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ABSTRACT

An experiment was performed to show that infants perceive auditory and visual stimuli within a common space and that they perceive the sound as an attribute of the visual object. Subjects were 22 infants aged 3 to 5 months. Each infant was presented with a toy that moved in a small arc from side to side of a small window at the rate of one arc per second. The back-and-fourth movements occurred in synchrony with a chime. The sound was wired either to come from the front window where the toy was located or from 90 degrees to the side behind a cloth. Two dependent measures were recorded: (1) limb and body movement, and (2) visual orientation to the left or right. Infants showed increases in agitated limb and body movement when presented with the chime spatially dislocated from its temporally synchronous visual source (the toy). Agitation was not shown when the chime and the toy were presented together in space. Infants who demonstrated adequate processing of the auditory information through accurate orientation behavior were most likely to show increased agitation. (Author/BRT)

INTEGRATION OF AUDITORY AND VISUAL SPATIAL INFORMATION DURING EARLY INFANCY [1]

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The research that I shall present today is aimed at exploring the infant's experience of an event which is composed of both auditory and visual features. The origins of man's ability to organize information from several quite different receptor systems into a unified perceptual world of objects and events, has long interested students of human nature. We do not experience visual, auditory, and tactile sensations as disconnected inputs. Instead we experience organized objects or events which have multimodal attributes, such as a dog who is soft and black and barks or, in Bishop Berkeley's classic example, a solid, shiny, clattering coach.

However, until recently psychologists have predominantly accepted Bishop Berkeley's (1709) view that the various perceptual modalities are structured initially as separate systems (e.g. Birch and Lefford, 1967; Pick, Pick, and Klein, 1967). Focusing his analysis particularly on spatial cues, he proposed that it is only through repeated experience of an association between crossmodal inputs that information comes to be correlated across modes.

Piaget is the developmental theorist most identified with this viewpoint (Piaget, 1952; Piaget, 1954). He describes early perceptual development as a process involving the gradual reciprocal assimilation of spatial schemas which are initially modality specific.

Others have disputed this theory and proposed that structures allowing for the spatial coordination of information from different modalities are

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a part of the human perceptual system. Among developmentalists, Bower (1972) has presented evidence that within two weeks after birth infants expect tactual cues as to size and distance of objects to covary with visual size and distance cues. Bruner and Koslowski (1972) have presented similar findings with pre-reaching infants.

Regarding coordination of visual and auditory information, recent neurophysiological research with lower mammals has shown that bimodal cells exist in the visual cortex of the cat which serve to correlate the spatial locations of concurrent auditory and visual inputs (Murata, Cramer and Bach-Y-Rita, 1965; Fishman and Michael, 1973). However, for the human infant, no conclusive evidence of early integration of auditory and visual spatial information has been provided to date. Even normative data on the development of spatial orientation behavior to auditory cues is meager and inconsistent. Visual orientation to auditory cues is not sufficient in itself, however, to demonstrate integration of visual and auditory perceptual information. Orientation of the head may be guided primarily by an auditory centering mechanism rather than a visual or audio-visual mechanism. Secondly, the presence of an oculomotor response to sound can, at most, indicate that auditory spatial information can be transduced into general directional information to the oculo-motor system. Such a response tells us nothing, however, about the organization of the visual and auditory perceptual processing which follows the motor response. Recent studies of concurrent auditory and visual processing in infants by Donnee (1973), Carpenter (1973) and Cohen (1973) have not directly addressed the issue of integration of spatial information.

Aronson and Rosenbloom (1971) did directly explore the issue of spatial integration by comparing the 4- to 10-week-old infant's response to spatially coincident and spatially separated presentations of mother's face and voice. They concluded that infants expect mother's face and voice to occur together in space and become disturbed if this expectation is violated. This interpretation is not clearly supported, however, due to the use of an unvalidated measure of disturbance, tongue protrusion, and the lack of a counterbalanced presentation order. Thus no comparison is presented in that study which distinguishes a response to the dislocation of sight and sound from a response to any change in the stimulus configuration. In addition, as Bower (1974) has pointed out, agitated behavior to the dislocation may have resulted not from a violation of expectation but from response or processing difficulty generated by the increased spatial complexity of the stimulus. Finally, McGurk and Lewis (1974) have recently reported their failure to replicate the Aronson and Rosenbloom findings with infants of 1 to 7 months of age when using an improved methodological paradigm.

