Performance of Able and Disabled Readers on Tasks of Intra- and Inter-modal Haptic and Visual Processing

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ABSTRACT

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This research consisted of three individual studies, examining intra- and inter-modal haptic and visual processing in able learners and reading disabled children spanning the elementary school grades.

Performance was measured in terms of: accuracy scores, haptic exploration scores, and exploration times. Higher scores were obtained on the intra-modal visual condition than on any of the conditions involving a haptic component. Increasing the exploration times for haptic stimuli did not significantly improve performance on tasks involving a haptic component.

Performance scores of poor readers were depressed on all tasks, suggesting a general deficit in sensory processing rather than an inter-sensory processing deficit. Poor readers further employed less sophisticated haptic exploration strategies than able readers, suggesting use of less efficient task strategies.

RESUMÉ

Le traitment de l'information tactile et visuelle intramodale et transmodal entre des enfants habile en lecture et déficiants en lecture

Cette recherche avait pour objet l'étude du traitement de l'information tactile et visuelle, intramodale et transmodale chez des enfants habil en lecture et des enfants déficiants en lecture, de la premiere à la sixième année.

Nous avons procédé à une analyse des notes de précision, des résultats de l'exploration tactile et des mesures du temps d'exploration pour évaluer leur rendement. Nous avons constaté que de meilleurs résultats ont été obtenus avec la condition intramodale visuelle qu'avec les conditions comprenant un élément tactile. Une augmentation du temps d'exploration des stimulis tactiles n'a pas amélioré de façon significative le rendement pour les tâches incluant un élément tactile.

Les résultats de rendement des déficiants en lecture était faibles pour toutes les tâches, suggérant un deficit général dans le traitement sensoriel plutot qu'un déficit intersensoriel. De plus, les déficiants en lecture ont employé des stratégies tactiles d'exploration moins developées que les enfants habil en lecture, suggérant des stratégies moins efficaces.

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CHAPTER I

INTRODUCTION

Historically, touch has been considered to be a very important sense. Aristotle, and the Stoic philosophers after him, had held that touch mediated every type of perception, even vision, and hence has some primacy among the five senses of the Artistotelian classification. By assigning to touch several sense qualities such as hard and soft, smooth and rough, and hot and cold, Aristotle was making of touch either a complex sensory modality or several separate senses (Boring, 1942). Later, Locke reported some interesting aspects relating touch and temperature determination, while Berkeley (1709) proposed that touch-kinesthetic sensations were the very basis of learning (Wertheimer, 1970). For the English Associationists, from Reid onwards, distinctions between sensations and perceptions were very important, a distinction fully recognized in the 19th century by Weber and Wundt, the latter regarded as the father of experimental psychology.

Psychologists have come to recognize three or four individuals as "intellectual giants" in the field of sensory perception of touch: Weber, Katz, Gibson, and more recently Geldard. Tribute to the former has been made by the recent translation into English of his two outstanding works (Ross and Murray, 1978), and to Katz and Gibson by the publication of a text by Schiff and Foulke in 1982. Tribute should also be paid to Wundt, whose psychological laboratory at Leipzig, utilizing and developing the work of Weber, trained a generation of experimental psychologists, some of whom later, in America, established psychology as an experimental science on this continent. Three among these (Hall, Cattell and Titchener) graduated students who presented Ph.D. dissertations on aspects of touch, these students graduating from Clark, Cornell and Columbia University (Dresslar, 1894, Griffing, 1895, and Washburn, 1894). In recent years Geldard, who describes himself as a "sensory generalist" devoted a lifetime of research to this topic, with texts and serial presentations from his laboratory, and work on the Orthohapt, a device for converting sound emissions into tactual reception (Geldard, 1953).

From early times there had been some recognition of a sixth sense, generally called a "muscle sense" (though later it was to be shown that sensations from joints were more important than the muscles) often referred to as "kinesthesis". Weber had titled his second major work as Der Tastsinn und Das Gemeingefuhl (1846), implying that as well as touch as commonly understood there was something which might be called "common sensibility", sensations generally taken to include pain, tickle, shudder, shiver, itch, muscular sensations, vasomotor sensations, nausea, thirst and hunger (Boring, 1942). Thus it is no surprise that much early sensory research following Weber and Wundt was directed to the delimitation of the named senses within the skin, research facilitated by physiological discoveries of sense endings and sensory processes. Kenshalo has provided an excellent review of this work under the title of Somesthesis (Kenshalo, 1971). Weber operated when the prevailing philosophy was, following Aristotle, for some primitive unity among the senses, but his experimental work and the theory of Johannes Muller on specific nervous energy, led others to a belief in an initial separation of the senses with any subsequent integration being due to later learning and experience. The controversy persists today.

The earliest reported attempts to investigate the tactual perception and recognition of the form of a solid figure was in 1898 when Titchener reported from the Cornell Laboratory on the work of his student, Major, on The Cutaneous Perception of Form . This had been explored by the use of passive touch, a method of investigation which persisted through the 1920's when interest was revived, as witness the writings of Zigler, and Dimmick (both Titchener's Ph.D. students graduating in 1924).

Throughout this period and later, the Gestaltists were responsible for much research on the determination of perception of form, of contours, of distinctive features, and of complexity, but only in the visual field (Hochberg, 1971). Piaget and Inhelder (1948, 1956) examined the exploratory aspect of touch in children and Soviet research on perception reported studies examining eye and hand movements of children (Zaporozhets, 1965, 1969). It was probably the "cookie cutter" experiment of Gibson (Gibson, 1962), followed by the experiments on sensory integration and cross-modal information processing (Friedes, 1974) and tactual experiments with blind subjects (Millar, 1971, 1972) which prompted attention to form and shape perception in a haptic modality, although even here the perception of form was often confined to the letter form, either in solid letters or the dot-pattern of their Braille equivalents. Much research needs to be undertaken in this area to bring it into line with research on the visual perception of form.

A more extensive review of the literature, provided in the next chapter, thus led to the definition of three major goals for the present research:

1. To examine developmental trends in intra- and inter-sensory haptic and visual processing in a population of able readers spanning the

elementary school grades, through the administration of four matching tasks: intra-modal haptic; intra-modal visual, inter-modal haptic-visual; inter-modal visual-haptic. The aim was to examine accuracy on each task, the types of exploration strategies used to explore the stimuli presented to the haptic modality, and the amount of time subjects spontaneously used to explore the individual haptic and visual stimuli.

2. To examine the effects of imposing substantially longer exploration times for the stimuli presented to the haptic modality than would be used spontaneously on accuracy scores on four tasks of intra- and inter-modal haptic and visual processing. More specifically, it was of interest to determine whether increasing exploration times for haptic stimuli would result in improved accuracy on tasks involving a haptic component, and whether these longer exploration times resulted in the use of more sophisticated (thorough) exploration strategies for the haptic stimuli.

3. To determine whether disabled readers differ in terms of performance on tasks requiring intra- and inter-modal haptic and visual processing relative to able readers. A point of particular interest in the present research was to determine whether the accuracy scores of the disabled readers relative to the able readers would support the intersensory deficit theory of reading disorders. In addition, it was of interest to examine the "task strategies" (exploration strategies for the individual haptic stimuli and exploration times for the individual haptic and visual stimuli) used by the poor readers, and to determine whether the disabled readers differed from the able readers on these measures.

This research was carried out over a period of three years, from 1979 through 1981.

CHAPTER II

REVIEW OF THE LITERATURE

Introduction

This chapter reviews the research on haptic and inter-sensory haptic and visual processing in able learners and reading disabled children. Section I reviews the fairly extensive research pertaining to haptic perception and inter-modal haptic and visual perception, under the following headings:

Historical Background
The Development of Haptic Perception
Inter-sensory Processing: Theoretical Formulations
The Relationship Between Touch and Vision
Inter-sensory Processing: The Research Literature
Research Involving Infants
Haptic Exploration Strategies
Exploration Times
Memory and Encoding

Section II addresses inter-sensory theories of reading disabilities and research involving assessment of the haptic modality in reading disabled children. The research studies are reviewed under the following headings:

Section I

Haptic Perception and Inter-modal Haptic and Visual Perception

Historical Background

Arising from the belief that there are five senses, as set out by Aristotle, vision, audition, taste, smell, and touch (or feeling), attention has usually been paid to the senses in the order named above, and such attention appears to have commenced when philosophers of the 17th century and later began to enquire into the origin of man's knowlege, and decided that "knowledge comes to the mind through the avenue of the senses" (Boring, 1942, p. 3).

As Flugel pointed out many years ago:

> a student [of the 1830's] interested in the problem of the human mind or curious concerning the behaviour of his fellow men had two main avenues of approach - Philosophy and Medicine. The former was the more obvious and better trodden . . . [though] . . . philosophy itself had become in a sense physiological through the labors of that sturdy trio of English empiricists - Locke, Berkeley and Hume. (Flugel, 1933, p. 10-11)

While philosophers were the first to make an impact in the field of perception, professionals in the field of medicine gradually gained dominance.

Locke's declaration of the "tabula rasa" (Locke, 1690) left it open to others to decide how man grew to be a sensing, knowing individual. According to Boring (1957), Berkeley's texts, An Essay Toward a New Theory of Vision (1709) and Principles of Human Knowlege (1710) placed him "on the left wing of empricism". Berkeley proposed that we only have knowlege of what we perceive, and if we ~~are not~~ perceiving we have no knowledge. Ideas are separated according to the senses used in their perception; vision and touch are more important than the objects they perceive, and what we perceive by touch is distinct from what is perceived visually.

Berkeley's immediate successsor, David Hume (1739, 1748) sought to restore to the word "ideas" what he thought had been perverted by Locke. Hume maintained that ideas were not given "a priori" but rather, arose from impressions. An idea is the experience we have in the absence of an object, impression in its presence (Boring 1957).

In France, de Condillac, a philosopher, published Traité des Sensations (1754), in which he asserted that one essential attribute of the mind is its capacity for sensations. Condillac asserted that ideas come through the senses, and sensations present together in consciousness give rise to new sensations through their combination. Of greater importance in the field were the publications of J.J. Rousseau. His work Emile (1762) has been descibed as "the greatest educational event in the 18th century"

(Compayré, 1895). Emile was a fictional character brought up "in nature" i.e. without the influence of society. Rousseau was pre-occupied with developing the senses of his "pupil" Emile; for he believed that the first faculties that are formed and perfected are the senses: " To call into exercise the senses, is, so to speak, to learn to feel; for we can neither touch, nor see, nor hear, except as we have been taught [italics added]." (Compayré, 1895, p. 295)

The impact of Rousseau's work was sufficient that when a so-called "enfant sauvage" was found in Aveyron in 1800, Itard (a physician) undertook to educate the boy, "Victor", even though he had been diagnosed by Pinel as an idiot (incapable of being trained or taught). Itard believed the child's condition to be the result of isolation from an early age and consequent lack of opportunity to acquire the habits and skills of civilized man. When he eventually gave up on Victor, Itard turned to the study of hearing, and in 1821 published Diseases of Hearing. In the last year of his life (1837), Itard accepted a young "idiot" from a Paris hospital into his program of "demutilization and language instruction" and one of his students, Edouard Seguin, continued this work after Itard's death. Seguin published a number of works, in which he provided details of the materials and methods that he used with mentally subnormal children, and showed how the methods could be extended for use with normal children (Seguin,1859, 1866). The importance of his work is that it focused on education of the senses, particularly vision and touch.

The last of the medically trained persons to enter into the field of education and sense training in general, was Maria Montessori (1912).

Working in a clinic with a population ranging from imbeciles and idiots to extremely mentally deranged, Montessori sought to continue the work of Itard and Seguin, maintaining that "mental deficiency presented chiefly a pedagogical rather than a medical one [problem]." She was later able to apply the apparatus and methods that she had developed for use with subnormals to normal pre-school children. Montessori's method is perhaps best known for its emphasis on sensory training and the primacy of touch over vision.

On the medical scene itself, the first quarter of the 19th century saw the independent discoveries of Bell (1811) in Scotland and Magendie (1822) in France of the conduction pathway in sensory and motor nerves, the former in the dorsal roots and spinal ganglia, the latter in the ventral roots of the spinal cord.

Detailed investigation of touch may be said to start with the work of E.H. Weber, a professor of anatomy and physiology, who published Der Tastsinn und das Gemeingefuhl (1846) which would roughly translate as The Tactual Sense and Common Sensibility. Weber was able to divide Der Tastsinn into three aspects - Der Ortsinn, Der Drucksinn, and Der Temperatursinn - translated as the sense of locality, of pressure, and of temperature. Von Frey (1894, 1896) confirmed pain as the fourth sense within the skin.

The bulk of psychological research prior to the 1930's involved sensation and perception. The establishment of the psychological laboratory by Wundt in Liepzig (1879) was particularly important (Boring, 1942). As Geldard (1972) notes, "over half of the studies issuing from

Wundt's laboratory and those of his students were concerned with sensation and perception" (p. i). Wundt's students, most notably Titchener and McKeen Cattell, brought his ideas and methods to America. Titchener defined the term "haptics" in Baldwin's dictionary (1905) as:

> The doctrine of touch with concomitant sensations and perceptions - as optics is the doctrine of sight and accoustics that of hearing . . . It may cover (and this is probably its best use) the whole range of function of the skin, muscle, tendon and joint, and even the static sense - thus including the sense of temperature and pain, and the perceptions of position, movement etc: or it may be restricted to cutaneous sensations and perceptions in the narrower sense. (p. 441)

Oddly enough, only one of the references given (in English) after this definition, used the word "haptic", this being Griffing, a student of Cattell, who used it throughout his dissertation. From a modern standpoint, missing was work on synesthesia (sensation produced in one modality when a stimulus is applied to another modality) and perception of forms.

Just prior to World War II, Lowenfeld (1939) produced a series of tests for haptical aptitude among creative people. Later, in his work with the U.S. Air Force, he extended the range and applicability of his tests. A description of these tests was provided in a later publication, entitled Tests for Visual and Haptical Aptitude (1945). Revesz had already published Die Formenwelt des Tastsinnes (1938)[1] , and System der Optischen und Haptischen Raumanschauugen (1934), roughly translated as Visual and

1 Later republished as Psychology and Art of the Blind (1950).

Haptic Perception of Space, and re-introduced the term "haptics" into the realm of sensory psychology.

By 1940, sufficient work had been done on perception in various sensory modalities for the Psychological Bulletin to publish a summary and comment by Ryan entitled Interrelations of the sensory systems in perception. It is interesting to note that Ryan was very dismissive of Hornbostel's and Werner's beliefs in a "unity of the senses", a topic which is dealt with later, and said very little about visual-tactual integration. By contrast, Friede's paper in the same journal in 1974 casts the whole topic in a different light, as its title and references indicate. Human information processing and sensory modality: Cross modal functions, information complexity, memory, and deficit included 184 references; of these only nine were prior to 1960, and 87 were from 1970 onwards, suggesting that the "geist" of the seventies must have been favorable to studies of cross-modal processing. What is perhaps even more remarkable, is that Friedes' paper does not contain a single reference to J.J. Gibson, held in some circles to be a prime mover of such work with his text The Senses Considered as Perceptual Systems (1966). A final note on this odyssey is in order -- both Dissertation Abstracts and Psychological Abstracts now have entries under both touch and haptics; the former shows that graduate research on haptic perception is widely diffused among a great number of universities, including McGill. Most recently, the Department of Space Medicine at McGill University conducted an experiment on haptic perception in space.

The Development of Haptic Perception

Gibson brought haptic perception more fully into the experimental literature in 1962 with his description of the differences existing between active and passive touch, although the terms were used by Stout in his 1899 manual and encountered in Titchener's definition in Baldwin's Dictionary (1905). Active touch involves an impression on the skin which is obtained by the perceiver himself, whereas in passive touch the stimulation is imposed on the perceiver by some outside agency. The hand can grope, palpate, prod, press and rub, thus detecting many of the properties of an object in the absence of vision. Gibson emphasized that active touch:

> does not fulfill the supposed criteria for a single sense modality. Nevertheless, it provides a quite definite channel of information about the external environment. It is a type of perception that is isolable from vision, audition, taste and smell and it needs to be studied in its own right. (Gibson, 1962, p. 479)

Gibson's own research (1966) confirmed the finding reported by Lashley (1951) that active haptic exploration provides more useful information for object and shape perception than passive touch or cutaneous stimulation. Haptic perception[2] , or active tactual perception, is the manipulation of objects by the hand in the absence of vision, to identify their particular

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2 The terms haptic perception and tactual perception are generally used synonymously in the literature to refer to active manipulation of an object in the absence of vision, though early experiments on haptic perception used passive touch. Kinesthetic perception, on the other hand, generally involves skin, muscle and joints, in the perception of objects in the absence of vision.

properties of shape, size, texture and configuration (McCarron and Horn, 1979).

Piaget and Inhelder (1948, 1956) provided a detailed description of the development of haptic perception and the exploratory aspect of touch in an extensive treatise on the study of haptic perception and space. They investigated the exploratory behaviour of young children discriminating objects and shapes by touch, and the degree to which these manipulations provided information about the objects being explored. A trend from passive and unsystematic exploration to active and systematic tactual exploration was found in children between two and a half and seven years of age. Piaget and Inhelder postulated that the development of haptic perception of shape is defined by several ontological sequential stages.

Stage 0 (below 2;6 years) Experimentation with hidden objects is not possible, although this by no means precludes the existence of spontaneous tactile recognition outside these experimental conditions.

Stage IA (ages 2;6 - 3:6) Child recognizes only familiar objects, but not shapes. Tactile exploration remains relatively passive. The child simply gropes the object and responds to chance discoveries.

Stage IB (ages 3;6 - 4;0) Child is able to recognize some abstract shapes. The shapes first recognized are topological rather than Euclidian (e.g. circle and square cannot be distinguished because they are both closed forms, but closed forms are distinguished from open forms). Shapes are explored as if they were three-dimensional.

Stage IIA (ages 4;6 - 5;5) Tactual exploration is more active although still rather empirical and tentative. Differentiation of rectilinear from curvilinear shapes is apparent later in this stage and recognition of certain more precise Euclidian relations such as circle versus ellipse and square versus rectangle is evident.

