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LEWKOWICZ, DAVID JOSEPH
INTENSITY-BASED INTERSENSORY EQUIVALENCE IN
HUMAN INFANTS.

CITY UNIVERSITY OF NEW YORK, PH.D., 1979

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INTENSITY-BASED INTERSENSORY EQUIVALENCE IN HUMAN INFANTS

by

David J. Lewkowicz

A dissertation submitted to the Graduate
Faculty in Psychology in partial fulfill-
ment of the requirements for the degree
of Doctor of Philosophy, The City University
of New York.

1979

This manuscript has been read and accepted for the Graduate Faculty in Psychology in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

May 3, 1979
date

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ABSTRACT

INTENSITY-BASED INTERSENSORY EQUIVALENCE IN HUMAN INFANTS

by

David J. Lewkowicz

The present study investigated the presence of intersensory equivalence in 3-4 week-old infants and examined a possible basis for such an equivalence. Schneirla suggested that functioning during early stages of development is based on the quantitative aspects of stimulation (effective intensity). Insofar as responsiveness during the early stages of development is based on the quantitative aspects of incoming stimulation, there is the possibility that inputs into the auditory and visual modalities that are equal in terms of their effective intensity are responded to by the infant as essentially the same.

To examine this possibility a habituation-dishabituation paradigm with a generalizaiton procedure was employed with magnitude of HR change as the dependent variable. Twenty-eight 3-4 week-old infants were first repeatedly (20 times) exposed to a 1 sec. patch of white light (11.36 ftL) following which they were then presented with seven different intensities of a 1 sec. burst of white noise spaced at 2 db intervals which ranged from 68 db to 80 db. These seven intensities ranged symmetrically around an intensity (74 db) judged by adult subjects to be equivalent in intensity to the light used as the habituating stimulus.

The data suggested that the infants did in fact respond to auditory stimuli as more or less equivalent to the visual stimulus as a function of their intensity. Thus, the infants showed the smallest cardiac response to the 74 db stimulus with increasingly larger responses as the stimuli departed in either direction from that 74 db stimulus. The one exception to this generality was the response to the 68 db stimulus which on a number of grounds was judged to be subthreshold. When this value was ommitted the existence of a cross-modal generalization gradient was indicated by a significant quadratic and no significant linear trend. Such a response pattern is markedly different from the monotonically increasing cardiac response obtained when infants are exposed to auditory stimuli of increasing intensities without prior exposure to visual stimuli. Further evidence of cross-modal intensity-based equivalence was obtained in a second group of 14 3-4 week-old infants who were repeatedly exposed to a higher intensity white light during the habituation phase of the study. Unlike the case for the first group, results from this group are best described as an inverted U with a significant quadratic and no linear trend. These results indicate that the effect of exposure to visual stimuli on subsequent responsiveness to auditory stimuli is not a general effect of prior stimulation but is rather determined by the intensity of the habituating stimulus. Such a specific effect can best be understood in terms of the infants responding to the auditory stimuli in terms of the degree of their similarity in intensity to the intensity of the visual stimulus.

Separate analyses for boys and girls indicated that the pattern of response to the different sound intensities was highly similar in the two groups but that overall girls were significantly more responsive than were the boys. Finally, results obtained from a group of 31 adults tested with the same procedures as those used for the infants revealed that although adults are capable of making cross-modal matches of intensity when asked to do so, unlike the infants, under spontaneous conditions they do not equate hetermodal stimuli in terms of their intensity.

Acknowledgements

I wish first and foremost to express my deepest gratitude to Dr. Gerald Turkewitz for serving as my advisor and for providing just the right measure of encouragement, guidance, criticism and friendship. I also thank the other members of my committee, Dr. H. Philip Zeigler and Dr. James Gordon, as well as the two outside readers, Dr. Bernard Karmel and Dr. Howard Topoff for their helpful comments and criticisms. Dr. Holly Ruff kindly read the manuscript and provided helpful comments.

For assistance during the course of this study I am grateful to Judith Gardner, Stephanie Phillips, and Bennett Celsa. Dr. Dirk Houben and Dr. Stanley Novak are two people without whose technical help this study would not have been possible and I am grateful to them.

Finally, I wish to thank my wife Robin whose unquestioning love made this seem that much more worthwhile.

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CHAPTER 1

INTRODUCTION

Understanding both the basis for processing of sensory input and the relationships between the various modalities during the early stages of development is important in the shaping of our views concerning the effective perceptual environment of the young infant. It has been suggested (Schneirla, 1959; 1965) that young organisms, instead of responding to the qualitative features of their environment, at first only respond to the quantitative aspects of stimulation. If quantitative aspects of stimulation do indeed form the basis for early sensory functioning then because responsiveness to input into the various modalities is based on a common characteristic of stimulation the various sense systems must be functionally equivalent. The primary aim of this study will be to examine aspects of the relationship between stimulus intensity and responding and some of its implications for intersensory equivalence.

Theories of Perceptual Development

In some discussions of perceptual development the notion of intersensory equivalence is noted explicitly while in others this idea is implicit in the authors' characterization of the nature of early sensory functioning.

Werner (1973) characterized development as a process of differentiation of parts and their subsequent subordination, or hierarchization. According to Werner, the most important characteristic of the early stages of development is the fact that there is a "syncretic unity of the senses", where the senses display a close intersensory relationship.

Werner states that "The sphere of the senses proper - of seeing, tasting, smelling, etc. - appears to exhibit a much closer intersensory relationship at the more primitive levels" (Werner, 1973, p. 86). In this undifferentiated state there is a merging of different sensory experiences into one, such as in the experience of synesthesia, where exposure to a tone results in not only hearing the tone but hearing a particular color as well.

According to Werner, synesthesia occurs under conditions of "vital sensation" which is a special form of sensation, distinguished from an objective type of sensation by virtue of the fact that it is a subjective phenomenon. While a person listening to a note played on the piano may hear the note as emanating from a particular source, a person experiencing a "vital sensation" feels as if that note actually originates within his or her body. Since during a vital sensation objective stimuli which impinge on the different senses are experienced as being within the single subjective body, the subject can no longer tell which modality is being stimulated. As a result, perception becomes intersensory in nature, mediated by what Werner refers to as a "sensorium commune". It is this "sensorium commune" which forms the basis from which the differentiation of specific sensory modalities during development takes place.

Piaget's (1952, 1954) consideration of the cognitive development of infants led him to the observation that when the infant enters the world he is equipped with a variety of reflexes. These reflexes constitute the first sensori-motor plans, or schemata. Through continuous use these reflexes become differentiated from being very global to more specific. Thus, for example, one of the schemata present at birth is the sucking reflex. At first sucking is a global kind of schema because the infant will suck any object that is put in its mouth. A little later, however, the sucking schema becomes differentiated so that objects containing milk are accepted, while those not containing milk are rejected. As a result of differentiation, the infant now posesses two schemata, one for objects containing milk, and one for objects containing no milk. The importance of the above example lies in the fact that initially the infant's sensori-motor functioning is global in nature. The infant treats all objects as equivalent, despite the fact that to the adult these objects are qualitatively very much different from each other.

The most recent major statement regarding the principles of perceptual development has been put forth by Gibson (1969). She makes the initial assumption that the environment, and the stimuli that make it up, does not give rise to simple sensations, but instead, since the stimuli in this environment are rich and varied, they give rise to diverse, meaningful, and complex perceptions. The limit on the extent to which the organism is responsve to the various features of the environment is imposed by the stage of development of the organism.

Gibson characterizes the general nature of the developmental process as starting with a crude and gross differentiation of the environment and proceeding until the organism becomes capable of discriminating more precisely features of the environment not discriminated previously. In other words, perceptual development is best described as a process of differentiation where there is a change in what the organism responds to; there is an increase in specificity, implying the learning or extraction of properties, patterns, and distinctive features that previously did not exist for the organism. The principles and mechanisms underlying this development are an abstraction of the differential properties of stimuli, filtering out of irrelevant variables of stimulation, and selective attention.

Working within a broad comparative context, Schneirla (1959; 1965) has offered an all-encompassing theory of behavioral development known as the Approach-Withdrawal Theory. One part of this theory, hereafter called the Intensity Hypothesis, states that the early stages of sensory/ perceptual functioning are based on responsiveness to the quantitative aspects of stimulation. These quantitative aspects of stimulation have been referred to as effective intensity, a notion which includes not only the physical intensity of stimulation but also such factors as species-specific properties of receptors, the organism's previous experience, the developmental status of the organism, and the state of arousal.

Based on Schneirla's proposition that young organisms respond primarily to the effective intensity of stimulation, it follows that various sensory systems respond to one and the same attribute of stimulation. This common attribute of stimulation serves as a common denominator for the various sensory modalities and as a result gives rise to the possibility that at first sensory systems operate as a sort of single entity. For this to be true, however, the various sensory modalities must have a mechanism that converts their input into a quantitative form with the result being something akin to what Werner (1973) calls the "sensorium commune". To take this argument one step further, if responding early in development is based primarily on the effective intensity of stimulation and if as a result sensory information is assessed in a similar manner regardless of the modality that receives the information, there must be some form of functional equivalence between the sensory systems at these early stages.

In summary, the most evident feature common to all the theories presented here is their insistence on a process of differentiation during development. The differences between the theories are concerned with the processes or mechanisms associated with this differentiation. Werner, Piaget, and Gibson all view the process of perception as the response of an organism to some features of the environment. The analysis of these features is crude at first but becomes more differentiated as development progresses. Secondly, Werner, Piaget, and Schneirla all view development as a process leading to the elaboration of qualitatively different levels of organization. Thirdly, unlike Gibson who proposes that distinctive features of stimuli are responded to, and unlike Werner and Piaget who do not specify what aspect of stimulation the young organism responds to, Schneirla proposes that early in development organisms respond to the effective intensity of stimulation, with a shift from a level of functioning based on responsiveness to the quantitative aspects of stimulation to another level based on responsiveness to the qualitative aspects of stimulation.

The primary aim of this study is to explore the possibility that responsiveness to effective intensity mediates a crude form of intersensory equivalence during the early stages of development. First, however, the likelihood that effective intensity is the mediator of responding in early development must be assessed and as discussed below there is considerable evidence suggesting that this may be so.

Evidence for the Role of Quantitative Factors in Early Development

Results from various studies indicate that stimuli differing in qualitative attributes are responded to differently by even very young organisms. However, the fact that young organisms respond differently to stimuli which differ qualitatively does not necessarily imply that the differential response is based on these qualitative differences.

Instead, the young organism may be responding to the quantitative aspects of these stimuli. If quantitative factors are indeed the mediators of early sensory/perceptual functioning, qualitatively different stimuli that are equivalent with regard to their effective intensity should elicit similar types of responding. In fact, a series of studies of imprinting in precocial birds indicates that an almost bewildering array of stimuli are equally effective in eliciting approach behavior even though they differ qualitatively.

Thus, a variety of visual stimuli have been found to be effective in eliciting approach. Hinde, Thorpe, and Vince (1956) found that a black box was as likely to be followed by Moorhens and Coots, as a Moorhen model. Fabricius (1951) reported that following was not differentially affected by differences in size or shape. In another study (Moltz, Rosenblum, & Stettner, 1960) it was found that a green cardboard box and a model of an adult Peking Duck were equally effective in eliciting following. Finally, James (1959, 1960) and Abercrombie and James (1961) reported that a flashing light at one end of an alley, or a stationary object with a flashing light next to it, were both effective in eliciting approach.

Several other studies have demonstrated the effectiveness of auditory stimuli. Collias and Collias (1956) showed that a repetitive tone was effective for several species of birds. A retreating rhythmic tone elicited strong following even if not associated with a moving object (Fabricius & Boyd, 1953). Smith and Bird (1963) reported that a repetitive tone from a loudspeaker at the end of the alley, or a moving pendulum were equally effective as imprinting stimuli.

Additive effects of stimuli from different modalities have also been noted. Gottlieb (1963) reported that Peking ducklings showed a stronger preference for a moving Mallard decoy emitting a sound, than for the decoy without the sound. Boyd and Fabricius (1965) observed the same effect with Mallards. This is important because it suggests the possibility that a common dimension of stimulation is responded to in the two modalities.

