

2 . 1

AUDITORY-VISUAL INTEGRATION OF TEMPORAL  
RELATIONS IN INFANTS

by

GARY KEITH HUMPHREY

B.A.(Hons.) University of New Brunswick, 1972

M.A. University of British Columbia, 1976

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF  
THE REQUIREMENTS FOR THE DEGREE OF  
DOCTOR OF PHILOSOPHY

in

THE FACULTY OF GRADUATE STUDIES  
(Department of Psychology)

We accept this thesis as conforming  
to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

November, 1979

© Gary Keith Humphrey, 1979

In presenting this thesis in partial fulfilment of the requirements for an advanced degree at the University of British Columbia, I agree that the Library shall make it freely available for reference and study.

I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by the Head of my Department or by his representatives. It is understood that copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Department of Psychology

The University of British Columbia  
2075 Wesbrook Place  
Vancouver, Canada  
V6T 1W5

Date

Nov. 13, 1979

## ABSTRACT

Three experiments examined auditory-visual integration of temporal relations by infants. In the first experiment infants of 3, 6 and 10 months of age were placed midway between two flashing visual displays. Tones, temporally synchronized to one of the visual displays, emanated from concealed speakers placed midway between the visual displays directly in front of the infants. The visual displays, and corresponding tones differed in temporal rate by a factor of four. No evidence was found for differential looking to the sound-specified visual pattern in any of the three age levels tested. The 3-month-olds showed a strong right-looking bias regardless of visual pattern or temporal rate of the tone, while the 10-month-olds preferred to look at the fast visual pattern regardless of position or tone rate. Both of these biases impaired the effectiveness of the simultaneous presentation paradigm to detect differential looking related to auditory-visual synchrony.

Experiments II and III used an habituation methodology which eliminated any effects of position and rate bias. Only 4-month-old infants were tested. In each experiment, one group of infants was first presented with temporally synchronous auditory and visual signals during habituation trials and then nonsynchronous signals during recovery trials. Two other groups of infants, one in each experiment, received the opposite sequence. In Experiment II the auditory and visual signals were spatially congruous, but they were separated by 90° in Experiment III. Since the pulse rate of the visual stimuli was changed for the nonsynchronous trials a control group was tested which received only the light during habituation and recovery trials. Both groups

initially presented with synchronous signals showed habituation and recovery. Neither group presented with nonsynchronous stimuli during habituation trials demonstrated recovery and only the group with the spatially separated sources habituated. The results suggest that 4-month-old infants are able to coordinate the temporal relations between auditory and visual signals.

## TABLE OF CONTENTS

	Page
Abstract . . . . .	ii
List of Tables . . . . .	v
List of Figures . . . . .	vi
Acknowledgements . . . . .	vii
Introduction . . . . .	1
Experiment I . . . . .	23
Method . . . . .	24
Results and Discussion . . . . .	32
Experiment II . . . . .	35
Method . . . . .	36
Results and Discussion . . . . .	40
Experiment III . . . . .	43
Method . . . . .	43
Results and Discussion . . . . .	44
General Discussion . . . . .	47
Footnotes . . . . .	58
Reference Notes . . . . .	60
References . . . . .	61
Appendix A . . . . .	66
Appendix B . . . . .	68

## LIST OF TABLES

Table		Page
I	Types of Amodal Correspondence . . . . .	3

## LIST OF FIGURES

Figure		Page
1	Model of sensory integration resulting from the convergence of specific sensory channels on the association cortex . . . . .	6
2	Three stages of sensory differentiation according to Bower (1974a) . . . . .	9
3	Schematic diagram of display for Experiment I . . . . .	25
4	Pulse patterns used in Experiment I . . . . .	27
5	Schematic diagram of laboratory arrangement . . . . .	28
6	Proportion of looking to right and left . . . . .	30
7	Proportion of looking to fast and slow visual displays . . . . .	31
8	Schematic diagram of display for Experiment II . . . . .	37
9	Pulse patterns used in Experiments II & III . . . . .	39
10	Mean duration of fixation per trial for groups $S_1$ and $NS_1$ . . . . .	41
11	Mean duration of fixation per trial for groups $S_2$ and $NS_2$ . . . . .	45

## ACKNOWLEDGEMENTS

I would like to give special thanks to Dr. Richard C. Tees and Janet Werker for giving so much assistance, encouragement and moral support throughout the project. Thanks are also due to Dr. Elinor Ames and Dr. Tannis Williams for their willing assistance during critical stages of this project. Dr. Michael Chandler and Dr. John Gilbert must be thanked for serving as members of my committee. My appreciation to Janet Werker and Mary-Catherine Rooney for their attentive infant observations. I am indebted to Mary Ann King for her relentless, intelligent and good-natured skepticism concerning many of my ideas about infant perception. Brian Moorehead designed and built the pulse generator and display apparatus. Thanks to Ruth Allan for typing the manuscript. Finally, I must thank the many infants and parents who participated in the experiments.

Much of this research was made possible by grants from the NSERC (PA-0179) and SSHRC(410-78-0222) of Canada to Richard C. Tees.

This thesis is dedicated to the memory of my mother and father.

## INTRODUCTION

In the course of an individual's interactions with the normal environment many events occur which result in stimulation of more than one sense. Such multimodal stimulation impinging on different sensory systems is, in some manner, coordinated leading to a unified perceptual experience of objects and events. It is not clear how and at what stage in development the ability to integrate sensory information occurs. Although several theories of perceptual and cognitive development contain speculations on the nature and development of sensory integration, systematic empirical evidence is lacking, particularly with respect to the capacity of infants. The focus of the present investigation was the processing of bimodal information during infancy. In particular, the research explored the influence of temporal synchrony and nonsynchrony of auditory and visual stimuli on infants' coordination of these stimuli. Some effects of spatial congruity and incongruity between the auditory and visual stimuli were also examined.

Although there are numerous interrelationships between the senses in general<sup>1</sup> and between audition and vision in particular<sup>2</sup>, those of most importance to the present report have been referred to as intersensory equivalence (Turkewitz & McGuire, 1978; Lawson, 1979). Two types of intersensory equivalence have been elaborated. The most common conception of intersensory equivalence is that a property specified in one modality is the same as that specified by another modality. The properties are physically identical but can be perceived through more than one modality. For example, a temporal pattern can be presented auditorily, visually and tactually. Since the same temporal pattern can be presented to each of these senses it is possible that the

temporal pattern can be abstracted regardless of the mode of specification. Such properties have been called "amodal", defined as "higher order relational stimulation which is not specific to a modality (Gibson, 1969; p. 219)." Amodal information can include a number of stimulus dimensions including shape, texture, movement, duration, location and number. Some of the most general types of amodal relations are depicted in Table I. Recently, it has been suggested (Mendelson, Note 1; Spelke, Note 2) that the common structural or amodal properties of human environments influence perceptual activity in very young infants. Furthermore, activity prompted by amodal features may be a foundation for learning more arbitrary relations such as those between particular sounds and particular visual events (eg., a mother's face and voice). This relates directly to the second type of intersensory equivalence.

Intersensory equivalence has also been used to refer to the perception that qualitatively different properties of an object can be used interchangeably to identify the object (Lawson, 1979; Turkewitz & McGuire, 1978). For example, as mentioned above, a face and a voice can independently identify a particular person. In this case the information identifies a common source but the attributes are physically very different. Thus two types of intersensory equivalence can be distinguished; one based on the common structural characteristics of information received through different modalities, the other in which qualitatively different kinds of information specify a common source. Both types of equivalence have long been a topic for theoretical speculation and more recently a subject for empirical research.

Philosophers and scientists from at least the time of Aristotle have speculated on the interrelations of the sensory systems (Marks, 1978). Aristotle developed the notion of a "common sense" which

Table I  
Types of Amodal Correspondences  
(From Mendelson, Note 1)

1. VALUES ALONG CONTINUA
  - a. Time - Onset - Independent of Space
  - b. Space - Position - Independent of Time
  - c. Intensity - Independent of Time and Space
2. DISCONTINUITIES
  - a. Temporal Events - Duration
  - b. Spatial Events - Location
  - c. Modulation of Intensity - In Time and/or Space
3. PATTERNS OF DISCONTINUITY
  - a. Rhythm - Pattern over Time
  - b. Form - Pattern over Space
  - c. Movement - Pattern over Time and Space
4. RATES OF PATTERN
  - a. Tempo - Rate over Time
  - b. Texture - Rate over Space
  - c. Speed - Rate over Time and Space
5. CHANGES OF RATE
  - a. Change of Tempo - Change over Time
  - b. Texture Gradients - Change over Space
  - c. Acceleration - Change over Time and Space

appreciated the "common sensibles". The common sensibles were those properties of sensation representing general aspects of the world which could be apprehended by any of the senses. These common sensibles included motion, rest, number, form, magnitude and unity. The common sense occupied a higher "level" than the specific senses and was sensitive to qualities like number or shape while the specific senses were responsive to properties like colour or odour. The distinction between the common sense and the specific senses is similar to the old distinction between perception and sensation. In terms of stimulus description the common sensibles bear an obvious similarity to amodal information.

More recently the interest of philosophers in intersensory integration had led them to ask whether a person born blind and restored to sight in adulthood would be able to name forms presented visually which had previously been known only by touch<sup>3</sup>. Successful naming would imply visual discrimination of the forms and the ability to relate previous tactile impressions or representations to the visual impression. Although modern research on selective rearing, perceptual deprivation and cataract operations has shown that this question was somewhat naive in its implicit assumptions, it was one of the first questions asked about intersensory equivalence which could lead to empirical investigations. Furthermore, it was concerned with the manner in which our abilities to perceive the world develop.

Two general approaches to the development of intermodal relationships have been emphasized (McGurk & MacDonald, 1978). One approach describes intersensory development, both phylogenetically and ontogenetically, as increasing integration of initially separate sensory modalities. According to this position separate sensory systems maximally responsive to different types of energy evolved at an early stage in phylogeny.

The different phyletic levels exhibit different degrees of organization among each of the sensory systems. As the evolutionary scale is ascended an increase in the capacity for intersensory integration is thought to occur. However, as McGurk and MacDonald (1978) have observed, comparative evidence supportive of this position is hard to find. In general, though, it does seem that there is increasing cortical convergence of different afferent systems. As you ascend the phylogenetic scale increasingly more neural tissue potentially subserves intersensory relations, particularly in the cerebral cortex.

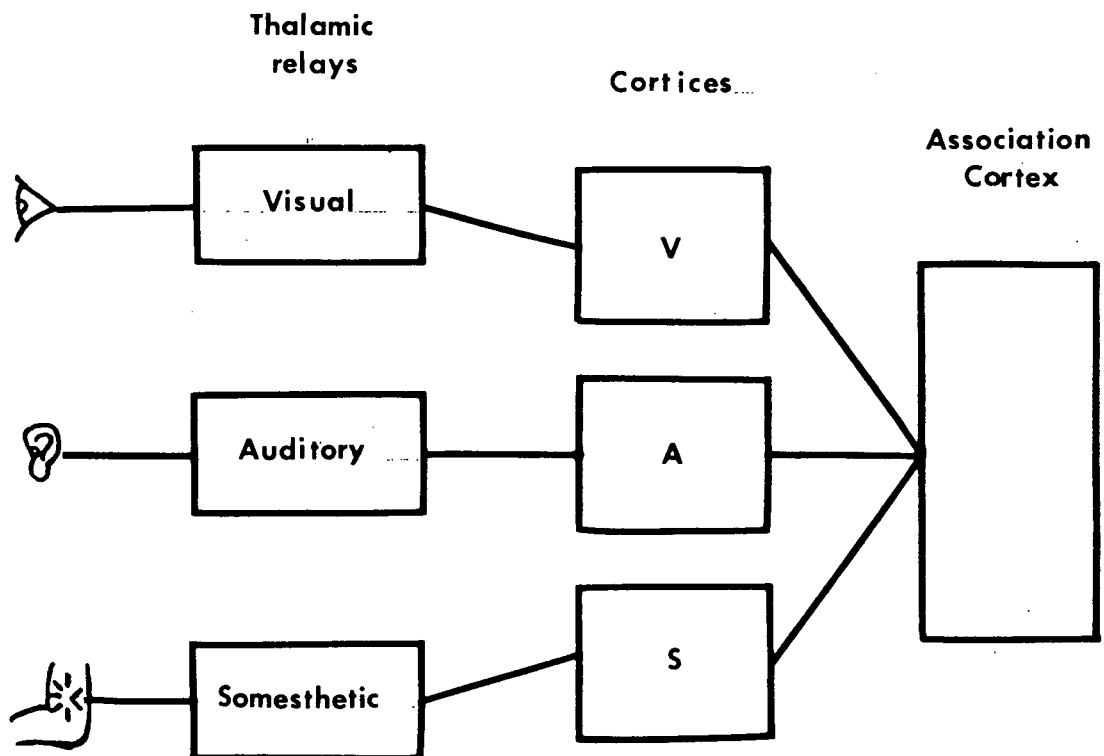
Variants of this view have been influential in the recent history of psychology. For instance Diamond and Hall (1969) have argued that the supposed expansion of the association cortex interposed between the sensory and motor zones fit the view prevailing in psychology in the early twentieth century. According to this view integration between the senses required a neurological process that relied upon having the neural counterpart of modality - specific sensation available. Two premises were important: 1) specific sensory channels were somehow represented in the brain, and 2) that in order for complex behavioural and cognitive tasks to be accomplished, activity of sensory areas must be associated in some other areas of the brain (Diamond & Hall, 1969, p. 252).

The simple model envisioned is presented in Figure 1.

In recent psychological theorizing Birch and Lefford (1963; 1967) have put forward a similar view which draws on parallels between phylogeny and ontogeny. They have stated that:

as one ascends in the vertebrate series from fish to man the unimodal sensory control of behavior comes to be superseded by multimodal and intersensory control mechanisms (1963, p. 3).