Stage IIB (ages 5;5 - 6;6) The child begins to be capable of differentiating Euclidian type shapes such as rhombus and trapezoid. Exploration becomes more active, although remaining unsystematic.

Stage III (ages 6;6 - 7;0) The most complex shapes (e.g. various shapes and crosses) are recognized, and the child is able to simultaneously take account of order and distance. The child exhibits systematic and methodological exploration techniques.

Laurendeau and Pinard (1970) provide a detailed treatment of Piaget's theoretical propositions on the development of topological and Euclidian space.

It is important to mention that Piaget's theory emphasized the critical role of manipulation or motor activity in cognitive and perceptual functioning and development. According to Piaget and his associates (Piaget, 1952, Piaget and Inhelder, 1956), cognition originates from the child's overt manipulation of objects in that cognitive or intellectual structures derive from the internalization of such overt acts. The view that cognition and perception are based on active overt contact with stimuli or sensorimotor behaviour has been entertained by other major cognitive developmental theorists as well (e.g. Bruner, 1966; Bruner, Oliver and Greenfield; 1966; Kephart, 1960; Werner, 1948).

Piaget and Inhelder's experiments have been criticized for methodological weaknesses. Few specifications were provided regarding the number and sex of the subjects, whether exploration was with one or two hands, the size of the objects (whether they could be held by the child in his/her hand), nor the number of observers, observations and the accuracy of recording. It is also important to note that Piaget and Inhelder's task involved manual exploration of an object or shape in the absence of vision and then naming or choosing it from a collection of alternatives presented for visual examination. As such it was a cross-modal haptic-visual comparison task as defined in later research. However, Piaget and Inhelder's observations have been substantiated by a number of other studies employing improved experimental designs. Page (1959) noted that haptic perception appears to be a function of the child's age. He found that "common objects" were the first recognized, followed by forms differing in topological transformations, and finally Euclidian forms. Similar findings were reported by Fischer, 1965; Laurendeau and Pinard, 1970; and Peel, 1959, although the results of these subsequent studies differ as to the age at which children attain the various stages as specified by Piaget.

Much research on haptic perception has established age related improvements on tasks of haptic matching throughout the childhood years (e.g. Butter and Zung, 1970; Conners, Schuette and Goldman, 1967; Davidson, Cambardella, Stenerson and Carney, 1974; Derevensky, 1976; Flanery and Balling, 1979; Goodnow, 1971a; Jackson, 1973; Klein (cited in Pick, Pick and Klein, 1967); Lattoni, 1981; Petrushka, 1978; Rudel and Teuber, 1964; Zinchenko and colleagues (reported in Zaporozhets, 1965)), and between childhood and adulthood (e.g. Abravanel, 1971b; Coté and Schaefer, 1972b; Flanery and Balling, 1979).

Inter-sensory Processing: Theoretical Formulations

Inter-sensory processing[3] refers to the ability to process, integrate and organize information arriving as inputs from different sensory modalities. As such, it is distinguished from intra-sensory perception which refers to the processing of information from one perceptual system. In terms of haptic perception the sensory modality of greatest interest in inter-sensory processing is vision.

Two main theoretical views have been proposed to explain the phenomenon of cross-modal processing (Ittyerah and Broota, 1983). The classical empiricist or separation theory holds that the eye and hand are initially separate and specific, becoming integrated in the course of development. During the developmental period, relationships between the haptic system and the visual system develop through association. The opposing view, often referred to as the developmental differentiation view, proposes that the visual and haptic senses are initially undifferentiated, gradually becoming differentiated with development. Each of these theories has its own proponents. Classically the former prevailed; more recently the latter has gained greater support.

Piaget (1952) postulated the initial independence of hand and eye activities, the two perceptual systems gradually becoming integrated under the direction of vision. In The Origins of Intelligence in Children

3 Note that the terms inter-sensory, inter-modal and cross-modal perception are used synonymously.

(1952), Piaget outlined five stages in the development of prehension. These stages progress from the simple reflexive grasping behaviour of the newborn infant to the well integrated coordination of vision, reaching and grasping characteristic of the older baby. In the first two stages the infant is involved in impulsive, reflexive (nonvoluntary) grasping and will grasp and hold for the sake of repetitive activity. In the third stage, vision becomes involved in the hand's activity, in the sense that the eyes attend to the hand's behaviour. The subsequent stage (stage four) is characterized by the hand moving to grasp a viewed object when both the hand and the object are in the visual field. It is only in the fifth stage that the hand will be brought from out of sight to grasp an object.

White (1971) also characterized vision and touch as independent systems which gradually become integrated into a "superordinate system which integrates their separate capacities" (p. 63). He describes the development of prehension in eight stages or age periods. The eighth stage, achieved at four to five months, is characterized as follows: "The visual-motor schemas of eye-hand and eye-object have now become integrated with the tactual-motor schema of the hand, resulting in the beginning of visually directed grasping" (White, 1971, p. 64).

Birch and his colleagues (Birch and Belmont, 1964; Birch and Lefford, 1963, Birch and Lefford, 1967) also espouse the empiricist position, maintaining that the hand and eye are initially separate, and become integrated during development. They proposed that perceptual development is characterized by a shift from tactual dominance (proprioceptive input) to visual dominance (teloreceptor systems) paralleled by an increasing liaison between the senses. Their viewpoint is summarized as follows:

> Information derived from proprioceptive input is dominant in controlling the actions of infants . . . .with age, proximoception comes to be increasingly replaced by teloreceptor control systems. Simultaneously with the emergence of teloreceptor preeminence, a second mechanism of input organizations seems to be evolving. It consists of the increasing tendency of the separate sensory modalities to integrate with one another and of organized and directed action to be subserved by inter-sensory or multimodal rather than unimodal patterning. (Birch and Lefford, 1967, p. 5-7.)

One of their studies (Birch and Lefford, 1963) involved presenting geometric forms from the Seguin Form Board to children aged five through eleven. Subjects were required to judge whether two forms perceived simultaneously were the same or different. Three conditions were presented: visual-kinesthetic (VK), haptic-kinesthetic (HK), and visual-haptic (VH). (Kinesthetic conditions involved the child gripping a stylus which passively followed the outline of the form; whereas haptic conditions involved active manipulation of the forms.) A fairly linear improvement with age was evident under all conditions, although rates of improvement differed between the conditions. Ability to integrate information from different sensory modalities (the visual, haptic and kinesthetic modalities) was found to increase with age, thus lending support to the empiricist theory.

> It was found that the ability to make the various inter-sensory judgements clearly improved with age. The improvement in function appeared to be adequately described by a typical logarithmic growth curve which supports the view that the development of inter-sensory functioning follows a general law of growth. (Birch and Lefford, 1963, p. 45)

In support of the developmental differentiation hypothesis, Bower has presented experimental evidence to support a primitive unity of the senses (Bower, 1972, 1974a; Bower, Broughton and Moore, 1970). Bower suggests that, ontogenetically, infants progress through stages from an initial unity of the senses to a gradual differentiation (Bower, 1974b). In a series of experiments, Bower found that infants as young as two weeks showed appropriate reaching responses based on the visual information available to them. If an object was placed in their visual field but out of reach they would cease attempting to reach for it, without showing any distress; however, they continued reaching for an object within their range (Bower, 1974a). When infants of this age were presented with an image of an object (a visual object empty to the sense of touch) within their range, their failure to make tangible contact with it (i.e. lack of tactile input when it was expected) resulted in distress and continued attempts to reach for it (Bower, Broughton and Moore, 1970). Bower concluded, "These findings do not support the notion that visual information can come to specify tactual properties only after a long period of apprenticeship" (Bower, 1974a, p.114).

Bower proposes that vision and touch become differentiated at around six months of age. By this age, vision is the dominant of the two sensory modalities.

> One can clearly observe the establishment of vision as the dominant sense. Infants between four and five months old will try to grasp a seen object and will continue to grasp an object which they cannot see. This indicates that both visual input and tactual input can specify the presence of an object to be grasped. Around six months of age, this is no longer true however. An infant will drop an object that he is grasping if he can no longer see it . . . it thus seems that one consequence of the differentiation of vision from touch is that touch loses its ability to specify the presence of an object and regains this ability only after a prolonged period. (Bower, 1974 a, p. 116)

Other research has provided evidence that infants as young as six months of age can transfer information between the tactual and visual modalities. This research is reviewed later in this chapter under the heading Research Involving Infants.

In a departure from these two major viewpoints (the empiricist and developmental differentiation view), the Gibsons (E.J. Gibson, 1969; J.J. Gibson, 1966) explain cross-modal processing in terms of invariant 'amodal' stimulus information. Such information is not modality specific but is rather invariant over the modalities: "Information gathered by one perceptual system is covariant, coincident or correlated with the information got by another perceptual system, and is therefore redundant or equivalent" (J.J. Gibson, 1966, p. 298). Information about distinctive features of objects or events which can be abstracted from one or more sensory experiences (such as corners, motions, temporal patterns and transitions) are amodal. Goodnow summarizes the amodal framework as follows:

> The equivalence of any two inspections depends on the degree of sampling overlap, on the extent of correspondence or isomorphism between the sets of properties sampled on the two occasions. The overlap may be direct (e.g. two inspections focus on the same corner of a shape) or indirect (e.g. one set of properties can be converted into another by some rule of correspondence or translation). (Goodnow, 1971c, p. 22)

The Relationship Between Touch and Vision

An assumption of the empirical or "separatist" theory of perception is the primacy of touch over vision. The assertion that visual perception is based on prior tactual, kinesthetic or proprioceptive experience has been highly prevalent in the history of perception (Pick, Pick and Klein, 1967). Bishop Berkeley (1709) was a strong proponent of this view. Montessori also emphasized the importance of early tactual exploration on subsequent development of visual perception.

> . . . among the various forms of sense memory that of muscular sense is the most precocious. Indeed many children who have not arrived at the point of recognizing a figure by looking at it, could recognize it by touching it, that is by computing the movements necessary to the following of its contour. (Montessori, 1964, p. 198)

Adherence to the view that "touch teaches vision" has been very strong in the Soviet literature on perception (reported in Pick 1964, and Zaporozhets, 1965, 1969). It is maintained that the sense organs, exemplified by the hand, obtain information by actively exploring objects in the environment. A motor theory of perception is proposed, in which the external stimulus elicits a motor response which copies certain properties of the original stimulus. The feedback from the copying response then serves as a basis for perception. The implication that there is a proprioceptive component to all stimulation is evident (Pick, Pick and Klein, 1967).

If touch were to educate or "teach" vision, it would be expected that the experimental literature would indicate a developmental sequence from haptic to visual processing of sensory information. However there is very little research evidence to support the view that touch is dominant in the early life of children:

1. At every stage of development visual processing of information is found to be more accurate than haptic perception.

2. When an experimental conflict between the two senses is produced, information from the visual modality is generally dominant in the individual's judgements.

3. Research seems to indicate that haptic information does not significantly improve performance on shape recognition tasks over judgements made on the basis of visual information alone.

The research literature pertaining to these points will be summarized briefly.

The superiority of visual over haptic processing. Doody and Long (1984) note that the dominance of vision over the other senses is a well established characteristic of human performance. There is little evidence to confirm the belief that young children spontaneously engage in active haptic/tactual perception of objects that they can see. At every stage of development, vision seems to be the preferred and the more accurate of the senses.

Evidence of the superiority of performance on intra-modal visual over intra-modal haptic matching tasks is abundant in the research literature investigating haptic and visual matching of shape. Gliner, Pick, Pick and Hales (1969) examined the visual and haptic discrimination of shapes and textures. Visual judgments were found to be more sensitive than haptic judgements; furthermore, while haptic sensitivity increased between five and eight years, visual sensitivity had reached its maximum by five years of age. The authors conclude:

> The results would seem to be incongruent with the empiricist position that the development of vision is based upon the prior development of the haptic modality. The present data add to the growing body of evidence which suggests that the empiricist position is incorrect and that visual sensitivity develops early and is not based on haptic sensitivity. (Gliner, Pick, Pick and Hales, 1969, p. 33)

In a study investigating intra- and inter-modal haptic and visual matching of geometric and nonsense forms, Rudel and Teuber (1964) found intra-modal visual matching to be the easiest and intra-modal haptic matching the most difficult for preschool children (aged three to six).

Similarly, Zinchenko and his colleagues (cited in Pick, Pick and Klein, 1967) reported visual matching of two dimensional nonsense shapes to be more accurate than haptic matching at all ages in their sample of three to seven year old children, with errors decreasing from 50% to 2% for visual matching and from 70% to 40% for tactual matching.

De Leon, Raskin and Gruen (1970) found that visual inspection of random shapes was superior to haptic perception in discriminating random forms in a population of 3 and 4 year old children. In a study involving kindergarten, first, second and third grade children, Butter and Zung (1970) found that while haptic performance improves gradually between kindergarten and third grade, visual performance has stabilized by five and a half years. Similarly, Goodnow (1971a), using kindergarten and fourth grade children as subjects, found matching by hand to be more difficult than matching by eye, the difference being larger at the youngest age level and then decreasing but remaining significant for the older children. She noted: "a sharp division appears, somewhere around [the age of] 5;6 . . . between chaos and relative accuracy in matching complex shapes by hand " (Goodnow, 1971a, p. 91). In contrast, children were capable of fairly accurate (90% accuracy) visual matching of shape at 5;0 years (Goodnow, 1971a). Appelle, Gravetter and Davidson (1980) investigated perception of proportion by adult subjects. Visual form perception was consistently superior to haptic form perception. Other research indicating the superiority of the visual perceptual system compared to the haptic system include Bryant and Raz (1975); Davidson, Cambardella, Stenerson and Carney (1974); Jackson (1973); Jones and

Robinson (1973); Millar (1971, 1972); Milner and Bryant (1970); Rudel and Teuber (1964, 1971). Visual matching is also superior for adults (e.g. Butter and Bjorklund, 1973; Cashdan, 1968; Friedes, 1975; Zung, Butter and Cashdan, 1974).

In summary, the bulk of research evidence points to the superiority of the visual system over the haptic system in form matching in children and adults. Furthermore, it seems that children under the age of five or five and a half seem to have a great deal of difficulty matching shapes by hand whereas visual perception of shape is apparently well developed and acccurate by this age.

Experimental conflict between vision and touch. Many research studies show that even when subjects are presented with conflicting visual and haptic information, vision is usually dominant in the individual's judgements. Rock and Victor (1964) used an optical cylinder to distort the shape of an object. Subjects were thus presented with an object whose visual shape differed from its haptic shape. Subjects presented with this conflicting haptic and visual information based their shape judgements on the visual information available to them. The authors conclude: "The results reveal that vision is strongly dominant, often without the observer being aware of the conflict" (Rock and Victor, 1964, p. 594).

Other studies, adopting a similar research design, confirm this conclusion. McGurk and Power (1980) used a distorting lens to present preschool children (48 through 61 months of age) with conflicting visual and tactual information concerning the shape of a target object. Selection of a matching object from a comparison array that was explored visually and tactually revealed a strong visual dominance. No cases of tactual dominance were found, and no subject indicated any awareness that different information was being presented to vision and touch.

> Our results suggest that by the preschool period the expectancy for objects to feel as they look is so entrenched as to ensure perceptual unity even under conditions of considerable potential conflict. Whether such unity is biologically given or an expectancy that develops through learning and experience is as yet an unresolved issue. (McGurk and Power, 1980, p. 680)

Power and Graham (1976) found that visual dominance persists despite training in making tactual judgements. In a subsequent experiment, Power (1981) found that subjects (adults) required to examine well known objects, such as dice and coins, reported that the objects were like or felt like their visual images, indicating that visual perception is more potent than tactual stimulation. Bacon and Shaw (1982) found that even when a highly salient clue directly alerted the subject to the fact that the seen and felt stimuli were different objects, visual dominance is complete.

Experimental results indicating visual potency have been reported by several other investigators (e.g. Hay, Pick and Ikeda, 1965; Kinney and Luria, 1970; Owen and Brown, 1970; Pick, Warren and Hay, 1969).

<u>The combined use of touch and vision</u>. Abravanel (1972a) investigated the cooperation of vision and touch to gather information about unfamiliar shapes. The haptic perceptual activity of nursery school and kindergarten

children was studied under two conditions: i) where it occurred without visual inspection, ii) with the combined operations of hand and eye. The children ignored the haptic information available to them when given an opportunity to combine handling and viewing of shapes for purposes of matching. Abravanel concluded:

> . . . it is tempting to conclude that by 4 years, and perhaps a good deal earlier, the young child has created a division of labour between eye and hand in which visual perception is given the major role for shape differentiation. (Abravanel, 1972a, p. 174)

A subsequent study (Abravanel, 1973a), designed to determine whether adults would perform similarly, found that adults did combine haptic and visual "pickup" when matching was with haptic comparison shapes. When the matching was with visual comparisons, information pickup was confined to visual inspection. While providing interesting information about developmental changes in strategies of perceptual activity, it is unclear why young children choose to perform on the basis of visual recognition in a situation where haptic information is also possible. Abravanel notes:

> . . . it may be that young children are relatively poor at integrating information from hand and from eye, and where possible, rely heavily on one source of information - namely, visually derived information . . . . at the same time, we cannot overlook the possibility that haptic information is bypassed because effective haptic perception of complex shapes is difficult for young children. (Abravanel, 1973a, p. 210)

A series of studies conducted by Butter, Cashdan and Zung (Butter and Zung, 1970; Cashdan and Zung, 1970; Zung, Butter and Cashdan, 1974) suggest that from five years through college age, individuals attain the same level of performance on matching tasks with visual information only as with visual plus haptic information. They suggest that haptic information is redundant when presented bimodally.

DeLeon, Raskin and Gruen (1970) examined the perception of shape by touch, by vision, and the integrated use of both touch and vision in younger children (three and four year olds). The integrated use of touch and vision in shape discrimination resulted in no better performance than that with vision only. Similar results were reported by Millar (1971) with a population of three and four year olds. For both age groups, visual plus haptic exploration of the standard with visual recognition (VH-V) was superior to the H-H, V-H and H-V conditions, but did not differ from the V-V conditions, indicating that visual recognition of nonsense shapes was not improved when haptic cues were added. On the other hand, for the four year olds, adding visual cues significantly improved haptic recognition, i.e. subjects at this age level performed significantly better on the VH-H task (visual plus haptic exploration of standard, with haptic recognition) than on the H-H task.