From the evidence reviewed above it is obvious that a wide variety of stimuli are effective in eliciting approach responses in precocial birds. There is no doubt that these stimuli are very different in kind and yet all are effective. One possible explanantion for this effect may be that such features as rate of movement, size, temporal patterning, etc., all contribute in some way to the effective intensity of a given stimulus. In terms of an actual neural mechanism, all of these features may be translated into effective intensity by activating groups of neurons whose activity is interpreted by the higher brain regions not as indicating a given feature, but simply as a given amount of gross neural activity produced.

Whether responsiveness to effective intensity is in fact the common underlying basis for the similar results observed in the above studies remains to be demonstrated by more directs methods. Nevertheless, it seems that a useful way to explain the effectiveness of such a diverse assortment of stimuli in eliciting approach behavior in precocial birds is to assume the existence of a common mechnism based on effective intensity. A variety of stimuli have also been shown to elicit similar responses in infants thereby providing further data in support of the Intensity Hypothesis.

Pratt, Nelson, and Sun (1930) observed that stimulation of the lips of a newborn infant was followed by the sucking reaction but that sucking was also elicited by thermal, gustatory, and olfactory stimuli. The authors went on to describe the infant at birth:

> "The infant at birth represents an organism in which differentiation has proceeded to the point where there are many effectors and many receptors. Its behavior, however, is generalized, that is, stimulation of almost any group of receptors by almost any kind of stimulus will lead to a response in almost any part of the organism (Pratt, Nelson, & Sun, 1930, p. 208)."

Bridger and Birns (1963), investigating the effectiveness of various soothing agents, found that head rocking and sucking on a pacifier were equally effective in lessening 2-5 day-old infants' response to stress. Results from both the imprinting studies and infant studies show that various forms of stimulation, different in kind, are effective in producing the same response. One interpretation of such findings may be that the aspect common to all of these different types of stimuli is the effective intensity of the stimulus.

Attempts to find the basis underlying the young infant's visual discriminative capacities have also suggested that effective intensity affects visual responding. Fantz (1958) found that infants under 14 months of age fixated a checkerboard longer than a square, and a bullseye longer than stripes. In a later study (Fantz, 1961) 2-3 month-old infants were shown to fixate patterns twice as long as non-patterned discs. The general conclusion from these studies was that young infants had the ability to discriminate patterns and subsequent studies have been concerned with discovering the basis underlying such discriminations. As noted below, various features of the visual stimulus such as contour density (Karmel, 1969), brightness (Hershenson, 1964), and size and number of elements (Fantz & Fagan, 1975) have been implicated as the key features underlying such discrimination in young infants. An interesting aspect of the visual fixation data from the present standpoint is that all of these studies have reported obtaining a similar relationship between a quantitative aspect of stimulation and directional responding, again suggesting that a common mechanism may mediate responding.

Hershenson (1964) examined the relationship between fixation preferences and the brightness of a patch of light and found an inverted U-shaped relationship between fixation and brightness. The results indicated that the patch of intermediate intensity was fixated more than the dimmer or brighter one. In an experiment designed to investigate visual preferences for angles, Hershenson, Munsinger, and Kessen (1965) obtained an inverted U-shaped relationship between fixation time and number of angles, such that patterns with an intermediate number of angles were fixated longer than those with fewer or more. Cohen (1969) obtained an inverted U-shaped function relating patterns of lights flashing at different rates and fixation time. Lastly, several studies concerned with the effects of contour density on fixation preferences have found that patterns with intermediate contour density were fixated longer than patterns with greater or lesser density of contour (Karmel, 1969; McCall & Kagan, 1967). Visual evoked potentials indicate a U-shaped relationship between contour density and the amplitude of the late-negative component peak in infants 6 weeks of age (Hoffmann,1978) and the amplitude of the positive component peak in infants two months and older (Karmel, Hoffmann, & Fegy, 1974).

Once again, it seems reasonable to assume that the various attributes of stimulation such as contour density, brightness, size, and number of elements are dimensions that can in some way contribute to the intensity of a stimulus. That is, a series of stimuli varying along one of the above dimensions can be thought to induce differential levels of neuronal acitivity at some level of the nervous system, resulting in differential responding. Evidence pertaining to this view, as well as a mechanism underlying such effects, has been presented by Karmel and Maisel (1975).

A number of other studies designed specifically to test various aspects of Approach-Withdrawal Theory including the Intensity Hypothesis have been carried out to date and this last section will consider them in some detail.

As previously outlined, the Intensity Hypothesis states that in addition to the objective intensity of external stimulation, organismic variables also contribute to effective intensity. One prediction arising out of this idea is that responding should be affected in the same way when external stimulation is varied and organismic variables are kept constant, and when external stimulation is kept constant and organismic variables are varied. Turkewitz, Fleisher, Moreau, Birch, & Levy (1966) varied one organismic variable, state of arousal, by testing infants pre- and post-feeding and observed a relationship between finger flexor and extensor movements and physiological state of arousal induced specifically by the infants' feeding cycle. An index of the direction of hand movement as given by the proportion of flexor to extensor movements was greater in infants who were tested prior to a feeding as compared to infants who were tested after a feeding. Recently, Gardner (Personal communication, 1979) examined the effects of variations in state of arousal on visual preferences in premature infants. She found that looking preferences to visual stimuli either flashing at different rates or consisting of different numbers of elements could be shifted by variations in the infant's state of arousal.

In another study (McGuire & Turkewitz, 1977) external, rather than internal stimulation was varied and effector extension and flexion were the responses that were measured. Infants were presented with a slowly rotating red cone. All organismic variables were kept constant as much as possible, while stimulus intensity was controlled by varying the size, distance, and brightness of the red cone. Looking at the direction of the infants' first finger movements it was found that the younger infants (10-15 weeks old) made finger extension movements to the least intense stimulus, and finger flexion movements to the most intense stimulus. Finger extension decreased significantly, while finger flexion increased significantly as a function of increasing stimulus intensity. As stated previously, Schneirla's Intensity Hypothesis is only applicable to the early stages of development. As development progresses, a shift away from effective intensity as the principal determinant of sensory/perceptual functioning takes place. Consistent with this view, McGuire & Turkewitz found that in the older group of infants (20-25 weeks old) no relationship between stimulus intensity and responding could be demonstrated.

Thus far it has been shown that organismic variables such as physiological arousal associated with hunger, and size, distance, and brightness together determine responding in a similar fashion in young infants. Other studies have also varied such quantitative dimensions of stimulation as size and brightness separately, where the measure of their effectiveness was assessed by looking at the infant's fixation preferences. If, for example, two stimuli differ from each other in terms of pattern, as well as effective intensity, as determined by size, then it is possible to examine the relative contribution that each makes to visual responsiveness. Ruff & Turkewitz (1975) showed pairs of visual stimuli consisting of a bullseye and a striped pattern, differing in size, to infants from 6 to 24 weeks old and found that infants 10 weeks or younger consistently fixated the larger stimulus of the pair, regardless of pattern, while the older infants fixated the bullseye more often, regardless of its size or the size of the striped pattern paired with it. Thus, it appears that young infants respond to the quantitative aspects of stimulation more than to the qualitative ones.

Finally, if what the organism responds to when faced with a number of stimuli is their effective intensity, then these stimuli, which can independently influence responding when presented together should summate to produce a net behavioral effect greater than each separately can produce. In a second study Ruff & Turkewitz (1979) report data that suggest that summation of two stimuli can produce an effect greater than that produced by each one separately. In this study specific sizes and brightnesses were combined to form five distinct levels of intensity. The five levels were then paired with each other and were presented to 9 week-old infants. Results indicated that fixation time increased as a function of increasing intensity. More important, although both size and brightness were independently effective, the combined stimuli appeared to be more effective than each separately.

Intersensory Integration - Equivalence

In addition to the issue concerning the basis for sensory/perceptual functioning in early development, a second issue of interest here is one regarding intersensory integration with a specific emphasis on intersensory equivalence. Perhaps the earliest statement of the problem of intersensory integration was made by Molyneux in a letter to John Locke (cited in Gibson, 1969). In the letter Molyneux asked whether a congenitally blind man who had learned to distinguish between a cube and sphere by touch would be able to distinguish the two objects by sight alone if his sight were suddenly restored. In effect Molyneux asked whether information acquired about a specific property of an object in one modality can be transfered to another modality to permit the identification of that object as the equivalent one.

There are a number of ways in which sensory systems may interact with one another (Ryan, 1940). Molyneux's query is an example of one type of interaction which is based on the cooperative functions of various sense systems. Multimodal inputs arising from objects or events may be used to provide equivalent information about these objects or events and result in the perception of a unified whole. Cooperation between the senses may also be used for localization of objects in space as for example starting a head turn in the direction of the sound of a car crash and stopping the moment we see the source of the sound. In other types of sensory interactions hetermodal stimulation may act either to change thresholds in a given modality or to change the qualitative characteristics of stimulation (see Ryan, 1940). The first kind of interaction is a form of facilitation and is exemplified by the increased sensitivity to short wavelengths of light in the presence of acoustic stimulation. The latter type of interaction may be illustrated by the fact that a low frequency tone may make a color seem darker and may shift its hue toward the red end of the spectrum.

As the foregoing makes evident, there are several ways in which sensory systems may interact with one another. The aspect of intersensory integration that is of particular interest here is intersensory equivalence, although of a rather different kind than that exemplified by Molyneux's query. To repeat, generally speaking, intersensory equivalence is the ability to recognize the same stimulus in different modalities. For example, after seeing a sequence of temporally distributed dots one is able to recognize the same temporal sequence when it is presented auditorily in the form of tones. Intersensory equivalence, as well as use of multimodal inputs, are both examples of what Ryan (1940) called the cooperative functions of the sense systems. However, the processes whereby multimodal inputs are used to specify a given stimulus are different from the ones operating in intersensory equivalence. Whereas the former merely involves the coordination of multimodal inputs, the latter is viewed as reflecting a more sophisticated process because the organism detects and responds to similarities and differences across modalities (Von Wright, 1970). While Von Wright's characterization of intersensory equivalence is useful, from the present standpoint it probably appplies to a higher level form of equivalence found after differentiation of input from various senses has taken place. As far as the young infant is concerned, however, if differentiation between the senses has not yet occurred all that he can respond to is the similarity between heteromodal stimuli. Thus, the kind of intersensory equivalence present in infants would be of a lower level than that found in adults.

The difference between the two forms of intersensory cooperation, equivalence and use of multimodal inputs, is illustrated by the following examples. When infants are shown two films side-by-side, one of which corresponds to a centrally placed soundtrack, they will look more at the film whose visual attributes are congruent with the auditory characterícstics of the sound (Spelke, 1976). Recognition of the correct film merely involves the ability to recognize the common stimulus properties of the two disjoined stimulus sources at the same time and does not involve the learning about some property of a stimulus in one modality and then transferring the information to another modality. Similarly, in experiments involving conditional learning where an animal is taught to respond differently to a light depending on whether it is or is not accompanied by a sound, no tranfer of information from one modality to another needs to take place.

In the "dialogue" among themselves, the various sense systems utilize a variety of features arising from the stimulus situation. Broadly speaking, these features can be divided into those that are amodal or universal in nature and those that are modality-specific. While the former may be used to specify stimulation in any modality, the latter, with the exception of synesthesia, can only be used to specify stimulation in one particular modality. Examples of some amodal features are intensity, rate, duration, spatial extent, and rhythm. Examples of modality-specific features are such qualities as redness, sourness, and pitch.