Their position regarding perceptual development in humans has been stated as follows:



**Fig.1. Model of sensory integration resulting from the convergence of specific sensory channels on the association cortex.**

information derived from proximoceptive input is dominant in controlling the actions of infants. However, with age, proximoception comes to be increasingly replaced by teloreceptor control systems. . . . Simultaneously with the emergence of teloreceptor preeminence, a second mechanism of input organization seems to be evolving. It consists of the increasing tendency of the separate sensory modalities to integrate with one another, and of organized and directed action to be subserved by intersensory or multimodal patterning rather than unimodal patterning. (1967, p. 5-6)

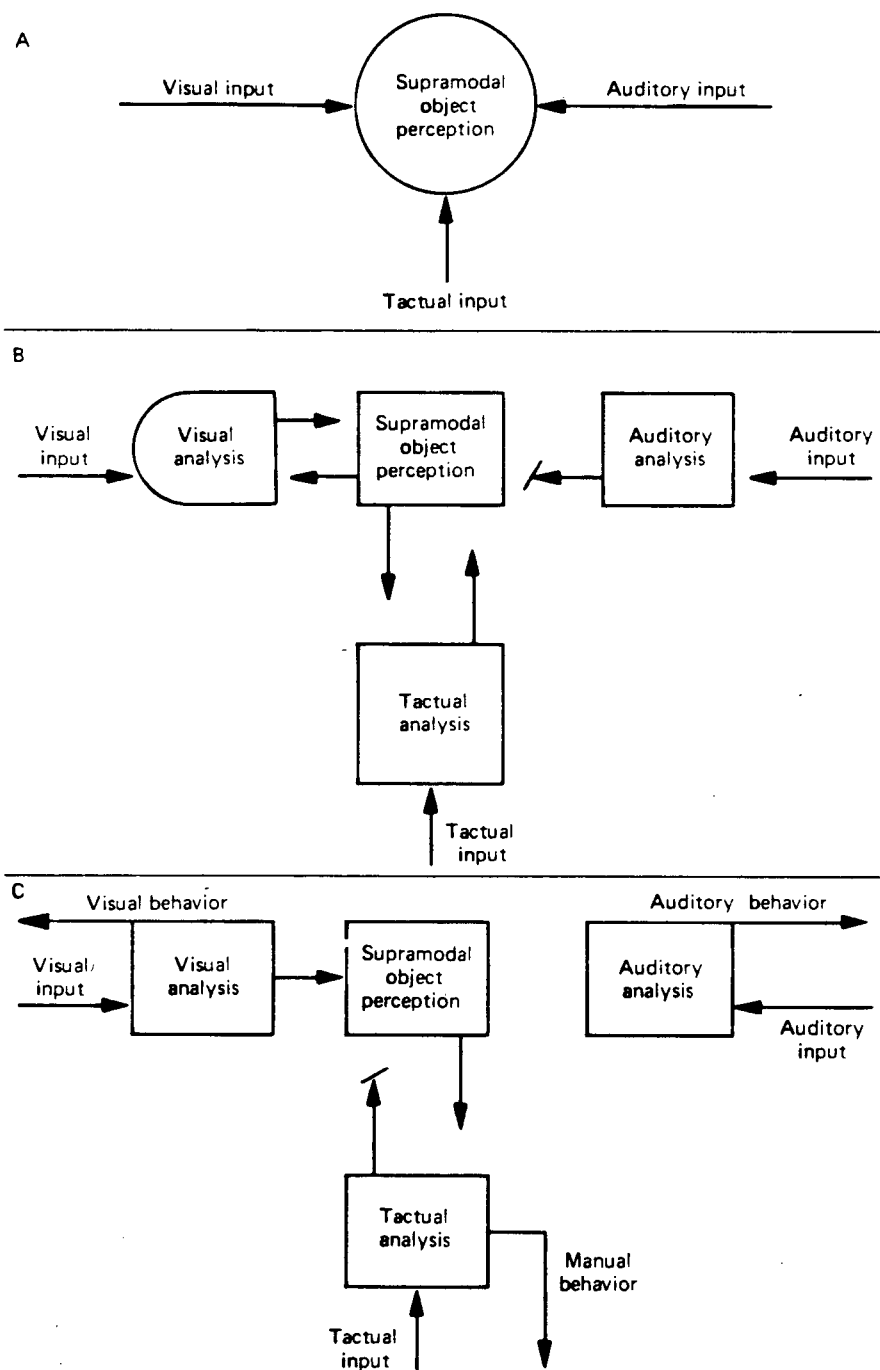
The position of Birch and Lefford is an expression of the classic empiricist view of intersensory development (Friedes, 1974) in which the input from separate sensory modalities form the basic building blocks of perception. Initially the sensory modalities are uncoordinated, but with development the separate sensory systems become integrated, leading ultimately to a unified perceptual world.

An alternative position that there is a primitive unity of the senses has been presented by Bower (1974a; 1974b; 1978). Development, both ontogenetically and phylogenetically, would thus proceed as a process of differentiation of an initial unitary "supra-modal" perceptual space. Bower (1974b) argues that the perceptual system evolved to respond to significant aspects of the world. The perceptual system does not respond to inputs from specific senses as such, but responds to changes and patterns of changes which can be presented through any modality. These amodal stimuli include transitions, gradients of change and temporal differences. These are the really significant features since they signal common structural properties of the world. Early in development, ontogenetically and phylogenetically, perceptual unity is primary. Sensory unity differentiates with development. Bower states that "as organisms evolved, and particularly as they began to grow their parts at different rates and to different sizes, this

early unity had to be abandoned. It is the fact of growth, with different growth rates of sense organs and effector organs that makes unity impossible for mammals with their complex skeletons (1974b, p. 515)." The ontogenetic problem is one of accounting for differentiation and articulation of the different modalities although, according to Bower (1978, p. 101), "we have only the vaguest clue about the psychological events which cause differentiation." Bower's conception of sensory differentiation is illustrated in Figure 2.

To recapitulate, there are two major hypotheses concerning early perceptual development which postulate significant changes in perception as the organism matures. According to one view the senses are initially separate and development of perceptual capabilities occurs as a result of the gradual coordination of inputs from different modalities. A second view suggests that development proceeds as a process of differentiation of an initial supramodal space which, initially, "does not register lights or sounds or smells or touches, or any other of the specific energies of nerves (Bower, 1978, p. 94)."

A third position, which is not really a theory of perceptual development, stems from the theorizing of J.J. Gibson (1966) and has been applied to infant bimodal perception by Spelke (Note 4). According to this position perceiving is the detection of invariants in stimulation. For instance, sights and sounds display spatial and temporal correspondences to which our perceptual systems are attuned. Such correspondences are guaranteed by the nature of the physical world and an invariant-detection theory of perception seeks to specify which of these relationships are used by the observer. The theory is not directly concerned with perceptual development. Rather, the concern is with what perception is; namely, the detection of invariants. The position does not deny that



**Fig. 2.** Three stages of sensory differentiation according to Bower (1974a, p.120): (A) birth – 4.5 months; (B) 4.5 – 6.5 months; (C) 6.5 months and on.

perceptual systems mature, but it does deny that the nature of perception changes. The process is always the same as the perceptual systems are inherently organized to detect invariants. Accordingly, the task for the developmental researcher is to specify which invariants are used and when sensitivity to such invariants occur. According to Spelke (Note 4) young perceivers experience neither a world of unrelated visual and auditory sensations, nor a world of undifferentiated, hetero-modal impressions, but appear to perceive a world of objects and events much as adults do.

As soon as one attempts to compare and evaluate the various theoretical alternatives one is immediately beset with many problems. For instance, there is the fact that not all types of intersensory equivalence are the same. For example, Davenport (1976) has reported on research which demonstrates cross-modal transfer of an intensity or pulse pattern discrimination in prosimians, rats and rabbits. No studies, however, have found evidence for visual-haptic object equivalence in animals other than monkeys. These phylogenetic differences are probably reflected, at least to a limited degree, in ontogenetic development. Ideally the various types of intersensory integration might be ordered along some dimensions of complexity. These dimensions would include, for instance, the neural mechanisms involved, the kind and number of relevant stimulus dimensions, the relative adeptness of the modalities involved (Freides, 1974) and the role of abstract coding systems such as language. With such a descriptive system the, probably different, developmental histories of various types of intersensory equivalence could be delineated. Now, unless the theories are addressing the same or similar types of sensory coordination then direct comparison is difficult. For example, it is not unlikely that intersensory coordination as discussed by Bower, involving

temporal differences, gradients of change, etc. could be quite different from the cross-modal equivalence of complex geometrical forms as discussed by Birch and Lefford. Perhaps Spelke's (Note 4) programmatic proposal is a reasonable strategy to begin with. Accordingly, the investigator of infant perception might focus on a relatively limited domain in order to assess sensitivity to various types of intersensory equivalence within that domain. Although, this would not necessarily lead to a well developed theory of intersensory integration in general, assuming a more limited approach could ultimately be more fruitful. If so, our best approach is to begin by examining those aspects of auditory-visual integration that have been investigated to date.

In general, the research indicates that the auditory and visual systems do not act independently in infancy, but interact in a variety of ways. Three main areas of research need to be described in some detail: the effect of auditory stimulation on visual localization behaviour, reactions to incongruous visual and auditory information from persons and objects, and the influence of common temporal patterns between visual and auditory events on perceptual activity.

Spatial location would appear to be an amodal property par excellence. Although there are auditory, visual, proprioceptive and olfactory spaces they are at least roughly coordinated. We can ask, however, whether there are modality-specific spaces which undergo a process of translation when referring one sense to another or, alternatively, whether there is one overall spatial framework which could be called a common space? Auerbach and Sperling (1974) provide psychophysical evidence which supports the common space hypothesis for visual-auditory location in young human adults. In their study subjects had to discriminate the spatial direction of two sound stimuli, two light stimuli, and a

sound and light stimulus. Because there was no variability in judgements which could be attributed to translating from one spatial representation to another, it was argued that auditory and visual sensations were referred to a common perceptual space. In terms of physiological evidence, Morrell (1972) reported that 70/169 cells recorded from areas 18 and 19 of the visual cortices of cats were responsive to both acoustical and visual stimulation. The response was such that the acoustical receptive field was "mapped onto" the receptive field organization for vision as a series of vertically oriented stripes. Moreover, cells sensitive to moving stimuli were usually selective in direction and the direction was the same for both modalities. Wickelgren (1971) obtained similar results recording from the intermediate grey area in the superior colliculus of the adult cat. Although a few research reports of this kind hardly provide definitive evidence in support of the common space hypothesis they are at least suggestive.

If there is some commonality between auditory and visual space in infants, stimulation in one modality might influence activity in the other. Specifically, auditory stimulation could provoke visual localization attempts. This was demonstrated in the classic study by Wertheimer (1961). He found that a newborn baby reliably turned her eyes in the same direction as a click sound which was presented randomly to either ear. However, McGurk, Turnure and Creighton (1977) observed neonatal oculomotor behaviour under various conditions of visual and auditory stimulation. They were not able to replicate Wertheimer's results and also showed that visual tracking was not influenced by the addition of moving or stationary auditory stimuli. They argued that their results suggest the modalities are initially independent and hence "the developmental problem is one of accounting for synthesis between perceptual

modalities rather than of accounting for the differentiation of systems that are innately unified" (McGurk et al., 1977, p. 143). Similarly, Butterworth and Castillo (1976) could not replicate Wertheimer's results but did find that most of the eye movements were contralateral to the locus of auditory stimulation.

Nevertheless, two recent studies have confirmed Wertheimer's original observation. In a series of studies using corneal reflection photography (Mendelson & Haith, 1976) it was shown that visual activity in neonates was influenced by auditory stimulation. The relation was spatially relevant in that laterally presented sounds resulted in initial fixation shifts toward the source of sound. In another investigation of localization (Muir, Field & Sinclair, Note 3) neonates were presented with two rattles, one opposite each ear. The rattles were moved simultaneously, but only one produced sound. The infants turned more often to the noisy rattle (they obtained a similar result when the sound was presented through speakers rather than rattles).

There are important differences between the studies of Mendelson and Haith and Muir and his coworkers and those of McGurk et al. which could account for the different results. Mendelson and Haith and Muir et al. used relatively continuous auditory stimulation; a 40-second presentation of a repeating 16 second loop of a person reading a poem and the presentation of a noisy rattle for 20 second intervals. McGurk et al. used brief clicks as their auditory stimuli and only recorded eye movements which occurred within 3 seconds of stimulus onset. The brief observation period and short stimulus presentation made for a very demanding test of localization, particularly given the rather "sluggish" motor system of the neonate.

It has been argued (Lawson, 1979; McGurk et al., 1977) that these localization responses indicate reflexive oculomotor responding rather than higher-level auditory-visual integration. Support for this interpretation comes from studies with both blind and sighted infants. With sighted neonates it has been demonstrated that visual localization of sound sources can be elicited whether an infant's eyes are open or closed (Turkewitz, Birch, Moreau, Levy, & Cornwell, 1966). Fraiberg (1977) has reported on reflex-turning of the eye toward a sound source in a blind infant at two months of age. At six months, as was true for other blind infants, the baby did not turn toward a source of sound. It would appear then that this initial oculomotor behaviour, which may be reflexive, is in need of visual input in order to be maintained. Normally, however, such behaviour may have significant consequences for "higher-level" auditory-visual coordination. A sighted infant looking in the direction of a sound source receives simultaneous bimodal information about the visual and auditory characteristics of an event. This bimodal specification may assist in the establishment of a "cross-modal dictionary" (Bryant, 1974) between particular sights and sounds. As such, qualitatively different characteristics of an object could come to independently identify the object.

One of the "objects" with which infants have a great deal of experience is the mother. The recognition of certain characteristics of the mother has been demonstrated in very young infants. It has been shown that infants 20 to 30 days old can discriminate between their mother's voice and voices of other females (Mills & Melhuish, 1974). Other research indicates that infants as young as 2 weeks of age can distinguish their mother from inanimate objects or from other female faces (Carpenter,

Tecce, Stechler, & Freedman, 1970). An interesting question is whether these characteristics are unified to form a common source. In an effort to answer this question several investigators have concentrated on infants' responses to the break-up of the location of mother's face and voice. This can be accomplished easily with microphone and speaker arrangements. Those employing this paradigm have argued that if multi-modal information available in objects is integrated by the infant then they should be "surprised" or "distressed" by the break-up of such information. In a widely discussed report, Aronson and Rosenbloom (1971) claimed to have shown a primitive unity of vision and audition in infants as young as 30 days. They measured infants' reactions (number of tongue protrusions) to spatially coincident and spatially separated presentations of mother's face and voice. Having obtained some positive evidence the authors suggested that infant perception occurs within a common auditory and visual space.

McGurk and Lewis (1974) subsequently pointed out that Aronson and Rosenbloom did not use a validated response measure and had an experimental design which lacked counterbalanced presentation. Using an improved methodology, McGurk and Lewis were unable to replicate the Aronson and Rosenbloom study. They concluded that "the nature and development of audiovisual coordination during early infancy remains an open question" (McGurk & Lewis, 1974, p. 650). More recently Condry, Haltom and Neisser (1977) were also unable to replicate the Aronson and Rosenbloom findings.

These "break-up" studies have employed a method which is based on the assumption that if infants combine auditory and visual information about their mother they will be distressed or surprised by a spatial

discrepancy. Failure to obtain positive results may mean that the infants do not combine such information or that they are not distressed or surprised by such a break-up. The number of behavioural measures supposedly related to distress and/or surprise makes assessment difficult. Such measures have included tongue protrusion (Aronson & Rosenbloom, 1971; Condry et al., 1977), frequency of smiling, vocalizing, fretting or crying (McGurk & Lewis, 1972).