Contrary to the findings cited in these studies (Abravanel, 1972a; Butter and Zung, 1970; Cashdan and Zung, 1970; DeLeon, Raskin and Gruen, 1970; Millar, 1971; Zung, Butter and Cashdan, 1974), Wolff (1972) found that visual recognition of nonsense forms was enhanced by haptic exploration in a sample of four to seven year old children, although it appears that this facilitation decreased with age. Wolff suggests: "It may be that haptic exploration is important in early perception, not as a modality in its own right, but for its contribution to visual perception" (Wolff, 1972, p. 428).

Thus, while the evidence is not unequivocal, the majority of research findings indicate that haptically acquired information does not significantly enhance shape recognition obtained on the basis of visual information alone.

Zung, Butter and Cashdan (1974) propose several explanations to account for the absence of improvement on form recognition matching tasks when haptic input is provided concomitant with visual input:

> First, if the stimuli and tasks are simple, S's visual scanning exclusively may be adequate to produce relatively accurate performance . . . . Secondly, S's may undervalue (and consequently not register) haptic input which appears largely redundant with visual input . . . . Thirdly, visual prepotency, referring to information processing habits which have been strengthened by long-term use in the visual mode, may shape and limit the extent of haptic activity . . . . A fourth consideration involves the possible influence of test modality upon bimodal performance . . . . Finally, requiring S's to attend to bimodal input may compel them to use unfamiliar and unpracticed strategies for acquiring and processing information, with the actual amount of information perhaps not as burdensome as the novelty of the learning situation. (Zung, Butter and Cashdan, 1974, p. 74)

Research specifically addressing memory and encoding characteristics of the two sensory systems (haptic and visual), and exploration times and strategies is discussed later in the chapter.

Inter-sensory Processing: The Research Literature

The importance of studying inter-sensory processing has been considered from a number of different viewpoints. Researchers have been interested in how information gained haptically can be compared with other kinds of sensory information, mainly visual information. There is a large body of experimental literature investigating cross-modal haptic and visual processing. Many of these studies have also examined intra-modal haptic and visual processing.

Generally, two kinds of research designs have been used to assess perception within and across the haptic and visual modalities. In the most widely used paradigm, the "equivalence" or "matching" method, a standard stimulus is presented to one modality, and comparison stimulus/stimuli presented either to the same modality as the standard (intra-modal task) or to a different modality (inter-modal or cross-modal task). When only one comparison object is used (paired comparison technique), the subject is required to judge whether the comparison object is the same as or different from the standard object. When more than one comparison object is presented, the subject is required to identify the one that is the same as the standard. The standard and comparison stimuli may be presented at the same time, allowing for simultaneous examination, or the comparison stimulus or stimuli may be presented after the standard object has been removed, resulting in successive examination. If there are two or more comparison stimuli, they may be presented at the same time or one at a time (successively).

The "transfer-of-training" method is used to specifically explore inter-modal functioning. Subjects are divided into two groups -- one group exploring several forms or shapes first visually and then haptically, the second group exploring the forms first haptically and then visually. If either the visual or haptic discrimination is learned more rapidly in the second phase, it is assumed that transfer from the first to the second task has occurred. As Jones (1981) has pointed out, very few studies have attempted to compare presentation methods and modality conditions, although method of presentation may account for much of the variance in results of different studies.

Extensive reviews of cross-modal haptic and visual processing have been provided by Derevensky (1978) and Friedes (1974). Although there is a lack of consistency in the findings in the research literature in this area, there are two frequently stated results: (a) age-related improvements in cross-modal perception (e.g. Birch and Lefford, 1963; Davidson, Cambardella, Stenerson and Carney, 1974; Jackson, 1973; Millar, 1972, Milner and Bryant, 1970); (b) superiority of intra-modal visual over cross-modal processing between the haptic and visual modalities (e.g. Davidson, Cambardella, Stenerson and Carney, 1974; Goodnow, 1971a; Ittyerah and Broota, 1983; Millar, 1971, 1972; Milner and Bryant, 1970).

Many studies report an asymmetry in inter-sensory processing; some studies have found haptic-visual processing to be easier than visual-haptic processing (e.g. Abravanel, 1968; Bryant and Raz, 1975; Connolly and Jones, 1970; Eastman, 1967, 1968; Gaydos, 1956; Hermelin and O'Connor, 1961; Krauthamer, 1968), while others have found the visual-haptic sequence easier (e.g. Abravanel, 1972b, 1973b; Blank, Altman and Bridger, 1968; Friedes, 1975; Garvill and Molander, 1968; Goodnow, 1971a; Jackson, 1973; Lobb, 1965; Milner and Bryant, 1970; Rose, Blank and Bridger, 1972; Rudel and Teuber, 1971).

Many of the studies examining inter-sensory processing lack intra-modal controls. Bryant (1968) noted that lack of intra-sensory controls makes it impossible to infer qualitative changes in perceptual integration, for unless it can be shown that inter-modal errors are greater than intra-modal errors, no conclusions can safely be made. Increased performance on cross-modal tasks might simply be due to children's increased ability to discriminate visual or haptic cues.

> In addition to cross-modality matching, the experimenter should include within-modality matching conditions. If more errors are consistently made in the cross- than in the within-modality conditions, the experimenter can properly conclude that the subjects are failing to integrate information across modalities. If, on the other hand, the errors made in the cross-modality conditions are no greater than the errors made in at least one of the within-modality matching conditions, no conclusion can be drawn about the ability to integrate information across modalities, since the errors in cross-modality matching are probably the result of a failure to discriminate cues coming through that modality. (Bryant, 1968, p. 128-129)

Several studies in the research literature which include intra-modal controls report cross-modal improvement mirrored by intra-modal improvement (e.g. Abravanel, 1971a, 1972b, 1973b; Cashdan, 1968; Davidson, Cambardella, Stenerson and Carney, 1974; Garvell and Molander, 1968; Hermelin and O'Connor, 1961; Milner and Bryant, 1970; Rose, Blank and Bridger, 1972; Rudel and Teuber, 1964).

The contradictory findings in research investigating intra- and inter-modal haptic and visual perception may be at least partly attributable to the following four factors (a) procedural differences (simultaneous or successive presentation of stimuli), (b) imposition of delays between presentation of standard and comparisons, (c) stimulus properties of shapes, and (d) the different age groups of subjects (adults, children, preschoolers) used in studies.

Jones (1981) proposed that cross-modal matching between vision and touch can be explained on the same basis as intra-modal matching: performance depends on processing in the modality which is the most efficient for the task. For instance, if visual processing is more efficient, a subject presented visual-tactual matching tasks involving successive presentation of items should have adequate knowledge of the visually inspected standard stimulus to be able to control tactual exploration of the comparison item(s) fairly efficiently. Tactual-visual matching tasks should be more difficult, as tactual exploration of the standard stimulus would not have provided the subject with sufficient information about the standard form to enable the subject to know what to look for in the comparison item(s). In an intra-modal tactual matching task, "pick-up" of information about both standards and comparisons would be inefficient. If such a model were true, the performance on modality conditions with successive presentation would be as follows: VV>VT>TV>TT. With simultaneous presentation, performance on TV and VT conditions would differ only if there is one standard stimulus and more than one comparison stimulus, in which case there are fewer items to explore haptically (tactually) in the TV condition. Therefore, the expected order would be TV>VT or possibly TV=VT, if the subject was provided sufficient time to explore all tactual alternatives adequately. Jones further postulated that developmental improvements in tactual perception should result in less pronounced differences between presentation method and the three conditions involving a haptic component, and the ordering should eventually be VV>TT=VT=TV.

Jones substantiated this theory by analyzing the results of fifteen studies (none of which involved a substantial delay between presentation of standard and comparison items) comparing the four intra- and inter-modal conditions: TT, TV, VT and VV . When presentation was successive, the ordering of cross-modal comparisons was either VT>TV or VT=TV (the latter in populations of adults or populations including older age groups), suggesting that the ordering becomes VV>TT=VT=TV with development. However, the order remained VV>VT>TV>TT even with adults or adolescents when the stimuli used were nonsense forms, and the order of VV>TT=VT=TV was found when the stimuli were three dimensional forms. The evidence is less clear cut for conditions involving simultaneous presentation of stimuli. Jones concluded:

> There is.... strong evidence that cross-modal matching of form ... between vision and touch may be determined by our efficiency in making visual judgements and our relative inability to make the same judgements through touch. There is little doubt that within-modal visual matching is more accurate than [within-modal] tactual matching, particularly in children, and the cross-modal comparison, VT, tends to be more acccurate than the converse TV task when standard and comparison items are not simultaneously present. We might reasonably conclude, therefore, that visual perception of the standard allows the more efficient pickup of information about the comparison sample in both the within- and the cross-modal conditions. (Jones, 1981, p. 123-124)

Other investigators have attempted to account for the superiority of the visual over the haptic modality in the processing of information concerning shape and the directionality found in cross-modal matches between the haptic and visual modalities in terms of memory and encoding characteristics, and exploratory strategies and exploration times. Research pertaining to these topics is discussed later in this chapter.

Research Involving Infants

The use of haptic information by infants and the ability of infants to transfer information between the haptic and visual modalities received considerable attention in the 1970's and early 1980's, focused on three issues:

• The extent to which the haptic system is capable of mediating perceptual and cognitive events in the absence of vision.

• Whether infants can use haptically processed information for cross-modal transfer to a visual task.

• Whether haptic perception adds anything to visual perception.

Much of the research studying transfer between the haptic and visual modalities (cross-modal processing) and intra-modal haptic processing in infants has been conducted by Gottfried, Rose and Bridger. An early study (Gottfried, Rose and Bridger, 1977) demonstrated the ability of one year old infants to gain information through active touch (with one hand or with the mouth) and to use this haptically acquired information for cross-modal transfer to a visual task. Visual recognition was tested by presenting the infant with two objects (the familiar and a novel stimulus), and measuring visual fixation times to the two stimuli.[4] This procedure for assessing recognition memory, developed by Fagan (1970), relies on the infant's natural tendency to show differential visual fixations to novel and familiar stimuli. In the recognition stage, the infants reliably looked more and reached more for the novel than the familiar stimulus.

In a similar study, Gottfried, Rose and Bridger (1978) investigated the effects of visual, haptic and manipulatory exploration of shapes on subsequent visual recognition of stimuli by infants aged 6, 9 and 12 months. The infants were divided into three familiarization conditions, in which they explored the shape either by looking at it (visual), looking at it and manipulating it (visual-haptic), or looking at the object enclosed in a

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4 This method of assessing recognition memory is particular to infant populations.

plastic box which could be manipulated (visual-manipulatory). Visual recognition memory was tested by a paired comparison technique. Preference for novel relative to familiar stimuli was found in all conditions for the 12 month olds, whereas younger infants showed evidence of memory only in the visual condition. These results contradict previous reports that six month old infants do remember objects that they have looked at and touched for brief periods (Rubenstein, 1976; Ruff, 1976). Even among the 12 month old group included in Gottfried, Rose and Bridger's study, the infants' preference for novel relative to familiar stimuli was significantly greater in the visual condition than in the visual-haptic and visual-manipulatory conditions. The authors concluded that haptic activity may interfere with visual recognition memory.

Soroka, Corter and Abramovitch (1979) found that 10 month old infants were capable of tactually discriminating novel and familiar shapes in the absence of vision. Infants were given two minutes of tactual exploration of an object in a totally darkened room. Subsequently half the infants were given the same object and half were given a novel object. Differential exploration times for novel relative to familiar forms were evident, confirming that there was recognition of objects when familiarization was exclusively tactual.

In subsequent studies, Rose, Gottfried and Bridger examined intra-modal tactual processing and cross-modal transfer in one year old infants (Gottfried and Rose, 1980; Gottfried, Rose and Bridger, 1981a). The infants were tested on tasks of visual-tactual cross-modal and tactual intra-modal processing. The results indicated that infants of this age were successful at differentiating novel from familiar objects in both intra- and cross-modal tasks with a familiarization period of 60 seconds, but were unsuccessful with shorter (30 second) familiarization periods. Intra-modal tactual processing was found to be superior to visual-tactual transfer. The authors concluded: "These results show that infants are able to recognize by touch objects previously seen as well as to acquire information about shape exclusively on the basis of tactual cues" (Rose, Gottfried and Bridger, 1981a, p.90).

A series of studies was conducted to investigate the ability of younger infants (six months of age) to transfer information about shape across modalities (Rose, Gottfried and Bridger, 1981b). The infants showed no evidence of cross-modal transfer on tasks of oral-visual and tactual-visual matching with 30 second familiarization times, but with exploration times of 60 seconds the infants showed evidence of tactual-visual transfer. The authors concluded that cross-modal transfer of information about shape is present in six-month olds, but that it is a less robust phenomenon than in older infants.

The results of these studies indicate that by six months of age, infants can use haptic information in matching tasks and are capable of cross-modal transfer. The latter finding adds support to the view of initial unity of the senses. Rose, Gottfried and Bridger conclude:

> The evidence for cross-modal transfer in infants indicates that language is not necessary for such functioning..... Furthermore, the emergence of cross-modal abilities so early in development indicates that one kind of sensory perception can be mapped onto another without extensive

> experience. Little is known, however, about the processes infants use to mediate transfer across modalities, the nature of the internalized representation of the stimuli, or the extent to which the tactual and visual perceptions are informationally equivalent. (Rose, Gottfried and Bridger, 1983 p. 687)

Haptic Exploration Strategies

Since the exploration strategies used in haptic perception are of considerable importance to the present research it will be necessary to review again under the present heading some studies previously discussed under different headings. To begin with, it should be noted that the extent to which performance on haptic tasks is hampered by unsophisticated exploratory strategies has received relatively little attention in the experimental literature. While the eye is capable of making regular and rapid exploration of the stimulus, haptic exploration is successive in nature, in that prehending the "whole" form involves taking a number of tactile samples over time (Revesz, 1950). Investigators have argued that the limitations imposed by haptic exploration in prehending whole aspects of the stimulus lead to inefficient coding of tactual input and/or less stable haptic memory (Davidson, Abbott and Gershenfeld, 1974).

Reference was made earlier to Piaget and Inhelder's (1948, 1956) definition of ontological, sequential stages in the development of the haptic perception of shape. While the younger child is only capable of recognition of topological shapes through the haptic modality, the older child is able to recognize Euclidian shapes. This transition to recognition of Euclidian shapes is mirrored by increasingly sophisticated haptic exploratory behaviours. While minimal exploratory behaviour is sufficient to identify the primitive relationships of topological shapes (e.g. order, enclosure, proximity and separation), recognition of Euclidian relations (involving metric and directional relationships in which objects are located relative to one another and according to coordinate axes) requires a coordination of many centrations or touches upon the object. The older child, who has developed more refined haptic search strategies, can cope with these complex requirements.

The Soviet literature on perception reports studies on the development of haptic perception and the exploratory strategies used at different ages. Zaporozhets (1965, 1969) reported research concerning the analysis and documentation of developmental differences in orienting and copying movements of the eye and hand in the visual and haptic exploration of shape. Ginevskaya (reported in Zaporozhets, 1965) recorded the haptic exploratory movements of preschool children (three to seven and a half years) required to acquaint themselves with objects through tactual exploration while keeping their eyes closed. The character of the tactile movements was observed to change with age. The youngest children used primitive hand movements (e.g. rolling, pulling, pushing of the object). By four years of age, the palping actions appeared to be separate from the hand's practical actions, but were still not exploratory in nature, and by six to seven and a half years, the children used more perfect methods of palping the object, determining its solidity and texture.

Zinchenko and Ruzskaya (reported in Zaporozhets, 1965) recorded the hand and eye movements of children three to six years of age exploring irregular forms. At three years of age, the children tended to play with the object rather than haptically exploring it, the palm of the hand remaining motionless. The four and five year olds explored objects more actively using the palm of the hand and the surfaces of the fingers. Exploration usually involved only one hand. By five years of age, the children generally used both hands in active exploration of the object and frequently focused on a specific feature of the object (such as a hollow or a projection) without locating the relationship of such features to the rest of the shape. Six year olds typically engaged in a systematic tracing of the outline of the object with the fingertips. The children's transition, with age, to more effective ways of acquainting themselves haptically with objects resulted in an increase in effectiveness of perception.

Abravanel (1968), as reported earlier, gave descriptive data of intra- and inter-sensory haptic and visual processing using length, distance and width as the critical properties to be matched. He noted that his results were strikingly similar to those of Ginevskaya's results for shape recognition. The children studied ranged in age from 3;4 through 14;2. Abravanel noted: "In terms of haptics, ...with development, perceptual processes become more effective as they become more active and as fine finger movements replace use of the structurally less effective palms" (Abravanel, 1968, p.43).

A number of other investigators have noted developmental changes in haptic exploratory strategies. In a study involving five through seven year olds, Vlietstra (1980) found that more careful exploration of the stimuli increased with age in her subject population of five, six and seven year olds. Younger children tended to clutch the stimuli, whereas older subjects palpated the objects carefully.

Kleinman (1979) administered a haptic matching task to kindergarten, second and fourth graders, and college students. Matching accuracy, exploration time, and use of efficient strategies increased between kindergarten and second grade, and to a lesser extent between fourth grade and college. Changes in exploration strategies were found to account for most of the improvement in accuracy. Second and fourth graders were more likely than the kindergarten children to examine the individual stimuli in detail and compare specific features and extensive sections of the standard and comparison stimuli, and college students more often compared extensive congruent sections than did school children. Kleinman noted that the development of haptic exploration is similar to that of visual scanning development. His results showed that haptic perception develops in two stages: (1) nonselective increase in information collection and comparison, (2) increase in examination and comparison of critical information.