The study I will present today had two aims: first, to replicate the essential features of the Aronson and Rosenbloom study with an improved methodology; second, to investigate Bower's alternative interpretation of response conflict by also monitoring the infant's auditory orientation responses.

METHOD

Twenty-two infants participated in the study, six at 3 months of age, eight at 4 months and eight at 5 months of age.

Request Figure One here

This is a schematic drawing of the experimental situation. Each infant was presented with a toy that moved in a small arc from side to side of the window at the rate of one arc per second. The back-and-forth movements occurred in synchrony with a chime. The sound was wired to issue either from the front window where the toy was located or from 90 degrees to the side from behind a cloth. Sound pressure levels were 70 decibels from both locations. Each subject observed two continuous episodes each of 80 seconds duration, one in which sound and object were collocated at the frontwindow, one in which sound was dislocated 90 degrees to the right. The order of presentation of these two episodes was counterbalanced across subjects. In order to emphasize the temporal relationship between sound occurrence and object movement, object movement with sound occurred during each episode in 8 5-second intervals alternating with 8 5-second intervals of no sound and no movement. Sound location change occurred during the eighth silent interval. In order to determine whether stimulus familiarity is am important factor in the infant's reaction to the spatial dislocation, the amount of prior exposure to the sounding object was also varied. Half of the infants viewed the counterbalanced test presentation after no previous exposure to the object; the other half viewed it after 160 seconds previous exposure to the sounding object.

Two dependent measures were recorded. The first was limb and body movement, shown by Haith, Kessen and Collins (1969) to be an infant behavioral response to an unexpected rule violation. The second behavior monitored was visual orientation to left or right as indexed by a head turn of approximately 30 degrees or more.

RESULTS

Analysis of variance of the movement and the orientation measures yielded the following results.[3]

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[3]Since within-group variances of both the movement and looking scores were found to be a linear function of group means, all scores were subjected to a square-root transformation before data analysis.

Request Table One here

Limb and body movement of the infants was more pronounced during the dislocation episode than during the collocated episode, regardless of the order of presentation ($F(1,10)=5.385$; $p<.043$). This effect was most evident during the second 40-second period of the episode ($F(1,10)=5.619$; $p<.040$). Neither the age of the infants nor the amount of prior exposure to the sounding object reliably affected the amount of limb and body movement.

Request Figure Two here

With regard to the orientation data, infants looked away from the forward object very infrequently. However, looking away to the right occurred more often during the first 40 seconds that the sound issued from the right than during the comparable period when the sound issued from the front. This effect was true only for the 4- and 5-month old infants, however. The 3-month-old infants, in contrast, looked to the right less during the dislocation episode (Age X Episode: $F(2,10)=6.069$; $p<.019$). Left looking was not related to any of the experimental factors. McGurk and Lewis, in their study, also reported accurate auditory orientation, to both right and left, by their 4- and 7-month-old subjects but not by their 1-month-old subjects.

An analysis of the relationship between looking behavior and movement increase on a subject-by-subject basis revealed that the infants who oriented at least once toward the dislocated sound were the infants most likely to show an increase in agitated movement during the dislocation episode (Fisher's Exact $P=.026$). Looking to the left, however, was not related to movement increase (Fisher's Exact $P=.490$) (See Table 2).

DISCUSSION

What conclusions can we draw from this pattern of results? The major finding was that agitated limb and body movement was more pronounced during the dislocation episode. This increased agitation cannot be attributed to stimulus change per se, since change of the sound from the dislocated to the normal position produced quieting.

Could the agitated behavior have resulted from a response conflict due to two concurrent spatial sources of input? Presumably, if this were the case, one would expect agitation to be most pronounced in the younger or the non-orienting subjects and to decline as response capabilities improve. This was not the case. Instead, it is the more mature, accurately orienting infants who show the most reliable increases in agitated movement. Response conflict might still be a credible factor if it could be shown that the agitation preceded auditory orientation over the course of the experimental trials. This was not the case. As mentioned earlier, right looking occurred most reliably during the first 40-second period while movement increase occurred most reliably during the second 40-second period. It should also be noted that when both episodes are considered left looking occurred as frequently as right looking yet left looking shows no relationship to movement increase. Response conflict alone then seems unlikely to be a determining factor causing the movement increases.

Could processing difficulty rather than response difficulty have been a major factor in the movement increases? The points that I have just mentioned also weigh against the processing difficulty hypothesis. The infants who demonstrate their ability to adequately process the bimodal spatial information are the same subjects who show the increases in agitated movement.