Although mothers undoubtedly are very significant to their infants the studies described above provide little information about the stimulus characteristics which may be important in linking complex visual and auditory events. One dimension that has often been implicated in the perception of auditory-visual correspondence is the temporal domain. Consider for instance the rather disconcerting experience of viewing a poorly dubbed foreign film. One's attention is constantly drawn to the temporal relationship between the movement of the speakers' lips and the sounds of speech. Since we are accustomed to a precise correspondence between speech sounds and mouth movements we find the "slippage" in the dubbed film annoying. This prosaic example illustrates our sensitivity to such bimodal input and the research of Dodd (1977), McGurk and MacDonald (1976), and Riesberg (1978) has shown that the information afforded by lip movements assists in the perception of speech. Using relatively abstract light and sound patterns it has also been shown that synchrony is the most important variable for obtaining recalibration of auditory and visual locations (Radeau & Bertelson, 1977).

Demany, McKenzie and Vurpillot (1977) and Chang and Trehub (1977) have shown in a series of studies that infants 2 1/2 and 5 months old, respectively, are sensitive to temporal groupings in auditory patterns. In both cases infants were habituated to one temporal pattern

and showed significant dishabituation to another. There is also one report in the literature on auditory-visual transfer in infants. Allen, Walker, Symonds and Marcell (1977) presented two groups of 7-month-old infants with a standard visual or auditory temporal sequence. After 15 habituation trials the infants were divided into four subgroups in which the presentation modality and/or the temporal sequence remained the same or different. Infants showed greater response recovery (increase in heart rate or skin potential) with a different temporal sequence regardless of the sensory modality in which the temporal sequences were presented. Thus by seven months the infants were capable of perceiving equivalences and differences in temporal sequence information within and across modalities.

Spelke (1976, Note 2, Note 4) and Bahrick, Walker and Neisser (Note 5) have adopted an interesting variation of the preference paradigm for investigating infants' sensitivity to intermodal relations. These authors have assumed that infants receiving information from one modality will explore in order to obtain information from another. For instance, an infant might seek visual information about auditory events in order to follow the events in two modalities. The procedure has been to present infants with two motion picture films of "natural events." The films are separated with the soundtrack of one of the films emanating from a speaker placed between the films. The infant is placed midway between the films in front of the concealed speaker. Various measures of the infant's looking at each film are used to assess the infant's sensitivity to the relationship between the soundtrack and the relevant film. Measures of preference and search behaviour have included mean looking time, direction of first look, latency of first look and the number of trials on which the infant looked for any duration to the

relevant film within a specified time period.

In one report (Spelke, 1976) infants aged 4 months were shown two motion picture films: one depicted a woman playing "peekaboo" and the other a wooden baton striking a wood block or tambourine repeatedly and rhythmically. Results indicated that the infants looked primarily at the event specified by the relevant soundtrack. These results could have been obtained, however, if the infant only linked the human voice sound with the motion picture of the woman: not an unlikely assumption given some recent results (Spelke & Owsley, 1979). The latter authors showed that at 15 weeks of age infants will search visually for a parent who is heard to speak in such a preference set-up. This occurs even when there is not any spatial or temporal information uniting face and voice. Given this result it might be that infants in the Spelke (1976) study would look at the woman upon hearing the voice and the 'non-person' otherwise. As such it is unclear whether Spelke answered the question which prompted her research; "Will infants explore sights and sounds whose relationship is specified by their internal structure?" (Spelke, 1976, p. 554).

This criticism has been more than met in recent investigations. Bahrick et al. (Note 5) found consistent and strong preferences for sound related films by 4-month-old infants. The authors presented infants with every pair-wise comparison of three films; a pattern of handclaps, the playing of a xylophone, and the movement of a slinky toy. Only the pairing of the xylophone and the slinky toy failed to reach statistical significance when the sound of the xylophone was presented. Spelke (Note 4) has shown that 4-month-old infants can perceive the relationship between the rate of sounds and the visible impacts of objects even if the sounds and impacts are not simultaneous.

That is, if infants are shown two motion picture films of a toy animal bouncing at two different rates they can detect the common rate of sound and visible movement even though they do not occur simultaneously. Infants could also detect the simultaneity of sound bursts and visible impacts even when the synchronized and non-synchronized objects moved at the same rate. The results of these studies were considerably weaker than the Bahrick et al. study particularly with regard to overall preference. The most consistent differences were found in measures of "visual search" which included the direction of first look, the number of trials on which the infants looked first or second to the synchronized and non-synchronized films, and the latency of looking.

These studies support the notion that infants will explore sights and sounds whose relationship is specified by their internal structure. The main variable specifying this internal structure has been the temporal relationship between the filmed objects' movements and the sounds thus produced. The infants are sensitive to this relationship.

Several investigators (Lawson, 1979; Spelke, Note 2; Lyons-Ruth, Note 6) have asked whether infants associate visual and auditory features of novel objects during brief exposures to the objects when there is a temporal and/or spatial correspondence between the visual and auditory events. Lyons-Ruth (Note 6) found that 4- and 5-month-old infants (but not 3-month-olds) who had briefly experienced an object spatially and temporally coincident with a sound showed distress (i.e., an increase in limb and body movement) when there was spatial dislocation between the sound and object. In a series of studies Spelke (Note 2) has presented evidence that 4-month-old infants can rapidly acquire knowledge of bimodally specified events on the basis of temporal synchrony between the visual and auditory aspects of the events. In the experiment

(Spelke, Note 2, Experiment III) that most clearly makes this point she used the same procedure as described previously. There were two phases to the experiment; a familiarization period, and a test period. During the familiarization period two films were projected side by side. One film was of a toy kangaroo, the other of a donkey, each "bouncing" at a rate of one bounce per 2 seconds. When either of the two objects hit the ground one of two sounds was heard; a gong, or a thump. During familiarization only the temporal structure of the sound united it with one of the films of the moving objects. On test trials both films were projected and infants were given brief presentations of the sounds separated by intervals when a small light was used to centre their gaze between the films before another presentation of the sound. Infants were divided into Synchrony and Non-synchrony conditions for the test trials. For the Synchronized condition presentation of the sound was synchronized with the impact of the object it had specified during familiarization trials. For infants in the Non-synchrony condition the sounds were not in phase with the objects to which they had previously been related. There were no significant differences during test trials between the conditions, and infants in both groups searched reliably for the sound specified object. Spelke argued that the infants had detected the temporal invariance which united the optic and acoustic stimulation during familiarization. This formed the basis for the acquisition of knowledge which led to relevant search behaviour even when the temporal correspondence between the objects and sounds was lacking.

Lawson (1979) also investigated some of the factors responsible for the establishment of the coordinated perception of the auditory and visual characteristics of a common object. To this end she systematically varied the degree of temporal and spatial congruity between the auditory

and visual characteristics of two separate object-sound pairs. In the only study which clearly showed coordinated perception, 6-month-old infants were first familiarized with an object that moved in synchrony with a periodic sound which emanated from the object. Testing consisted of presenting the familiar and a novel object simultaneously, with either the familiar or a novel sound coming from a speaker midway between the objects. Infants spent a significantly greater proportion of their fixation time and a significantly greater duration of fixation, looking at the familiar object in the presence of the familiar sound. In the presence of the novel sound they did not show differential fixation. The other conditions included temporal synchrony between the object and sound but with 90° spatial separation, and two conditions of spatial congruity coupled with temporal incongruity. In one condition the object moved continuously while producing a periodic sound and in the other condition there was periodic movement of the object with continuous sound. All test results were negative except for one object-sound pair in the spatial congruity condition involving continuous object movement and periodic sound. The results of these studies indicate the importance of spatial and temporal congruency in the coordination of auditory and visual stimuli. The spatial separation of 90° between object and sound was much greater than in the Spelke (Note 2) investigation. Given Spelke's positive results with temporal synchrony and a slight spatial discrepancy it would seem that the spatial factor might be a matter of degree.

In general, the empirical research indicates that the auditory and visual modalities of infants interact in a number of ways. The visual search behaviour of young infants is influenced by the spatial location of sound sources. The degree of sensitivity to temporal relations both within and between the modalities is quite impressive.

Sensitivity to these various amodal properties may facilitate the learning of more arbitrary or specific cross modal associations (Mendelson, Note 1; Spelke, Note 2) and it appears that some of these associations can be established quite rapidly.

## EXPERIMENT I

As indicated earlier, it has been shown that when 4-month-olds are presented with two films simultaneously on either side of a speaker, the infants look at the sound specified film (Spelke, 1976, Note 2, Note 4; Bahrick et al., Note 5). Such results have been interpreted as demonstrating that infants detect the rhythmic stimulation which unites the visual and auditory events and that, given the opportunity, infants will attempt to follow events in two modalities.

Typically, the stimuli used in such studies are of a multidimensional nature, and it is not clear what characteristics are of assistance in guiding the infant's visual attention. As a matter of fact, the most consistent incidence of preference behaviour has been obtained in the case of film strips of highly dissimilar objects paired with correspondingly different soundtracks (i.e., Spelke, 1976; Bahrick et al., Note 5). Indeed, when the films were of the same object but merely differed in tempo, the preference for the sound related film was much weaker (Spelke, Note 4). It is not clear, therefore, whether infants would show such preferential looking when visual and auditory events are only linked by a common temporal relationship.

In the present study the number of stimulus dimensions was kept to a minimum using simple light and sound patterns. A preference technique similar to that devised by Spelke (1976) was used, except that the pattern of elements of the two visual displays and the sound which accompanied the visual patterns were the same in all respects, except for temporal rate. The study was designed to investigate whether infants would show preferential looking to the sound-related visual event when the visual and sound patterns differed only in temporal rate. In order to detect possible developmental changes three age levels were tested.

## METHOD

Subjects

Forty-two infants participated in the experiment. Data for 6 of these 42 infants were not fully collected due to equipment failure or excess fussiness during testing and have been excluded from analysis. The three groups of 12 infants had mean ages of (Group 1) 3 months, 10 days (S.D. = 12 days), (Group 2) 6 months, 19 days (S.D. = 19 days) and (Group 3) 10 months, 11 days (S.D. = 14 days). Infants were recruited through advertisements in the local newspapers. No attempt was made to balance or control for race, sex or socioeconomic status.

Stimuli

The visual stimuli were five light emitting diodes (LED's), embedded in clear plastic (5 cm apart) and arranged in a cross pattern (see Fig. 3). The visual angle subtended by the pattern was approximately 7.2 deg. A red translucent plastic sheet was placed over the diodes in order to enhance their brightness. Two such stimulus panels, separated by 70 cm., were used; one placed to the infant's right, the other to the left. A small green fixation light was placed midway between the panels. The visual angle between a panel and fixation light was approximately 26° at the viewing distance used. Auditory signals were produced by commercially available Sonalerts (model SC628) manufactured by P.R. Mallory Co. Inc. with a nominal frequency rating of 2900<sup>+</sup> 500 HZ. These were concealed and placed midway between the visual panels. Ambient noise level measured at the infant's head was 52 db according to a General Radio Company sound level meter (model 1551C). The sound level was 62 db with the tone present.

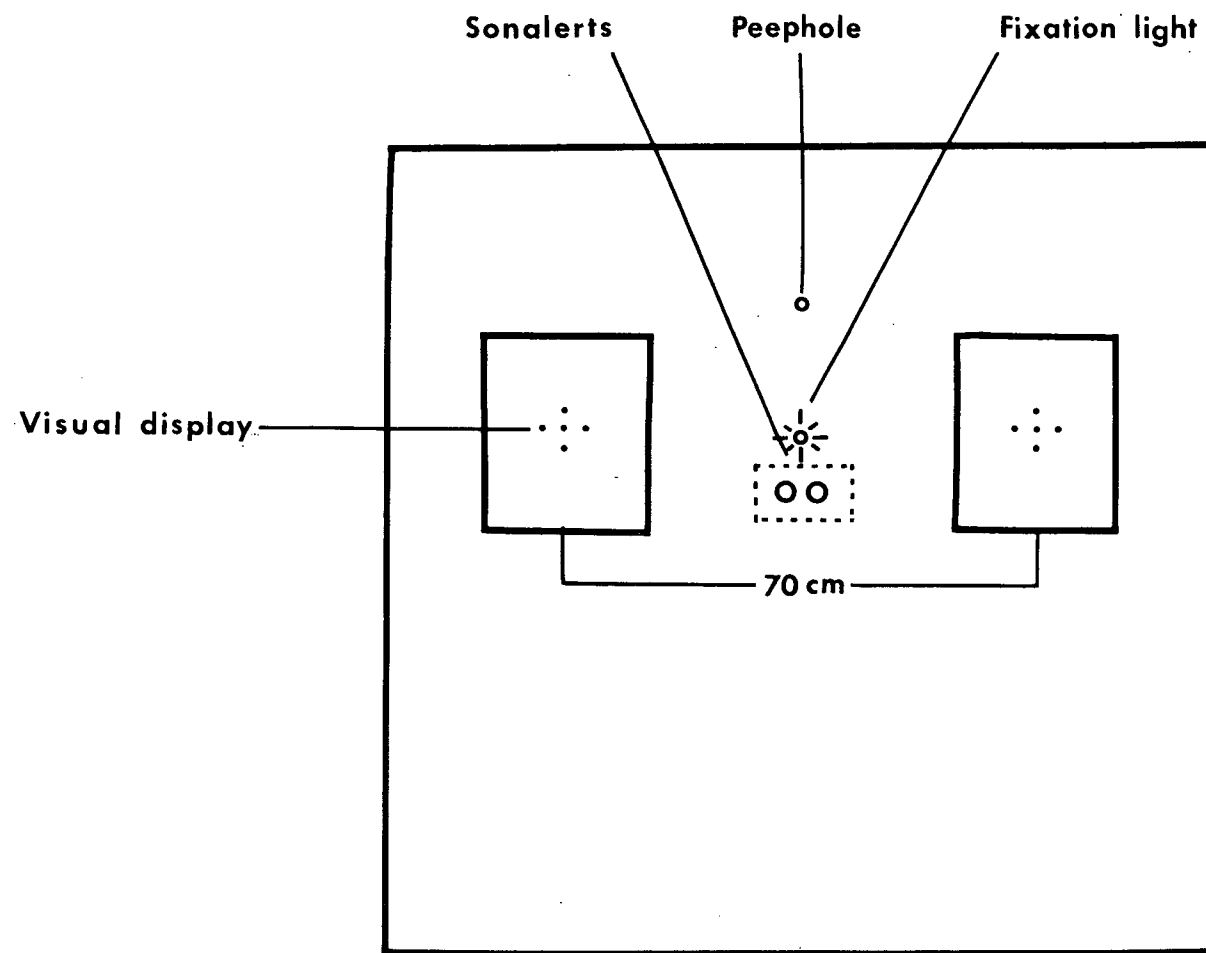


Fig.3. Schematic diagram of display for Experiment I

The stimulus patterns were generated by a specially constructed two channel pulse generator. Two temporal rates were controlled by separate channels of the signal generator. The cycle time for the "slow" pattern was 1.4 sec with the stimuli on for 1.0 sec and off for 0.4 sec. For the "fast" pattern the cycle time was 0.35 seconds with a 0.25 sec on period and 0.10 off period (see Fig. 4).

### Design and Procedure

Three different age groups of infants were tested. Each infant received two trials with the "fast" auditory pattern and two trials with the "slow" auditory pattern. Order of fast and slow patterns was randomized across infants. Half of the infants in each group had the fast visual pattern on their right, and the slow visual pattern on their left, while the other half were presented with the opposite arrangement.