Two research studies conducted at McGill University provide added insight into the haptic exploratory strategies used by children. Derevensky (1976) developed a "Haptic Perception Scoring Sheet" delineating five general levels of haptic exploration, ranging from minimal exploratory movements to complete and systematic exploration. Within each of the five levels, specific types of exploratory movements were differentiated, enabling the experimenter to record the level of exploration as well as a more specific description of the child's movements. The research included children four through seven years of age. Younger children were found to use haphazard and unsystematic exploratory strategies, wheras the older children demonstrated use of more systematic and comprehensive exploratory strategies. Exploration strategies were correlated with accuracy i.e. children using more sophisticated exploration strategies had higher accuracy scores on an intra-modal haptic matching task. Using a similar mechanism for scoring haptic exploration strategies, Petrushka (1978) found developmental increase in the use of more complex and systematic exploratory techniques in a population of six through eight year olds. She noted two other trends in haptic exploration strategies:

1. Children at all grades (kindergarten, grade one and grade two) used more sophisticated exploration strategies for the standard stimulus than the comparison stimulus in a paired-comparison task (i.e. a "same-different" task involving one standard stimulus and one comparison stimulus). Petrushka interpreted this finding as possibly indicating that having explored the standard completely, the comparison stimulus is then superficially examined for key or essential cues necessary to identify it as identical to or different from the standard stimulus.

2. In general, performance under inter-modal conditions involved slightly more advanced exploratory behaviours than that under intra-modal conditions.

Davidson (1972) compared congenitally blind subjects and blindfolded controls on a task that required judging curvature. The congenitally blind subjects showed superior accuracy. Analysis of exploration strategies revealed that sighted subjects used scanning strategies that focused on local features, whereas the congenitally blind subjects tended to use exploratory strategies that encompassed the whole stimulus. The performance of the sighted subjects improved when they were required to use more holistic strategies.

In a task that involved finding tactual shapes on a map, Berla and Butterfield (1977) found that children who scanned haptically in a regular manner, attending to the distinctive features of the shapes, demonstrated relatively good performance. Moreover, performance on this task improved with training that emphasized regular scanning and attention to distinctive features, indicating that performance is sensitive to haptic exploratory strategies and strategies respond to training.

Locher (1982) examined the performance of adults required to assemble a six piece jigsaw puzzle in a frame. A number of experimental conditions were administered, including a haptic condition which involved exploring the shape of the puzzle piece, and the outline of the frame haptically (in the absence of vision), to determine where the piece should fit. Upon completion of the task, subjects were asked to describe the strategies used to assemble the puzzle in the haptic condition. Locher notes:

> . . . subjects reported that they relied heavily upon tactual information obtained by actively scanning the stimuli and found it difficult to generate and maintain "visual" images of the stimuli. Furthermore, they reported that the use of verbal labels to describe features of the stimuli did not provide adequate detailed information to touch when assembling the puzzle in this condition. While far from conclusive, such

> reports argue against the frequently held view that sighted individuals must recode tactual information into visual images or that haptic perception is mediated by verbal recoding . . . tactual information may be held in long term memory in a form unique to the haptic mode, especially when haptic perception is independent of vision. (Locher, 1982, p. 73)

In summary, studies which have examined haptic exploration strategies have consistently noted developmental trends to the use of more thorough and efficient strategies, and have also provided evidence of increased accuracy on haptic tasks with the use of more thorough haptic exploration strategies. However, there is a noticeable dearth of research which has examined the haptic exploration strategies used with individual stimuli. Such data would enable comparison of the way subjects explore the standard as opposed to comparison item(s) on an intra-modal haptic task or the strategies used for standard and comparison items on intra-modal as opposed to inter-modal conditions.

Exploration Times

Davidson, Abbott and Gershenfeld (1974) made videotaped recordings of subjects' (undergraduate students) hand movements in tasks involving intra- and cross-modal equivalence matching between vision and touch. Increasing the exploration time (from 4 to 16 seconds) of either the standard or the comparison stimuli or both resulted in improved accuracy on the intra-modal haptic condition. On cross-modal conditions, only increased exploration time of the standard stimulus resulted in increased accuracy. Subjects used a greater variety of haptic scanning strategies on conditions in which increased exploration time enhanced accuracy.

Butter and Bjorklund (1973) also investigated the disparity in information gathering capacities of the haptic and visual systems in terms of exploration times. Thirty seconds of one-handed haptic exploration resulted in a performance comparable to two seconds of visual exploration in their population of adults. Butter and Bjorklund emphasized the necessity of allotting different exposure times to equate the amount of initial information in the two modalities:

> If this initial amount of input is not controlled in a visual-haptic experiment, any differential results may occur not because of differences in the processing of information between the two modes but because more information was available in one system than the other. (Butter and Bjorklund, 1973, p. 792)

In a follow-up study, Butter and Bjorklund (1976) found that 20 to 30 seconds of two-handed haptic exploration was approximately equivalent to just two seconds of visual exploration, which result coupled with that of the 1973 investigation seem to indicate that two hands are only slightly better than one in haptic exploration. They speculated that the serial processing required by haptic exploration imposes constraints on the subject's memory.

> Such processing, where information must be integrated over time, may severely limit the absolute level of performance which can be attained from haptic search. Similarly, a subject may be overly taxed when the haptic mode is used. Areas of a form which are searched early may be

forgotten by the time the later sections are inspected. Each form must be constantly reinspected in an attempt to re-learn sections of the figure which have since been forgotten as other areas of the stimulus are examined. Perhaps only by overlearning dimensions of a stimulus can all relevant aspects of a form be held in memory long enough to accurately reproduce the form. (Butter and Bjorklund, 1976, p. 119)

Ittyerah and Broota (1983) found that inter-modal processing (haptic-visual and visual-haptic) of shape takes significantly more time than intra-modal processing. They proposed that inter-modal processing takes longer due to the added demand of transforming the original information regarding the standard, so that it can be matched with input pertaining to comparisons coming from the other modality. This hypothesis is particularly pertinent to the present research.

Derevensky (1976) examined exploration times used by children aged five through seven for the standard stimulus and the comparison stimulus in an intra-modal haptic (paired comparison) task. By the age of 5;5 a stable pattern emerged with children spending more time exploring the standard than the comparison stimulus. Derevensky interpreted this finding as lending support for the "distinguishing features" hypothesis: children make a thorough and complete identification of the standard shape while internally noting its features; however, when the comparison stimulus is being explored, exploration may center on the "distinguishing features" of the object (a process which presumably takes less time than a thorough examination of the object). The child is then capable of making a decision as to whether the standard and comparison stimuli are identical.

Derevensky further noted that haptic exploration time appeared to be related to accuracy, older children and children with higher accuracy scores on the haptic matching tasks tending to spend longer exploring the stimuli. Petrushka's (1978) research, involving children aged six through eight, confirmed longer exploration times for the standard stimulus than for the comparison stimulus in an intra-modal haptic task. She further reported that visual processing of both standard and comparison stimuli requires less time than haptic processing of these stimuli, confirming that visual scanning of the stimulus complex is faster than haptic exploration.

Very little information is available on the exploration times used for the individual haptic and visual stimuli. For example, it would be interesting to examine the exploration times used for the standard shape as opposed to the comparison shape(s) on intra-modal haptic and visual tasks, or the kinds of patterns evident in the exploration times for the different stimuli in inter-modal haptic-visual and visual-haptic tasks. There is a lack of empirical research detailing exploration times for individual stimuli in intra- and inter-modal haptic and visual shape matching tasks. There is also a dearth of research examining developmental trends in exploration times. It would be of interest to know whether the exploration times for various haptic and visual stimuli change over the course of development.

Memory and Encoding

Much of the research already mentioned in this chapter points to the possibility that haptic information is less useful in matching tasks than visual information because it is less well retained. This section reviews studies that have specifically addressed the encoding and retention characteristics of the two systems.

Posner (1967) designed a task to compare the retention of distance information obtained visually with information obtained kinesthetically over two types of retention intervals. An unfilled interval of 20 seconds between initial learning and reproduction resulted in a decrement in information acquired kinesthetically but not in information acquired visually. An attention demanding task interpolated between the learning and testing phase resulted in a marked decrement in retention of visual information, but no further decrement in kinesthetically acquired information. Posner maintained that visual and kinesthetic codes have different central processing requirements. Visual information can be "rehearsed" during an unfilled interval. Kinesthetic information is not "rehearsable" and therefore is subject to decay even over an unfilled interval. As the kinesthetic system is not equivalent to the haptic system, Posner's results cannot be generalized as applying directly to haptic processing. However, the view that the difficulty in processing haptic information lies in the weakness or transience of the haptic trace has received support from a number of studies.

Millar (1972) examined intra-modal and inter-modal matching of shape by children aged three to eight under conditions of simultaneous input, unfilled delay and two types of task filled delay (digit repetition and visual memory task). Intra-visual, but not intra-haptic matching was found to deteriorate in the task filled delay condition. Effects on cross-modal matches were inconsistent. These results are similar to Posner's, and were interpreted by Millar as due to differences in coding mechanisms in the two modalities. In terms of cross-modal matches, she offered the possible hypothesis that: "Cross modal matches are limited by differences in discriminability and coding between modalities because these require extra decisions; for instance on which of the two inputs to rely more, and whether to ignore added information from the "better" modality" (Millar, 1972, p. 174).

Goodnow (1971c) also hypothesized that memory for information gathered by hand is less stable than information gathered by eye. She examined the performance of kindergarten and fourth grade children on four tasks of intra- and inter-modal haptic and visual matching. Matching by hand was consistently poorer than matching by eye, the difference being very large at the youngest age level and then decreasing but remaining significant at the fourth grade level. An interaction was found between the form of initial input (visual or haptic) and its resilience to memory demands, cross-modal matches starting from a haptic standard being more difficult than matching tasks starting from a visual standard. In another study, Goodnow (1971a) examined the effect of increasing the number of comparison items. Subjects in this study were college students. Increasing the number of comparison items made no difference on the accuracy scores on the V-V task. However, a marked effect on accuracy was evident on the T-T task, the effect appearing with the increase from three to five comparison items. With the cross-modal conditions, the effect of increasing the number of comparison items was evident at an earlier point, particularly in matches starting from a tactual standard. On T-V tasks, an increase from 1 to 3 comparison items resulted in a much higher error rate; on the V-T condition, there was very little difference in the error rate whether 1 or 3 comparison items were presented. Goodnow concluded:

> Results point to an interaction between the form of the initial information (gathered by eye or by hand), and the type of demand on memory. One kind of demand occurs primarily as a function of time, or time plus interference from encountering objects similar to the first object. Intra-modal matching can be viewed as making this kind of demand. The demand appears to have little effect on information gathered visually, but does disturb information gathered by hand. A second kind of demand comes from the need to transform the original information, to reduce or change it in some way so that it can be matched against later information. Transformation is not in itself a direct memory demand but it can have a strong effect on the amount remembered, the size of the effect varying with the difficulty of the transform. In a sense, the S's grasp on the information is weakened by the need to switch attention to the task of transforming. (Goodnow, 1971a, p. 93-94.)

Employing a similar research design, Davidson, Cambardella, Stenerson and Carney (1974) investigated the effects of memory demand on intra- and cross-modal haptic and visual matching of shapes by children aged eight to eleven. Memory demand was varied by changing the number of comparison stimuli in a successive presentation paradigm. Increasing memory demand influenced all conditions involving a haptic component.

Haptic-visual matching was more affected by low memory demand (one comparison stimulus) than other modality conditions. These results are very similar to those reported by Goodnow (1971a) and were attributed to deficits in haptic retention stemming from poor pickup, transformation and storage of tactual information.

Rose, Blank and Bridger (1972) assessed the effect of delay on the ability of three year old children to utilize intra- and inter-sensory haptic and visual information to match shapes and textures. When there were no memory demands (simultaneous condition), performance was equally good on all four matching tasks. However, imposition of a 15 second delay between presentation of a stimulus and its comparison hampered all conditions involving a tactual component. The authors attributed this decrement in performance to the inefficient storage of haptic perceptions, and concluded that the young child's difficulty in retaining tactual information is probably one of the major determinants of his/her established difficulty in inter-sensory integration.

Derevensky (1976) also noted that children aged four to six found intra-modal haptic perception of shape more difficult in a successive presentation paradigm than a simultaneous presentation paradigm. He attributed these findings to the young child's difficulty in storing haptically perceived information.

Milner and Bryant (1970) studied the effects of imposing time intervals of 0, 5 and 30 seconds between presentation of standard and comparison items on tasks of intra- and inter-modal haptic and visual matching. Subjects ranged from five to seven years of age. The authors reported a greater weakening in inter-modal than intra-modal performance at delays of 5 and 30 seconds but not at 0 second delays. They suggested a tendency for stored representations of shapes to be more inaccessible for cross-modal than for within-modal comparison after a delay of a few seconds.

In summary, the results of these studies indicate the instability of information obtained haptically compared to information obtained visually. Memory for haptic information is weakened by almost any type of memory demand: by successive presentation of stimuli (Derevensky, 1976), imposition of delays between presentation of standard and comparison stimuli (Milner and Bryant, 1970; Rose, Blank and Bridger, 1972), or increasing the number of comparison items (Davidson, Cambardella, Stenerson and Carney, 1974; Goodnow, 1971a). Visual information, on the other hand, is fairly resilient to such demands on memory, but is weakened under conditions of a task filled delay between exploration of standard and comparison items, seeming to indicate that visual information is "rehearsable". Only imposition of a task that interferes with the ability to rehearse visual information, such as rehearsal of digits, significantly weakens memory for visual information (Millar, 1972; Posner, 1967). There is further evidence that cross-modal matching starting from a haptic standard is more influenced by memory demands than cross-modal matches starting from a visual standard (e.g. Davidson, Cambardella, Stenerson and Carney, 1974; Goodnow, 1971a).

Summary of Section I

Two main theoretical views have been proposed to explain the development of haptic and visual perception and the phenomenon of cross-modal processing. The classical empiricist (or separation) theory postulates that the hand and eye are initially separate and specific, becoming integrated during the course of development. The developmental differentiation view postulates that the visual and haptic systems are initially undifferentiated, gradually becoming differentiated with development. Examination of the research literature provides evidence that infants as young as six months of age are capable of cross-modal transfer between the haptic and visual modalities, lending support to the view of initial unity of the senses (developmental differentiation theory).

Further evidence weakening the credibility of the empiricist notion comes from a large body of research literature providing clear evidence that the visual perceptual system is more efficient and more accurate at shape matching tasks at every stage of development than the haptic system. Even at pre-school age, the expectancy for objects to feel as they look is so strong that children presented with conflicting visual and tactual information will base their judgements solely on the visual information available to them. Other research has demonstrated that when provided with the opportunity to use haptic and visual information, children tend to rely only on the visual information;, haptic information is considered redundant. In fact, research indicates that children have extreme difficulty using the haptic modality in shape matching tasks before the age of five or five and a half, whereas matching by eye is fairly accurate by this age. These findings seem to refute the older empiricist notion, which postulates that the development of vision is based on the prior development of the haptic perceptual system. It seems that very early in life, children learn to appreciate the efficiency of the visual perceptual system compared to the haptic system, and come to rely almost exlusively on it. Nevertheless, fairly consistent developmental (age-related) improvement in haptic information processing, as measured by performance on haptic matching tasks, has been reported in the literature.

While there are many inconsistencies in the literature reporting research on inter-modal haptic and visual processing, as for example whether cross-modal matches starting from a visual standard are more or less accurate than those starting from a haptic standard, there are two consistently reported findings (a) age related improvements in cross-modal perception, and (b) superiority of intra-modal visual over cross-modal haptic-visual/visual-haptic processing.

The relationship between intra-modal processing and inter-modal processing is unclear. In part, this may be due to weaknesses in experimental methodology. Many studies examining inter-sensory processing (between the haptic and visual modalities) lacked intra-modal controls; of those that included intra-modal conditions, many found cross-modal improvement to be mirrored by intra-modal improvement. While intra-modal visual processing is superior to inter-modal processing involving both the haptic and visual modalities at every stage of development, no consistent pattern of performance on intra-modal haptic versus inter-modal haptic-visual and visual-haptic tasks emerges. Jones

(1981) has advanced a specific theory to explain cross-modal processing on the basis of intra-modal matching, performance depending on the modality which is the most efficient. Other investigators have attempted to account for the superiority of the visual over the haptic modality and the directionality found in cross-modal haptic and visual processing in terms of memory and encoding characteristics (e.g. Davidson, Cambardella, Stenerson and Carney, 1974; Derevevensky, 1976; Goodnow, 1971a; Millar, 1972; Milner and Bryant, 1970; Posner, 1967; Rose, Blank and Bridger, 1972), in terms of method of haptic exploration (e.g. Abravanel, 1968; Berla and Butterfield, 1977; Devevensky, 1976; Piaget and Inhelder, 1948, 1956; Zinchenko and Ruzskaya, 1965), and also upon the amount of time required to explore haptic as opposed to visual stimuli (Butter and Bjorklund, 1973, 1976).

It is evident that more comprehensive research involving intra- and inter-modal haptic and visual processing is required. The present research represents an attempt to overcome some of the weaknesses evident in previous research, and at the same time answer some questions that have not been systematically examined in previous research. These points are outlined below, under four separate headings.

Experimental Tasks

It is evident that to adequately assess intra- and inter-modal processing requires administration of four tasks: intra-modal haptic (Haptic-Haptic); intra-modal visual (Visual-Visual); an inter-modal task starting from a haptic standard (Haptic-Visual); and an inter-modal task starting from a visual standard (Visual-Haptic). Moreover, these tasks should be administered in a repeated measures experimental design, thereby measuring performance of the same subjects on the four tasks of intra- and cross-modal processing. This experimental design was adhered to in the present research. The populations sampled were administered four tasks of intra- and inter-modal haptic and visual processing in a repeated measures design.

Variables Measured

The majority of research studies have measured only accuracy scores on the various tasks (conditions) administered. The "task strategies" used by subjects to perform the tasks (in other words their approach to the task) have been largely ignored. Two important and easily measured variables in the way subjects perform tasks of intra- and inter-modal haptic and visual processing are: (i) the type of exploration strategies used to explore stimuli presented to the haptic modality, and (ii) the amount of time subjects spontaneously explore individual haptic and visual stimuli. The present research involved use of accurate methods of recording qualitative measures of haptic exploration strategies, and the time subjects used to explore individual haptic and visual stimuli.