As mentioned, the 3-month-old infants did not orient toward the dislocated sound. Thus, one cannot conclude unequivocably that the 3-month-old subjects were coordinating the auditory and visual information. Response conflict, however, can be ruled out as an explanation for the pattern of behavior of the three-month-old infants. Post-session responses to a lateralized sound, in the absence of a competing visual stimulus, were collected from a subsample of 12 infants from the present study and from a larger sample of 90 infants aged 11 to 16 weeks of age. Only 10% of the infants 11-13 weeks of age oriented head and eyes toward the auditory stimulus, while 81% of infants aged 16 weeks did so (X^2_3 = 19.196, $p < .001$). Thus, auditory orientation is not an available competing response for the younger infants.

Slower processing speed, on the other hand, may have influenced the younger infants' responses though apparently with the effect of diminishing, rather than enhancing, the movement response. Of the subgroup of subjects given the orientation post-test, those who failed to orient on the post-test also failed to orient within the experimental session. During the experimental episodes, those non-orienting infants showed marked quieting before beginning to activate motorically, both at the onset of the session and at the change in sound location, whether the change occurred toward or away from the visual stimulus.

In contrast, orienting subjects quieted only to the change toward the stimulus and activated to the change away from the stimulus (Orientation Group X Change Score: $F(2,16) = 6.447$, $p < .009$). This tendency of the less mature infants to quieten to stimulus change suggests that quieting rather than activation is the most likely behavioral reaction to a difficult processing task. Though the non-orienting infants did register the change, they may have had more difficulty processing the stimulus information in the time allowed. The data taken as a whole suggest that the younger infants were processing the visual and auditory information but more slowly than the older infants. Data from longer experimental presentations are needed to evaluate this interpretation.

Some further data support the interpretation that the agitation of the infants results from a rule violation rather than from the physical complexity of the dislocation episode per se. An additional group of 8 4-month old infants were presented with the same procedure with two modifications: (i) no sound was initially associated with the forward object and (ii) when the sound occurred 90 degrees to the right there was also an object on the right. The spatio-temporal information presented was thus equally complex in the 90-degree condition, but no rule violation was involved. Under these circumstances the infants showed a non-significant tendency to decrease, rather than increase limb and body movement ($F(1,6) = 3.569$; $p < .108$).

The disparity between these results and the lack of positive findings by McGurk and Lewis is most likely due to the different dependent variables monitored as indices of infant disquiet. The two significant effects obtained in their study, accurated auditory orientation from 4 months of age and decreased smiling after the dislocation at 4 months of age, support the present conclusions.

The pattern of the data, then, supports the conclusion that (i) the spatio-temporal information presented is being adequately processed by the older infants and that (ii) the agitated movement is occurring in response to this information. Thus, the infants appear to interpret the dislocation according to the following rule: Sounds which occur in temporal synchrony with the movements of a visual object are features of that object and should move in space with that object. The unfamiliarity of the objects presented and the lack of a differential effect of prior exposure suggest that a coordinated auditory-visual percept does not develop through extensive prior experience but is the direct product of a prestructured multimodal perceptual system. On the basis of the present data it is also proposed that the perceptual system is prestructured to attribute a sound to a particular visual source on the basis of temporal synchrony in the occurrence of auditory and visual change. From very early, then, visual and auditory features are <u>not</u> preceived according to spatially separate, modality-specific schemas. Instead, visual and auditory features are perceived within a common spatio-temporal framework as aspects of the same event. The infant experiences a solid, three-dimensional object which chimes.