Testing took place in a specially constructed darkened enclosure (1.2 x 1.3 x 1.9 m) in a dimly lit, quiet room. The infants were held by the mother at a distance of approximately 80 cm from a point midway between the visual panels. The infants were viewed through a peephole midway between the visual panels. Both the mother and observer heard music through headphones which masked the auditory stimulus throughout the testing session. Only one observer was used throughout the experiment (see Fig. 5).

The observer began the trial when the infant oriented to the green fixation light. A small light went off at the end of a trial to inform the observer of trial end. Trial duration was controlled by a Lafayette VIII Bank Timer (model 5431A) and was 60 sec. Whenever the infant was judged to be looking at a visual panel during a trial the observer depressed one of two switches; one switch for looking

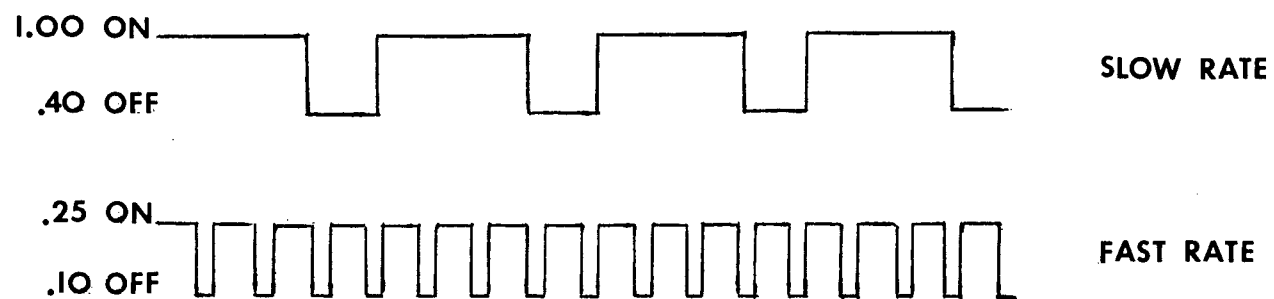


FIG.4. PULSE PATTERNS USED IN EXP.1

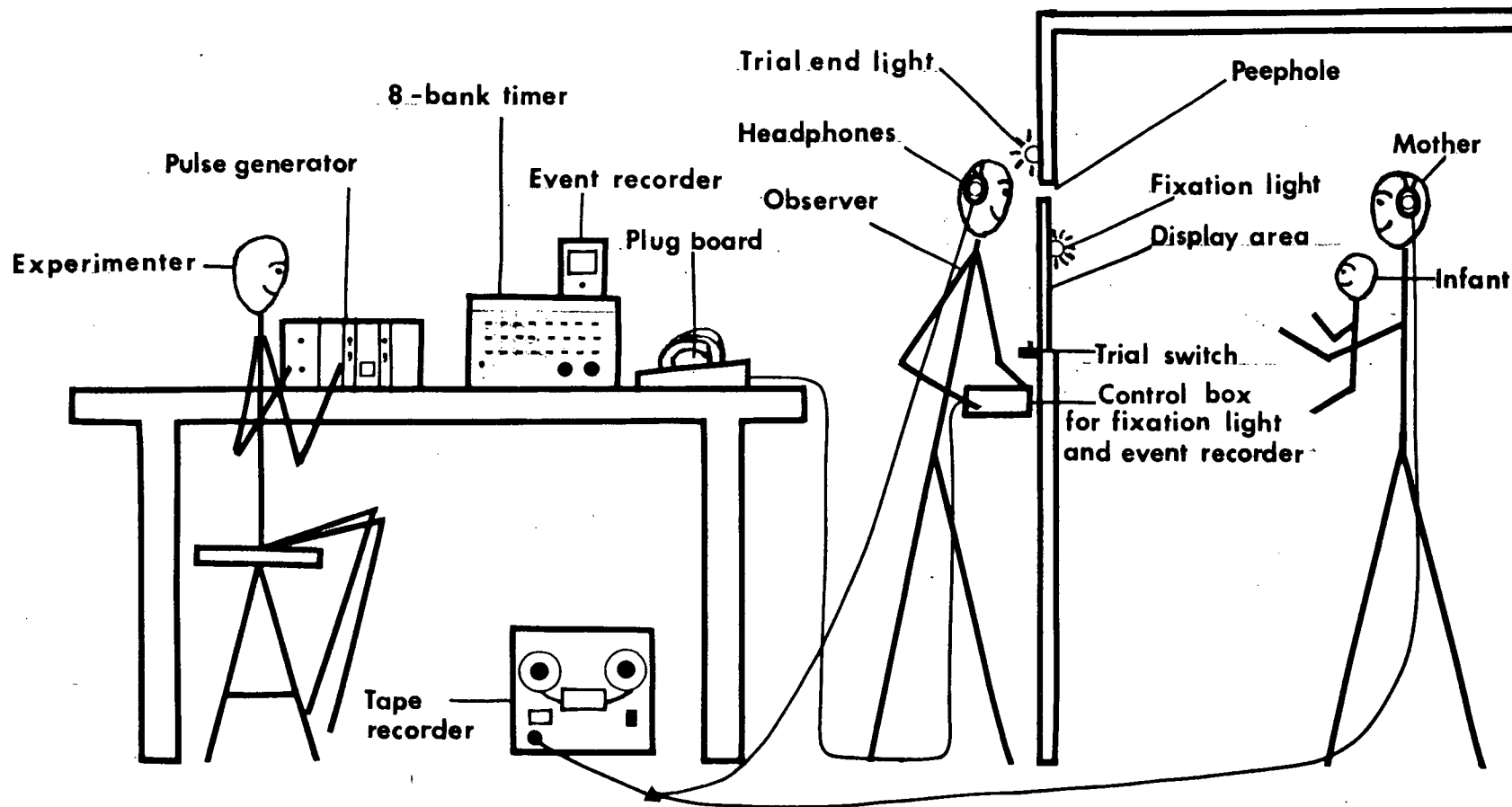


Fig. 5. Schematic diagram of laboratory arrangement.

at the right panel, the other for looking at the left. The switches activated separate pens on a Rustrak Event Recorder model 92.

### Measures of Looking

Two biases in the data required correction. In spite of the control for position bias between subjects there was a strong tendency for the infants, particularly in the two younger groups, to look more toward one side than the other (see Fig. 6). This looking bias was highly consistent in group 1 with the infants showing a strong right-turn bias. Group 3 demonstrated a strong preference for the visual pattern with the faster temporal rate, regardless of accompanying sound or position (see Fig. 7).

The rationale behind such corrections, which have previously been used by Lawson (1979) and Ruff and Birch (1974), is that if an infant has a strong right-looking bias, then left-looking time should be given more weight because the stimulus on the left has to be especially attractive to pull the infant's attention from the preferred side. The method of correction consisted of taking the length of looking to the right, for example, and finding what proportion that time was of the total right-looking time. For instance, if an infant's total looking time to the right was 100 sec and to the left, 30 sec, and in a given trial the infant looked to the left for 6 sec and to the right, 25 sec, the corrected proportions would be 0.20 and 0.25, respectively.

As mentioned above the measure of preference was total length of fixation time to each visual pattern. A measure of "visual search" used by Spelke (Note 2; Note 4) was also used. This was latency of looking, which was the duration of elapsed time between the beginning of a trial

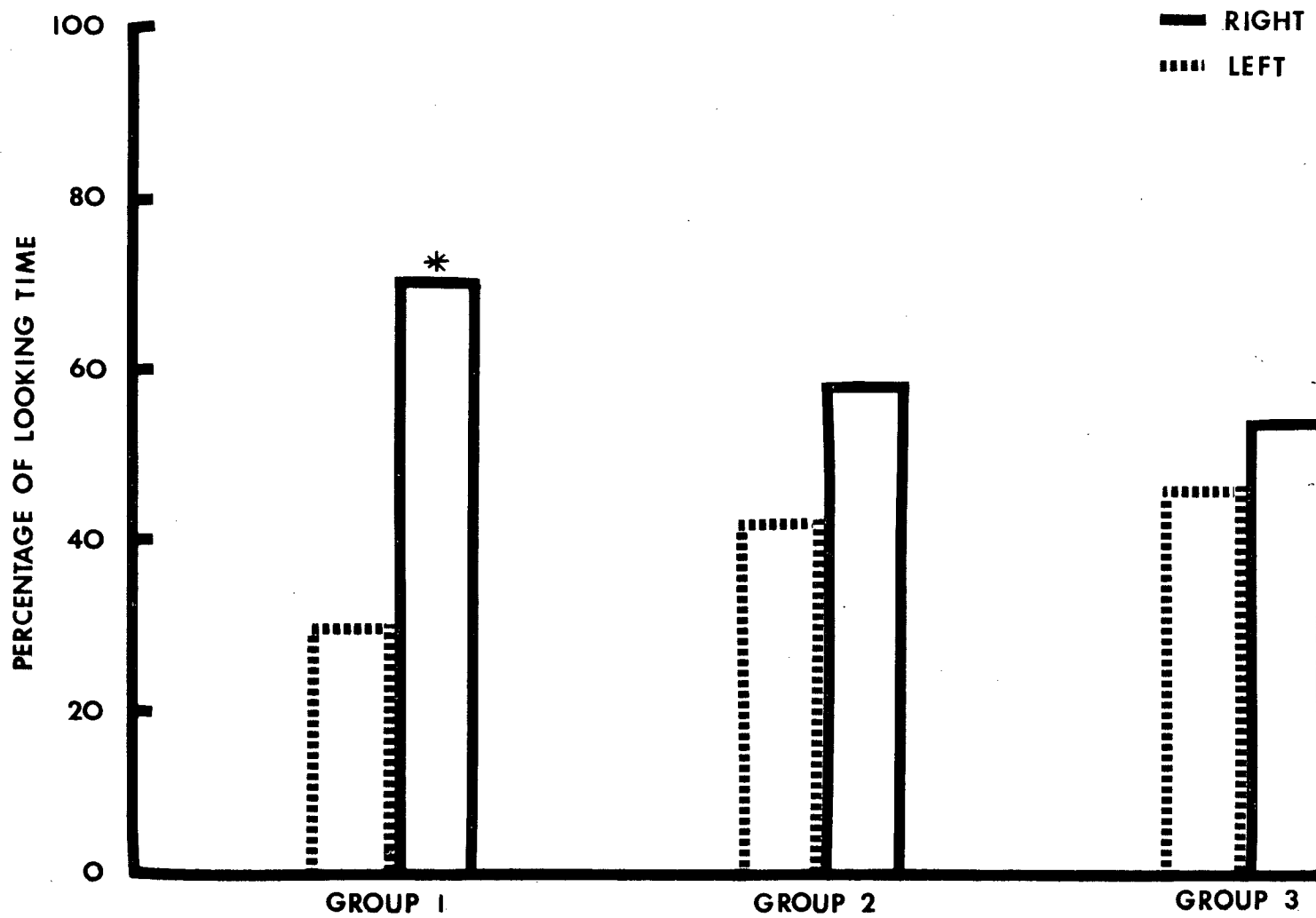
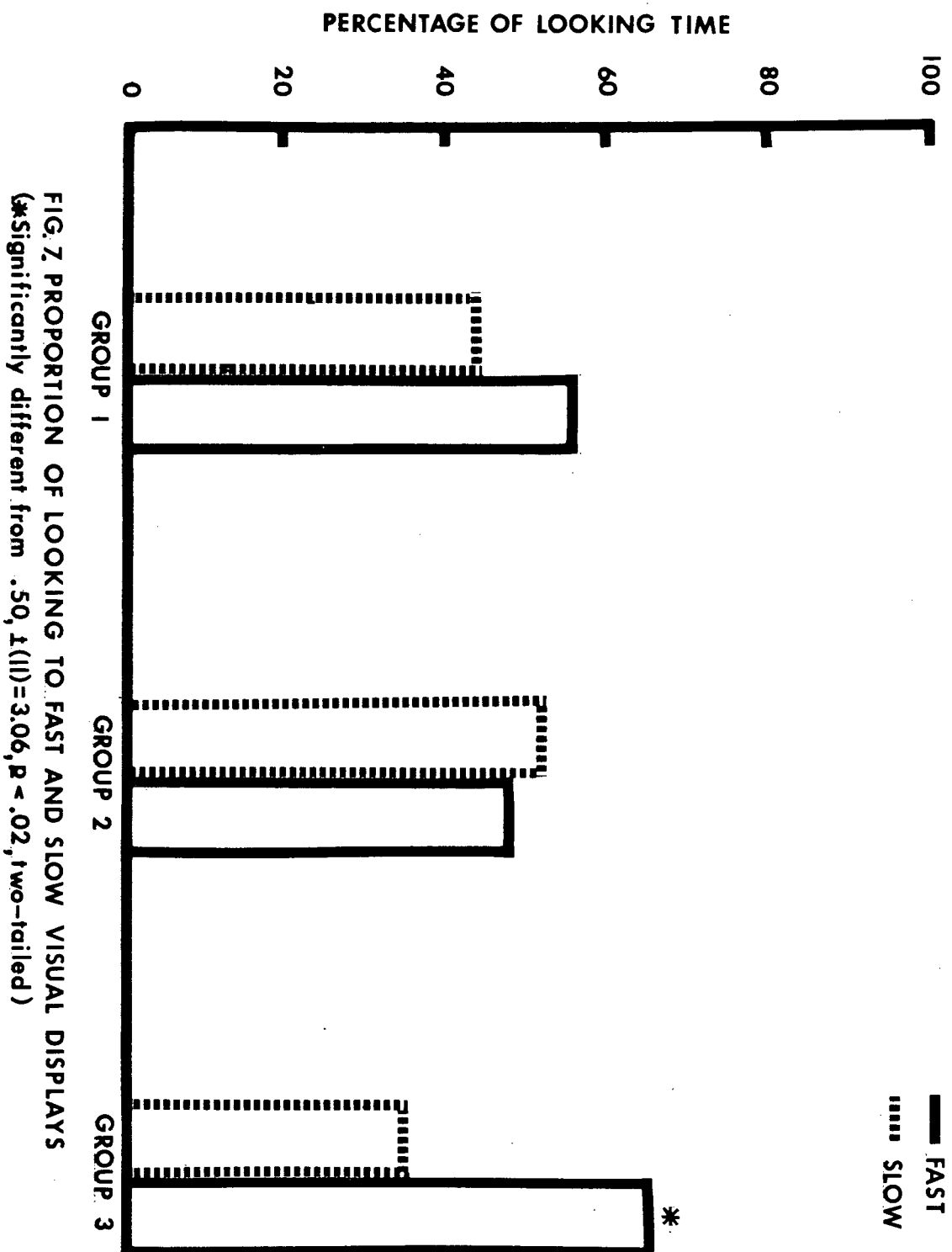


FIG. 6. PROPORTION OF LOOKING TO RIGHT AND LEFT  
 (\* Significantly different from .50,  $t(11)=2.30, p < .05$ , two-tailed)



and the infant's first look to the synchronized visual stimuli and similarly, to the non-synchronized stimuli. Also, the number of looks to each visual pattern was calculated. Both of these measures were also corrected for position and rate bias.