Experimental Intervention

It was stated above that two important variables in terms of techniques subjects use to perform tasks of intra- and inter-modal haptic and visual processing are the strategies used to explore the haptic stimuli, and the amount of time used to explore individual haptic and visual stimuli. These variables could also be experimentally controlled. In fact, it has been suggested that by experimentally controlling haptic and visual exploration times, it may be possible to equate the amount of initial information available in the two modalities (Butter and Bjorklund, 1973). The present research examines the effects of imposing "fixed" exploration times for haptic and visual stimuli (these exploration times being substantially longer for haptic stimuli than for visual stimuli), on (i) accuracy scores, and (ii) the type of strategies used to explore haptic stimuli.

Populations Studied

Much of the previous research in this area has studied the performance of subject populations over a relatively narrow age range. To adequately assess developmental trends in intra- and inter-sensory processing requires sampling a wide age range. A second problem evident in some of the research has been the small number of subjects at each age or grade level. Use of small numbers of subjects at different age levels weakens the validity of statistical analyses, therefore making interpretation of the data difficult. In an attempt to overcome these problems, the populations sampled in this research involved a fairly large number of subjects in grades spanning the elementary school levels.

The incorporation of these four elements in a final research design will be outlined later. Since the inclusion of a population of reading disabled children is an integral part of the present research, a review of the relevant literature concerning reading disabilities will be covered at this point.

Section II

Reading Disabilities

Historical Perpective

> No disorder of childhood has generated more interest or prompted more controversy than severe and pervasive reading disorder in otherwise normal children, commonly referred to as developmental dyslexia or specific reading disability. (Vellutino, 1979, p. 1)

The earliest studies of reading disability were reported by physicians. The disorder was initially described by W. Pringle Morgan, an English school doctor, in 1896. Morgan described the case of a fourteen year old boy who showed no evidence of brain injury but who was unable to learn to read in spite of normal intelligence and normal vision. He suggested that a single type of reading disability might occur as an isolated disorder in an otherwise normal child and that such a disorder might be congenital. In his article in the British Medical Journal in 1896, Morgan referred to this disorder as "congenital word blindness", and described the disorder as: ". . . evidently congenital and due most probably to defective development of that region of the brain, disease of which in adults produces practically the same symptoms, that is, the left angular gyrus."

Around the same time, J. Hinshelwood, a Scottish eye specialist, initiated a series of studies that examined the role of the brain in reading failure (Hinshelwood, 1900). He wrote a description of acquired alexia or.

"visual word blindness" in adults resulting from damage to the visual memory centre for words in the left angular gyrus. His book Congenital Word Blindness was published in 1917.

Very little was written about specific reading disability, as it is now known, in the first quarter of the twentieth century (Thompson, 1966). In 1925, Samuel Orton, an American neurologist and psychiatrist, published a paper proposing a different theory of reading disability. While agreeing with Hinshelwood's assumption that reading involves the use of visual word images that are stored in a particular part of the brain, he did not believe that the disorder was caused by structural deficiency of the brain. Instead, he hypothesized reading disability to be the result of a lag in the development of left hemisphere dominance for language abilities. This developmental lag resulted in "strephosymbolia" or "twisted images", the failure to suppress mirror images of visual representations which Orton believed to be stored in the two hemispheres, characterized by misperceiving b as d or on as no. Orton's theory is probably the most influential of any that has appeared in the literature of reading disabilties (Vellutino, 1979).

Renewed interest in reading disability was evident in the 1950's (Doehring, Trites, Patel and Fiedorowicz, 1981). The more sophisticated and objective research methods of experimental psychology replaced the case history methods used in earlier research. The typical methodology in this research involved comparison of an experimental group of so called disabled readers with a matched control group of normal readers on specific measures or abilities in an attempt to isolate the underlying causes of reading disability. Research from this perspective thus seeks to demonstrate that dysfunction in a particular process, such as selective attention, serial processing, visual perception or auditory-visual integration is the crucial discriminator between normal and disabled learners. Underlying this research methodology is the assumption that a single syndrome or factor underlies the problem (reading disability).

More recently emphasis has focused on multifactor theories of reading disabilities. These theories propose that the etiology of specific reading disability is heterogeneous in nature, there being more than one type of process disorder causing reading problems. Although the multifactor orientation is becoming widely accepted, it has yet to be translated into widespread research efforts to identify subtypes. As MacKenzie (1981) has noted, the complexity and degree of integration demanded of research within the multifactor orientation is undoubtedly intimidating, and the identification of well defined subtypes an arduous, time consuming operation.

Perhaps the best known multifactor theories are those of Birch (1962) and Johnson and Myklebust (1967). In a theoretical paper, Birch (1962), who believed that reading disorders stemmed from failure to undergo the necessary developmental changes which take place over time in childhood, probably due to impairment in the nervous system, proposed a three-factor theory of reading disorders. He hypothesized that three separate subtypes of reading disorders could be identified: (a) dysfunction in visual analysis and synthesis, (b) inadequate development of appropriate hierarchical organization of sensory systems (i.e. dominance of vision and audition), and (c) failure to establish inter-sensory equivalences. Of these proposed subtypes, the group purportedly suffering inter-sensory deficits has received the most attention in the research literature. Johnson and Myklebust (1967) also delineated three subgroups, based on an analysis of clinical case studies. These were described as follows: (i) visual processing problems, (ii) disturbances in auditory processing, (iii) problems in making visual-auditory association, the latter subgroup being similar to the inter-sensory deficit problems proposed by Birch.

An important distinction is made in the literature between developmental delay theories and deficit theories of learning/reading disabilities. A large number of theorists and practitioners in the fields of psychology and education attribute learning problems in otherwise normal children to a delay in the development of skills necessary for mastery of these school related tasks. Research has generally indicated age-related growth among normal populations of children in processes related to academic success, such as perceptual motor functioning (Bender, 1938, 1956), selective perceptual motor attention (Hagan and Hale, 1973), serial processing (Torgensen, 1977), inter-sensory integration (Birch and Belmont, 1964, 1965), and hemispheric lateralization (Bryden and Allard, 1976; Satz, Bakker, Teunissen, Goebel and Van der Vlug, 1975). Further evidence suggests that children with learning problems exhibit behaviour similar to that of younger normal learners in many of these areas (e.g. Bender, 1957; Bakker, 1972; Corkin, 1974; Koppitz, 1973; Tarver, Hallahan, Cohen and Kaufman, 1977).

As noted above, Orton (1925) was an early proponent of a developmental lag approach to understanding reading problems, espousing that reading disability is caused by a lag in development of lateral dominance. More recently, deHirsch, Jansky and Langford (1966) and Satz and his colleagues (Satz and Sparrow, 1970; Satz and Van Nostrand, 1973), have presented a clearly articulated hypothesis of developmental delay. Satz and his colleagues maintained that disabled readers of at least normal intelligence and without emotional or social handicaps have a lag in maturation of the left hemisphere, resulting in delayed acquisition of skills necessary for the reading process (rather than a lack of them). Thus, the observed pattern of disorders should change with increasing maturity. Skills which develop ontogenetically earlier during childhood (visual-perceptual and cross-modal sensory integration) should be delayed in younger children with reading problems, whereas skills which have a slower rate of development during childhood (such as language and formal operations) are more likely to be delayed in older children with reading problems. Satz and his associates have provided some research data to support this theory, including longitudinal studies (Satz and Friel, 1974; Satz, Friel and Rudegean, 1976; Satz, Taylor, Friel, and Fletcher, 1978), and research comparing normal and disabled readers at two different age groups (ages 7 to 8 and 11 to 12) on specific developmental skills considered to be essential to learning to read (Satz, Rardin and Ross, 1971). The latter study is described in more detail later in the chapter.

The deficit approach conceptualizes learning disabilities within a medical or disease model. It holds that an abnormality in cerebral structures or functions underlies the failure to acquire age-appropriate reading skills. This view differs from the developmental delay theory in that there is no necessary expectation that children who suffer from the deficit(s) will ever catch up with their normal age mates in those skills required for age-appropriate reading. Early proponents of a deficit theory of reading problems included Morgan (1896) and Hinshelwood (1900, 1917). More recently, there is evidence that bilateral parietal anomalies are often implicated in reading and spelling disorders (Benton, 1975; Geschwind, 1968; Spreen, 1976). While details of research concerning these theories (developmental delay theory and deficit theory) will not be presented here, it should be kept in mind that the issue of whether or not areas of weakness remain stable or consistent over time in reading disabled or learning disabled children has important practical implications, and will be considered when interpreting the data for the sample of reading disabled children included in the present research.

In an extensive and comprehensive review of theories of dyslexia, Vellutino (1979) stated that the etiological constructs and explanations in the current literature on dyslexia reduce to hypotheses that focus on deficiencies in the following four areas: (a) visual perception and visual memory, (b) inter-sensory integration, (c) serial order recall, and (d) verbal processing. As mentioned above, the inter-sensory deficit hypothesis, i.e. the theory that reading disorder is associated with difficulties in integrating information from different sensory modalities, has received considerable attention in the research literature. This theory is of particular relevance to the present research.

Inter-sensory Deficit Theory of Reading Disabilities

Originally proposed by Birch in 1962 (Birch, 1962), the inter-sensory deficit theory has attracted much attention and support in reported research. The theory itself has intuitive appeal since the process of reading involves the ability to transform visual patterns of perception into auditory patterns of response.

Birch initially studied inter-sensory integration in normal children. Reference was made earlier in this chapter (Section I) to Birch and Lefford's research involving integration of information from the visual, haptic and kinesthetic modalities (Birch and Lefford, 1963). This study, which involved children 5 through 11 years of age, required subjects to simultaneously perceive two forms from the Seguin Form Board test and to make a same-different judgement. Making a distinction between the kinesthetic and haptic modalities, Birch and Lefford imposed three conditions: Visual-Kinesthetic, Haptic-Kinesthetic, and Visual-Haptic. A fairly linear improvement in accuracy on all three conditions was interpreted as indicating a developmental increase in ability to integrate information from different sensory modalities. However, as pointed out by a number of critics, improvement with age on cross-modal tasks could be an indication of developmental improvement in ability to make equivalence judgements about stimuli presented to the same modality (intra-sensory processing) rather than an indication of developmental improvement in ability to process information from different sensory modalities.

A series of studies designed to examine this inter-sensory deficit theory of dyslexia was conducted by Birch and his colleagues. Birch and Belmont (1964) compared the performance of normal and retarded readers between the ages of nine and ten (150 poor readers and 50 normal readers) on a task of auditory-visual equivalence. The task involved identification of a visual-spatial dot pattern that corresponded to the patterning of a temporally structured auditory stimulus (a series of taps presented in morse-like code). Retarded readers were less able than normal readers to equate the two stimuli. The results were interpreted as indicating that deficits in auditory-visual integration (AVI) contribute to reading incompetence.

In a subsequent study, the same task was administered to children from kindergarten through sixth grade (Birch and Belmont, 1965). Tests of reading achievement and intelligence were also administered to the subject population. Auditory-visual integration was found to increase rapidly in the earliest school years and reached an asymptote by fifth grade; a correlation between reading achievement and auditory-visual integration was found only in the first and second grade children. Fairly high correlations between I. Q. and reading achievement were found at all ages above kindergarten, and these increased with age until the sixth grade. The authors concluded that auditory-visual integration may be very important in the initial stages of learning to read, but that at later stages intellectual factors may be more influential.

Kahn and Birch (1968) suggested that the disappearance of a significant relationship between auditory-visual integration and reading achievement in the older children in Birch and Belmont's (1965) sample may have been an artifact of the test ceiling. A longer test of the same kind would have a higher reliability, and could provide a higher ceiling and greater discrimination among testees. They (Kahn and Birch) administered an extended version of the auditory-visual integration task used by Birch and Belmont to 350 elementary school boys in grades two through six. Auditory-visual integrative competence as measured by this extended version of the AVI test was found to be positively associated with reading achievement at all grade levels; even with the effects of I.Q. partialled out, auditory-visual integration continued to be related to reading skill, especially word knowledge. None of the variables suggested as mediators of the relation of auditory-visual integration to reading (visual and auditory discrimination skills, auditory rote memory, application of verbal labels to the auditory-visual physical stimuli) satisfactorally accounted for individual differences in AVI performance.

The results of the studies cited above have met with criticism due to some methodological weaknesses, especially lack of certain controls (Blank and Bridger, 1966; Bryant, 1968; Gould, 1977; Rudnick, Sterritt and Flax, 1967; Sterritt and Rudnick, 1966; Vande Voort, Senf and Benton, 1972), the major gounds of criticism being: (a) lack of a visual-to-auditory matching condition, (b) inadequate control for the effect of intra-modal functioning on inter-modal functioning, and (c) inadequate control for the effects of the spatial-temporal dimension on modal functioning. Other criticisms of this early research include: lack of memory controls; lack of statistical control for the effects of I.Q.; lack of control for the type of reading disability; possible confounding of visual with auditory stimuli. More recent studies have addressed these issues. This research will be briefly summarized here.

Visual-to-auditory integration task. Muehl and Kremenak (1966), employing a format of test construction similar to that used in the Birch studies, tested all possible combinations of the visual and auditory stimuli, including intra-modal visual and auditory tasks, a visual to auditory integration task (visual stimuli presented first followed by auditory matching), and an auditory-visual task. The subject population consisted of 119 first grade children tested at the beginning of the school year. Both auditory-visual and visual-auditory tasks made significant contributions in predicting end-of-year reading scores whereas intra-modal auditory and visual tasks were not correlated with reading achievement.

Beery (1967) administered three inter-sensory tasks to small but carefully matched groups of poor and normal readers between the ages of 8 and 13. The three tasks included Birch and Belmont's auditory-visual task; a lengthened version of this task; and a visual-to-auditory matching task using the same configurations. The performance of the sample of poor readers was inferior to that of the normal readers on all three tasks, leading Beery to conclude that the phenomenon reported by Birch and Belmont is a general one, seeming to be independent of the age group studied, nationality, form and length of the test, and the manner in which the stimuli are presented.

Intra-modal controls. A pertinent criticism of Birch's work was that he did not adequately assess intra-modal sensory functioning, so it was possible that any deficits evident in inter-sensory processing were mirrored by intra-sensory deficits. The only control Birch and Belmont used for intra-sensory confounding was a test for auditory memory for digits (Digit Span subtest on the WISC). As Gould (1977) has pointed out, to adequately control for intra-modal confounding, the intra-modal task should be as nearly identical as possible to the inter-modal task, the only difference in conditions occuring in the presentation of stimuli to different sensory modes. Since no intra-modal auditory and visual conditions were included in the

Birch and Belmont studies, it is impossible to assess the relationship between inter-modal and intra-modal processing i.e. whether improvements in inter-modal processing were paralleled by improvements in intra-modal processing and/or whether deficits in inter-modal processing were paralleled by deficits in intra-modal processing. Subsequent studies, including intra-modal conditions, fail to indicate any clear relationship between intra-modal and inter-modal auditory and visual functioning and reading ability in children.

As mentioned above, Muehl and Kremenak's (1966) research involving intra-modal auditory and visual tasks as well as inter-modal tasks found that only the inter-modal tasks correlated with reading achievement. Zigmond (1966, cited in Steger, Vellutino and Meshoulam, 1972) tested the sensory integration hypothesis using unimodal and heteromodal paired associate tasks. Poor readers were found to have greater difficulty than normal readers in learning Auditory-Auditory and Visual-Auditory associations. There was no difference between the groups in terms of learning Visual-Visual or Auditory-Visual pairs, leading the authors to conclude that auditory deficiencies are a more important factor in reading disability than either visual inadequacies or inter-sensory disorder.

Vande Voort, Senf and Benton (1972) found disabled readers (48 boys between the ages of 8;0 and 12;11) performed more poorly on tasks of intra-modal (Auditory-Auditory and Visual-Visual) and cross-modal (Auditory-Visual) matching than a matched control group of normal readers. The normal readers showed similar developmental patterns on intra-modal and inter-modal tasks. Retarded readers were deficient on all tasks and their performance failed to improve with age. This study is particularly interesting in that measures for selecting the disabled readers were fairly stringent, and all the subjects in this sample were drawn from a school specializing in remediation of educational deficiencies.

Similar results were reported by Zendel and Pihl (1983) who compared the performance of 47 learning disabled (aged 8;0 through 10;5 years) subjects and 41 controls matched for age, sex and grade on intra- and inter-sensory auditory and visual tasks. The learning disabled children performed more poorly than the normal children on all four of the matching tasks. No single psychological factor (such as encoding ability, short term memory or general comprehension) emerged to explain performance on the integration tasks.

Effects of the spatial-temporal dimension on modal functioning. Birch and Belmont noted that the stimuli they used differed not only in modality but also along the spatial-temporal dimension -- the visual stimuli being presented spatially and the auditory stimuli temporally. As Blank and Bridger (1966) have pointed out, quite different perceptual and cognitive processes may be involved in handling spatial versus temporal stimuli. It is therefore impossible to ascertain whether the relatively poor performance of the retarded readers on the tasks administered was due to difficulty in inter-modal integration or in establishing equivalences between temporal and spatial stimuli, or both. Goodnow (1971b), for one, has argued that the difficulty in auditory-visual integration tasks lies in the translation from space (vision) to time (audition) rather than transfer between the sensory modalities per se. A number of studies have examined the temporal-spatial dimension in sensory processing.

In an attempt to determine whether auditory-visual integration or temporal-spatial integration is the critical factor in accounting for the poorer performance of reading disabled subjects on pattern matching tasks, and to examine the effect of type of learning disability on pattern matching performance, Hatchette and Evans (1983) presented six pattern matching tasks to three groups of subjects (grades two through four). The subject groups were defined as normal readers, and two reading disabled groups -- defined as learning disabled readers with an auditory processing dysfunction, and learning disabled readers with a visual processsing dysfunction. Six pattern matching tasks were presented: 1) auditory-temporal/ visual-spatial; 2) auditory-temporal/ visual-temporal; 3) visual-temporal/ visual-spatial; 4) auditory-temporal / auditory-temporal; 5) visual-temporal/ visual-temporal; 6) visual-spatial/ visual-spatial. The finding that there was a significant difference between normal and reading disabled subjects (both groups) on the auditory-temporal/ visual-spatial and auditory-temporal/ visual-temporal but not on visual-temporal/ visual-spatial tasks led the authors to conclude:

> In the present study the finding of a significant difference between normal and LD readers on the At-Vt task as well as the At-Vs task lends support for the explanation that it is AVI which accounts for the differential performance of normal and LD readers . . . deficient TSI [temporal spatial integration] alone cannot explain the poorer performance of the LD readers. (Hatchette and Evans, 1983, p. 540)

Vande Voort and Senf (1973) compared nine year old normal and retarded readers on four matching tasks: 1) visual-spatial/ visual-spatial 2) visual-temporal/ visual-temporal 3) auditory-temporal/ auditory-temporal 4) auditory-temporal/ visual-spatial. Results indicated that tasks 1 and 3 distinguished between the two groups whereas tasks 2 and 4 did not, leaving the hypothesis of an auditory-visual integration deficit in retarded readers unsupported, but also seeming to indicate that the translation between temporal and spatial stimuli did not cause a problem for either normal or disabled readers.