Schneirla's proposition that responsiveness to effective intensity is the principal mode of functioning in young infants suggests that early in development the capacity for the perception of intersensory equivalence is of a low level. It, therefore, follows that only certain of the amodal features can be used by the young infant. Thus, only quantitative factors (specifying amount of stimulation) may be used by the infant in the perception of intersensory equivalence. Candidates from the previously mentioned list of amodal features are intensity, duration, and rate. As development progresses the infant may acquire new types of integration allowing him to respond to more complex heteromodal inputs specifying shape or form of an object or the temporal characteristics of a moving and sounding object such as its rhythm. Because animals at various phyologenetic levels are different with regard to the complexity of their organization, examination of cross-modal perception of equivalence at different phylogenetic levels may suggest alternative modes of cross-modal organization which may prove fruitful in examining the development of intersensory equivalence in the human infant.

Insofar as some species of animals are more advanced with a concommitant elaboration of their nervous systems, these species should be able to utilize the more complex kinds of stimulus properties both unimodally and cross-modally. Indeed, Maier and Schneirla (1935), in their attempt to formulate a phylogenetic series based on the plasticity of behavioral mechanisms, regarded an animal's capacity for integrating sensory information from different modalities as important in determining the animal's psychological status. It must be noted, however, that such a basis for ordering organisms does not result in the same relationships as would a series based upon the organism's ability to utilize complex forms of unimodal stimulation. Thus, although rats and octopuses may both be quite adept at making discriminations of visual form (Lashley, 1938; Sutherland, 1957) rats are more likely to be able to use that information in learning a discrimination in the tactual modality. This is because in the octopus, at least, no interaction between the visual and tactual sense systems is possible since the projection areas for these two modalities are in different parts of the octopus's brain and no interconnections exist between the two (Young, 1965). Recently Ward, Yehle, & Doerflien (1970) issued a plea for more studies of species differences in cross-modal transfer capacities based on the proposition that such capacities and the kinds of stimulus dimensions responded to may very well differ with phylogenetic position.

Phylogenetic Differences in Intersensory Perception of Equivalence

A number of studies provide evidence pointing to phylogenetic differences in capacities for detecting stimulus equivalence across different modalities. Studies of human infants as well as animals such as apes, monkeys, bushbabies, cats, rabbits, mice, and rats indicate that the more advanced species are capable of utilizing more complex stimulus properties for detection of cross-modal equivalence, while less advanced species are capable of detecting cross-modal equivalence of the simpler kinds of stimulus properties. In addition to reviewing phylogenetic differences in the perception of cross-modal equivalence, data regarding developmental differences will also be reviewed (developmental data are only available for the human infant). Studies dealing with infants will be reviewed first followed by a consideration of other species.

A close examination of the existing data on intersensory functioning in infants suggests that there may be developmental differences in the kinds of intersensory tasks the infant is capable of performing. That is, these developmental differences may reflect a low level of intersensory organization at early developmental stages and higher levels at later stages. Thus, at the early stages the infant's sensory systems may be integrated on the basis of the simple kinds of stimulus features while at later stages intersensory integration may be based on additional and more complex kinds of features.

Allen, Walker, Symonds, & Marcell (1977) employed the habituation paradigm to investigate the 7-month-old infant's ability to respond to the equivalence of temporal sequences presented to two modalities.

Briefly, the habituation paradigm involves the repeated presentation of one stimulus until a designated response wanes. This is followed by the presentation of a novel stimulus at which time there is typically a recovery or dishabituation of the response. Recovery of response is taken as an indication that the infant has recognized that there has been a change in stimulation.

Infants were first presented with either an auditory or visual sequence of 3 intermittent stimuli over 15 trials. Following habituation, either the same or a different intermittent sequence was presented in a different modality. Both sequences consisted of three elements (tones or lights); in the first sequence the first and second elements were separated by .3 seconds and the second and third by .9 seconds, while in the second sequence the elements were separated by .9 seconds. Although some dishabituation was observed when modality of stimulus presentation changed without any change in temporal pattern, significantly greater dishabituation of both heart rate and the galvanic skin response was observed in infants who were presented with a different temporal sequence in another modality. Thus, it appears that 7-month-old infants are capable of cross-modal recognition of similarities and differences in temporal patterns. However, a different interpretation is also possible. Due to the difference in the interval separating the first two elements in the two different sequences (.3 sec. vs. .9 sec.) it is possible that the infants were making the discrimination on the basis of the duration of this interval and not on the basis of the whole temporal pattern.

The transfer of shape information from touch to vision has been one of the most intensively studied aspects of intersensory equivalence in infants. Several studies have obtained evidence of transfer of shape information from touch to vision in the first year of life. Ruff & Kohler (1978) allowed 6-month-old infants to hold in their hands, without seeing, either a cube or a sphere. In order to assess the infants' memory for the previously felt object, a pair of objects consisting of the familiar and a novel object was then presented visually. Unfortunately, presumably because the sphere was more salient it elicited more looking time in all infants regardless of whether they had previously felt the sphere or the cube. Interestingly, however, the infants who were tactually familiarized with the cube showed significantly less looking time to the sphere than those infants who were familiarized with the sphere. This indicated that previous tactual experience had a differential effect on subsequent processing and that some transfer from touch to vision had occurred.

Bryant, Jones, Claxton, & Perkins (1972) obtained more convincing evidence of transfer of shape information from touch to vision. They first familiarized 6-11 month-old infants with an object which made a sound tactually and then presented that object plus another object of a different shape visually. The infants showed evidence of cross-modal recognition since the number who reached for the previously felt object was significantly greater than chance.

Finally, in a study of 1 year-old infants, Gottfried, Rose, & Bridger (1977) obtained evidence of both haptic to visual and somesthetic to visual transfer. Infants were allowed either tactual or oral (object placed in the mouth) familiarization followed by a visual recognition trial. Cross-modal transfer of shape following both tactual and oral familiarization was evidenced by the fact that infants looked and reached significantly more for the novel object.

In a second study, using the same procedure as above, Rose, Gottfried, & Bridger (1978) replicated the above findings with another group of full-term infants but found that preterm infants tested at the same conceptional age did not show cross-modal transfer on these tasks. Rose et. al. hypothesized that the observed lag on cross-modal tasks observed in these prematures may be due to one of three problems: (1) a deficit in the processing of tactual information, (2) a deficit in the processing of information in all modalities, and (3) a deficit specifically related to the cross-modal transfer of information. Whatever the problem, if one regards the premature infant as lagging in normal development relative to the full-term infant, the premature infant may be viewed as representative of an earlier stage of development and consequently of a younger full-term. This line of reasoning raises the possibility that the younger full-term infant should also exhibit a deficit in cross-modal transfer of shape, though, he may still be capable of transferring simpler types of stimulus properties. Likewise, the older premature infant who is not capable of cross-modal transfer of shape information may be able to use simpler stimulus properties for cross-modal functioning.

Animal Studies

In general, studies designed to investigate intersensory equivalence in animals have employed one of two paradigms: (a) matching to sample, or (b) transfer of training. The first paradigm involves teaching an animal to make a discrimination in one modality (touch) and then using the information acquired in that modality to choose the same object in another modality (vision). In the transfer paradigm, an animal is first taught to make a discrimination based on some property of the stimulus (eg. shape) in one modality and is then trained to make the discrimination in another modality utilizing the same attribute of the stimulus. If significant transfer of training occurs then animals in the transfer condition should exhibit a considerable savings in their learning score over those animals who either did not learn the problem in the other modality first or those for whom the previously unrewarded shape is now rewarded (negative transfer).

Data regarding intersensory functioning in apes and monkeys indicate quite clearly that these animals can detect the cross-modal equivalence of complex information obtained in one modality to identify the same object in another modality. Davenport & Rogers (1970) and Davenport, Rogers, & Russel (1973) trained apes in a simultaneous matching-to-sample task to choose an object identical to the sample in a second modality. The results indicated that the animals performed above chance in choosing either the haptic equivalent of the visual sample or vice versa. Even more impressive, however, was the finding that when required to choose the correct photographic representation of a haptic sample, chimpanzees were able to do this both in a simultaneous matching task as well as in a delayed matching task where a delay interval was imposed between presentation of the haptic sample and presentation of the photograph (Davenport, Rogers, & Russel, 1975).

Despite repeated attempts to demonstrate intersensory perception in monkeys (Ettlinger, 1967; 1973; Frampton, Milner, & Ettlinger, 1973; Milner, 1970) a number of early studies were unable to do so. Recently, however, it has become clear that it wasn't so much the monkey's inability to utilize information acquired in one modality to recognize the same stimulus in another, but rather the experimenter's inability to properly test the animal for its existence. Cowey &

Weisekrantz (1975) and Weisekrantz & Cowey (1975) devised a technique whereby rhesus monkeys were taught a tactual discrimination in the dark by being given food shapes half of which were edible and half of which were inedible (adulturated with quinine). These animals learned very quickly to eat only the edible shape and to reject the inedible one. The matching test consisted of presenting the same pair of shapes visually and recording the animal's choice. The monkeys were able to choose the edible shape significantly more often that the inedible one. The above findings were replicated by Elliot (1977) in rhesus monkeys and extended to cebus monkeys and chimpanzees. Likewise, Jarvis & Ettlinger (1977), using an adaptation of the Davenport & Rogers (1970) procedure, were able to show cross-modal recognition of visual shape in rhesus monkeys as well as in chimpanzees, and for the first time tactile recognition of an object previously learned visually in rhesus monkeys.

Recently, on the basis of some rather limited data, Hewett & Ettlinger (1978) have indicated that there may be a difference between a non-human primate's ability to perform cross-modal matching tasks and cross-modal transfer tasks. In the former case, the animal is typically given a small number of discrimination trials (6) and then is immediately given a cross-modal recognition trial. In the latter case, the animal is usually given a large number of discrimination trials until a criterion is reached and is then given a similar number of training trials in the second modality. Evidence of cross-modal transfer is obtained by way of a savings score.

Hewett & Ettlinger (1978) report that out of four animals who previously showed good cross-modal matching, two rhesus monkeys and one chimpanzee failed to show any evidence of cross-modal tranfer, while one chimpanzee did. The authors cite these differences in matching and transfer abilities as a reflection of different processes but because their assertions are based on just four animals, one of which did in fact show cross-modal transfer, they should be accepted with caution.

In one of two studies examining transfer of an intensity discrimination in the monkey (Wegener, 1965) negative results were reported. Rhesus monkeys were first trained to press a door on one side if a light stimulus was bright and to press the other door if the light was dim. After acquisition, transfer of training was assessed by training the animals to make the same discrimination with an auditory cue. The auditory cue, however, differed not only with respect to intensity but also frequency. Although in the original report the author found no evidence of transfer and in fact found that training in the first modality interfered with learning in the second modality, a recent reanalysis of these data (Frampton et al., 1973) has revealed a statistically significant effect of cross-modal transfer on trials 1-10, but not for trials 11-20 or 20-30 of the transfer task. Admittedly the above effect is rather weak and further judgement regarding the monkey's ability to use intensity cues cross-modally must be reserved. Several factors may have militated against the finding of more robust transfer effects. One was that the discrete trial procedure used in this study may have emphasized absolute rather than relational stimulus properties during discrimination training. Two, that unless the polysensory stimuli were first matched so as to be of the same intensity from the animal's standpoint, the only way of demonstrating cross-modal transfer of intensity is by emphasizing the relational properties of stimuli during discrimination training. Finally, as is always the case with negative or weak findings, there is the possibility that more extensive training procedures would demonstrate the phenomenon. This point is especially á propos here in the light of recent succesful demonstrations of cross-modal abilities in monkeys which earlier work was not able to demonstrate due to inadequate training procedures.

A study by Wilson & Zeiler (1976) represents the only other attempt to test for the presence of a cross-modal transfer effect of intensity in monkeys. In one respect, the design of this study seems to be an improvement over Wegener's (1965) since it provides a more explicit opportunity for the animal to learn the relational rather than the absolute nature of the stimuli. Squirrel monkeys were required to learn to press a panel on one side in the presence of one intensity of either light or sound and to press the panel on the other side in the presence of the other intensity. To provide a reference intensity for the other two intensities and thus facilitate relational learning, a stimulus judged to be midway between the two intensities was also provided. During auditory training the middle intensity was only present during the interstimulus interval but during visual training the middle intensity light remained on during stimulus presentation as well as during the interstimulus interval. Thus, for example, during training the following contingency was present, high intensity - respond left; low intensity - respond right. Comparison of the positive transfer and negative transfer groups did not reveal any savings in the number of trials to criterion in the second modality for the positive transfer group. Thus, no evidence of a cross-modal transfer of intensity was obtained.