## RESULTS AND DISCUSSION

Three separate between-groups ANOVA's were performed on the mean looking time, the average latency to the first look, and the average number of looks. The groups did not differ on mean looking time but did so on latency,  $F(2,33) = 4.34$   $p < .025$ , and number of looks,  $F(2,33) = 9.74$   $p < .001$ . Tukey (a) tests (Winer, 1971, p. 198) indicated that group 3 made significantly more looks than group 1 ( $p < .005$ ), and group 2 ( $p < .01$ ), while groups 1 and 2 did not differ from each other in this respect. Tukey tests also showed that latency to first look was significantly greater in group 2 than group 3 ( $p < .05$ ). The difference in latency between group 1 and group 3 did not reach significance using the Tukey procedure, but did with a Newman-Keuls test ( $p < .05$ ). Groups 1 and 2 did not differ in latency to first look.

After correction for bias the total preference for the sound related visual stimuli was calculated, for each infant, as the mean proportion of fixation to the sound-related visual stimulus for the 2 sound conditions. Two  $t$  tests were performed on the data for each group; one for the slow rate condition and one for the fast. In each case the proportion of looking time to the sound related visual stimulus was compared to the proportion expected by chance (i.e., 0.50). Not one of these tests reached significance for the preference measure.

This was also the case for the number of looks measure and the latency of looking measure. This is not surprising, as all of these measures are highly related. The Pearson correlation between the bias corrected preference measure and the number of looks was 0.89 and between the corrected preference measure and the corrected latency measure (to the sound-related visual stimuli) was -0.78.

The results of the present study do not agree with those from some previous investigations using the modified preference methodology (Spelke, 1976; Bahrick et al., Note 5). Even after correction for position and temporal rate bias the infants failed to show any consistent preference for the sound-related visual events. This was true of all measures employed.

There are two points of interest in the results of the present experiment which, while not directly related to auditory-visual coordination, nevertheless, point to developmental differences between the groups. The two sources of bias; position and temporal rate, show a developmental change from what is probably a greater control of attention by organismic factors in the younger group to stimulus factors in the older groups. Position bias has been noted by other researchers, particularly in younger infants (Cohen, 1976; Lawson, 1979; Ruff & Birch, 1974). The preference for the faster temporal pattern in the older infants probably results more from the weakening of the position bias than from a new bias for the faster pattern. Support for this contention comes from a subsequent test of successive preference with 10 four-month-old infants which indicated a marginally significant preference for the fast pattern (see Appendix A).

The other developmental change concerns the number of looks and the latency of the first look. The older infants looked more often and with

shorter latency than the two younger groups. (The mean number of looks were 5.9 (S.D. = 3.6); 7.9 (S.D. = 2.3) and 13.8 (S.D. = 7.3) for groups 1, 2 and 3 respectively. Groups 1, 2 and 3 had mean latencies of 3.6 (S.D. = 2.4); 4.0 (S.D. = 2.2) and 2.0 sec (S.D. = .7) respectively.) The groups did not differ, however, in average fixation time. The infants in the older group may have different processing strategies, perhaps resulting from maturation of central control and peripheral executive mechanisms.

## EXPERIMENT II

The results of Experiment I indicate that infants do not show differential looking toward sound related visual events when the only difference between the patterns is temporal rate. Consequently the habituation-recovery paradigm (e.g., see Cohen, 1976) was used to further investigate auditory-visual processing in infants. By presenting patterns successively, position bias is controlled. Only one rate was used throughout the habituation and recovery phases, thus controlling for rate bias. Using a habituation procedure Demany et al. (1977) and Chang and Trehub (1977) have shown that infants of 2-1/2 and 5 months of age are sensitive to temporal groupings in auditory patterns. Other habituation research has indicated that 7-month-old infants are capable of perceiving equivalences and differences in temporal sequence information both within and across the auditory and visual modalities (Allen et al., 1977). Thus, the habituation methodology has been successfully employed to investigate the processing of temporal patterns by infants.

Two groups of infants were presented with synchronous and non-synchronous visual and auditory stimuli. In one condition infants were presented during habituation trials with a simple pulse pattern in which visual and auditory stimuli were synchronized. They were then put out-of-phase for the recovery period. Another group of infants was given the opposite sequence of events; nonsynchronous signals during habituation and synchronized signals during recovery. It was hypothesized that the group receiving synchronous information during habituation would show significant habituation and recovery, and the other group would show less habituation and no recovery. These predictions follow from models of habituation similar to that proposed by Sokolov (1963).

According to such a model habituation depends upon stimulus encoding. Successful encoding, or representation, should lead to habituation and recovery, while difficulty in forming a representation should lead to slower habituation and a possible lack of recovery.

## METHOD

### Subjects

Sixty-seven infants aged 3 months 23 days to 4 months 17 days (mean age 4 months, S.D. 6 days) participated in the experiment. Data for 7 of these 67 infants were not fully collected due to equipment failure or excessive fussiness during testing, and have been excluded from the analyses. Infants were recruited through advertisements in the local newspapers. No attempt was made to balance or control for race, sex or socioeconomic status.

### Stimuli

As before, the visual stimulus was five red light emitting diodes (LED's), embedded in clear plastic (5 cm apart), and arranged in a cross pattern. The visual angle subtended by the pattern was approximately 7.2 deg. Auditory signals were produced by commercially available Sonalerts. The Sonalerts were concealed and placed immediately below the visual pattern (see Fig. 8). Ambient noise level measured at the infants head was 52 db according to a General Radio Company sound level meter (model 1551C). The sound level was 62 db with the tone present.

The stimuli were generated by the specially constructed pulse generator. The temporal pattern for synchronous light and sound was controlled by a single channel which sent the same pulse rate to the LED's and Sonalerts. For the nonsynchronous stimuli, separate channels

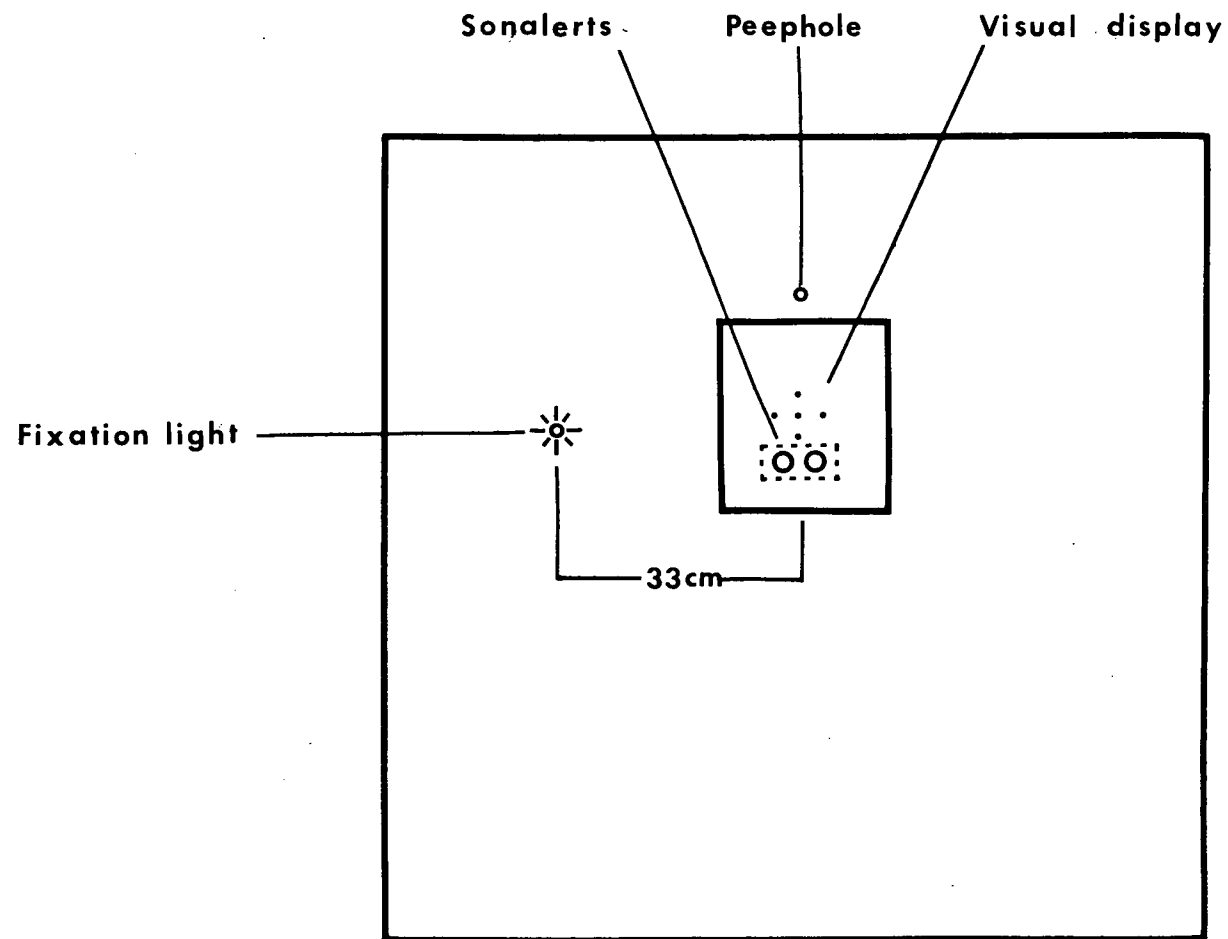


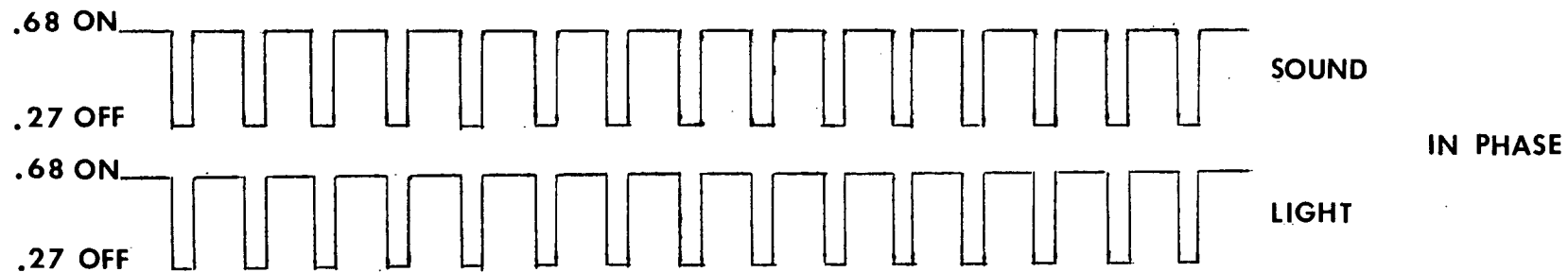
Fig. 8. Schematic diagram of display for Experiment II

delivered different rates to the diodes and Sonalerts. Cycle time for the synchronous pattern was 0.95 sec, with the stimuli on for 0.68 sec and off for 0.27 sec. For the nonsynchronous pattern, the cycle time for the sound was the same as in the synchronous case, but, for the light, was 0.89 sec, with a 0.64 sec on and 0.25 sec off period (see Fig. 9). This produced an auditory-visual temporal relationship which constantly changed throughout each trial.

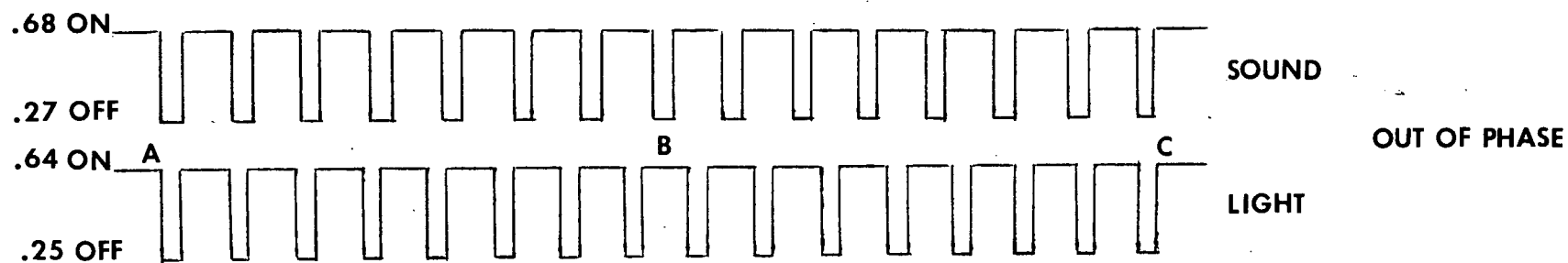
### Design and Procedure

Three groups of infants were tested. During habituation trials one group received synchronous visual and auditory stimuli (group  $S_1$ ). After 10 trials the light and sound were put out of phase for 5 recovery trials. A second group received the nonsynchronous signals during habituation trials and the synchronous stimuli during recovery trials (group  $NS_1$ ). Since the cycle time of the visual stimulus was decreased during the nonsynchronous condition, a third group of infants who only received the visual stimuli was also run as a control. Half of these infants received the faster rate during habituation and the slower rate during recovery trials (group VF), while the other half received the opposite sequence of events (group VS).

Testing took place in the darkened enclosure (1.2 x 1.3 x 1.9 m) in a dimly lit, quiet room. The infants were held by their mothers at a distance of approximately 80 cm directly in front of the visual panel. The infants were viewed through a peephole 2 cm above the light panel. A small, green incandescent fixation light was placed 33 cm from the centre of the visual pattern to the infant's left. Both the mother and observer, who were not informed of the test condition, heard music through headphones that masked the auditory stimulus.



15 SEC TRIAL



A&C - MINIMUM PHASE DIFFERENCE

B - MAXIMUM " "

FIG. 9. PULSE PATTERNS USED IN EXP'S. 2 & 3

The observer began the trial when the infants oriented to the green fixation light. A small light went off at the end of a trial to inform the observer of trial end. Trial duration was controlled by a Lafayette VIII Bank Timer and was 15 sec. The duration of the interstimulus intervals was determined by the amount of time it took for the infant to orient to the fixation light; the average interval was 6.9 sec. During a trial the observer judged when the infant was looking at the visual panel and depressed a switch which activated a pen on the Rustak Event Recorder. Two observers were employed throughout the experiments (II & III); the interobserver reliability, calculated as a Pearson correlation on total looking time per trial for 135 trials, was 0.92.