Blank and Bridger (1966) compared normal and retarded readers on a task that required converting temporally distributed stimuli into spatially distributed stimuli within the visual modality (selecting a spatial dot pattern that represented a sequence of flashes of light). The authors found that fourth grade retarded readers (one year below grade level in reading) had difficulty relative to the normal readers on this task of intra-modal transfer, indicating that retarded readers had difficulty converting temporally distributed stimuli into spatially distributed stimuli even within the same modality. A subsequent study with first grade retarded readers found similar results (Blank, Weider and Bridger, 1968). The authors hypothesized that the deficit was due to difficulty in applying conceptual categories or the correct verbal labels to temporally distributed stimuli. Such a deficit would cause difficulty in inter-modal and intra-modal transfer of stimulus equivalences. On tasks in which the need for coding the temporal stimuli was eliminated (through the imitation of rhythms) or when coding was of identical spatial patterns, there was no difference in performance of retarded and normal readers.

Bryden (1972) compared the performance of fourth grade normal and poor readers on tasks that involved making same-different judgements for various combinations of auditory-sequential (temporal), visual-sequential (temporal), and visual-spatial patterns. Poor readers made more errors on all tasks administered. The fact that poor readers showed deficits on all tasks involving matching one pattern to another, whether auditory-visual transformation was required or not, led Bryden to conclude:

> These findings do not provide any support for the contention that reading disability is related to a specific deficit in auditory-visual integration, nor even to a more general deficit in temporal rhythm perception. The failing of poor readers, extending as it does to tasks involving both auditory and visual presentation, and both sequential and spatial patterns, must be an even more general one. (Bryden, 1972, p. 831)

Bryden found that, even with the influence of I.Q. removed, there was a high correlation between reading ability and matching performance in the group of poor readers, but only a very small correlation in good readers. This pattern would seem to indicate that matching performance is a good predictor of reading ability only in poor readers, once a certain level of reading ability has been achieved, it no longer serves to predict reading ability.

Rudel and Denckla (1976) assessed the ability of normal (N=51) and learning disabled (N=23) subjects between the ages of 7 and 12 to match spatially arranged patterns of dots (spatial presentation) as well as sequences of light flashes (temporal presentation) within a single modality -- vision. Four tasks were administered: temporal to temporal; temporal to spatial; spatial to spatial; and spatial to temporal. The subject samples differed significantly on all tasks involving a temporal component (the temporal to spatial, spatial to temporal and temporal to temporal tasks), but not on the spatial/spatial task. These results seem to indicate that the problem experienced by disabled readers may involve temporal processing, lending support to Bryden's findings. It is interesting to note that developmental improvement was evident in the group of normal subjects, i.e. the oldest normal subjects performed better than the youngest subjects on all tasks, however no such developmental improvement was evident in the learning disabled children. This pattern seems to conform to the deficit paradigm mentioned earlier.

In summary, it is difficult to make any conclusions concerning the effects of the spatial-temporal dimension on modal functioning. The contradictory findings of the research in this area is noteworthy, and could perhaps be interpreted as indicating the need for further more systematic research in this area.

Memory factors. While the role of memory factors in inter-sensory processing has been mentioned by many researchers in the field, few studies have been designed to specifically examine memory factors. In fact, lack of attention to memory factors was a recurring but minor criticism of the studies of Birch et al. Vande Voort, Senf and Benton (1972) found no evidence to support a theory of differential memory for initial pattern as an explanation for the difference in performance between average and retarded readers on tasks of within-modal and cross-modal auditory-visual tasks. On the other hand, Payne, Davenport, Domangue and Soroka (1980) concluded that a deficit in auditory memory rather than cross-modal perception appears to be a factor in poor reading comprehension.

Role of I.Q. While many studies match the control group to the experimental group in terms of I.Q., or select only subjects who fall within the average range of intellectual functioning (e.g. Beery, 1967; Blank and Bridger, 1966; Bryden, 1972; Muehl and Kremenak, 1966; Vande Voort, Senf and Benton, 1972), there is a dearth of studies which specifically investigate the role of intelligence upon reading and performance on inter-sensory processing tasks. Rae (1977) examined this relation in a sample of 165 fifth grade boys and girls. Auditory-visual integration (matching visual dot patterns to tape recorded tones) was found to be significantly related to intelligence and reading achievement. However, even with the effects of intelligence controlled, inter-sensory transfer remained a significant predictor of reading achievement.

Jorgenson and Hyde (1974) report that I.Q. was not a significant contributor to the correlation between AVI and reading in their sample of first and second grade children. Sterritt and Rudnick (1966) found that their auditory test (auditory-temporal/ auditory-spatial matching task) was a significant independent predictor, accounting for 23% of the variance of reading scores in addition to the 46% contributed by Mental Age. Rudnick, Sterritt and Flax (1967) concluded that general intelligence and auditory and/or cross-modal perceptual abilities become more important in relation to individual differences in reading ability as the child moves from third to fourth grade. Gregory and Gregory (1973) found that their Morse-form of auditory-visual integration test was highly correlated with reading ability, with age and intelligence partialled out. Ford (1967), on the other hand, found that controlling for the effects of I.Q. reduced the level of correlation between auditory-visual integration and all measures of reading performance to an insignificant level.

Type of reading disorder. In spite of a growing interest in multifactor theories of reading disability, there is also a dearth of studies in the literature which examine the interaction between type of reading disorder and intra- and inter-sensory processing, a notable exception being the work of Hatchette and Evans (1983) previously discussed. In addition to finding that disabled readers as a total group were deficient relative to normal readers in auditory-visual processing, the authors also reported a significant effect of type of disability (the two types of disabled readers being those with an auditory processing dysfunction, and those with a visual processing dysfunction) on the task requiring visual-spatial/visual-spatial matching, disabled readers with a visual processing disorder performing more poorly on this task.

Confounding of visual with auditory stimuli. Sterritt and Rudnick (1966) pointed out that in the Birch and Belmont studies (1964, 1965) the subject was asked to choose a spatial dot pattern that matched a temporal pattern that could presumably be seen and heard (pencil tapping). It is therefore not clear to what extent Birch and Belmont's results may have reflected the subject's ability to transpose from temporal to spatial dimensions within the visual modality rather than between audition and vision. Sterritt and Rudnick's research employed three tests: one involved rhythms that were tapped out by a pencil that could be seen and heard (as in the Birch and Belmont test), a second employed purely auditory stimuli

(A-test) and a third used purely visual stimuli (V-test) to form the temporal patterns. The child's task was to select the spatial dot pattern that corresponded to the temporal pattern presented. Of these three measures, the A-test was a significant predictor of reading ability in the fourth grade sample studied, indicating that either the ability to transpose from the auditory to the visual modality or the more specific ability to transpose from auditory-temporal to visual-spatial formats may be the critical function in reading at this age level. That subjects were only drawn from one grade level, and were apparently all considered normal achievers at this grade level limits the generalizability of this study.

A study by Gregory and Gregory (1973, mentioned previously) also sheds light upon the question of confounding of visual with auditory stimuli. Two forms of auditory-visual integration tasks were administered to the subject population (6 through 11 year olds): the Birch and Belmont (1964, 1965) AVI test and a test utilizing temporal patterns similar to morse code rather than pencil taps. With age and intelligence partialled out, the Morse form of the test was a better predictor of reading ability than the Birch and Belmont measure, the correlation between the Morse test and reading ability being .51 whereas the correlation between the Birch test and reading ability was .21.

<u>Summary of research investigating the inter-sensory deficit theory of reading disability</u>. Having examined the bulk of research in the area, it is evident that while many studies provide support for Birch's theory that children with reading problems suffer deficits in auditory-visual integration (e.g. Beery, 1967; Gregory and Gregory, 1973; Hatchette and

Evans, 1983; Muehl and Kremenak, 1966; Rae, 1977; Sterritt and Rudnick, 1966); the research is far from conclusive. It is even more difficult to evaluate the broader inter-sensory deficit theory which holds that reading disorder is associated with difficulties in integrating information from different sensory modalities. While the original Birch and Lefford study (1963) investigated the ability to integrate information from the visual, haptic and kinesthetic modalities, the bulk of subsequent research focused on the auditory and visual modalities. Very little research has been published on the performance of reading disabled populations on tasks of haptic processing and inter-modal haptic-visual processing. Carner (1981) suggests that one of the major roadblocks in conducting research in this area has been the dearth of instruments to assess various aspects of haptic functioning.

Another point is noteworthy. It is difficult to evaluate the inter-sensory deficit theory of reading disabilities within a developmental delay or deficit theory, even though Satz and colleagues (e.g. Satz, Taylor, Friel and Fletcher, 1978) specifically mention cross-modal sensory integration as one of the skills (necessary for the reading process) which develops ontogenetically early. In a study conducted in 1971, Satz, Rardin and Ross measured specific developmental skills considered to be essential to learning to read in normal and disabled readers at two different age groups (ages 7 to 8 and ages 11 to 12) on specific developmental skills considered to be essential to learning to read. One of the measures administered was Birch and Belmont's AVI task. The younger dyslexic group had lower correct performance on this task than the younger (normal reading) controls, although the difference in scores did not reach significance. The subject samples in this research were small (10 normal and 10 dyslexic subjects at each of the two age groups), making statistical interpretation difficult.

Research Involving the Haptic or Tactual Modality in Reading Disabled Children

Steger, Vellutino and Meshoulam (1972) administered visual-tactile and tactile-tactile paired associate tasks to small groups of normal and poor readers (age range 8;2 through 12;2). Neither the visual-tactile nor tactile-tactile conditions yielded any differences between the two reading goups. The authors propose that a general perceptual deficit does not exist in poor readers; but rather that a specific integration problem in auditory-visual pairing may exist. Similar results were reported by Ford (1967), who examined the relationship of auditory-visual integration and tactual-visual integration to intelligence and reading achievement in 121 fourth grade boys. While auditory-visual integration was significantly related to intelligence and reading achievement, tactual-visual integration skills were not. It was also reported that the two inter-sensory tasks were not significantly related to each other.

Using a subject sample with a similar age range to the subject sample in Steger et al's research (24 boys in each of grades two, four and six), Lawton and Seim (1973) investigated the relationship between reading scores and performance on two inter-sensory tasks, tactual-visual and visual-tactual matching. Visual-tactual performance was related to both reading comprehension and reading vocabulary scores for the total samples but failed to reach significance for the individual grades. When tactual-visual scores were collapsed over grades, no significant relation between integration and reading was evident. Within grades, the only significant correlation occurred between integration scores and reading comprehension at sixth grade. It is important to keep in mind that neither of the above studies (Ford, 1967 and Lawton and Seim, 1973) compared normal and disabled readers; but rather both examined the relationship between inter-sensory tactile and visual integration and reading ability in normal learners. Further, Lawton and Seim's tactual task involved active exploration of raised geometric shapes that were made by gluing 1/8 by 1/8 inch strips of balsa wood onto 3 1/2 inch by 3 1/2 inch squares of cardboard. As such, the tactual exploration was confined to feeling this raised form, a rather different task than manipulating and exploring a shape in the hand(s).

Payne, Davenport, Domangue and Soroka (1980) investigated intra- and cross-modal processing in the visual, auditory and tactual modalities with two groups of subjects: those poor in reading comprehension but average in terms of reading vocabulary; and average readers (average in terms of reading comprehension and vocabulary scores) spanning third through sixth grades. Subjects were presented intra- modally or cross-modally with two sequential stimulus patterns, one after the other, and were required to judge whether they were the same or different. The performance of the retarded readers was poorer than the performance of the normal readers in any condition involving audition as the modality of the first pattern and on the visual-auditory condition but not in other combinations of modalities.

Two theses completed at the University of Miami shed further light on the relationship of haptic processing to reading. Reisboard (1972) administered the Modality Assessment Profile (MAP) to good and poor readers at the second and fifth grade levels. The MAP, designed and developed by Carner and Reisboard, assesses haptic functioning as an isolated perceptual trait and also in association with other modalities and cognitive abilities. This measure (MAP) consists of six subtests, two of which are of particular interest in terms of the present research: the Haptic Discrimination Test and the Haptic-Visual Matching test. Of these two tests, Reisboard found that the Haptic-Visual Matching test differentiated between good and poor readers at second and fifth grade levels, but that the Haptic Discrimination Test did not differentiate good and poor readers at either grade level.

Subsequent research, conducted by Gurucharri (1973), examined the relationship of haptic functioning (assessed by the MAP) and reading achievement in first grade children. She found that the total MAP was significantly related to reading achievement. Significant relationships were found between the Haptic Discrimination, Haptic Spatial and Haptic Motor Performance subtests and measures of reading ability. The Haptic-Visual matching test did not correlate with reading ability at this age. Commenting on this research, Carner notes: "It is apparent that more definitive research is needed in the area of haptic functioning as a correlate to reading achievement" (Carner 1981, p. 30).

Summary of Section II

It is evident that research investigating the relationship between inter-sensory procesing and reading declined sharply after the mid-1970's; very few research studies were published after this date. Futhermore, the research evidence is inconclusive, with a number of problems evident. Discussion of these is instructive for the present research.

Populations Sudied

Some research studies have compared a population of reading disabled children with a population of normal readers on tasks of inter-sensory processing; others have taken a population of "normal" readers and have looked at the relationship between reading ability and performance on tasks of inter-sensory processing. As Vande Voort and Senf (1973) and Bryden (1972) have pointed out, it cannot be assumed that the skills that correlate most highly with reading achievement among adequate readers are the same skills deficient in readers who fall significantly below the reading level expected for their age. In other words, children with reading problems could have inter-sensory processing deficits but this does not necessarily imply that performance on inter-sensory tasks is related to reading achievement in good readers. A second problem evident in a number of the studies is the age range of the population. To adequately assess the generality of any possible deficit among poor readers requires sampling a wide age range, with the youngest subjects being at an early stage of reading instruction. The proposed research will involve a comparison of a strictly defined population of "able" readers with a strictly screened population of poor readers, both subject samples spanning the elementary school grades.

Measures Used

Most of the research investigating intra- and inter-sensory processing in reading disabled children has examined the visual and auditory modalities. These sensory modalities have been of interest because learning to read is thought to involve integration of visual and auditory information. However, it is unclear whether possible deficits in intra- and/or inter-sensory processing are specific to the auditory and visual modalities or may be more general i.e. involving other sensory modalities. There is a dearth of research investigating the performance of reading disabled children relative to able readers on tasks requiring integration of information from the haptic and visual modalities.

Moreover, it appears essential that research include four measures -- two intra-sensory and two inter-sensory tasks. As mentioned earlier in this chapter, performance on inter-sensory processing cannot be evaluated independently of intra-sensory processing; it is essential to examine the relationship between the two. Furthermore, one of the biggest problems with the traditional auditory-visual tasks used in much of the research is the problem of the translation required between the spatial and temporal dimensions. Some research suggests in fact that children with reading problems have difficulty converting temporally distributed stimuli into spatially distributed stimuli even within the same sensory modality (e.g. Blank and Bridger, 1966; Blank, Weider and Bridger, 1968; Denckla, 1974). An advantage of examining the haptic and visual sensory modalities is the closer "equivalence" of stimuli. It is possible to take the same stimuli (two dimensional shapes), and present them to the haptic and visual modalities. The proposed research will involve four conditions: two conditions of intra-modal processing (haptic-haptic and visual-visual) and two conditions of inter-modal processing (haptic-visual and visual-haptic).

Approach to the Task

It is evident that in the research analyzing the performance of able readers and poor readers on tasks of intra- and inter-sensory processing, there is a lack of focus on the "task strategies" applied to matching tasks, i.e. the methods or techniques children use to perform the tasks. Analysis of task strategies is particularly important when examining the performance of poor readers and able readers. It has been suggested by a number of researchers (e.g. Torgenson, 1986; Torgenson and Licht, 1984) that children with learning problems often do not apply the efficient task strategies employed by able learners to the task at hand. If differences exist between the populations of able and disabled readers in terms of accuracy scores on any of the conditions in the present research, it is important to try to isolate any differences between the populations in terms of the task strategies used. Two important variables in the way subjects perform tasks of intra- and inter-modal haptic and visual processing are easily measured: (a) the type of exploration strategies used to explore the individual stimuli presented to the haptic modality, and (b) the amount of time subjects examine individual haptic and visual stimuli. These variables will be carefully analyzed in the present research.

CHAPTER III
RATIONALE

Analysis of the research reviewed in Chapter II led to the definition of three general goals for the present research. These goals are outlined below.

The first goal was to examine the performance of a subject sample of able learners spanning the elementary school grades on intra- and inter-modal haptic and visual matching tasks, performance being measured in terms of accuracy, haptic exploration strategies, and haptic and visual exploration times, making it possible to (a) determine whether performance on the four conditions fit into Jones' (1981) theory, (b) examine patterns and developmental trends in the haptic exploration strategies for the individual haptic stimuli, and (c) determine the time taken to process the information about the individual stimuli in each condition.

Measurement of haptic exploration strategies for each haptic stimulus and exploration times of individual haptic and visual stimuli will be fairly exploratory in nature as previous research has not documented such detailed data. It was hoped that this information would give insight into the "techniques" elementary school-aged children use to perform shape matching tasks within and across the haptic and visual modalities.