The problem here is that while the middle stimulus may provide an "anchor" and facilitate relational learning, it also introduces the possibility that the animal is learning different contingencies signaled by different discriminative stimuli. On the one hand, during auditory training the animal learns high intensity - respond left; low intensity - respond right, and middle intensity - do not respond. On the other hand, during visual training the animal learns high intensity + middle intensity - respond left; low intensity + middle intensity - respond right, and middle intensity - do not respond. Thus, during auditory training the animal learns three contingencies each one signaled by a different and single stimulus, while during visual training the animal learns three contingencies, two of which are signaled by a compound visual stimulus. Given the above contingencies the design of the study does not provide an appropriate test for cross-modal transfer of intensity. Had the middle intensity light been confined to just the interstimulus interval, the above discussed problem would have been obviated. Even then, however, it may be that the discrete trials paradigm may not be as efficacious in demonstrating cross-modal transfer as may an operant conditioning one be.

In sum, the criticisms offered previously regarding the Wegener study apply equally well to the Wilson & Zeiler study and the question of cross-modal transfer of intensity in monkeys must remain an open one until further studies are done. In view of the monkey's ability to transfer complex shape information cross-modally, it seems unlikely that these animals are incapable of utilizing intensity for detecting stimulus equivalence in different modalities.

Cross-modal transfer of another simple stimulus property such as rate has been demonstrated in the prosimian primate, the bushbaby, as well as, the cat, rabbit and mouse. In a study of go-no-go shock avoidance task (Ward et al., 1970) bushbabies were first trained to discriminate between two intermittent visual stimuli (3/sec vs. 18/sec) or two auditory stimuli. Transfer tests in the second modality indicated significant effects of previous training regardless of which modality was used during training. Ward, Silver, & Frank (1976) carried out a partial replication of the Ward et al. (1970) procedure and found a significant facilitation of discrimination learning in the auditory modality following visual training. Interestingly, Ward et al. (1976) also made an attempt to obtain discrimination of a more complex stimulus such as rhythm. The animals were required to discriminate either between two rhythmic patterns of flashes or two rhythmic patterns of clicks. Both patterns consisted of nine elements in clusters of three with the difference being that in the irregular pattern the interval between the elements within a cluster was not the same. Although these tests were conducted after completion of the main experiment, where the animals had extensive training with intermittent flashes and clicks, they showed no evidence of being able to make discriminations of the rhythmic patterns. This was the case even after as many as 1200 discrimination training trials. However, when an intensity difference was superimposed unto the rhythm difference the bushbabies had no difficulty making the discrimination. Unfortunately, although the authors report succesful discrimination of intensity differences within a modality, there is no mention of any attempt to test cross-modal transfer of such a discrimination.

John & Kleinman (1975) trained 2 cats on a go-right, go-left conditional discrimination task to two rates of intermittent auditory stimuli. Transfer of training was evident in that fewer trials were required for the learning of the same discrimination in response to two intermittent rates of lights after learning had first taken place in the auditory modality.

Yehle & Ward (1969) and Ward & Yehle (1970), using a classical conditioning paradigm established a discrimination in rabbits between two rates of intermittent stimulation in either the visual or auditory modalities. Both the eyeblink response and heart rate showed evidence of transfer of training to the second modality. Response to CS+ in the second modality was maintained at the same level as in the last stages ofacquisition training and the positive transfer group performed significantly better than the negative transfer group.

Oliverio & Bovet (1969) trained mice in an avoidance conditioning paradigm by pairing an intermittent tone with shock. In the cross-modal transfer test the mice who were presented with an intermittent visual stimulus of the same rate as the sound (3 cps) showed a significant transfer of avoidance conditioning relative to a group who received a constant stimulus in the second modality.

Finally, in the only succesful demonstration of the cross-modal transfer of an intensity discrimination, Over & Mackintosh (1969) trained rats to either discriminate between two intensities of white noise or two intensities of white light. Barpressing in the presence of one intensity was rewarded and not in the presence of the other. Regardless of the modality in which training took place, significant transfer of training was found for all groups of animals in the positive transfer condition as compared to the negative transfer condition. Yeterian, Waters, & Wilson (1976) and Yeterian (1977) in studies concerned with the role of visual and auditory neocortex in cross-modal transfer in the rat, provided a partial replication of the Over & Mackintosh (1969) results. Sham-operated rats showed significant transfer of a visual discrimination of intensity to the auditory modality.

Neural Mechanisms of Cross-Modal Perception

A number of studies, using a variety of species, have explored the question of the neural mechanisms underlying cross-modal perception. In a study which was a partial replication of the Over & Mackintosh (1969) procedure, Yeterian et al. (1976) made lesions in the posterior neocortex of rats and found that these lesions interfered with cross-modal transfer of discriminative learning of intensity. In a second study, Yeterian (1977) made more discrete lesions confined either to the visual or auditory cortex and again tested for cross-modal transfer of an intensity discrimination of light or sound. Results indicated that while neither the auditory nor visual cortex is essential for learning of an intensity discrimination in either modality alone, both are essential for transfer of the discrimination from one modality to the other.

In bushbabies, on the other hand, association cortex does not seem to be necessary for the transfer of a discrimination from one modality to another. Ward et al., (1976) placed lesions in the posterior neocortex, an area lying between the primary visual and auditory projection areas, and found that cross-modal transfer of a rate discrimination was not affected.

In monkeys, as in rats, lesions in various parts of the cortex result in cross-modal deficits. Cross-modal matching of shape, based on the Cowey & Weisekrantz (1975) method, is disrupted by lesions placed in the foveal prestriate and posterior inferotemporal cortices, but not by lesions in the anterior inferotemporal cortex (Sahgal, Petrides, & Iversen, 1975). Lesions to the first two cortical areas interrupt visual information flow to a multisensory convergence area in the depths of the superior temporal sulcus and cause some damage to the sulcus itself. Lesions placed in the arcuate sulcus also produce deficits in cross-modal tasks (Petrides & Iversen, 1976) as well as deficits in responding to a compound visual-auditory stimulus (Petrides & Iversen, 1978).

Ettlinger (1977) discusses some data obtained by Humphreys on the effects of bilateral striate cortical lesions in monkeys. Following training to reach for visually presented objects the destriate monkeys showed immediate transfer to reaching to an "auditory object" which was a sound presented in the dark. Since striate lesions disrupt pattern perception but leave discriminative abilities of flux differences intact, these findings of immediate transfer suggest that this transfer is based on the intensive aspects of the stimuli and is most likely subcortically mediated.

Because so few data are available, a discussion of the possible brain mechanisms involved in cross-modal perception must of necessity be largely speculative. On the basis of their data, Ward et al. (1976) argue that cross-modal processing of such simple stimulus features as rate, which are easily encoded in all modalities, does not depend on cortical mechanisms but may instead depend on subcortical ones. Processing of more complex stimulus dimensions such as shape or rhythm may require a more elaborate neural substrate. Thus, the data from the monkey may be cited in support of the above position if it is assumed that cortical mechanisms are indeed necessary for cross-modal transfer of shape information. Taking this line of reasoning one step further, one should not expect to see any deficits in cross-modal transfer of intensity or rate discrimination following damage to the association neocortex in the monkey. While this is an empirical question, the answer will have to await the demonstration of cross-modal transfer of intensity or rate in the monkey.

The above conclusions are complicated, however, by the Yeterian findings of a deficit in cross-modal transfer of an intensity discrimination in the rat after damage to the cortex. To account for his data, Yeterian adopts a different line of argument which is equally intriguing. He notes that the evolution of the mammalian neocortex has probably proceeded from an animal whose neocortex was a point of convergence for both auditory and visual information and suggests that the rat may have proceeded far enough in evolution to acquire modality-specific areas while still retaining the phylogenetically old convergence area. Data indicating the existence of convergence areas in the cortex may be found in the cat where auditory and visual input converges unto single cells in the primary visual cortex (Bental, Dafny, & Feldman, 1968; Spinelli, Starr, & Barrett, 1968) and unto single cells in the sensory association cortex (Bental & Bihari, 1963). It is presumably these convergence areas of cortex which are responsible for cross-modal transfer of an intensity discrimination in the rat. Yeterian does, however, entertain the possibility that despite the importance of the auditory and visual cortices for intersensory perception, it is still not out of the question that the critical region for convergence may be in some subcortical structure.

In addition to the above two explanantions, one other possibility is that there are qualitative differences in the kinds of tasks that the neocortex of different species subserves such that a rat's cortex may be capable of cross-modal transfer of simple stimulus dimensions but not the more complex ones. The cortex of the non-human primate, on the other hand, may subserve only the most complex tasks with the simpler ones now relegated to the subcortical areas. This would explain why transfer of a rate discrimination in the prosimian primate takes place even in the absence of association neocortex. In the human, where the cortex is involved in the most complex functions, cross-modal transfer of simple stimulus dimensions such as intensity may also be mediated via subcortical pathways. In the young infant whose cortex has not as yet been fully myelinated (Yakovlev & Lecours, 1967) nor functionally differentiated one may only be able to find functioning on such a low level. As development proceeds and as cortical mechanisms come to exert increasing domination over the infant's behavior, the kinds of sensory/perceptual capacities,with cross-modal transfer being one subset of them, become more complex in nature. Data from a recent study by Hoffmann (1978) looking at the relationship between contour density in a visual stimulus and amplitude of various components of the visual evoked response recorded from different brain sites support the view (Bronson, 1974) that at least in the visual modality a shift from subcortical to cortical mechanisms takes place. In infants 6 weeks of age only the amplitude of the late-negative wave, presumably reflecting collicular activity, was related to contour density, whereas in infants 10 weeks of age the amplitude of the early positive wave, presumably reflecting cortical activity, was sensitive to stimulus variation.

If it is true that young infants' responsiveness is based primarily on the effective intensity of stimulation then two stimuli different qualitatively will be perceived and responded to as equivalent given that their effective intensity is the same. The purpose of the present study will in part be to examine whether stimuli in different modalities are equivalent (psychologically) at early stages of development. More specifically, the question of whether infants will respond to a sound and a light as equivalent on the basis of their effective intensity will be examined.

If infants do in fact respond to heteromodal inputs as equivalent, it would imply the existence of a close liason between the various sense systems at the early stages of development. Such intersensory integration, however, is of a low level and qualitatively different from the more sophisticated kind where the organism treats heteromodal inputs as equivalent on the basis of such features as shape.

The paradigm employed in this study is similar to the one used by Rubel and Rosenthal (1975) in their study of the development of auditory frequency generalization in the chicken in that it also consists of a habituation and dishabituation phase, but different in that it is used for the study of cross-modal rather than intramodal sensory/perceptual processes. In their study, Rubel & Rosenthal first repeatedly presented a tone of one freqency until there was habituation of the eye-opening response; following this, a generalization test was administered which consisted of presenting nine stimuli of different frequencies where one of those stimuli was the original habituation stimulus while the other eight represented four frequencies below and four above the habituating stimulus. In the generalization test response to the original habituating stimulus was lowest and became increasingly larger to stimuli further removed in frequency on either side of the habituating stimulus.

Data obtained with the use of this habituation-generalization paradigm may be used to make inferences about the discriminative capacities of an organism. Detection of a difference between two stimuli is indicated by a recovery or dishabituation of a response to one stimulus following habituation to another. This, in fact, is the rationale underlying the use of the habituation paradigm in research on infant discriminative abilities (Jeffrey, 1976). Because habituation of a response to a given stimulus results in the generalization of that habituation to other stimuli (Thompson & Spencer, 1966) it also becomes possible to study the extent of that generalization by introducing a range of stimuli graded along the relevant dimension. Given that during the generalization test the stimulus identical to the habituating stimulus is perceived as being the same (or least discriminable) and that stimuli around it are perceived as less similar (or more discriminable) the further they are in either direction from that central stimulus, then response during the generalization test should be lowest to the stimulus identical to the habituating stimulus and should increase the further these stimuli are away from the habituating stimulus.