## RESULTS AND DISCUSSION

The data were analyzed in terms of one major response index; looking time per trial. Figure 10 shows the course of visual attention for average total looking times for the two main groups. A comparison of the average looking time during the 10 habituation trials showed that group  $NS_1$  looked significantly longer than  $S_1$ ,  $t(38) = 6.1$ ,  $p < .0005$  (one-tailed)<sup>4</sup>. The means for each of Trials 1 and 2 ( $T_1$ ), 9 and 10 ( $T_2$ ) and 11 and 12 ( $T_3$ ) were subjected to a 2 x 3 Analysis of Variance in which the variables were Group ( $S_1$  and  $NS_1$ ) by Trials ( $T_1$ ,  $T_2$ ,  $T_3$ ). Both the Trials,  $F(2,76) = 25.33$ ,  $p < .001$ , and Group by Trials,  $F(2,76) = 6.1$ ,  $p < .003$ , effects were highly significant. Analysis of simple main effects showed that the groups were not significantly different at  $T_1$  or  $T_3$ , but were so at  $T_2$ ,  $F(1,114) = 9.61$ ,  $p < .005$ . T-tests for correlated samples revealed that group  $S_1$  showed significant differences between  $T_1$  and  $T_2$ ,  $t(19) = 7.86$ ,  $p < .0005$ , (one-tailed), and significant

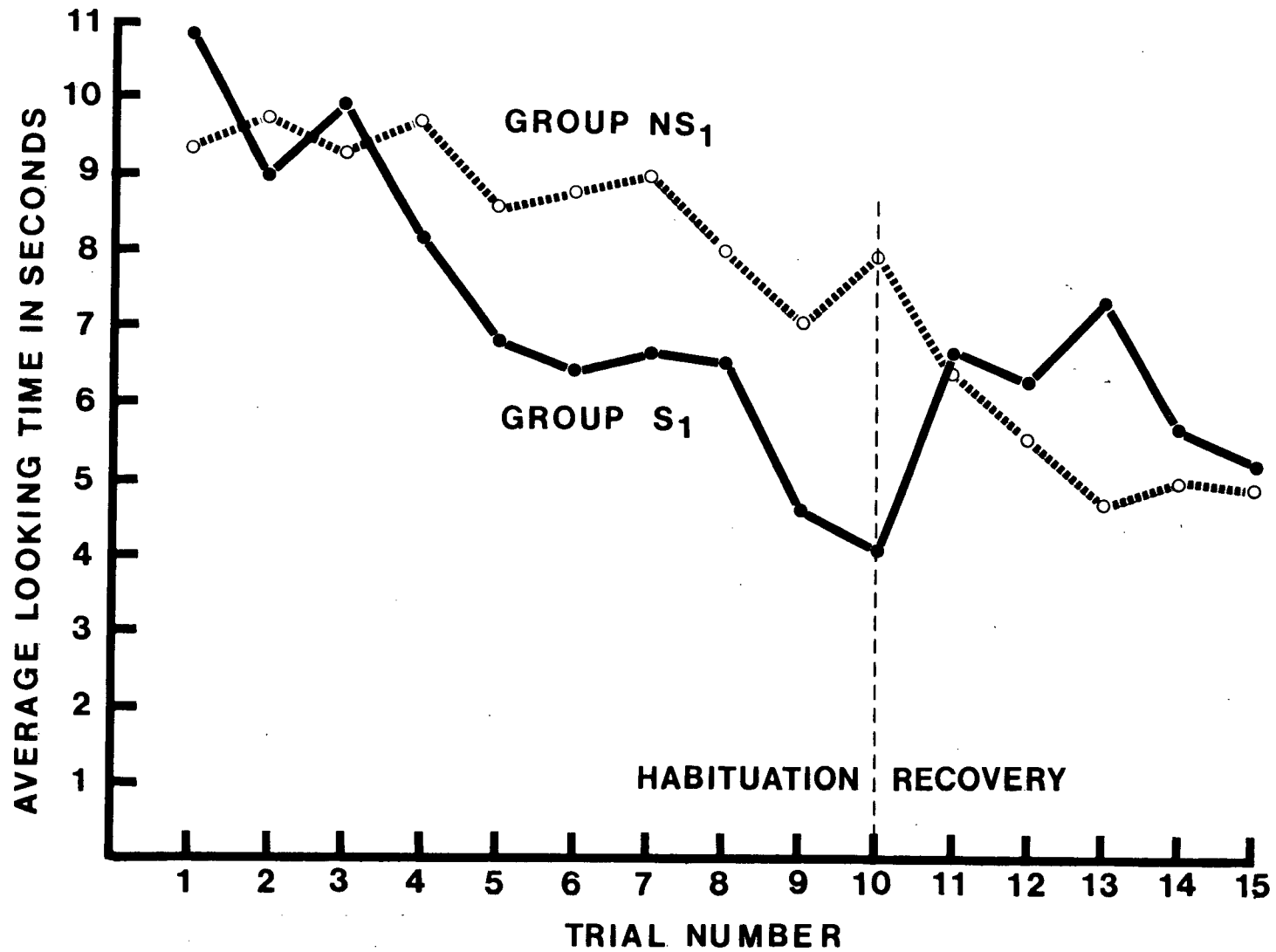


Fig.10. Mean duration of fixation per trial for groups  $S_1$  and  $NS_1$ .

differences between  $T_3$  and  $T_2$ ,  $t(19) = 3.12$ ,  $p < .005$  (one-tailed), in the predicted directions. However for group  $NS_1$  neither the difference between  $T_1$  and  $T_2$  nor  $T_3$  and  $T_2$  reached significance.

A comparison of the mean looking times for group VF and VS over the 10 habituation trials revealed no significant difference. A  $2 \times 3$  ANOVA on Group (VF, VS) by Trials ( $T_1$ ,  $T_2$ ,  $T_3$ ) did not yield any significant differences.

The results of Experiment II support the predictions. Group  $S_1$  showed significant habituation and recovery while group  $NS_1$  showed neither. Moreover, group  $NS_1$  showed significantly more looking at  $T_2$  than group  $S_1$ . These results cannot be attributed to the detection of or preference for the faster light as there was no evidence of difference between the two visual groups. It should be noted that the trial factor was not significant in the visual condition indicating a lack of habituation. It appears that 4-month-old infants are able to coordinate the input from the modalities and display a high degree of sensitivity to the phase<sup>5</sup> relationship between the light and sound.

## EXPERIMENT III

The results of Experiment II were obtained with spatial congruity between the light and sound. Some recent research (Lawson, 1979) has suggested that infants may need both temporal and spatial congruity in order to coordinate auditory and visual information under some conditions. Also, since the light and sound in Experiment I were separated by approximately  $26^{\circ}$ , this may have made coordination difficult. The question of interest in the third experiment was therefore, whether infants can detect the phasic relationships between light and sound when the sources of stimulation are widely separated. The groups were run as in Experiment II, but with the light and sound stimuli separated.

## METHOD

Subjects

Forty-five infants aged 3 months 18 days to 4 months 17 days (mean age 4 months 4 days, S.D. 8 days) participated in the experiment. Three infants were excluded from analysis due to fussiness and 2, because of equipment failure. As in the first two experiments, no attempt was made to balance or control for race, sex or socioeconomic status.

Stimuli

The stimuli and temporal patterns were the same as those used in Experiment II, except that the Sonalerts were placed at a  $90^{\circ}$  angle to the infants' line of regard at the visual stimulus. Half of the infants in each group had the auditory stimulus on the left, the other half on their right. The Sonalerts were approximately 60 cm from the infant's ear.

### Design and Procedure

Group  $S_2$  received the synchronous visual and auditory signals during habituation and the nonsynchronous signals during recovery. Group  $NS_2$  received the nonsynchronous stimuli during habituation and the synchronous stimuli during recovery. Half of the infants in each group had the Sonalerts on their right, while the other half had them on their left.

### RESULTS AND DISCUSSION

The major index of analysis was looking time per trial. The course of visual attention for mean looking time for the two groups is illustrated in Fig. 11. As there were no significant differences dependent upon the side of the sound source, data was combined in the subsequent analyses. A comparison of the average looking time during the 10 habituation trials showed that group  $NS_2$  did not differ significantly from group  $S_2$ .

Only the main effect for Trials reached significance,  $F(2,76) = 31.4$ ,  $p < .001$ , in an ANOVA on Groups ( $S_2$ ,  $NS_2$ ) by Trials ( $T_1$ ,  $T_2$ ,  $T_3$ ).<sup>6</sup> Independent  $t$ -tests indicated that the groups were not significantly different at  $T_1$ ,  $T_2$  or  $T_3$ .  $T$ -tests for correlated samples demonstrated significant differences between  $T_1$  and  $T_2$  for group  $S_2$ ,  $t(19) = 4.49$ ,  $p < .0005$ , (one-tailed), and for group  $NS_2$ ,  $t(19) = 4.4$ ,  $p < .001$  (two-tailed). Group  $S_2$  showed significant recovery,  $t(19) = 2.27$ ,  $p < .025$  (one-tailed), while the difference between  $T_3$  and  $T_2$  did not reach significance for group  $NS_2$ ,  $t(19) = .510$ ,  $p > .50$  (two-tailed).

The significant habituation and recovery for group  $S_2$  suggests that spatial congruence between the visual and auditory stimuli is not

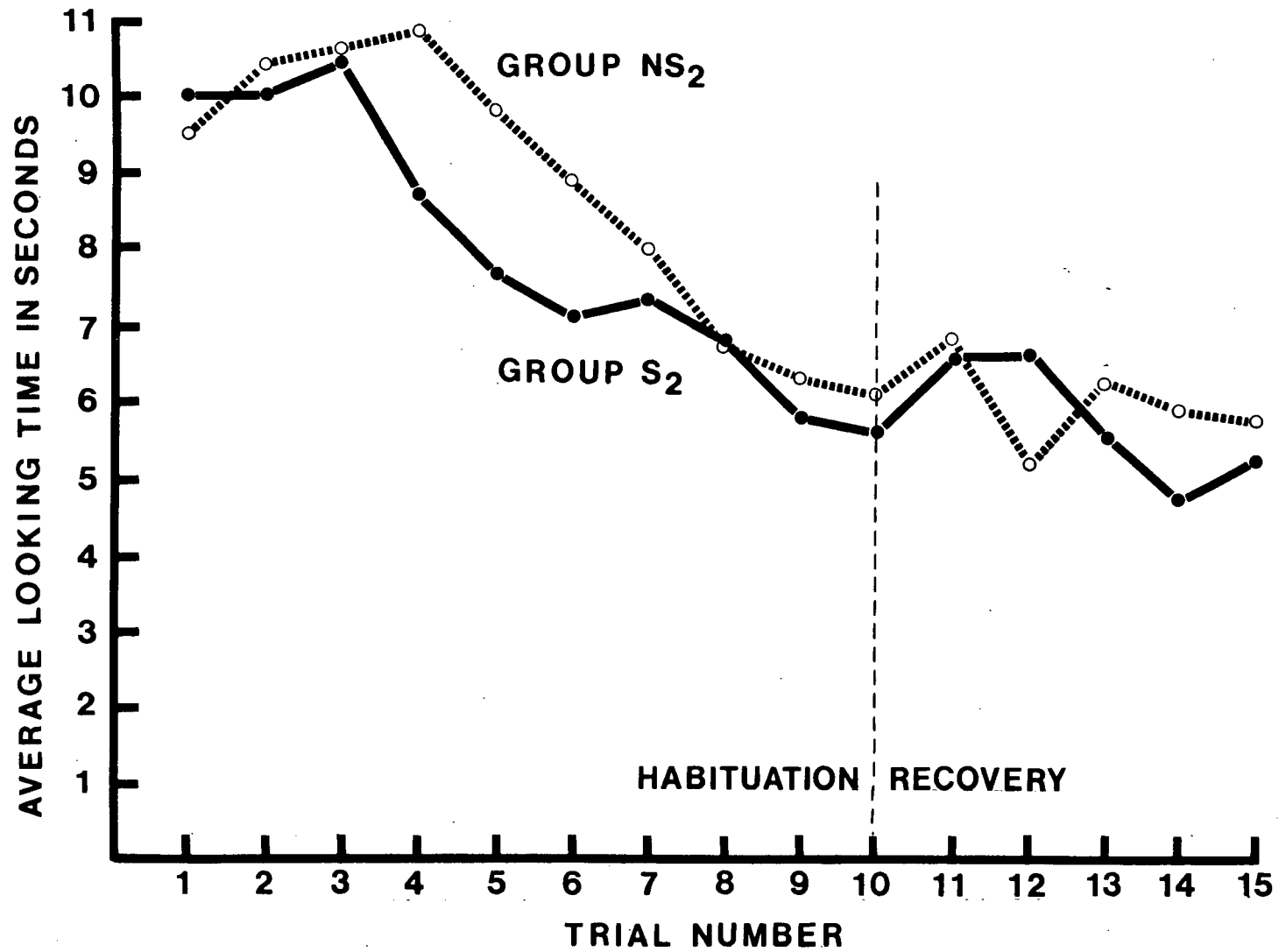


Fig.11. Mean duration of fixation per trial for groups S<sub>2</sub> and NS<sub>2</sub>.

a necessary condition for coordination if there is synchrony between the stimuli. Group NS<sub>2</sub> showed habituation in the same way as S<sub>2</sub>, but did not show recovery. It is difficult to know what the infants were habituating to in this condition, although it is possible that they were habituating to one of the components of the compound stimulus. Further research could possibly clarify this.

## GENERAL DISCUSSION

In Experiment I infants were presented with two visual stimuli differing in temporal rate. The questions of interest were whether infants would exhibit differential looking to the stimulus that was synchronous with a sound and whether such looking would change as a function of age. Such preferential looking has been demonstrated in other investigations when both the auditory and visual stimuli have differed in many dimensions (Spelke, 1976, Note 2, Note 4; Bahrick et al., Note 5). In this study the number of dimensions was reduced to one - temporal rate - in order to investigate whether looking to the sound-related visual event would be demonstrable under such stringent conditions. In the case of the present study the difference in temporal rate was obviously large; that is, one pattern's cycle time was four times greater than the other. However, no evidence was found for differential looking to the sound-specified visual pattern at any of the three age levels tested.

It is unlikely that the lack of differential looking was the result of an inability to discriminate between the patterns, as the findings of the successive preference study (Appendix A) indicated that 4-month-olds are probably able to differentiate the patterns. However, the effectiveness of the simultaneous presentation experimental situation to detect differences related to auditory-visual synchrony was clearly impaired by the differential looking associated with position and temporal rate biases. The younger infants looked more to the right, regardless of the temporal rate of sound or light pattern, and the oldest infants looked more at the fast visual pattern regardless of position or auditory rate.

Even with correction for both position and rate bias, there was no demonstration of differential looking to the sound related visual pattern. Those investigations which have shown positive results, in the past, have employed stimuli which differed along a large number of dimensions. The stimuli used have been film strips of relatively familiar "natural events" (Spelke, 1976; Bahrick et al., Note 5). Such events are certainly more complex than those used in the present study. For instance, the visual events differed in colour and form, while the accompanying sounds differed in spectral frequency composition. Furthermore, the rhythmic relationship between the auditory and visual stimuli was complex and much less repetitive than in the present study. All of these differences could have promoted differential looking to the sound-related visual stimuli. To date no research has sorted out the contribution of these various factors to such preferential looking, although the results of the present study, and some of the results of Spelke's (Note 4) study, suggest that rate differences themselves are not enough to produce differential looking to the sound-related visual events.

