions are extracted. The following are but a few interpretations that we have seen in the walker stimuli: three-dimensional configurations rotating or oscillating in the horizontal plane; substructures, such as the upper and lower body, that may be connected or remain apart; wrist and hip point-lights that are perceptually grouped; and a host of other configurations that are consistent with the morphology of the human form but do not capture its holistic character. Thus, even within this one level there exists a range of configurations that might be perceived.

Although relative motions could have been extracted from as few as two lights in these displays, we think that this was not the case for the infants in our studies. Relative motions among clusters of two or three lights are easily seen by adults in the anomalous walker. Yet, infants failed to demonstrate discrimination between the upright and inverted version of this display, whereas the inverted canonical walker was discriminated from its upright version. It appears therefore that the basis for this discrimination involved the extraction of relative motions from more than two or three point-lights.

Biomechanically appropriate motions. It is also possible to perceive in point-light walker displays a nesting of pendular and twisting motions (Cutting & Proffitt, 1981). The relative twisting motions of the hip and shoulder lights are first extracted relative to a center of moment within the torso. This unmarked center specifies the perceived common motion path of the walker's translation. Upper and lower body components are seen as having pendular motions through a logically ordered, hierachical extraction of relative motions. For example, once the hip's motion has been extracted, this point serves as a static center for the relative pendular motion seen in the knee. Having extracted the knee's motion, the perceptual system defines this point as a static center for specifying the relative rotation of the ankle. The upper body's motions are seen through a similar hierarchical process of information extraction. The twisting and pendular motions seen by adults describe the internal dynamics of human biomechanical structure. More generally, nested pendular motions may serve as a defining characteristic of biomechanical motion, and thus observers who are sensitive to this level of interpretation may respond to such motion in a categorical fashion.

Causal (kinetic) relations. Adults not only see the relative motions appropriate for the human structure, but they also see these relative motions as causing the support and locomotion of the organized form. Thus, the motions of component parts are seen to be caused by motions of other parts, and moreover, the motion of the whole is seen to be produced by these coordinated relative motions. Runeson and Frykholm (1981) demonstrated adult sensitivity to kinetic relations revealed in motions by showing that their observers could determine relative weights by viewing point-light walkers lifting a point-light box varying in heaviness. Thus, it is possible for the observer to be sensitive to the causal relations, as well as the motion and figural relations, revealed in the point-light walker displays.

Identification of human form. Finally, these point-light walker displays could be identified as locomoting persons. The specific understanding accompanying identification depends upon the experience of the observer.

Overview

It is apparent that our results neither demonstrate nor refute the possibility of infant sensitivity at the level of identification, nor for that matter at the preceding two levels, i.e., causal relations or biomechanically appropriate motions. We do, however, feel that these studies clearly demonstrate infant sensitivity at the level of figural coherence. Whether or not these displays were actually detected as figural wholes or segmented into smaller substructures (though still encompassing too many point-lights to make possible the detection of absolute motions) remains open to further investigation.

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