The second goal was to determine whether requiring subjects to explore haptic stimuli for substantially longer (measured in seconds) than they explore visual stimuli, and also longer than they spontaneously explore haptic stimuli, results in any changes in accuracy scores and/or haptic exploration scores. Butter and Bjorklund (1973) suggested the necessity of allotting different exposure times for haptic and visual stimuli, in order to equate the amount of initial information, as visual processing is regular and quite rapid, whereas haptic perception is "successive" in nature. "Requiring" that the subject explore haptic stimuli for a longer time than visual stimuli might help equate the amount of information available to the two perceptual systems. There is also some evidence that subjects who explore haptic stimuli longer use a greater variety of haptic scanning strategies and achieve higher accuracy scores (Davidson et al., 1974).

The third goal was to determine whether differences exist between able readers and disabled readers in terms of intra- and inter-sensory haptic and visual processing, performance being measured in terms of accuracy, haptic exploration strategies, and exploration times.

The present research sought to apply a more refined experimental design and more sophisticated statistical analyses than had been used in previous research investigating intra- and inter-sensory processing in able and disabled readers. In terms of experimental design, it was attempted to:

- Use a sufficiently large number of subjects in each population involved in the research.
- Sample the population spanning the elementary school grades.
- Use a repeated measures design, making it possible to measure performance of the same subjects on tasks of intra- and cross-modal haptic and visual processing.
- Apply a rigorous quantitative and qualitative method of recording the strategies used to explore each stimulus presented for haptic examination.
- Develop a rigorous and accurate method of recording the time taken to explore each haptic and visual stimulus.

With the goals listed above, the research was structured to consist of a pilot study followed by a main investigation of three studies.

Study 1 examined the performance of a group of able learners spanning the elementary school grades on tasks of intra- and inter-modal haptic and visual processing. Four shape matching tasks were administered to each subject: haptic-haptic (HH), haptic-visual (HV), visual-haptic (VH), and visual-visual (VV), the first term denoting the modality in which the standard stimulus was presented, and the second term denoting the modality of the comparison stimuli. There were one standard (S) and two comparison stimuli (C1 and C2). A successive presentation paradigm was used, with no delay imposed between presentation of the stimuli. The following measures were recorded (a) accuracy scores on each of the four tasks, (b) method of exploration for each stimulus presented for haptic exploration, and (c) time taken to explore each haptic and visual stimulus. Analysis of this data would indicate: the patterns of accuracy of the different conditions at each grade level; exploration strategies used for individual haptic stimuli; exploration times for individual haptic and visual stimuli; as well as developmental patterns in accuracy scores, haptic exploration strategies, and exploration times.

Study 2 involved another population of able learners, matched in terms of number, grade level and sex to the population included in Study 1. "Fixed" exploration times were imposed for the individual stimuli, the exploration times for haptic stimuli being substantially longer than the exploration times allowed for visual stimuli. The following measures were recorded (a) accuracy scores on each of the four tasks, and (b) method of exploration for each stimulus presented for haptic exploration. Comparison of these data with the data collected for Study 1 would reveal whether imposition of "fixed" exploration times affected accuracy scores on the conditions involving a haptic component and/or exploration strategies used for individual haptic stimuli.

Study 3 involved identifying a population of disabled readers, matched by grade level to the able readers in Study 1. This population was tested under the same experimental conditions as used in Study 1 of the research, making it possible to compare able and disabled readers in terms of: (a) accuracy scores on each of the four tasks (HH, HV, VH, VV); (b) method of exploration for each stimulus presented for haptic exploration (haptic exploration score), and (c) time taken to explore each haptic and visual stimúlus.

CHAPTER IV

PILOT STUDY

The pilot study was designed to determine possible differences in terms of accuracy, "thoroughness" of haptic exploration, and exploration times between one-handed and two-handed haptic exploration of shapes in an intra-modal haptic task.

While the efficacy of one-handed as opposed to two-handed haptic exploration is an interesting research question in itself, this was considered a pilot study because the results would determine the method of haptic exploration (one-handed or two-handed) used in the main investigation (studies 1, 2 and 3). At the same time, it provided the opportunity to assess the suitability of the stimuli and the successive match-to-sample experimental paradigm for elementary school aged children.

Method

Subjects

A total of 66 children enrolled in a lower-middle class school in a suburb of Montreal served as subjects in the pilot study. All were English speaking, were considered able learners[5] by their teachers, and were placed at the appropriate grade level for their chronological age. There were 20 subjects in kindergarten (8 boys, 12 girls), 24 subjects in grade two (13 boys, 11 girls) and 22 subjects in grade four (13 boys, 9 girls). All subjects were right-

5 Able learners, as defined to the teachers, were children who were achieving at or above grade level in all subject areas, who were not receiving any remedial help, and who were placed at the appropriate grade level for their chronological age.

handed. The average age of the subjects, in years and months, at each grade at the beginning of testing, was as follows: kindergarten --5 years, 10 months; grade two -- 7 years, 9 months, grade four -- 10 years, 2 months.

Materials

The test apparatus consisted of a wooden box[6], constructed of plywood and painted blue. (Details of the haptic perception box are provided in Appendix A.) In the front of the box were two holes, each of which was covered by a felt material with a slit up the centre, which allowed the child to put his/her hand(s) in the box for haptic exploration of the stimuli, while restricting any visual information of the stimuli. The back of the box (experimenter's side) was open to facilitate presentation and removal of the stimuli, and to permit observation of the child's haptic exploratory activity. A clock/counter[7] was placed behind the haptic perception box, out of the child's view. A trip switch, which activated the timer, was placed on the experimenter's side of the box, enabling the experimenter to start the timer upon presentation of a stimulus.

The stimuli used in the four practice items and the twenty-four experimental items are reproduced in Appendix B. There were three shapes per item, a standard and two comparison stimuli. All shapes, except those in practice item 1, were irregular puzzle-like shapes. They were designed in this manner so as not to be easily labelled verbally. The

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6 The haptic perception box was adapted from Derevensky (1976) and utilized by Derevensky (1976), Lattoni (1982) and Petrushka (1978).

7 Lafayette Company, Model #54519, 1/1.000 second clock/counter.

shapes can be classified according to two major categories: those having curved edges (curvilinear), and those having straight edges (rectilinear). Within each item, the three shapes were either all curvilinear or all rectilinear. Twelve experimental items were composed of curvilinear shapes, and twelve of rectilinear shapes. (See Appendix B.) The stimuli were designed so that one comparison shape differed from the standard on a critical dimension (e.g. size of a feature, direction of a feature, shape of one of the parts of the stimulus, addition or deletion of a part of the shape, etc.). The other comparison shape in each item was identical to the standard shape. In half the items (6 curvilinear, 6 rectilinear), comparison 1 was the correct choice; in the remaining twelve items (6 curvilinear, 6 rectilinear), comparison 2 was the correct choice. (See Appendix B for details.)

All the shapes were two dimensional. They were cut from a stiff bristol board (stiff quality cardboard with a smooth surface), and fitted into a 7 cm. x 7 cm. square. It had been determined by previous research (Derevensky, 1976; Lattoni, 1982; Petrushka, 1978) and careful field testing that this design of shapes permitted easy haptic manipulation by children of elementary school age.

Two different scales were employed for scoring haptic exploratory activity. For one-handed explorations, an adaptation of the scoring sheets used by Derevensky (1976) and Petrushka (1978) was used to record a qualitative measure of the child's haptic exploratory activity of each shape.[8] (See Appendix C.) The scoring sheet defines four global levels ranging from minimal and haphazard manipulation to complete and systematic exploration. Each of these four levels contains more specific descriptions of exploratory activities within the level. Slight modifications in the scoring sheet were made for scoring two-handed haptic exploration. (See Appendix D.)

Experimental Conditions

Each child was administered two conditions of an intra-modal haptic matching task. In condition 1 the subject explored the shapes with the right hand.[9] In condition 2, the child was instructed to use both hands for haptic exploration of the shapes. There were 24 items in each condition. A match-to-sample paradigm was used. In each item the child was presented, for successive exploration, a standard shape (S), followed by two comparison shapes, a comparison 1 (C1) shape and a comparison 2 (C2) shape (presented separately). The child's task was to select the comparison shape that was identical with the standard shape. Appendix

8 The scoring sheet devised by Derevensky (1976) was based on protocols provided by Laurendeau and Pinard (1970) and on Hoop's (1971) scoring mechanism. Derevensky (1976) completed extensive pilot work, and several raters provided inter-rater reliability on this scoring measure.

9 The decision was made to use the right hand in all phases of the research as the bulk of previous research reported either use of the right hand or the dominant hand for haptic exploration, or did not specify which hand was used, in which case judgement was made that exploration was probably with the dominant hand. Use of the right hand in this research meant that results could be more easily compared to other findings in the research literature.

E provides details of which comparison stimulus (C1 or C2) was identical with the standard stimulus for each item.

Children were individually administered each of the two conditions on separate occasions. A two week interval was imposed between the separate administrations. Presentation of conditions was counterbalanced as closely as possible for order and sex at each grade level. (See Appendix F.) The same female experimenter and female research assistant administered the two conditions to all subjects. The experimenter depressed a trip switch while placing each shape in the subject's hand(s), thus activating the reaction timer; the research assistant was responsible for stopping the reaction timer manually when the subject had finished exploring each shape, and for recording the exploration time for each shape. While it was recognized that experimental error enters into this method of obtaining exploration times, it was felt to be the only practical method to use in this particular experimental design using children of this age. It was assumed that errors of timing would be fairly constant across conditions and subjects. The exploration strategy used by the subject for each stimulus (standard, comparison 1, comparison 2) was recorded as a score, according to the appropriate Haptic Exploration Scoring Sheet. (See Appendix C and Appendix D.)

In condition 1 the child placed the right hand (upturned) in the haptic perception box. The child explored the standard shape, comparison 1 shape and comparison 2 shape successively for an unlimited length of time. When the child indicated he/she had completed exploration of the standard shape, it was removed from the hand, and comparison 1 shape was placed in the child's hand. Similarly, when the child had finished exploring comparison 1 shape, it was removed from the hand, and comparison 2 shape was presented. Upon completion of exploration of comparison 2 shape, the experimenter inquired of the subject which comparison shape was the same as the standard shape. The subject was not permitted to re-explore the standard or either of the comparison shapes once it had been removed from the hand.

Condition 2 involved the same procedure as condition 1 except that the subject placed both hands (upturned) in the haptic perception box, and was encouraged to use both hands for haptic exploration of the shapes. If the child placed one hand on top of the other in the box, the experimenter placed the stimulus in whichever hand was on top; if the child kept both upturned hands separate, the shape was placed in his/her right hand.

The same 24 items were used in condition 1 and condition 2. The shapes within each item remained constant in the two conditions. Two different randomized orders of presentation of items within each condition were organized. (See Appendix E.) Details of the distribution of subjects in each grade receiving each order of presentation of conditions and each order of items within conditions is provided in Appendix F.

Procedure

Before experimentation began hand dominance was assessed by having the child print or write his/her name on a piece of paper using the preferred hand. As classroom teachers had previously been requested to refer only children who were right-handed to participate in the research, this short verification measure was considered adequate to verify handedness.

Each child was brought individually to the testing room by the research assistant. Informal conversation was encouraged to establish rapport with the child and to reduce anxiety. The child was shown the front of the haptic perception box, and was told that he/she was going to play games with this "house". (See Appendix G for instructions given for each condition.) Four practice items were administered. One or two of these practice items were administered using the visual modality, and were then readministered using the haptic modality. This procedure was adopted to facilitate the subject's understanding of the task. Only children who demonstrated by their performance on the practice items that they understood the concept and procedure involved in the tasks were retained in the study. For condition 1, the child placed the right hand in the right hand slot of the haptic perception box; for condition 2, the child placed each hand in the corresponding slot. In this position the child was able to bring both hands together inside the box. Children were not informed about the accuracy of their responses, but were told in a general way that they were performing well on the task.[10] At the end of each session, the child was thanked for taking part in the experiment.

Results

It was found that most of the kindergarten children included in this research population were not able to understand the requirements of the task. Even after repeated trials of the practice items, some using visual presentation of the three shapes in each trial, and use of different terminology, only three or four of the children at this grade level were

10 This procedure was adopted to avoid the possiblity of a 'perceptual set' after strong reinforcement, and to prevent differential reinforcement of children as this may be confounded with age differences in task performance (Johnson, 1973).

able to grasp the concept involved in this intra-modal haptic match-to-sample task. They would typically be unable to give any answer, would try to give an answer after having explored only one comparison shape, or would consistently choose either comparison 1 or comparison 2 as the correct answer for every item. It is somewhat surprising that the five year olds could not understand this task, as Derevensky (1976) and Petrushka (1978) both found five year old subjects capable of performing haptic matches. Both of the aforementioned studies involved paired comparison tasks (i.e. one standard stimulus and one comparison stimulus requiring a same/different judgement). It is possible that kindergarten children found such a task easier than the match-to-sample type task involved in this research.

Details of the data analyzed for the pilot study will not be presented, except in terms of the findings which relate to the choice of method of haptic exploration (one-handed or two-handed) used in the main investigation (studies 1, 2 and 3).

1. There were no significant[11] differences between condition 1 (one-handed exploration) and condition 2 (two-handed exploration) in terms of accuracy scores at either grade two (mean accuracy for condition 1 = 17.29, for condition 2 = 16.66; t = .986) or grade four (mean accuracy for condition 1 = 17.50, for condition 2 = 17.64; t= .834).

2. At both grade levels, exploration times were significantly longer for condition 2 (two-handed exploration) than condition 1 (one-handed exploration). The mean exploration times (across the three stimuli) for grade two were 15.53 for condition 1 and 16.98 for condition 2 (t= 9.603,

11 The .05 level of significance was adopted.

$p < .001$); for grade four the mean exploration times were 15.88 for condition 1 and 17.23 for condition 2 ($t = 7.965$, $p < .001$).

Since these results indicated that one-handed haptic exploration of shapes with the dominant hand was as accurate as, and more time-efficient than two-handed exploration, one-handed exploration was used in the main investigation (studies 1, 2 and 3).

Four other trends evident in condition 1 will be mentioned here, as they are relevant to the hypotheses proposed for the main investigation:

1. A consistent developmental trend in haptic exploration strategy scores was evident, mean exploration scores (across the three stimuli) being 3.16 for grade two, and 3.24 for grade four.

2. Haptic exploration strategy scores were higher for the standard stimulus than the comparison stimuli at both grade levels. Mean haptic exploration scores for grade two were 3.32 for the standard stimulus, 3.09 for the comparison 1 stimulus, and 3.07 for the comparison 2 stimulus. Mean exploration scores for grade four were 3.41 for the standard stimulus, 3.17 for the comparison 1 stimulus, and 3.14 for the comparison 2 stimulus.

3. Exploration times of the grade four subjects were longer than exploration times of the grade two subjects (mean exploration times for grade two and grade four being 15.53 and 15.88 respectively).

4. Exploration times were longer for the standard than either of the comparison stimuli, and a trend toward longer exploration times for the comparison 1 stimulus than the comparison 2 stimulus was evident. Mean exploration times for grade two were 6.57 for the standard stimulus, 4.51 for the comparison 1 stimulus, and 4.45 for the comparison 2 stimulus. Mean exploration times for grade four were 6.71 for the standard stimulus, 4.62 for the comparison 1 stimulus, and 4.55 for the comparison 2 stimulus.

CHAPTER V

STUDY 1

Study 1 involved administering four tasks of intra- and inter-modal haptic and visual processing (haptic-haptic, haptic-visual, visual-haptic, visual-visual)[12] to a sample of able learners spanning the elementary school grades. Subjects were allowed unrestricted times for exploration of the individual haptic and visual stimuli. The aim was to examine: a) accuracy scores on each of the four tasks (conditions), b) method of exploration for each stimulus presented for haptic exploration (haptic exploration score), and c) exploration times for the individual haptic and visual stimuli. In some respects, this study is an extension of research previously conducted at McGill University by Derevensky (1976) and Petrushka (1978).

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12 Note the use of the following abbreviations in Chapters V through VII:
HH denotes the haptic-haptic condition
HV denotes the haptic-visual condition
VH denotes the visual-haptic condition
VV denotes the visual-visual condition
S denotes the Standard stimulus
C1 denotes the Comparison 1 stimulus
C2 denotes the Comparison 2 stimulus
Thus, HHS is the Standard stimulus in the haptic-haptic condition, HHC1 is the Comparison 1 stimulus in the haptic-haptic condition, HHC2 is the Comparison 2 stimulus in the haptic-haptic condition, etc.

Method

Subjects

The subject sample involved in this study consisted of thirty-two children (16 boys and 16 girls) at each of grades one, two, four and six. Grade one subjects were included rather than kindergarten children as the pilot study had indicated that most children in kindergarten were unable to understand the requirements of a match to sample task as used in this research. While it would have been preferable to include subjects from each grade level in elementary school (grades one through six) in the research, time constraints and availability of subjects made it necessary to limit subject sampling to four grade levels. The subject sample was drawn from three schools in Ottawa, all of which drew their populations from lower middle and middle class neighbourhoods. This subject sample will henceforth be referred to as Group 1. As in the pilot study, all children were considered able learners by their classsroom teachers, and were appropriately placed in terms of grade level for their chronological age. All subjects were right-handed. The average ages of the children at each grade at the beginning of testing was as follows: grade one -- 6 years, 8 months; grade two -- 7 years, 10 months; grade four -- 9 years, 9 months; and grade six -- 11 years, 9 months.

Materials

As in the pilot study, the test apparatus included the haptic perception box, a clock/counter, and a trip switch to activate the timer. A carousel slide projector[13] (used to project images of the stimuli for the visual

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13 Kodak Auto Focus #30.

modality) was placed behind and slightly to the left (from a front view) of the haptic perception box. A moveable reverse mirror screen (17 cm. x 22 cm.) was attached to the left side (from the front view) of the box, at the child's eye level. A remote control button (for the slide projector) mounted on a piece of plywood was placed on the table in front of the screen so that the child could place the left hand on the table and press the button with the forefinger of the left hand. A small apparatus which timed the length of exposure of visual stimuli on the screen completed the experimental equipment. Details of these apparatuses are provided in Appendix H.

The stimuli used for haptic exploration were the same as those used in the pilot study. (See Appendix B.) Tracings of each shape, photographed and projected on slides as two dimensional dark forms on a light background, were used as visual stimuli. Care was taken to ensure that the projected size of the visual shapes was the same as that of the haptic shapes, and that the orientation of the shapes relative to the subject was the same for visual and haptic presentation. The Haptic Scoring Sheet for one-handed explorations (Appendix C) was used to assess haptic exploratory activity.