Familiarity also could have been a factor in the investigations that have yielded positive results. It could have had an influence in one of two ways. First, if one of the pair of stimuli used was more familiar than the other, preferential looking might be facilitated. The preference shown in Spelke's (1976) study, which paired a film-strip of a woman playing peekaboo with one of a wooden baton striking a wood block, could have resulted from such a difference in familiarity. The infants may have looked to the woman when the sound of a person's voice was heard and to the "non-person" when the other sound track was presented. Such a preference would probably be based on prior

association, rather than the detection of the common auditory-visual rhythm. Familiarity also could be influential in another way. The film strips of the objects presented to infants are representative of a class or classes of objects with which they have had prior experience. Both Lawson (1979) and Spelke (Note 2) have shown that cross-modal associations can be formed very rapidly. Hence, it is not totally unreasonable to suppose that prior experience with a class of objects could have assisted in the production of differential looking to the sound related visual stimuli. More research is necessary to clarify the role of prior experience.

Position bias has been reported in previous studies which have used measures of visual preference (Cohen, 1976; Lawson, 1979; Ruff & Birch, 1974). For instance, Cohen (1976) reported on experiments in which there were longer fixation times to the right, despite the presentation of identical patterns on both sides. Similarly, Ruff and Birch (1974) found that even though they controlled for position bias, with left-right pattern reversals, there was a tendency for infants to look more toward one side than the other. Caron (1967) found significantly more "spontaneous" right head turns than left head turns and Siqueland (1968) reported more successful conditioning of a right head turn response than a left turn. Turkewitz, Gordon and Birch (1968) have also shown that tonic neck responses in neonates are directed to the right about 80% of the time. The meaning of such position bias is not clear, although some authors have suggested that lateral differences may reflect neurobehavioural organization (Hammer & Turkewitz, 1974). Cerebral asymmetries are often implicated in such views of neurobehavioural organization. However, while a cerebral asymmetry is easily linked to hand preference (Bresson, Maury,

Pierant-Le Bonniec & de Schonen, 1977; Caplan & Kinsbourne, 1976).

it is difficult to see how this would account for looking preferences.

The temporal rate bias exhibited by the oldest group of infants is in accord with the findings and speculation of other researchers. The results of Karmel et al. (1977) showed that inverted U-shaped functions, with similar maxima, described visual attention and signal strength/sec of the visually evoked potential of 3-month-old infants to temporally modulated patterns. This finding is support for the view advanced recently that the amount of visual attention that a stimulus structure elicits is governed by the level of neural excitation it produces (Bornstein, 1978; Haith, 1977; Karmel & Maisel, 1975). That is, visual attention is seen as being highly correlated with the "firing rate" of neurons in the visual cortex. Stimuli that produce maximum firing (to an asymptotic level) will elicit most visual attention<sup>7</sup>. In the present investigation the oldest group (Experiment I) and the 4-month-old infants tested successively (Appendix A) both showed a preference for the faster visual pattern. This is consistent with the findings of Karmel et al. (1977) and, according to the above interpretation, this preference should be correlated with the level of neural excitation.

The difference found between the oldest (group 3) and younger (group 1 & 2) infants in latency of first look was hardly surprising. Other investigators have also found a decrease in latency to fixation of peripherally presented targets as a function of age (Aslin & Salapatek, 1975; De Schonen, McKenzie, Maury, Bresson, 1978; Tronick, 1972). However, the ages tested have been much younger than those of the present experiment and the measures and experimental conditions have varied. Such a decrease in latency could result from more efficient

eye and head control, an increase in the 'size' of the effective visual field, attentional changes or some combination of these factors. Although it is not possible to determine the controlling factor(s) on the basis of the present results, it should be noted that the faster rate pattern appeared to be a powerful "attention-getting" stimulus (Cohen, 1973) for the older infants. That is, the older infants, who had less position bias than the younger infants, were especially sensitive to such a peripherally presented stimulus; it recruited their notice very quickly.

The infants in group 3 also exhibited a greater number of looks than those in groups 1 and 2. This could result from a more fully developed motor system, or from different information-processing strategies or both. The groups in the present study did not differ in average fixation time. Hence the time per look was greater in the younger groups. Such a difference is suggestive of more active scanning by the older infants and is reminiscent of an observation made by Ames and Silfen (Note 7, p. 6): "It appears to us that while the older infant may be capturing stimuli with his visual behaviour, the young infant is captured by the stimuli". It remains to be determined what such a speculation actually means in terms of the development of perceptual processing. (For discussion see Bronson, 1974; Haith, 1977; Harris, 1973).

Since the preference methodology failed to produce differential looking related to auditory-visual synchrony, the habituation paradigm was used in Experiments II and III. The processing of temporally synchronous and nonsynchronous visual and auditory stimuli under conditions of spatial congruity and separation was examined. It was hypothesized that the groups ( $S_1$  &  $S_2$ ) receiving synchronous auditory and visual signals during habituation and nonsynchronous signals during

recovery trials would show significant habituation and recovery.

The groups ( $NS_1$  &  $NS_2$ ) receiving the opposite sequence of signals, during habituation and recovery trials were predicted to show less habituation and no recovery. These predictions follow from models of habituation similar to that proposed by Sokolov (1963). According to such a model habituation depends on stimulus encoding. Successful encoding or representation should lead to habituation and recovery if the stimulus is changed, while difficulty in forming a representation should lead to slower habituation and possible lack of recovery.

There are a number of ways to encode the synchronous light and sound patterns used in Experiments II and III, but the simplest would be to use a relative rather than an absolute code. An absolute code would involve, within some reasonable limits, the representation of the duration of the pulse and inter-pulse interval. A relative code would require only that the synchrony between the light and sound be represented and would not depend upon the encoding of absolute information<sup>8</sup>. Accordingly, it is the constant relationship between the visual and auditory stimuli which needs to be represented for habituation to occur. It could be argued that the habituation and recovery demonstrated in the case of the synchronous groups ( $S_1$  &  $S_2$ ) resulted from the presumably successful encoding of the temporal relation between the light and sound, which was not influenced by the relative location of the stimulus sources. Also, the lack of habituation in the conditions in which the infants were only presented with the light pattern (groups VS and VF) further attests to the difficulty that may be involved in representing absolute temporal information. It is possible, however, that the coding of such temporal information may be more difficult for the visual modality than for the auditory modality. It has been argued that the visual

modality is more adept at coding spatially patterned information, while the auditory modality is better equipped to deal with temporal information (Freides, 1974). Research has demonstrated that matching of simple frequency rates and rhythms is more accurate when done intramodally by the ear, than cross-modally by the eye and ear (Cole, Chorover & Ettlinger, 1961; Gebhard & Mowbray, 1959). Thus, absolute auditory temporal information could possibly be encoded.

The infants in the groups presented with nonsynchronous signals during habituation trials ( $NS_1$  &  $NS_2$ ) did not show evidence of recovery. However, the group with the light and sound separated ( $NS_2$ ) habituated, while those presented with the light and sound spatially congruous ( $NS_1$ ) did not. The infants in these groups could have been attempting to encode the stimulus in an absolute or in a relative manner. An absolute code could be used to represent the pulse rate of the light or sound. But, if such a code had been employed by the infants it would probably not have led to habituation and certainly not to recovery. Infants in the visual-only condition did not habituate or recover. If they had encoded any absolute information, it is most likely that it was the auditory pattern. In that case there could be no recovery as the temporal rate of the auditory signal was the same for both habituation and recovery trials.

The infants were probably attempting to coordinate the visual and auditory information in some manner, at least in group  $NS_1$ . The reasons for this argument are, first, that the infants in the synchronous groups did coordinate the information. More importantly, there were temporal relationships between the stimuli that could have provoked attempts at coordination. The light and sound patterns had very similar pulse rates. Other research has shown that infants are sensitive to similar temporal rhythms between visual and auditory

events even if they are not synchronized (Spelke, Note 4). The phase relationship between the light and sound was such that the stimuli were maximally out of phase in the middle of the trial but appeared to be in phase at the beginning and end of the trial (see Fig. 9). Such an "interestingly" unpredictable pattern could have provoked attempts at coordination: "Finally the light and sound sources were spatially congruous for the  $NS_1$  group.

The lack of recovery for both non-synchronous groups suggests that the infants were not able to form a representation of the out-of-phase pattern which could then be discriminated from the synchronous pattern. The lack of habituation in the  $NS_1$  group suggests that there was continued interest over trials if the light and sound are spatially congruous. However, when the light and sound were separated, as was the case for the  $NS_2$  group, significant habituation occurred. This is perplexing, as it is difficult to know what the infants were habituating to in the  $NS_2$  group. One suggestion is that with spatial separation and lack of temporal synchrony between the sources the sound became more salient and the infants were able to encode it. This is a highly tentative suggestion which further research could examine.

What sort of mechanism could accomplish auditory-visual integration of the kind demonstrated in Experiments II and III? One approach to "mechanism" is to examine cells, or systems of cells, which could accomplish such integration. According to current neurophysiological theorizing certain nerve cells are equipped to respond selectively to particular "features" of the external world (see Barlow, 1972 for an extreme statement of this position) such as the well-known "spot" and "line" detectors of the visual system. Might some of the feature detectors be multimodal? Could each of Aristotle's attributes of the

common sense - motion, rest, number, form, magnitude, duration - be represented neurally in single cells?

Thompson, Mayers, Robertson, and Patterson (1970) have found a few cells (5 out of 500 sampled) in the association cortex of cats which appear to be "counting" cells. Such a cell would fire only if a fixed number of stimulus events occurred consecutively. The cell would discharge regardless of modality, provided the correct number of stimulations was presented. The authors cautioned, however, that "it remains to be demonstrated that these 'counting' cells function to code number of stimulus events under condition of normal behavior (Thompson et al., 1970, p. 273)."

There has also been some interesting Soviet research on cells with "time - receptive fields" (Chelidze, 1975). These neurons (again, a very small percentage of those sampled) were found in the visual cortex of the rabbit. They respond selectively to specified intervals between flashes of light. Other research has shown that there are cells in the superior colliculus (Wickelgren, 1971) and the parastriate and the striate cortex (Fishman & Michael, 1973; Morrell, 1972) which are responsive to both light and sound. Moreover, the visual and auditory receptive fields of these cells are closely aligned, having the same horizontal boundaries.

These few results are intriguing, but none of these kinds of cells (even if they represented a large proportion of cells performing sensory analysis) would be adequate to the task of "explaining" the auditory-visual coordination demonstrated in the present studies. According to the interpretation of the results of Experiments II and III some mechanism would have to "measure" the time relationship between the auditory and visual signals. The process involved would be akin to

a temporal crosscorrelation of the signals in which the time difference between the auditory and visual signals was determined. Multimodal cells with time-receptive fields might possibly play some kind of role, although such cells would have to be but one component in a more complicated neural system which ultimately led to habituation at a behavioural level. Many different non-sensory areas of the brain appear to underlie (such as the hippocampus and the reticular system) the process of behavioural habituation (Sokolov, 1975).

The other components of such circuits would have to be higher-order integrators that can put together information over time and space and go beyond the detection of simple stimulus attributes. According to Sokolov (1975) the "neuronal model of the stimulus registers not only the elementary, but also the complex properties of the signal, such as coincidence or succession of several stimuli in time (p. 218)." Of course, the positing of such neurons is highly speculative, and hazardous. The whole exercise can become quite painfully circular whenever one finds oneself "fabricating" particular types of feature detectors to perform each and every perceptual task (see Dodwell, 1975) and there are alternative ways of looking at perception, even at the neural level. For example, Whitfield (1979) has suggested that a whole network of neural elements is responsible for each perceptual act. This network is distributive and is contained in many parallel paths. One should not expect to find single units or even groups of units, which are responsible for the perception of objects. Maffei (1977) has also expressed a similar notion: "If one wants to correlate neural activity with the actual perception of complex visual stimuli, the consideration of cortical cell activity in isolation from millions of their neural neighbours seems to me rather naive (p. 63-64)."

Such a view does not necessarily deny the existence of neurons that act like feature detectors, but it does deny that feature detection, at an elementary level, is enough to accomplish complex perceptual acts.

Of course, it is possible to theorize about perception without a detailed consideration of underlying neural mechanisms. At a more global level the results of the present investigation could be seen as support for the suggestion that our perceptual systems are sensitive to regularity or pattern and have a limited capacity to absorb random or unpredictable events (Barlow, 1974). In Experiments II and III the synchronous signals bear a simple and regular temporal relationship to each other, while the nonsynchronous signals are essentially unpredictable. An early sensitivity to the invariant relationships between auditory and visual information has obvious adaptive value and may play an important role in perceptual development. As others have suggested (Mendelson, Note 1; Spelke, Note 2) the detection of amodal properties which bear structural relations could be the basis for the acquisition of knowledge about specific aspects of the environment such as which particular sounds 'go with' which particular sights.

## Footnotes

1. For instance, consider the many cross-modality matching experiments which indicate that stimuli presented in one modality can be psychophysically equated, by scaling, to stimuli in another modality. Or, more esoterically, there is the phenomena of synesthesia, in which, for example, a particular sound may evoke vivid visual images. These are two of many types of sensory interrelation which have been most recently and thoroughly reviewed by Marks (1978).
2. For example, it has been shown that changes in the physical rate of a fluttering sound can cause changes in the apparent flicker rate of a simultaneously viewed light, even though the physical rate is held constant (Regan & Spekreijse, 1977). Taylor and Campbell (1976) found that the presentation of an irrelevant noise, during a visual reaction time task, decreased latency to response. These are but two of many investigations which have shown that stimuli presented in one modality can influence activity in other modalities.
3. This question was originally posed by William Molyneux in the early part of the eighteenth century and was addressed to the British philosopher, John Locke. The issues raised by this question became the focus of some intense philosophical debate at the time (see Morgan, 1977).
4. One-tailed tests were used for comparisons for which there were specific directional predictions, otherwise two-tailed tests were used. However all non-significant results with two-tailed

would not have reached significance with one-tailed tests and all significant results with one-tailed tests would still be significant using two-tailed tests.

5. Strictly speaking the term 'phase' refers to the temporal relationship between two or more signals of identical period. I am using the term in a non-technical manner for purposes of exposition.
6. At this point it is customary to proceed no further with post hoc statistical analyses not having obtained a significant interaction. However, since apriori predictions were made T tests were used to further analyze the data. Also, such tests were seen to aid comparison of the results with those of Experiment II.
7. The importance of the "meaning" of the stimulus to the infant is being ignored for purposes of exposition. However for any full account of infant visual behaviour, particularly after 6-8 weeks, this is a most important factor (see Bronson, 1974; Haith, 1977).
8. The strengths of relative over absolute codes for solving perceptual tasks have been emphasized in other contexts as well (see Bryant, 1974).