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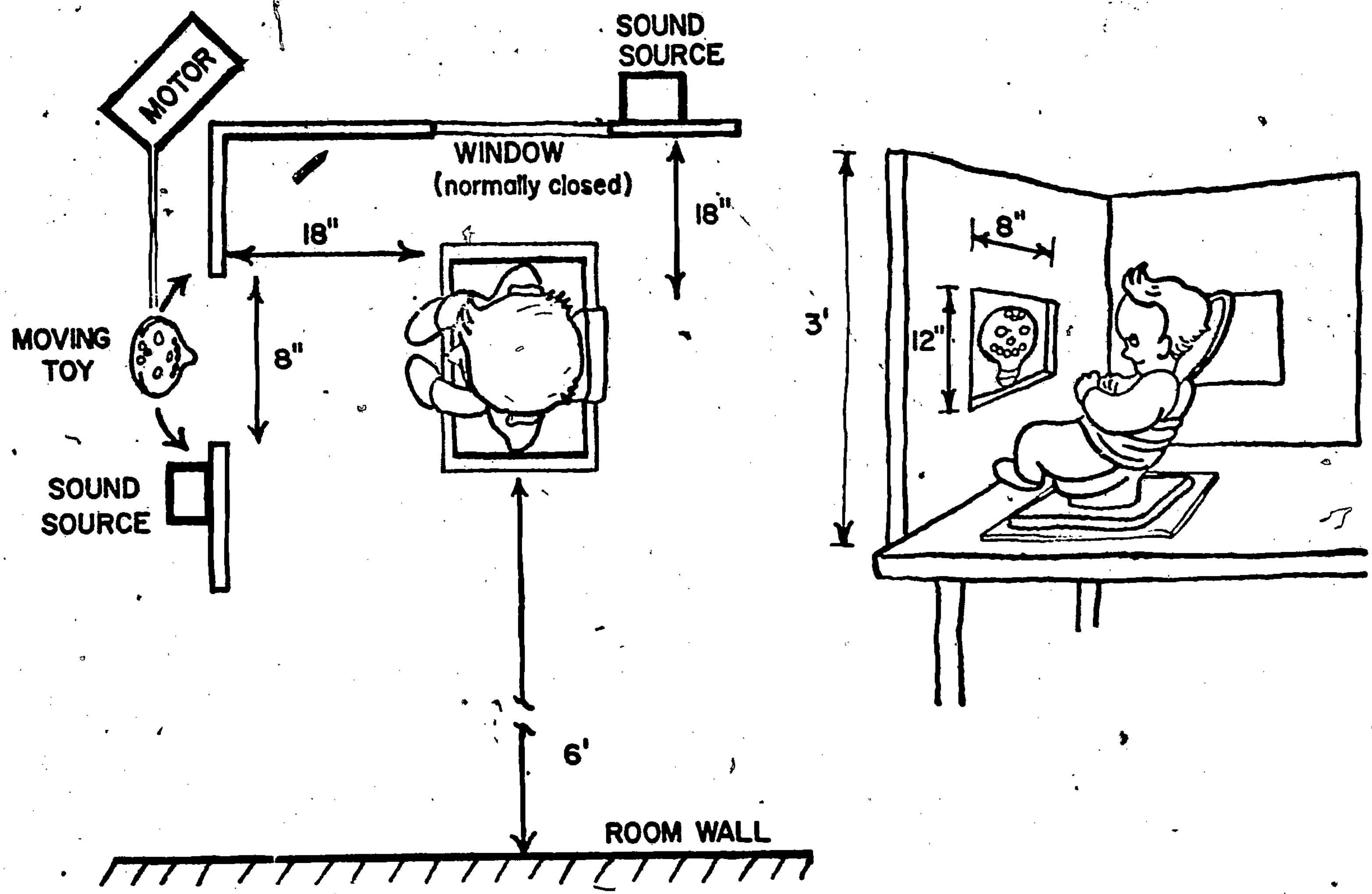

FIGURE 1. Schematic diagram of apparatus for Study I

Table 1. Influence of auditory-visual dislocation on infants' limb and body movements. Sound issues from the front in episode A; from the right in episode B. Each score is the mean number of millimeters of recording pen deflection produced per 5-second interval.

AGE (months)	PRIOR EXPOSURE (secs)	SEQUENCE OF EPISODES	Limb and body movement scores (mms.)	
			EPISODE A	EPISODE B
3	0	A-B	2.375	3.750
		B-A	3.938	5.750
	180	A-B	9.625	12.188
		B-A	9.750	9.250
4	0	A-B	8.250	9.406
		B-A	8.406	10.875
	180	A-B	17.344	28.219
		B-A	9.906	11.500
5	0	A-B	5.219	12.031
		B-A	11.781	16.813
	180	A-B	7.813	14.938
		B-A	5.969	9.938

TABLES 2 A,B

THE RELATIONSHIP BETWEEN RIGHT AND LEFT LOOKING AND INCREASED LIMB MOVEMENT DURING THE DISLOCATION CONDITION: STUDY I

Twelve-Week-Old Infants

Limb Movement During Period Two	Presence of Right or Left Looking During the Dislocation Condition					
	Right Look Present	Right Look Absent		Left Look Present	Left Look Absent	
Greater to Dislocation than Standard	1	3	4	1	3	4
No Greater to Dislocation than Standard	0	2	2	0	2	2
	1	5	6	1	5	6