To provide a range of stimuli which might include a pair of equivalent heteromodal stimuli, a cross-modal matching technique was used (Stevens & Marks, 1965) and consisted of presenting adults with a fixed intensity of a white light and then asking them to match the loudness of a white noise stimulus to the brightness of that light. These adult values were then used to provide an estimate of the range within which the infants' match might lie. The one auditory intensity judged by adults to be psychologically equivalent to the light intensity was then used in conjunction with six other sound intensities, three higher and three lower, in a study of intersensory equivalence of intensity in infants. This study consisted of a habituation phase where the light used during the cross-modal matching study was repeatedly presented for a predetermined number of trials followed by the presentation of the seven sound intensities during the dishabituation-generalization phase. Assuming that under spontaneous conditions infants do respond primarily to the quantitative characteristics of stimulation, then according to the logic discussed above, the sound intensity that most closely matches the habituating light intensity should elicit the smallest recovery of response whereas sound intensities that are less equivalent should elicit increasingly greater recovery of response.

When given explicit instructions to match heteromodal stimuli adults are capable of doing so; however, it is not clear that they would do so without explicit directions to that effect. Therefore, to determine whether under these same conditions adults would spontaneously perceive intersensory equivalence of intensity, a second group of adults was tested using the same procedure. Based on the assumption that adults do not pay attention primarily to the intensity of stimulation, it was predicted that no orderly generalization gradient would be obtained in this group.

CHAPTER 2

METHOD

Cross-Modality Matching, Method of Adjustment

Subjects

There were 14 subjects (2 males and 12 females) in this study. The majority of the subjects were undergraduates at Hunter College and all had volunteered to participate in the study.

Apparatus

Testing took place in a sound attenuated chamber (IAC Corp.) which was dimly illuminated by a 7½ watt incandescent lamp. The auditory stimulus was a burst of white noise presented through an 8 in. speaker (Realistic MC-500) suspended approximately 32 in. above the seated subject's head. The visual stimulus was a circular patch of white light subtending 10° of visual angle andplaced approximately 61 cm. in front of the subject. All stimulus-generating equipment was located outside the chamber. With all equipment in operation the ambient sound pressure level at the site of the subject's head was 27 db (A), 55 db (linear), measured on a Bruel & Kjaer precision sound level meter. When measured with a Bruel & Kjaer octave filter, the ambient sound pressure levels varied from 57 db at 31.5 Hz to 16 db at 1600 Hz.

Broad band white noise (50-10,000 Hz) was produced by a Grason Stadler (Model 901B) noise generator. A Hewlett-Packard attenuator was used to vary the noise intensity at the speaker. In order to circumvent the problem of an impedance mismatch between the attenuator and the speaker, an amplifier (Southwest Technical Tiger 01) was inserted between the output of the attenuator and the speaker.

The white light was produced by two 14 watt (15 in.) GE Deluxe Cool (F14T12, color temperature 4200°K) white flourescent lamps mounted inside a 52x39x32 cm. wooden box. The box was painted glossy white inside to permit maximum reflectance and flat black on the outside. The front panel of the box contained a circular 10.5 cm. diameter opening with ground glass inserted in it to provide a homogenous field of white light. To permit the instantaneous onset of the lamps during stimulus presentation, the lamps were kept "warm" by supplying a constant 9 VDC charge to them. As a result, during the interstimulus interval a faint reddish glow could be seen. The two lamps were connected in parallel and together drew a current of 3.8 ma. from a 300 VDC power supply. The brightness of the light was constant at 11.36 footlamberts as measured with a Spectra Pritchard Photometer. A Lafayette automatic timer was used to control stimulus onset and duration.

Procedure

The purpose of this study was to determine the point of subjective equality (PSE) of the white noise and the white light. To do this the psychophysical method of adjustment was adopted to use with heteromodal stimuli, a technique more commonly known as cross-modality matching (Stevens & Marks, 1965). The subject was seated and dark adapted for approximately 5 minutes at which time testing commenced. The subject's task was to match the loudness of the white noise to the brightness of the light. Each trial began with a different sound intensity, with the order of starting intensities being random and the same for every subject. Upon presentation of the light and the sound the subject was required to signal to the experimenter by pushing one of two buttons whether the sound intensity should be increased or decreased. The experimenter would then either decrease or increase the sound intensity in 1 db steps until the subject signaled by pushing both buttons simultaneously when a match had been made. At this time a new trial began. Time between each trial was 8 seconds.

A single test session consisted of 10 trials with the first two being practice trials and thus not included in subsequent analyses. Each trial began with the simultaneous onset of the light and sound which lasted for 1 second.

Cross-Modality Matching, Method of Constant Stimuli

Subjects

There were 14 subjects in this study (5 males and 9 females). The majority of subjects were undergraduates at Hunter College and all had volunteered to participate in the study.

Apparatus

On the basis of the first study a series of 7 sound intensities were chosen with the middle sound intensity of 74 db (re. .0002 dynes/cm^2) being the subjective match to the light and the others varying in 2 db steps. The lowest intensity was 68 db and the highest 80 db. All other apparatus was the same as above.

Procedure

In order to provide independent confirmation of the validity of the previous match, this study was run employing the method of constant stimuli. Each trial consisted of the simultaneous presentation of the standard light and one of the seven sound intensities. The subject's task was to indicate by pressing a button whether the sound was of greater intensity than the intensity of the light. If so the subject was to signal "yes". If the sound was judged to be either equivalent or less than, the subject was required to respond "no". Each session consisted of 70 trials where the order of sound intensities was randomized and was the same for each subject. An interstimulus interval of 9 seconds separated the presentation of each light-sound pair.

Cross-Modal Generalization - Adults

Subjects

There was a total of 37 subjects in this study, with 6 of those subjects being dropped from the experiment due to either equipment failure or unscorable records. The remaining sample of 31 subjects consisted of 17 females and 14 males. All subjects were either undergradute or graduate students at Hunter College who were approached and asked to participate in the study. All had volunteered to do so.

Apparatus

All stimulus-generating equipment was the same as in the matching study. The stimuli consisted of the standard white light and the seven white noise intensities employed in the constant stimuli study. In addition, a Beckman (Type R) dynograph was used to record the subject's electrocardiogram.

Procedure

Each subject was seated in a comfortable chair. During the dark-adaptation period a set of Beckman Bipotential electrodes, filled with Beckman paste, was attached in a Lead I configuration. That is, one differential electrode was placed on one arm and the other differential plus the ground electrode were placed on the other arm. Instructions were to relax, move as little as possible, and to keep awake. All subjects were given a written description of the study and were asked to sign an informed consent form.

Following 1 to 2 minutes of heart rate (HR) recording the session began. A habituation-dishabituation paradigm with a generalization procedure was used. During the habituation phase a series of 20 white light stimuli was presented. Following the habituation phase, dishabituation-generalization testing commenced with the presentation of one of the 7 white noise stimuli. In order to maintain a state of habituation a series of 5 light stimuli was presented after the first sound and prior to the presentation of the second of the 7 sound stimuli. This procedure was repeated until all 7 intensities of white noise were presented. The entire session lasted 19 minutes and 36 seconds. The order of presentation of the 7 sounds was random with the requirement that across subjects each of the 7 intensities be represented at the beginning of the sequence an approximately equal number of times.

The duration of each stimulus was 1 second and all stimuli were presented at an interstimulus interval of 20 seconds. This interval was chosen, in part, on the basis of available data and also to allow enough time for the heart rate response to recover sufficiently following stimulation and prior to the presentation of the next stimulus.

Scoring Procedure

The subject's cardiac response was scored directly from the polygraph record. Paper speed of the polygraph was 10 mm/sec. A response on any given trial consisted of the difference between the pre-stimulus HR for the 7 beats immediately preceding stimulation and the post-stimulus HR for the 7 beats following stimulation, omitting the first 2 beats (Hammer & Turkewitz, 1974). The reason for omitting the first 2 beats is due to the fact that in infants the cardiac response has a latency of approximately 1 second (Steinshneider, Lipton, & Richmond, 1966). While the adult resting HR is approximately one-half that of the infant, making it likely that the latency of response in adults is somewhat different, in order to make the scoring comparable in the two groups, the first 2 post-stimulus beats were also omitted for the adults. Thus, the mean cardiac rate during the third to ninth cardiac cycles following stimulation was used for comparison with the pre-stimulus rate.

Cross-Modal Generalization - Infants (Group I)

Subjects

The names and addresses of all subjects were obtained from the birth records of the hospital of the Albert Einstein College of Medicine. Letters soliciting the parents' interest were first sent, followed by a phone call. Infants were selected for the study if they had a 1 minute Apgar score of 8 or higher and a 5 minute score of 9 or higher. To obtain 28 subjects for this study, a total of 67 infants was scheduled for testing.[1] There were 16 males and 12 females who ranged in birthweight from 2620 g. to 4470 g. ($\bar{X}$ = 3444 g.; S.D. = 465 g.) and who were from 21 to 31 days of age ($\bar{X}$ = 25.6 days; S.D. = 2 days). The remaining 39 infants were not included due to equipment failure or experimenter error (11 infants), crying (22 infants), unscorable data (3 infants), refusal to accept the pacifier (2 infants), falling asleep during test session (2 infants), and hiccups (1 infant).

Apparatus

Both, the stimulus-generating equipment and stimuli were identical to those used in the adult cross-modal generalization study. However, instead of using the Beckman dynograph, the infants' cardiac signal was fed through a Tektronix Series 122 preamplifier (High Frequency Response filter set at 50 Hz, Low Frequency at .8 Hz) directly to an Ampex tape recorder. For scoring purposes the tape was later played back through a Beckman (Type R) dynograph to produce a paper record of the test session.

Infants were tested in a different sound attenuated chamber (IAC Corp) which was dimly illuminated by a 7½ watt incandescent lamp. With all

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[1] An additional sample of 12 infants was tested initially. These subjects were tested during the "pilot" stage of the experiment and their data were not used.

equipment in operation the ambient sound pressure level at the site of the subject's head was 66 db (linear scale). The box containing the flourescent lamps and the speaker were both placed in a plane parallel to the supine subject and at a distance of 64.8 cm. above him. The light subtended a visual angle of $9^{\circ}24''$. After Beckman Bipotential minature electrodes were attached in a three-electrode chest configuration, the infants were placed in a padded basinette. To insure that the infant looked at the light and to minimize lateral movements, the head was placed in a padded U-shaped device. A blind pacifier was provided to all the infants throughout the test.

Procedure

Infants were first dark-adapted for approximately 5 minutes and during that time they were prepared for recording. Parents were allowed to remain in the testing room and were asked to remain as quiet as possible during the testing. During the testing session all infants sucked on a pacifier held by the experimenter. Despite the use of the head-holding device, the infant's head would not always remain in the midline, and as a result, on occasion it was neccessary for the experimenter to reposition the infant's head.

The state of the infant was rated by the experimenter using a modification of the Prechtl (1965) scale. The following crieteria were used: State 1: eyes closed, no movement; State 2: eyes partially open, some movement; State 3: eyes closed, movement; State 4: eyes open, some or no movement; State 5: eyes open, movement and vocalizations; State 6: crying.

The stimulus sequence was identical to the one used in the adult cross-modal generalization study.

Scoring Procedure

The scoring procedure was the same as that used in the adult cross-modal generalization study.

Cross-Modal Generalization - Shift Group

To ascertain whether the nature of the response to the various sound intensities in the first group of infants was influenced by prior exposure to a specific light intensity, the intensity of the light used during the habituation phase was increased for a second group of infants.

Subjects

The subjects in this study were selected on the basis of the same criteria as the infants in the previous study and their participation was solicited in the same way. 26 infants were scheduled for testing and of these the data from 14 infants were used. The other 12 infants were not included due to equipment failure (1 infant) crying and/or refusal to accept the pacifier (10 infants), falling asleep (1 infant). There were 6 males and 8 females, who ranged in birthweight from 2600 g. to 5120 g. ($\bar{X}$ = 3534 g.; S.D. = 595 g.) and who were from 22 to 32 days of age ($\bar{X}$ = 25.7; S.D. = 595 days).