## REFERENCE NOTES

1. Mendelson, M.J. Amodal properties and auditory-visual coordination in infancy. Paper presented at the International Conference on Infant Studies, Providence, March 1978.
2. Spelke, E.S. The infants' acquisition of knowledge of bimodally specified events. Manuscript submitted for publication, 1979.
3. Muir, D., Field, J., & Sinclair, M. Infants' orientation to sound from birth to three months. Paper presented at the meeting of the Society for Research in Child Development, San Francisco, March 1979.
4. Spelke, E.S. Perceiving bimodally specified events in infancy. Manuscript submitted for publication, 1979.
5. Bahrick, L.E., Walker, A.S., & Neisser, U. Infants' perception of intermodal relationships in natural events. Manuscript submitted for publication, 1978.
6. Lyons-Ruth, K. Integration of auditory and visual spatial information during early infancy. Paper presented at the meeting of the Society for Research in Child Development, Denver, April 1975.
7. Ames, E.M. & Silfen, C.K. Methodological issues in the study of age differences in infants' attention to stimuli varying in movement and complexity. Paper presented at the meeting of the Society for Research in Child Development, Minneapolis, 1965.

## REFERENCES

- Allen, T.N., Walker, K., Symonds, L., & Marcell, M. Intrasensory and intersensory perception of temporal sequences during infancy. Development Psychology, 1977, 13, 225-229.
- Aronson, E., & Rosenbloom, S. Space perception in early infancy: Perception within a common auditory-visual space. Science, 1971, 172, 1161-1163.
- Aslin, R.N., & Salapatek, P. Saccadic localization of visual targets by the very young human infant. Perception and Psychophysics, 1975, 17, 293-302.
- Auerbach, C., & Sperling, P. A common auditory-visual space: Evidence for its reality. Perception and Psychophysics, 1974, 16, 129-135.
- Barlow, H.B. Single units and sensation: A neuron doctrine for perceptual psychology. Perception, 1972, 1, 371-394.
- Barlow, H.B. Redundancy and Perception. In M. Conrad, W. Guttinger, and M. Dalcin (Eds.), Lecture notes in biomathematics 4. New York: Springer-Verlag, 1974.
- Birch, H.G., & Lefford, A. Intersensory development in children. Monographs of the Society for Research in Child Development, 1963, 28, (Serial No. 89).
- Birch, H.G., & Lefford, A. Visual differentiation, intersensory integration and voluntary motor control. Monographs of the Society for Research in Child Development, 1967, 32, (Serial No. 110).
- Bornstein, M.H. Visual behavior of the young human infant: Relationships between chromatic and spatial perception and the activity of underlying brain mechanisms. Journal of Experimental Child Psychology, 1978, 26, 174-192.
- Bower, T.G.R. Development in infancy. San Francisco: Freeman, 1974(a).
- Bower, T.G.R. The evolution of sensory systems. In R.B. MacLeod and H.L. Pick (Eds.), Perception: Essays in honor of J.J. Gibson. Ithaca: Cornell University Press, 1974(b).
- Bower, T.G.R. Perceptual development: Object and space. In E.C. Carterette and M.P. Friedman (Eds.), Handbook of perception (Vol. VIII). New York: Academic Press, 1978.
- Bresson, F., Maury, L., Pieraut-Le Bonniec, G., & de Schonen, S. Organization and lateralization of reaching in infants: An instance of asymmetric functions in hands collaboration. Neuropsychologia, 1977, 15, 311-320.
- Bronson, G. The postnatal growth of visual capacity. Child Development, 1974, 45, 873-890.

- Bryant, P.E. Perception and understanding in young children: An experimental approach. New York: Basic Books, 1974.
- Butterworth, G., & Castillo, M. Coordination of auditory and visual space in newborn infants. Perception, 1976, 5, 155-161.
- Caplan, P.J., & Kinsbourne, M. Baby drops the rattle: Asymmetry of duration of grasp by infants. Child Development, 1976, 47, 532-534.
- Caron, R.F. Visual reinforcement of head-turning in young infants. Journal of Experimental Child Psychology, 1967, 5, 489-511.
- Carpenter, G.C., Tecce, J.J., Stechler, G., & Freidman, S. Differential visual behavior to human and humanoid faces in early infancy. Merrill-Palmer Quarterly, 1970, 16, 91-107.
- Chang, H.N., & Trehub, S. Infants' perception of temporal grouping in auditory patterns. Child Development, 1977, 48, 1666-1670.
- Chelidze, L.R. Neuronal reactions of the rabbits visual cortex as a function of the interval between flashes of light. In E.N. Sokolov & O.S. Vinogradova (Eds.), Neuronal mechanisms of the orienting reflex. Hillsdale: Lawrence Erlbaum Associates, 1975.
- Cohen, L.B. A two process model of infant visual attention. Merrill Palmer Quarterly, 1973, 19, 157-180.
- Cohen, L.B. Habituation of infant visual attention. In T.J. Tighe and R.N. Leaton (Eds.), Habituation: Perspectives from child development, animal behavior and neurophysiology. New Jersey: Lawrence Erlbaum Associates, 1976.
- Cole, M., Chorover, S.L., & Ettlinger, G. Cross-modal transfer in man. Nature, 1961, 191, 1225-1226.
- Condry, S.M., Haltom, M.K., & Neisser, U. Infant sensitivity to audio-visual discrepancy: A failure to replicate. Bulletin of the Psychonomic Society, 1977, 9, 431-432.
- Davenport, R.K. Cross-modal perception in apes. Annals of the New York Academy of Sciences, 1976, 280, 143-149.
- Demany, L., McKenzie, B., & Vurpillot, E. Rhythm perception in early infancy. Nature, 1977, 266, 718-719.
- De Schonen, S., McKenzie, B., Maury, L., & Bresson, F. Central and peripheral object distances as determinants of the effective visual field in infancy. Perception, 1978, 7, 499-506.

- Diamond, I.T., & Hall, N.C. Evolution of neocortex. Science, 1969, 164, 251-262.
- Dodd, B. The role of vision in the perception of speech. Perception, 1977, 6, 31-40.
- Dodwell, P.C. Contemporary theoretical problems in seeing. In E. C. Carterette and M.P. Friedman (Eds.), Handbook of perception (Vol.V). New York: Academic Press, 1975.
- Fishman, M.C., & Michael, C.R. Integration of auditory information in the cat's visual cortex. Vision Research, 1973, 13, 1415-1419.
- Fraiberg, S. Insights from the blind: Comparative studies of blind and sighted infants. New York: Basic Books, 1977.
- Freides, D. Human information processing and sensory modality: Cross-modal functions, information complexity, memory and deficit. Psychological Bulletin, 1974, 81, 284-310.
- Gebhard, J.W., & Mowbray, G.H. On discriminating the rate of visual flicker and auditory flutter. American Journal of Psychology, 1959, 72, 521-529.
- Gibson, E.J. Principles of perceptual learning and development. New York: Appleton Century-Crofts, 1969.
- Gibson, J.J. The senses considered as perceptual systems. Boston: Houghton-Mifflin, 1966.
- Haith, M.M. Visual competence in early infancy. In R. Held, H. Leibowitz, & H.L. Teuber (Eds.), Handbook of sensory physiology (Vol. VIII). Berlin: Springer-Verlag, 1977.
- Hammer, M., & Turkewitz, G. A sensory basis for the lateral difference in the newborn infant's response to somesthetic stimulation. Journal of Experimental Child Psychology, 1974, 18, 304-312.
- Harris, P.L. Eye movements between adjacent stimuli: An age change in infancy. British Journal of Psychology, 1973, 64, 215-218.
- Karmel, B.Z., Lester, M.L., McCarvill, S.L., Brown, P., & Hofmann, M.J. Correlation of infants' brain and behavior response to temporal changes in visual stimulation. Psychophysiology, 1977, 14, 134-142.
- Karmel, M.Z., & Maisel, E.B. A neuronal activity model for infant visual attention. In L.B. Cohen & P. Salapatek (Eds.), Infant perception: From sensation to cognition. New York: Academic Press, 1975.
- Lawson, K. Spatial and temporal congruity and intersensory integration in infants. Unpublished doctoral dissertation, The City University of New York, 1979.

- Maffei, L. Spatial frequency channels: Neural mechanisms. In R. Held, H. Leibowitz & H.L. Teuber (Eds.), Handbook of sensory physiology (Vol. VIII). Berlin: Springer-Verlag, 1977.
- Marks, L.E. The unity of the senses: Interrelations among the modalities. New York: Academic Press, 1978.
- McGurk, H., & Lewis, M. Space perception in early infancy: Perception within a common auditory=visual space? Science, 1974, 186, 649-650.
- McGurk, H., & MacDonald, J. Hearing lips and seeing voices. Nature, 1976, 264, 746-748.
- McGurk, H., & MacDonald, J. Auditory-visual coordination in the first year of life. International Journal of Behavioural Development, 1978, in press.
- McGurk, H., Turnure, C., & Creighton, S.J. Auditory visual coordination in neonates. Child Development, 1977, 48, 138-143.
- Mendelson, M.J., & Haith, M.M. The relation between audition and vision in the human newborn. Monographs of the Society for Research in Child Development, 1976, 41 (Serial No. 167).
- Mills, M., & Melhuish, E. Recognition of mothers voice in early infancy. Nature, 1974, 252, 123-124.
- Morgan, M.J. Molyneux's question: Vision, touch and the philosophy of perception. Cambridge: Cambridge University Press, 1977.
- Morrell, F. Visual system's view of acoustic space. Nature, 1972, 238, 44-46.
- Radeau, M., & Bertelson, P. Adaptation to auditory-visual discordance and ventriloquism in semirealistic situations. Perception and Psychophysics, 1977, 22, 137-146.
- Reisberg, D. Looking where you listen: Visual cues and auditory attention. Acta Psychologica, 1978, 42, 331-341.
- Regan, D., & Spekreijse, H. Auditory-visual interactions and the correspondence between perceived auditory space and perceived visual space. Perception, 1977, 6, 133-138.
- Ruff, H.A., & Birch, H.G. Infant visual fixation: The effect of concentricity, curvilinearity, and number of directions. Journal of Experimental Child Psychology, 1974, 17, 460-473.
- Siqueland, E.R. Operant conditioning of head turning in four-month-old infants. Psychonomic Science, 1964, 1, 223-224.

- Sokolov, E.N. Perception and the conditioned reflex. New York: Macmillan, 1963.
- Sokolov, E.N. The neuronal mechanisms of the orienting reflex. In E.N. Sokolov and O.S. Vinogradova (Eds.), Neuronal mechanisms of the orienting reflex. Hillsdale: Laurence Erlbaum Associates, 1975.
- Spelke, E.S. Infants' intermodal perception of events. Cognitive Psychology, 1976, 8, 553-560.
- Spelke, E.S., & Owsley, C.J. Intermodal exploration and knowledge in infancy. Infant Behavior and Development, 1979, 2, 13-27.
- Taylor, R.L., & Campbell, G.T. Sensory interaction: Vision is modulated by hearing. Perception, 1976, 5, 467-477.
- Thompson, R.F., Mayers, K.S., Robertson, R.T., & Patterson, C.J. Number coding in association cortex of the cat. Science, 1970, 168, 271-273.
- Tronick, E. Stimulus control and growth of the infants effective visual field. Perception and Psychophysics, 1972, 11, 373-376.
- Turkewitz, G., Birch, H.G., Moreau, T., Levy, L., & Cornwell, A.C. Effect of intensity of auditory stimulation on directional eye movements in the human neonate. Animal Behaviour, 1966, 14, 93-101.
- Turkewitz, G., Gordon, B.W., & Birch, M.G. Head turning in the human neonate: Effect of prandial condition and lateral preference. Journal of Comparative and Physiological Psychology, 1968, 59, 189-192.
- Turkewitz, G., & McGuire, I. Intersensory functioning during early development. International Journal of Mental Health, 1978, 7, 165-182.
- Wertheimer, M. Psycho-motor coordination of auditory-visual space at birth. Science, 1961, 134, 1692.
- Whitfield, I.C. The object of the sensory cortex. Brain and Behavioural Evolution, 1979, 16, 129-154.
- Wickelgren, B.G. Superior colliculus: Some receptive field properties of bimodally responsive cells. Science, 1971, 173, 69-72.
- Winer, B.J. Statistical principles in experimental design. New York: McGraw-Hill, 1971.

## Appendix A

The oldest group of infants in Experiment I showed a strong preference for the faster visual pattern, while the younger groups had a position bias. The purpose of the present experiment was to check for preferences in 4-month-olds, and hence ability to discriminate, between the fast and slow rates used in Experiment I, when there was control for position bias. This was accomplished by presenting the patterns successively, rather than simultaneously.

### Method

#### Subjects

Twelve infants participated in the experiment. Data for 2 infants were not fully collected due to fussiness during testing and have been excluded from the analysis. The mean age of the infants was 4 months, 11 day (SD = 3 days). Infants were recruited as before. No attempt was made to balance or control for race, sex or socioeconomic status.

#### Stimuli

The stimuli were the same as in Experiment I, except that they were presented from a position directly in front of the infant (as in Experiments II and III). The pattern with the faster rate was always accompanied by the synchronized sound, as was the slower rate pattern.

#### Procedure

Each infant was tested in the experimental enclosure as used in all of the experiments. The procedure was identical to that used in Experiment II except that the infants received only 12 trials; 6 with the faster and 6 with the slower rate, presented in a random order to each infant.

## Results and Discussion

A t-test for correlated samples was performed on the average looking time for the fast vs. the slow rate.

The resulting t value (t (9) = 1.93) was significant at the one-tailed, but not the two-tailed .05 level.

The infants demonstrated a marginal preference for the faster rate pattern, as did group 3 in Experiment I, when their looking was controlled for position bias. Other researchers (Karmel, Lester, McCarvill, Brown & Hoffman, 1977) have shown that the visual attention and occipital brain response of 13 week old infants to temporal frequency covary, with visual attention and neurophysiological response functions having similar maxima at 4.8 HZ and 5.8 HZ, respectively. The infants displayed less visual attention to temporal frequencies both higher and lower than the maxima. Although, in the present experiment, the flashing light pattern was also accompanied by sound and the on-off periods were not equal, the results are complementary. A preference was found in the same direction as that found by Karmel et al.

## Appendix B

## Consent Form

THE UNIVERSITY OF BRITISH COLUMBIA

2075 Wesbrook Mall

VANCOUVER, B.C., CANADA

V6T 1W5

Department of Psychology

## CONSENT FORM

This experimental procedure has been requested by

Keith Humphrey

I have been informed of the procedures and understand them. I also understand that the procedures may be terminated at any time at my request.

## Procedure:

The infant will be held on his/her guardian's lap in front of the testing apparatus. The infant will see and hear various patterns of light and sound. An investigator will watch the baby through a peephole and make a record of what the baby looks at. The baby will be held by, and be under the control of, the guardian at all times. Whenever the guardian desires there will be a break in or termination of the testing session.

My signature below certifies that I consent to the experimental procedure which has been described and which is to be conducted on the following date:

in the following place Psychology Annex, U.B.C.

and designated in the following manner: As Above

Date: \_\_\_\_\_ Name: \_\_\_\_\_

Signature: \_\_\_\_\_