Fisher's Exact . $p = .667$ for right looking, $p = .667$ for left looking

Seventeen- and Twenty-Two-Week-Old Infants

Limb Movement During Period Two	Presence of Right or Left Looking During the Dislocation Condition					
	Right Look Present	Right Look Absent		Left Look Present	Left Look Absent	
Greater to Dislocation than Standard	8	2	10	4	6	10
No Greater to Dislocation than Standard	1	5	6	2	4	6
	9	7	16	6	10	16

Fisher's Exact $p = .025$ for right looking, $p = .611$ for left looking

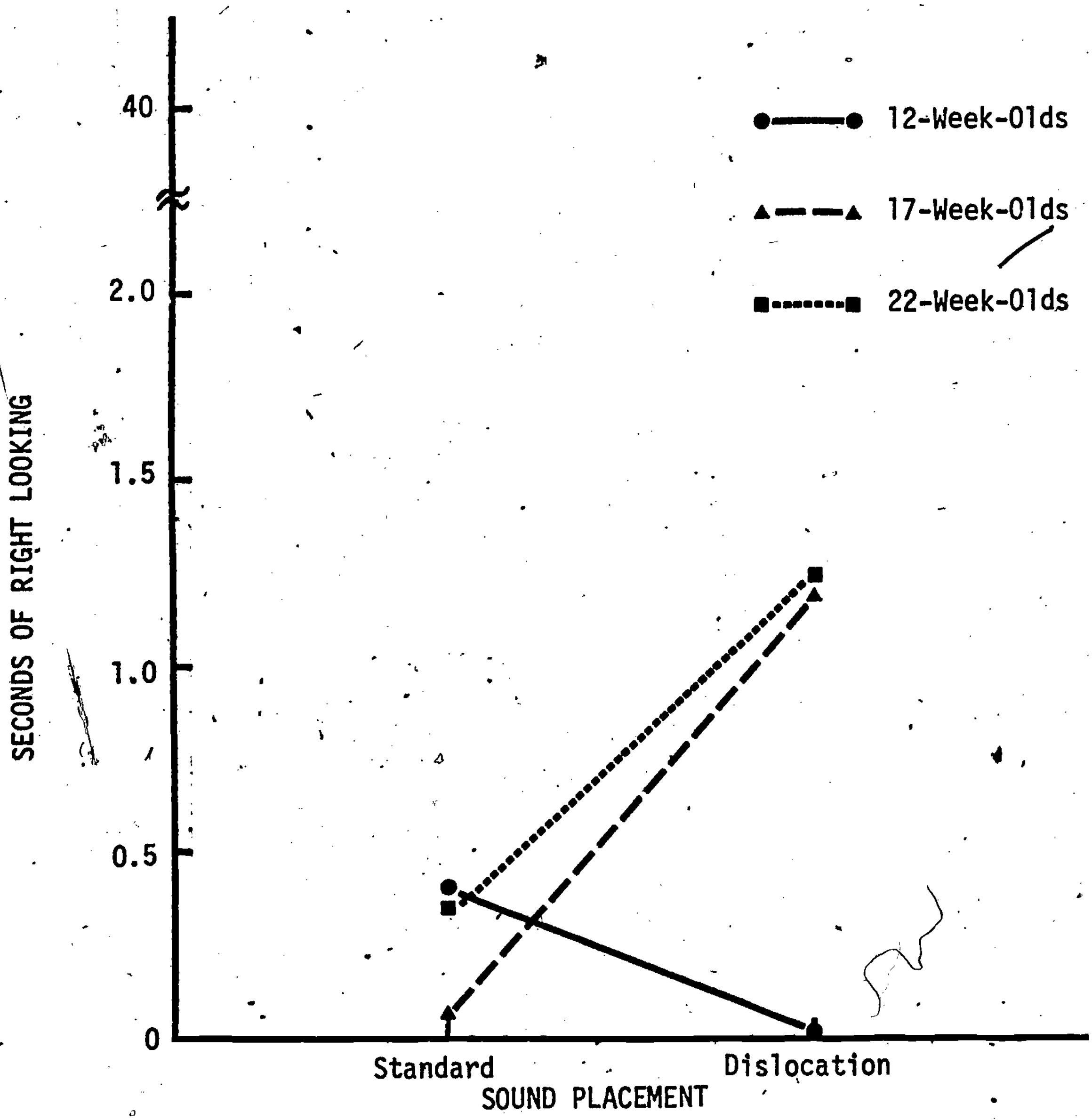

FIGURE 2. Right looking during Period One as a function of sound placement and age: Study I