Apparatus

Same as in Infant Group I with one exception. While the 7 auditory stimuli remained the same, the brightness of the light was now 40.2 footlamberts(this particular luminance was selected primarily because it was easily discriminable from the luminance used in the study with the first group of infants).

Procedure

Same as for Infant Group I.

Scoring Procedure

Same as for Infant Group I.

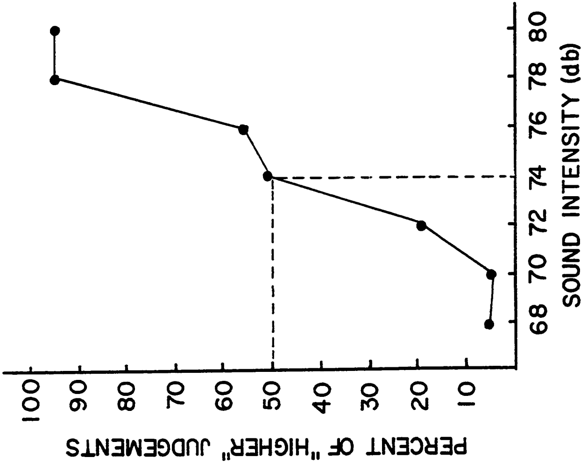
CHAPTER 3

RESULTS

Since the function of the cross-modality studies was solely to provide a range of auditory intensities which might contain an intensity that is equivalent to the intensity of the light, the data from those studies will not be presented in detail. The first study employed the method of adjustment and results from 14 subjects indicated that the mean PSE for the auditory stimuli was 74 db and ranged from 64 db to 74 db, S.D. = 2.3 db. The results of the second study employing the method of constant stimuli confirmed the above finding. Figure 1 shows the percentage of trials on which subjects responded by indicating that the comparison stimulus was higher in intensity than the light. As may be seen, the probability of responding "higher" when presented with a 74 db sound was 50%. Because subjects were instructed to respond "no" (ie. the sound was not greater in intensity than the light) not only to sounds that were lower but also to sounds that were equal in intensity, all sounds that were judged to be equal in intensity elicited a "no" response. Thus, instead of being equally distributed between the two judgment categories, all sound intensities that seemed equal to the light intensity contributed a response in the "no" category. This fact most likely accounts for the shallowness of the curve between 74 and 76 db.

Thus, using both the method of adjustment and the method of constant stimuli a sound of 74 db was found to be equivalent to the light presented. This value was therefore used as the midpoint in the range of auditory stimuli to be used as dishabituating stimuli in the main experiment.

Figure 1. Percent "higher" judgements made by adults having to compare different intensities of sound to a constant intensity light.


PERCENT OF "HIGHER" JUDGEMENTS
100
90
80
70
60
50
40
30
20
10
SOUND INTENSITY (db)
68
70
72
74
76
78
80

Generalization

Adult subjects

The principal data for this study consist of the subjects' cardiac responses to the various intensities of sounds following repetitive exposure to the standard light. Because the infants' pre-stimulus HR is nearly double that of the adults (Infant $\bar{X}$ = 151.8 beats/min.; Adult $\bar{X}$ = 79.44 beats/min) to facilitate comparisons the measure of cardiac change was adjusted for pre-stimulus HR by calculating a percent cardiac change score for each trial for every subject using the formula (change in bpm/pre-stimulus HR) x 100.

The response of the adults to the various sound intensities is depicted in Figure 2. As may be seen, there was no systematic relationship between the mean percent cardiac change and sound intensity. Trend analyses of these data did not reveal any significant effects.

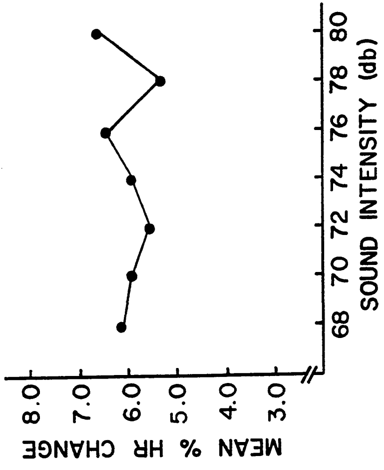
Because sounds of different intensity were presented in a random order, a response to a given sound intensity may have been influenced by the sounds that preceded it. Therefore, to examine the nature of the response in the absence of any possible sequence effect, cardiac change to the first sound presentation following the 20 habituation trials was analyzed separately. When this was done no systematic relationship between mean percent cardiac change and sound intensity was noted.

Finally, it was possible that the response was affected by the sound's ordinal position in the series and that such an effect resulted in a systematic relationship between stimulus intensity and response magnitude. Inspection of the data, however, revealed no systematic differences in magnitude of cardiac change as a function of the ordinal position of the sound.

Infants

The pattern of response in the infants was markedly different from

Figure 2. Effect of different intensities of auditory dishabituating stimuli on cardiac response following exposure to a light (in adults).


MEAN % HR CHANGE
8.0
7.0
6.0
5.0
4.0
3.0
SOUND INTENSITY (db)
68
70
72
74
76
78
80

that in the adults. As Figure 3 shows, the mean percent cardiac change in infants varied systematically as a function of sound intensity. Inspection of the figure reveals that with the exception of the cardiac change at 68 db there is a U-shaped relationship between cardiac change and auditory intensity with the lowest point at 74 db and a nearly symmetrical rise in the magnitude of cardiac change as stimuli are further away in intensity from 74 db.

In view of the fact that responding to 68 db is markedly lower than that to 70 db and in view of the U-shaped relationship between magnitude of cardiac change and the other intensities of sound, it is likely that the low level of cardiac change at that intensity is due to that particular sound being either at or below the infants' threshold.[1] Assuming this to be true, the data at 68 db were omitted from subsequent analyses.

Analysis of the data[2] for various components of trend indicated that the function relating magnitude of cardiac change and auditory intensity (70-80 db) could best be described by a quadratic trend, $F(1,27) = 4.66$, $p < .05$. No other components of trend (linear or cubic) were significant.

As was done with the data from the adults, to eliminate the possibility of a sequence effect, cardiac change to the first presentation of a sound was analyzed separately. Figure 4 shows[3] that the overall shape of the

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[1] There are two reasons why cardiac change to this intensity should be considered below threshold. One is that Turkewitz, Moreau, Birch, & Davis (1971) found that in newborns cardiac change to 70 db did not differ from HR change to catch trials while higher intensities evoked significantly higher HR changes. Two is that this is the only intensity at which the "Law of Initial Values" (see p.55) was not found to operate.

[2] Out of a total of 168 trials data were not available for 5 trials because of crying or an unscorable record. These missing data were replaced by the grand mean for purposes of the analysis.

[3] The graph includes the data from 7 infants who did not complete the entire session but did receive the first sound. There were 5 infants tested at each intensity.

Figure 3. Effect of different intensities of auditory dishabituating stimuli on cardiac response following exposure to a light (in the first group of infants).

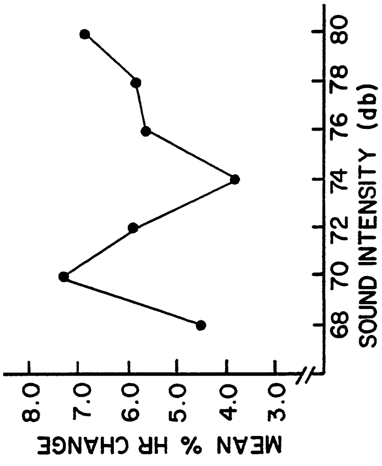
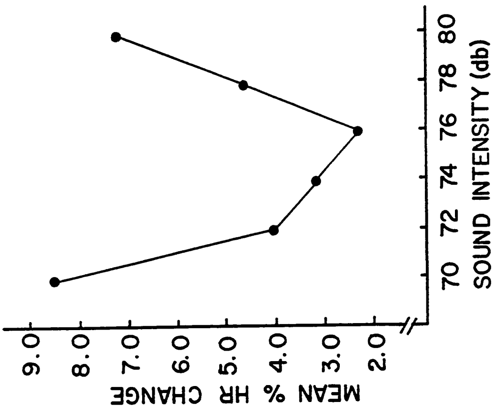

MEAN % HR CHANGE
8.0
7.0
6.0
5.0
4.0
3.0
68
70
72
74
76
78
80
SOUND INTENSITY (db)

Figure 4. Effect of different intensities of auditory dishabituating stimuli on cardiac response following exposure to a light analyzed for responses to the first auditory stimulus of the dishabituation series only (in the first group of infants).


MEAN % HR CHANGE
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
70
72
74
76
78
80
SOUND INTENSITY (db)

function is similar to the one including all sound trials. As was the case when the data including all trials were considered, an analysis of the data from 70 to 80 db for the presence of orthogonal trend components revealed the presence of a significant quadratic trend, $\underline{F}(1,24) = 4.93$, $\underline{p} < .05$. It should be noted that although the overall shape of the function is maintained, the lowest point is now at 76 db, not at 74 db.

Inspection of the data with respect to the influence of the sound's ordinal position on cardiac change did not indicate any systematic effects.

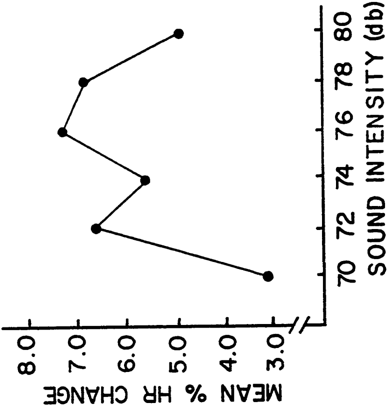
Because these data consist of responses made while the infants were in different states, there is the possibility that the results were influenced by a differential distribution of states at the different sound intensities. Analyses indicated that this was not the case. The infants spent over two-thirds of their time in an awake, alert state (state 4). The proportion of trials on which the infant was in state 4 when the different intensities of sound were presented ranged between .63 and .82, with no systematic relationship between trials spent in state 4 and sound intensity. Further analyses asessing the relationship between percent cardiac change at a given intensity and proportion of time spent in state 4 indicated an absence of any correlation. As a final check on the influence of state, the data were analyzed considering only those trials on which the infant was in state 4. Once again, the overall shape of the function was essentially the same as that representing data from all states. No trend analyses were attempted due to the large number of cells with missing data when all trials on which the infant was not in state 4 were eliminated.

Another factor that might have influenced the response function is pre-stimulus HR. Bridger & Reiser (1959) reported that the magnitude of cardiac response in infants was influenced by the "law of inintial values". That is, the size and direction of response varied as a function of pre-stimulus HR. They found that when pre-stimulus HR was low the typical response was a large acceleratory response, when it was high the typical response was a large deceleratory response, and when it was neither high nor low but somewhere in-between the response could be either an acceleration or deceleration and was small relative to other conditions. Because of this phenomenon, if there were a differential distribution of pre-stimulus HR at the different sound intensities, the obtained results may simply reflect such a distribution. Analysis of the data with regard to this possibility indicated that the "law of initial values" was in fact operating at each sound intensity. There was a significant negative correlation between cardiac change (taking direction of change into account) and pre-stimulus HR at sound intensities 70-80 db ($\underline{r}$'s ranged between -.61 and -.73, all $\underline{p}$'s$<.001$). Despite this, analysis of mean pre-stimulus HR indicated no differences between the different sound intensities. The mean pre-stimulus HR for the different intensities ranged from 149.6 to 155.7 beats/min.

Shift Infants

To determine whether the results obtained in the cross-modal generalization test were due to the infants first being exposed to a given intensity of light, the intensity of the light was shifted to a higher level in a separate group of infants. If the infants were in fact responding to the various sounds in terms of the degreee of their similarity to the light stimulus, exposure of this group to a brighter light should result in a shift of the PSE to some higher intensity of sound and a corresponding shift in the generalization gradient. Figure 5 shows the results for this second "shift" group of infants. The overall

Figure 5. Effect of different intensities of auditory dishabituating stimuli on cardiac response following exposure to a light (in the shift group of infants).


MEAN % HR CHANGE
8.0
7.0
6.0
5.0
4.0
3.0
70
72
74
76
78
80
SOUND INTENSITY (db)

shape of the function for the shift group of infants seems to be curvilinear. Analyses of trend for data between 70 and 80 db[4] did in fact reveal a significant quadratic trend, $\underline{F}(1,13) = 4.68$, $\underline{p} < .05$. Despite the fact that both groups showed significant quadratic trends, it is quite obvious that the overall shape of the function for the shift group is markedly different from that of the first group of infants. For purposes of direct comparison, the data for both groups of infants are shown together in Figure 6. There are several aspects of the differences between the results of the two groups that are interesting.

The cardiac change to sounds between 72 db and 78 db shows no systematic relationship to sound intensity. Cardiac change to 70 db shows a large drop in the shift group while it is rising in the first group of infants. Finally, cardiac change to 80 db drops in the shift group while it rises in the first group.

The response to only the first sound was not examined due to insufficient data. No effects of the ordinal position of the sound were found.

Gender Differences

Infants

Although a review of a number of studies does not indicate any substantial differences in auditory responsiveness between infant boys and girls (Maccoby & Jacklin, 1974), the finding of such a difference would no be surprising given the fact that girls develop at a more accelerated rate. To determine whether boys differed from girls in their response to the different sound intensities, the data were therefore analyzed separately for the two genders. As is evident in Figure 7, the shape of the functions for boys and girls in the main study is strikingly similar,

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[4] The mean percent cardiac change to a 68 db sound was 5.6.

Figure 6. Effect of different intensities of auditory dishabituating stimuli on cardiac response following exposure to a light (in both groups of infants)

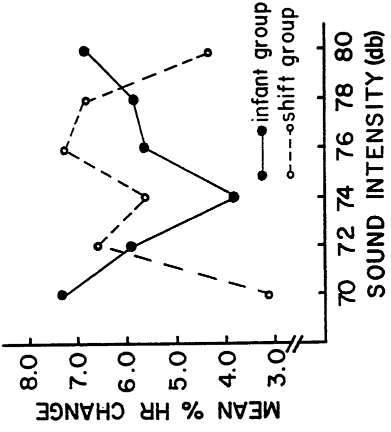
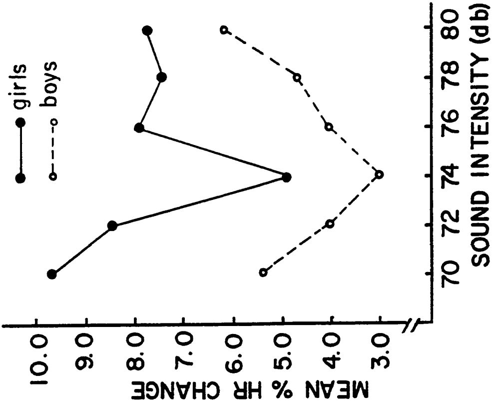

MEAN % HR CHANGE
8.0
7.0
6.0
5.0
4.0
3.0
SOUND INTENSITY (db)
70
72
74
76
78
80
infant group
shift group

Figure 7. Effect of different intensities of auditory dishabituating stimuli on cardiac response following exposure to a light (in boys and girls of the first group of infants).


girls
boys
MEAN % HR CHANGE
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
70
72
74
76
78
80
SOUND INTENSITY (db)

although the girls' cardiac change was at a consistently higher level. A two-way repeated measures analysis of variance on responses to all sounds, with gender and intensity as the two factors, and subjects the repeated factor nested within gender, indicated a significant effect of gender, $F(1,26) = 7.39$, $p < .05$, and intensity, $F(5,130) = 2.32$, $p < .05$ but no significant interaction.

Shift Infants

Separate analyses of the generalization data in the shift group of infants for the two genders indicated that the shape of the function for boys was highly similar to the overall function for this group, while the function for girls did not show any systematic trends. In order to compare the shapes of the two functions directly, the same analysis of variance that was used for the first group of infants was performed. There was no significant effect of intensity and gender, and there was no significant gender x intensity interaction.

Adult Subjects

Analysis of the audlt data with respect to gender by use of the same repeated measures analysis of variance as employed in the two infant groups indicated that there was no effect of gender or intensity. Although the gender x intensity interaction approached significance, $F(6,174) = 1.87$, $p < .10$ and inspection of the data from the males suggested the presence of a curvilinear relationship between cardiac change and intensity, analyses of trend did not reveal a significant quadratic trend.

Effect of Direction of Cardiac Change

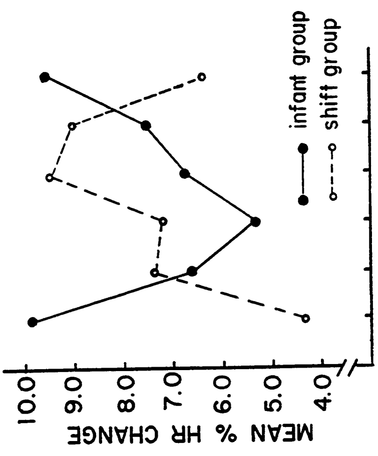
Thus far all data analyses have been based on the magnitude of cardiac change irrespective of direction, however, because the majority of studies with young infants have found acceleration to be the most frequently occurring cardiac response and because acceleration and deceleration may represent the operation of different processes (Graham & Clifton, 1966), the data were also analyzed separately for those trials on which acceleration or deceleration occurred. Examination of the frequency of occurrence of the two types of responses indicated that during the cross-modal generalization test acceleration was the predominant response in infants of both groups. Overall, in the first group of infants, out of a total of 178 trials where a response occurred (a change of 2 or more beats), 72% were trials on which acceleration occurred. In the shift group. out of a total of 83 trials, 75.9% were ones where acceleration occurred. Separate analyses at each sound intensity comparing the number of accelerations vs. the number of decelerations revealed that in the first group of infants acceleration was the predominant response at 4 out of the 7 intensities (p's $<.05$, 1-tailed, Binomial test), while in the shift group acceleration occurred significantly more often than deceleration at 3 intensities (p's $<.05$, 1-tailed, Binomial test) and was marginally more frequent at 3 other intensities (p's $<.10$, 1-tailed, Binomial test).

Inspection of the data where only acceleration occurred (Figure 8) reveals that the general shape of the function relating cardiac change to sound intensity in the first group of infants is nearly identical to the function including both acceleration and deceleration. Figure 8 also shows the response of the shift group during those trials when only acceleration occurred and once again the shape of this function is nearly identical to that for trials including both types of cardiac change.

The data for trials when only deceleration occurred were not examined because of the very low number of trials when this type of response was observed.

Accelerations and decelerations were equally frequent in adults.

Figure 8. Effect of different intensities of auditory dishabituating stimuli on cardiac response following exposure to a light on only those trials when acceleration occurred (in both groups of infants).


MEAN % HR CHANGE
10.0
9.0
8.0
7.0
6.0
5.0
4.0
70
72
74
76
78
80
SOUND INTENSITY (db)
● infant group
○ shift group

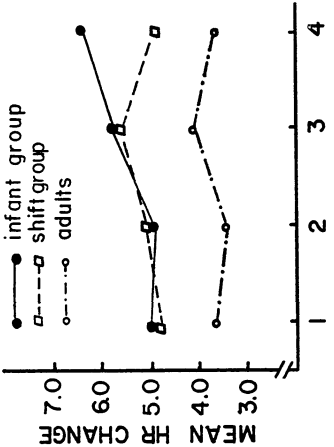
Overall, out of a total of 184 trials on which cardiac change occurred, acceleration occurred on 45.1% of them. Examination of the data revealed no systematic trends when the two types of response were considered separately.

Habituation

To determine whether there was a decrement in response over the 20 habituation trials, the mean cardiac change for blocks of 5 trials was computed for every subject. No evidence of habituation was found in any of the groups of subjects. Figure 9 depicts cardiac change during the habituation trials for all three groups of subjects. As may be seen, cardiac change neither increased nor decreased in the adult subjects throughout the course of the habituation procedure. Further analysis indicated that the pre-stimulus HR in the adults remained essentially unchanged over trials.

Inspection of Figure 9 shows that in the infant group there was a slight increase in the magnitude of cardiac change as a function of trial blocks. Analysis of variance indicated that the only significant effect was that for subjects, $F(26,78) = 4.59$, $p < .001$, meaning that infants differed in their response during the habituation trials. One reason for the observed increase may be that pre-stimulus HR changed as a function of trials. This, however, was not the case as there was no systematic change in pre-stimulus HR over trials. A possible clue to the slight increase in the magnitude of cardiac change is what appears to be a systematic change in state as a function of trials. Examination of state reveals that there was both a decrease in the percentage of infants who were in state 4 and a concommitant increase in the percentage who were in state 1 and 2. For the four blocks of 5 trials each, the percentage of infants who were in state 4 was 90.6,

Figure 9. Effect of repeated presentation of the habituating visual stimulus on cardiac response in both groups of infants and in adults.


infant group
shift group
adults
MEAN HR CHANGE
7.0
6.0
5.0
4.0
3.0
1
2
3
4
TRIAL BLOCKS

82.2, 75.6, and 81.6%, respectively. The percentage of infants who were in state 1 and 2 combined, was 2.2, 2.2, 8.6, and 10.0%, respectively for the four blocks of habituation trials. In fact, the relationship between magnitude of cardiac change and change in state 1 and 2 as a function of trials was marginally significant, (r = .38, $p < .10$).

In the shift group, the mean cardiac change increased in magnitude between trial blocks 1 and 3 and then decreased to a level comparable to that on the first block (Figure 9). Analysis of variance indicated no significant effect of cardiac change as a function of trials, $F(3,39) = .31$, n.s., but did once again indicate a significant effect of subjects, $F(13,39) = 2.35$, $p < .025$. Again there was a systematic change in state 4. The percentage of infants in state 4 for the four blocks of trials was 90.2, 83.0, 74.4, and 70.0%, respectively, while the percentage of infants in state 1 and 2 for the four blocks was 2.8, 11.4, 21.4, and 21.4%, respectively.

CHAPTER 4

DISCUSSION

The results of the present study indicate that 3-4 week-old infants are differentially responsive to auditory intensity and that their response to various intensities of sound can be markedly affected by prior exposure to a visual stimulus. Infants were repeatedly exposed to a light of a fixed intensity following which they were presented with a range of auditory stimuli which varied in intensity around what for adults constitutes the PSE. Magnitude of cardiac response to these intensities of sound varied in a curvilinear fashion. The function relating auditory intensity and magnitude of cardiac change was U-shaped with its lowest point at the PSE and increasing on both sides in a nearly symmetrical manner.

These results are in marked contrast to the results obtained by Bartoshuk (1962 a,b), Steinschneider et al. (1966), and Turkewitz et al. (1971) who found that in the absence of any prior stimulation in another modality, cardiac response to increasing intensities of white noise increased monotonically as a function of intensity.

Because no evidence of habituation was obtained, interpretation of the above results according to the logic of the habituation-generalization paradigm is somewhat uncertain. Specific reasons for failure to obtain evidence of habituation cannot be discussed due to the lack of any other experimental reports attempting to obtain habituation of HR to the type of stimulus employed in this study. In general, it might be speculated that (1) the interval between each presentation of the light (20 sec.) was too long, (2) the duration of the stimulus was too short, and (3) had the habituation phase consisted of more stimulus presentations perhaps then habituation would have been obtained. In point of fact, as regards point (3) the finding that magnitude of cardiac change declines after the third block of trials in the shift group raises the possibility that had more trials been given habituation would become evident. Also, it may be that this decline is in some way related to the intensity of the habituating light since the same decline is not seen in the first group of infants. Whatever the case may be, further work is needed before any firm conclusions can be made.

Insight into the unexpected, albeit nonsignificant, trend towards greater cardiac change during the habituation trials may be gained through examination of the state changes occurring during the habituation phase. There were some weak suggestions that infants in both groups gradually changed from being predominantly alert and awake to being somewhat more drowsy and asleep. In fact, there was some weak indication of a significant correlation between the increase in magnitude of cardiac change and a change towards being less aroused. It should be noted, however, that these conclusions are further weakened by the fact that even though the pattern of state changes in the shift group is very clearly in the direction of less arousal, there is a decrease rather than an increase in the magnitude of cardiac change. Thus, while it is not totally clear, there is the possibility that the slight increase in response may be an artifact of state changes.

Whatever the case may be with regard to habituation of the cardiac response, the state changes observed during the habituation trials may be taken as partial evidence that at least behaviorally there were some signs of habituation.

The regularity of the results obtained during the generalization test is rather compelling. To repeat, it seems as though the infants are discriminating between the different intensities of sound and that their response to these intensities is influenced by the intensity of the preceding light. If response to a given auditory intensity is based on how similar that intensity is to the intensity of the light and if different auditory intensities are therefore responded to differently, then this implies that the infant is performing intensity equations between a pair of heteromodal stimuli. Herein lies the problem, however, for if varying degrees of stimulus equivalence are indeed being indexed and if the method employed here is sensitive enough to detect such differences even in the absence of habituation, then clearly a process different from the habituation-dishabituation one must be responsible for this outcome.

By being repeatedly exposed to a stimulus, the infant may learn about that stimulus without producing response decrement. The information gained during such repeated exposure may then permit him to discriminate between that stimulus and any other novel stimulus. Such a process is in fact implicit in the familiarization-novelty paradigm which has been used succesfully in studies of infant discriminative capacities (Gottfried et al. 1977; Rose et al., 1978; Ruff & Kohler, 1978; & Fagan, 1974). The method involves a short period of familiarization followed by the presentation of the familiar and novel stimulus. Recognition of the familiar stimulus is indicated by a preference for the novel stimulus over the familiar one. Relevant to the problem encountered here, Fagan (1974) distinguished between the familiarization-novelty method and the habituation-dishabituation paradigm by noting that discrimination of a novel stimulus may be obtained after a very short familiarization period and long before the occurrence of any evidence of habituation, "perhaps even by the end of the first 'habituation' trial" (Fagan, 1974, p. 356).

Thus it is quite likely that although no evidence of habituation was found, the repeated presentation of the light was sufficient for the infants to become familiar with it allowing them to subsequently respond to the auditory stimuli in terms of their similarity to the light. Despite the absence of habituation, magnitude of cardiac change may therefore indicate differences in response to auditory stimuli as a function of the degree to which they are different in their intensity from the light.[1] Thus, it seems that the infant responds to the intensive dimension of stimulation in both modalities and uses this common dimension for equating heteromodal inputs such that those that are closely matched in terms of their intensity are treated as equivalent and those that differ in their intensive value as less equivalent.

Although the difference between the data from the first group of infants and that from studies showing a monotonic relationship between cardiac change and auditory stimulus intensity is most likely due to the fact that the infants in this study were first exposed to the light, it is not certain whether the infants were responding specifically to the intensity of that light. If the relationship between cardiac change and auditory intensity could be changed by shifting the intensity of the initial light then it could be concluded that responding was based on the intensive aspects of the light and that cross-modal equation of intensity was indeed taking place.

The evidence obtained in the shift group of infants shows that by shifting the intensity of the light the shape of the function is altered. In particular, is should be noted that exposure to a light of greater intensity

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[1] Inspection of the raw data (unadjusted for pre-stimulus HR) obtained in the first group of infants in response to the different sound intensities revealed that mean HR change in response to 74 db was 5.6 beats/min. and greater to all other intensities. Inspection of the mean HR change obtained during the last habituation trial indicated a change of 5.6 beats/min. Thus, while all other intensities elicited a response greater than that during the last habituation trial, 74 db elicited an equivalent amount of cardiac change.

has the effect of changing the shape of the function from a U-shape to an inverted U-shape. Two aspects of the difference between these two functions are of particular importance. The most important one is that the magnitude of cardiac change to the highest intensity (80 db) should be highest if the infants are simply responding on the basis of auditory intensity, however, increasing the light intensity had the effect of reducing cardiac response to that intensity. This drop in response magnitude is especially important because it is consistent with predictions one would make concerning the effects of shifting the intensity of the light to a higher level. In fact, it seems as though magnitude of cardiac change begins to decline beyond 76 db, suggesting that had the shift infants been presented with higher intensities of sound a U-shaped function similar to that obtained with the first group of infants but having its lowest point at some higher intensity would have been obtained. Furthermore, assuming for the moment that the lower auditory intensities presented to the shift group are too different in effective intensity to be treated as similar to the light, then one might speculate that cardiac response to these intensities is independent of the preceding light intensity. As a result, the linear portion of the function from 70 to 76 db may represent responding similar to that observed in infants presented with increasing intensities of sound without prior exposure to a visual stimulus. Intensities beyond 76 db, on the other hand, may be viewed as within the range of similarity to the light intensity and the drop in response magnitude may therefore represent the left portion of the U-shaped function. These outcomes, of course, remain to be tested.

The second aspect which is important is that the magnitude of cardiac change in response to 70 db is markedly elevated in the first group of infants. If the infants were responding purely on the basis of auditory intensity then the magnitude of cardiac change in response to 70 db in in the first group of infants should be at the lowest point relative to all the higher intensities. That, however, is not true in the first group but is in the shift group. In fact, the magnitude of cardiac change in response to 70 db in the first group is at maximum at that intensity.

In conclusion, it may be stated that the results of the two studies discussed above argue for the view that 3-4 week-old infants are capable of utilizing the quantitative dimensions of stimulation in equating inputs to different sensory modalities.

In addition to the finding of cross-modal perception of equivalence, results from the first group of infants indicated that girls were consistently more responsive to the various intensities of sound than were the boys, while in the shift group response to a given intensity was not dependent on the gender of the subject. Findings from the infant group are in accord with a number of studies (cited in McGuinness & Pribram, 1979) which show that in older subjects females are more sensitive in tests involving response to intensity. The present findings are the earliest indication yet of differences in responsiveness to auditory intensity in the two sexes.

Recently Nelson,Clifton, Dowd, & Field (1978) have shown that the direction of HR change in response to auditory stimuli is related to sucking activity by the infant. That is, during non-nutritive sucking, if tone onset is coincident with the onset of a sucking burst the response will be acceleration; if tone onset comes at the end of the sucking burst deceleration wiil be the typical response. In view of the fact that all infants in the present study were given a blind pacifier at the start of the session and were allowed to suck throughout the session one might raise questions concerning the meaning of the results given that no information about the relationship between the occurrence of sucking and onset of noise is available. Although the Nelson et al. findings are important for distinctions between the orienting and defense reflexes (Graham & Clifton, 1966) as well as for defining the conditions under which either type of response may be found, they do not in any way alter the validity of the present findings. First, the concern in this study was not with the direction of the cardiac change but with magnitude of response. In fact, the shape of the function relating cardiac change and sound intensity was little affected by whether accelerations and decelerations were considered together or whether accelerations were considered alone. Second, how the infant's response to these stimuli is mediated - whether it is mediated by the cardiovascular system or as the Nelson et al. (1978) results suggest by the somatic system - is immaterial here.

In sum, it appears that 3-4 week-old infants are capable of cross-modal utilization of intensity and use such information in their perception of cross-modal equivalence. This constitutes the first demonstration of such abilities in infants and is the earliest demonstration of the presence of cross-modal equivalence in infants.

The results obtained in the adult study are very different from those of the infants. HR change to different intensities of sounds did not seem to be influenced by previous exposure to the light. Because the adults failed to show any evidence of habituation there is once again the problem of interpreting the results of the generalization test, although in this case the absence rather than the presence of cross-modal generalization must be explained. One very real possibility, of course, is that had habituation taken place evidence of cross-modal perception of equivalence would have been obtained. Despite the absence of habituation, if we assume for a moment that exposure to the light was sufficient for allowing the adults to extract intensity information about the stimulus, then there is the possibility that as reflected in the cardiac response these subjects did not utilize this information in their perception of the different intensities of sounds. Thus, this may be a true failure to obtain cross-modal equivalence of intensity. However, it may be that these results merely reflect the insensitivity of the cardiovascular measure in the adult to intramodal variations in sound intensity and may therefore not be related to the cross-modal nature of the task. What is needed to answer this question is an intramodal group which is first repeatedly exposed to one auditory intensity and then tested with intensities which are both higher and lower than the training intensity. If this group's HR change shows a symmetrical generalization gradient around the training intensity then it may be concluded that the results of the present study truly represent a failure in cross-modal perception. While it is not certain what the outcome of such a procedure would be, especially since no attempts in this direction can be found in the literature, it is at least clear that a habituation-dishabituation procedure using another autonomic response is sensitive to intramodal variations in intensity (Edwards, 1975).

Because the data of the two age groups are different and because they were obtained under identical conditions, it may be tentatively concluded that as regards the utilization of intensity for perception of cross-modal equivalence, 3-4 week-old infants do and adults do not utilize such information. These findings are in agreement with Schneirla's (1959, 1965) Intensity Hypothesis which states that young organisms respond to the intensive rather than the qualitative aspects of stimulation. It appears that infants do in fact respond to the intensive aspects of stimulation, a consequence of which is a closer liason between the senses. Adults, on the other hand, do not seem to use intensity for equating heteromodal inputs under these conditions. It is very important to emphasize the fact that these results do not imply that adults are incapable of using intensity cross-modally for it is abundantly clear that when asked to equate heteromodal stimuli in terms of their intensity they can readily do so (see Stevens & Marks, 1965 and the data from the present cross-modal matching study). Thus, the important distinction is between spontaneous utilization under non-instructed conditions and ability or capacity to utilize such information. The present data indicate that under conditions when a subject is given the opportunity to spontaneously and without explicit instructions match heteromodal stimuli in terms of their intensity infants do so while adults do not. The foregoing conclusions are in a broad sense consistent with Schneirla's Intensity Hypothesis but differ in that they emphasize the idea that the differences between infant and adult processing of sensory information may reflect differences in the characteristic mode of functioning rather than abilities. That is, infants may very well be capable of responding to qualitative differences in stimulation; likewise, adults may and are capable of responding to intensive differences in stimulation. The differences may lie in their spontaneous utilization of such information.

There are other techniques one may use to study cross-modal equivalence in infants. In order to study cross-modal equivalence of intensity a subject must first be provided with heteromodal stimuli which are in fact equivalent. One way of finding out what intensity in one modality corresponds to a given intensity in another modality is to use the cross-modality matching technique. A problem arises, however, with infants because the cross-modality matching procedure cannot be used with them. One solution to this problem (the one adopted here) is to use the intensity values reported to be equivalent by adults as an indicator of the range within which the infants' match lies. An alternative approach, however, involves first obtaining data in infants relating response magnitude to increasing intensities in each modality separately. Those intensity values that elicit the same magnitude of response in each modality separately can now be taken to be equivalent stimuli and can then be used in a study of intersensory equivalence. This alternative approach will in fact be used in the future to provide corroborating evidence for the phenomenon demonstrated in this study.

Finally, the results of this study, like those of Allen et al., (1977) raise doubts about the validity of the Birch & Lefford (1963) hypothesis of intersensory integration. Although Birch & Lefford were mainly concerned with intersensory integration at later ages, their assertions that intersensory integration is only present at later stages of development implies that at early stages the senses operate somewhat independently. This is clearly not the case. Allen et al. consider a modification of the Birch & Lefford hypothesis by proposing that there may be qualitative differences in the level at which sensory systems are integrated at different developmental stages but reject it in favor of another hypothesis. This hypothesis assumes that sensory systems are integrated from the start and that developmental differences in sensory integration are due to increased sensory differentiation and increased specialization in the processing of sensory information.

Although the present data do not provide a test of these two alternatives, if the basis for sensory/perceptual processing changes from intensity to quality during development then it is likely that the kinds of intersensory functions found at different stages of development may be different in kind.

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