Experimental Conditions

Experimental condition was the within-subjects factor in a repeated measures experimental design. There were four experimental conditions: intra-modal haptic (HH condition), inter-modal haptic-visual (HV condition), inter-modal visual-haptic (VH condition), and intra-modal visual (VV condition), the first term in each condition designating the modality of the standard, and the second term the modality of the two comparison shapes. The same four practice items and 24 test items were included in each condition as had been used in the pilot study. Shapes were presented for successive exploration in all conditions, in a match-to-sample paradigm.

Each child was individually administered each of the four conditions on separate occasions. A two-week interval was imposed between the separate administrations. Two different randomized orders of presentation of items within each condition were organized. (See Appendix I for presentation orders in the four condiuons.) There were four different orders of presentation of conditions:

1) HH→HV→VH→VV

2) HV→VH→VV→HH

3) VH→VV→HH→HV

4) VV→HH→HV→VH

Details of the distribution of subjects in each grade receiving each order of presentation of conditions and each order of items within conditions is provided in Appendix J.

The same female experimenter administered all the tasks with the help of a female research assistant. Subjects were permitted unrestricted exploration times of haptic and visual stimuli. For haptically explored shapes, the experimenter placed each shape in the subject's hand, simultaneously activating the reaction timer. The research assistant stopped the timer when the subject had finished exploring the shape. For visually presented stimuli, the subject pressed a button, which projected the appropriate slide onto the screen, and simultaneously activated the reaction timer. When the subject finished viewing the stimulus, he/she pushed the button again, thereby causing the slide to disappear from the screen and simultaneously stopping the timer. The experimenter recorded the haptic exploration score for each haptic stimulus and accuracy for each item (correct or incorrect); the research assistant recorded the exploration time for each item, and reset the timer after comparison 2 shape had been explored by the subject. Children were not aware that their explorations were being timed.

Procedure

As in the pilot study, classroom teachers had been requested to identify only right-handed children in their classrooms to participate in the research. Handedness was also checked by the experimenter by asking the child to print or write his/her name on a piece of paper. (All of the identifications of the teachers were verified.)

As in the pilot study, children were brought individually to the room by the research assistant. The experimenter and research assistant engaged in informal discussion with the child before experimentation began, and the child was shown the haptic perception box ("the house") with which games were going to be played. Four practice items were administered to ensure that the child understood the concept and procedure involved. (See Appendix K for instructions given to the subjects.) If the child seemed confused about operating the projector, the practice items were readministered until he/she felt comfortable with the procedure. Children were thanked for their participation at the end of each session.

Statement of Hypotheses

A number of specific hypotheses are presented for Study 1. These hypotheses are listed for accuracy, haptic exploration strategy scores, and exploration times. Due to the exploratory nature of this research, many interesting questions are suggested which are not stated as hypotheses. These are listed after the hypotheses.

Accuracy: Hypotheses

• Developmental improvement would be evident in all conditions, more particularly in the three that involved a haptic component (HH, HV and VH).

• In terms of accuracy, the ordering of conditions would correspond to the order that Jones (1981) suggested would apply to successive presentation matching tasks using nonsense forms as stimuli, i.e. VV>VH>HV>HH, at all grade levels. Further, as suggested by Jones, it was expected that this pattern would be more pronounced at the early grade levels (grades one and two) than at later grade levels (grades four and six).

• No effects for order of presentation of conditions would be evident in accuracy scores.

• No sex differences would be evident in accuracy scores.

Haptic Exploration Strategy Scores

Hypotheses

• Developmental trends would be evident in the haptic exploration scores i.e. with increasing age (grade level), subjects would use more "sophisticated" (or thorough) haptic exploration techniques, reflected in higher exploration scores.

• No effects for order of presentation of conditions would be evident in haptic exploration scores.

• No sex differences would be evident in haptic exploration scores.

• Haptic exploration scores would be higher for the standard stimulus (S) than for the comparison stimuli (C1 or C2). This follows from Petrushka's (1978) findings.

Questions

• Was there a difference in the haptic exploration strategy scores for HHS and HVS, i.e. did knowledge that the comparison stimuli were going to be presented haptically (an intra-modal task) or visually (an inter-modal task) affect the strategies subjects used to explore the standard stimulus presented for haptic inspection?

• Was there a difference in the exploration strategy scores for the comparison 1 shape compared to the comparison 2 shape in the HH and HV conditions, i.e. HHC1 vs. HHC2 and VHC1 vs. VHC2?

• Was there a difference in the exploration strategy scores for the HH comparison stimuli and the VH comparison stimuli, i.e. HHC1 + HHC2 versus VHC1 + VHC2 ? In other words, did the exploration modality of the standard stimulus (determining whether the match would be intra-modal or inter-modal) affect the exploration strategies subjects used to explore the haptically presented comparison stimuli?

• Was there a difference in exploration strategy scores for the HHS as opposed to the VH comparison stimuli (VHC1 and VHC2)?

• Was there a difference in exploration strategy scores for the HVS and the VH comparison stimuli?

Exploration Times

Hypotheses

• Exploration times would be shorter for the visual than for the haptic stimuli.

• Exploration times would be shorter for the intra-modal visual condition (i.e. VVS + VVC1 + VVC2) than for any other condition.

• Exploration times used for the standard stimulus would be longer than the exploration times for each of the comparison stimuli on each of the intra-modal conditions (HH and VV).

This hypothesis is based on Petrushka's (1978) research, which suggests that the standard stimulus is explored longer than a comparison stimulus on intra-modal haptic tasks. It was expected that the same trend would be evident for the exploration times of stimuli on an intra-modal visual task.

• No effects for order of presentation of conditions would be evident in exploration times of either the haptic or the visual stimuli.

• No sex differences would be evident in exploration times of either the haptic or the visual stimuli.

Questions

• Were developmental trends evident in exploration times?

While there is little previous research to indicate whether such trends in exploration times occur, and/or what direction such trends would be, it might be expected that exploration times used for the haptically explored stimuli would increase with age, whereas exploration times for the visually explored stimuli would decrease slightly with age. These predictions were based on the following factors:

1. Visual processing is considered fairly accurate and efficient by the age of five (e.g., Butter and Zung, 1970; Gliner et al, 1969; Goodnow, 1971c); however children probably become quicker in the mechanics of a matching task, such as the one used in this research, with increasing age. If so, this would be reflected in decreasing exploration times for visual stimuli with increasing age (grade).

2. Research evidence suggests that tasks requiring haptic matching of shape are extremely difficult for children under the age of five, and that after this age, haptic processing improves (e.g., Goodnow, 1971c; Petrushka, 1978). Improved performance may arise with age because the mechanics of the matching task become easier, and/or because the methods used for gathering haptic information improve. Subjects can rely on two techniques of gathering more useful haptic information: a) using more "thorough" haptic exploration strategies, and b) exploring haptically presented stimuli longer. If the latter technique is adopted by subjects, this would be reflected in developmental changes toward increasing exploration times for haptic stimuli.

- How do the exploration times differ between conditions?

While it was stated in the hypotheses (above) that exploration times would be shorter for the VV condition (VVS + VVC1 + VVC2) than for any of the conditions involving a haptic component, it is less clear how exploration times for the other three conditions (HH, HV, VH) would compare. On the one hand, the HV and VH conditions involve one or more visual stimuli and it would be expected that exploration times of visual stimuli would be shorter than exploration times of haptic stimuli. Hence, it might be expected that exploration times for conditions involving one or more visual stimuli (HV and VH) would be faster than the HH condition, which involved haptic inspection of all three stimuli. On the other hand, the process of integrating information from different sensory modalities may be time consuming (as suggested by Ittyerah and Broota, 1983), in which case inter-modal processing (HV and VH conditions) might take as long as or longer than intra-modal haptic matching.

- Was there a difference in the exploration times for the HHS and HVS (the HH and HV conditions both requiring haptic exploration of the standard stimulus)? In other words, did knowledge that the comparison stimuli were going to be presented haptically (an intra-modal task) or visually (an inter-modal task) affect exploration times of these standard stimuli?
- Was there a difference in the exploration times for the VHS and the VVS (the VH and VV conditons both involving visual exploration of the standard stimulus)? In other words, did knowledge that the comparison stimuli were going to be presented haptically (inter-modally) or visually (intra-modally) affect exploration times of these standard stimuli?
- Was there a difference between the exploration times of the HHC1 and HHC2, and between VHC1 and VHC2 (the HH and VH conditions both requiring haptic exploration of the two comparison stimuli), i.e. HHC1 vs. HHC2; VHC1 vs. VHC2?

• Was there a difference in the exploration times for the HH comparison stimuli and the VH comparison stimuli, i.e. HHC1 + HHC2 versus VHC1+VHC2? In other words, did the exploration modality of the standard stimulus (determining whether the match would be intra-modal or inter-modal) affect the amount of time subjects used to explore the haptically presented comparison stimuli?

• Was there a difference between the exploration times of the HVC1 and HVC2, and between the VVC1 and VVC2 (the HV and VV conditions both requiring visual exploration of the two comparison stimuli)?

• Was there a difference in the exploration times for the HV comparison stimuli and the VV comparison stimuli, i.e. HVC1 + HVC2 vs. VVC1 + VVC2 ? In other words, did the exploration modality of the standard stimulus (determining whether the match would be intra-modal or inter-modal) affect the time subjects explored the visually presented comparison stimuli?

• Were there differences in the exploration times of the haptically explored standard stimulus in the HH condition as opposed to the two haptically explored comparison stimuli in the VH condition, i.e. HHS vs. VHC1 + VHC2?

• Were there differences in the exploration times of the haptically explored standard stimulus in the HV condition as opposed to the two haptically explored comparison stimuli in the VH condition, i.e. HVS vs. VHC1 + VHC2?

• Were there differences in the exploration times of the visually explored standard stimulus in the VH condition as opposed to the two visually explored comparison stimuli in the VV condition, i.e. VHS vs. VVC1 + VVC2?

Results

Experimental Design

The experimental design will be described again at this point, as comprehension of the design is essential to understanding the manner in which the results are presented. There were three dependent variables in Study 1: accuracy scores, haptic exploration scores, and exploration times. The study involved a repeated measures design, with three between-subjects factors and one within-subjects factor, and can be represented as follows: S (A X B X C) X E, where S stands for Subject, A for Grade, B for Sex, and C for Order. In the case of accuracy scores, E stands for Condition; in terms of haptic exploration strategies, and exploration times, E stands for Stimuli. The analyses of variance were carried out using the MANOVA subprogram of SPSSX (1986).

Presentation of Data

Accuracy, haptic exploration scores and exploration times were examined separately. Due to the number of tables required to present this data, the tables included in this chapter provide the relevant means for the above dependent variables, but only a summary of the factors reaching significance for the analyses of variance for each independent variable.[14] Complete tables for the analyses of variance are provided in Appendix N.

Mean accuracy scores for Group 1 are presented in Tables 1 through 3. The accuracy scores reflect the mean number of items correct out of 24 in each condition. Table 4 presents a summary of the analyses of variance for

[14] The .05 level of significance was adopted.

accuracy scores, these analyses relating directly to the hypotheses proposed earlier (page 103).

Mean haptic exploration scores (delineating the level of exploratory movement for each haptic stimulus) for Group 1 are presented in Tables 5 through 7. These scores reflect the mean exploration score over the 24 items for each haptically explored stimulus (HHS, HHC1, HHC2, HVS, VHC1, VHC2). Table 8 presents a summary of the analyses of variance for haptic exploration scores. These analyses relate directly to the hypotheses and questions advanced earlier (pages 103 - 105).

Mean exploration times for Group 1 are provided in Tables 9 through 12. These scores reflect the mean exploration time, measured in 1/100 seconds, over the 24 items for each stimulus. Table 13 presents a summary of the analyses of variance for exploration times. These analyses relate directly to the hypotheses and questions proposed earlier (pages 105 - 108).

Accuracy Scores

Table 1 indicates a steady increase in accuracy scores with increasing grade level for each condition (HH, HV, VH, and VV), and likewise an increase in mean accuracy (accuracy across all conditions), which increases from 17.12 at first grade to 19.76 at sixth grade. These patterns are reflected in a significant main effect for grade for mean accuracy (i.e. accuracy across all conditions) and for accuracy scores for each condition (Table 4). Since the omnibus test for grade was significant, the decision was made to analyze the various single degree contrasts for grade analytically, using the methods suggested by Keppel (1982 Chapters 6, 13, 14, and 18).

Table 1

Mean Accuracy Scores for Grade and Condition – Group 1

	Condition				
Grade	HH	HV	VH	VV	
1	16.06	15.47	16.09	20.84	17.12
2	15.66	16.00	16.59	22.00	17.56
4	17.84	16.66	17.13	23.13	18.69
6	18.59	18.38	18.56	23.50	19.76
	17.04	16.63	17.09	22.37	

Table 2

Mean Accuracy Scores for Order and Condition – Group 1

	Condition				
Order	HH	HV	VH	VV	
1	17.16	16.10	16.81	22.25	18.08
2	17.13	16.13	16.75	22.78	18.20
3	17.50	17.38	17.69	22.22	18.70
4	16.38	16.91	17.13	22.22	18.16

Table 3

Mean Accuracy Scores for Sex and Condition – Group 1

	Condition				
Sex	HH	HV	VH	VV	
Boy	16.94	16.83	17.17	22.47	18.35
Girl	17.14	16.42	17.02	22.27	18.21

Table 4

Analysis of Variance for Accuracy Scores -- Group 1

Condition	Factors and Pairwise Comparison Reaching Significance
Mean Accuracy (i.e. accuracy scores across conditions)	Grade ($p < 0.0$)
	1 vs. 2 N.S.
	1 vs. 4 ($p < .01$)
	1 vs. 6 ($p < .01$)
	2 vs. 4 ($p < .01$)
	2 vs. 6 ($p < .01$)
	4 vs. 6 ($p < .01$)
	Grade x Sex x Order ($p < .037$)
Haptic - Haptic	Grade ($p < .000$)
	1 vs. 2 N.S.
	1 vs. 4 ($p < .01$)
	1 vs. 6 ($p < .01$)
	2 vs. 4 ($p <.05$).
	2 vs. 6 ($p < .01$)
	4 vs. 6 N.S.
Haptic - Visual	Grade ($p < .000$)
	1 vs. 2 N.S.
	1 vs. 4 ($p < .05$)
	1 vs. 6 ($p < .01$)
	2 vs. 4 N.S.
	2 vs. 6 ($p < .01$)
	4 vs. 6 ($p < .01$)

Table 4 Cont'd

Visual - Haptic	Grade ($p < .000$) 1 vs. 2 N.S. 1 vs. 4 N.S. 1 vs. 6 ($p < .01$) 2 vs. 4 N.S. 2 vs. 6 ($p < .01$) 4 vs. 6 ($p < .01$)
Visual - Visual	Grade ($p < .000$) 1 vs. 2 ($p < .01$) 1 vs. 4 ($p < .01$) 1 vs. 6 ($p < .01$) 2 vs. 4 ($p < .01$) 2 vs. 6 ($p < .01$) 4 vs. 6 N.S.
Haptic - Haptic versus Haptic - Visual	Condition[a] ($p < .054$) Order ($p < .026$) Grade x Order ($p < .022$)
Haptic - Haptic versus Visual - Haptic	-------------
Haptic - Haptic versus Visual - Visual	Condition ($p < 0.0$)
Haptic - Visual versus Visual - Haptic	Condition ($p < .027$)
Haptic - Visual versus Visual - Visual	Condition ($p < 0.0$) Order ($p < .021$)
Visual - Haptic versus Visual - Visual	Condition ($p < 0.0$)

[a] Condition is a comparison of the conditions.

The comparisons between individual grades are presented in Table 4.

Analyses of variance were performed to test for significance of difference in accuracy scores of the different conditions at each grade level.[15] Results indicate the following pattern:[16]

Grade one	VV>VH=HH=HV
Grade two	VV>VH=HV=HH
Grade four	VV>HH=VH=HV (where accuracy scores on the HH condition are significantly higher than accuracy scores on the HV condition.)
Grade six	VV>HH=VH=HV

At each grade level there was a significant difference in accuracy scores for the VV condition compared to the accuracy scores of any condition involving a haptic component (i.e. HH vs. VV, HV vs. VV and VH vs. VV), scores being higher for the VV condition in each case. At grades one, two and six there were no significant differences in accuracy scores of the three conditions involving a haptic component; at grade four there was a significant difference in the accuracy scores of the HH and the HV conditions, scores being higher for the HH condition.

Referring once again to Table 4, the pairwise comparisons of conditions reveals that across all grade levels, the pattern of accuracy in the

15 These analyses were pairwise comparisons, of the conditions, after splitting the sample by grade. These analyses are presented in Tables 12 through 15 in Appendix N.

16 Conditions are ordered, from highest to lowest (left to right) even when this ordering was not reflected in significant differences (.05 level) between the conditions.

different conditions is VV>VH=HH>HV, indicating: a) accuracy scores were significantly higher for the VV condition than for any other condition, and b) a significant difference in the accuracy scores of the two inter-modal conditions, reflecting higher accuracy scores on the VH condition.

There were no significant effects for order of presentation of conditions on mean accuracy or accuracy for each condition.

There were no sex differences in accuracy scores.

Haptic Exploration Strategy Scores

Table 5 indicates a small but steady increase in haptic exploration scores for each stimulus (HHS, HHC1, HHC2, HVS, VHC1, VHC2) with increasing grade level. This is paralleled by an increase in mean haptic

Table 5

Mean Haptic Exploration Scores for Grade and Stimulus -- Group 1

	Condition						
Grade	HHS	HHC1	HHC2	HVS	VHC1	VHC2	
1	3.30	3.08	3.06	3.32	3.05	3.09	3.15
2	3.42	3.15	3.11	3.45	3.19	3.10	3.24
4	3.70	3.35	3.31	3.65	3.27	3.23	3.42
6	3.83	3.53	3.43	3.77	3.38	3.32	3.54
	3.57	3.28	3.23	3.55	3.22	3.19	

Table 6

Mean Haptic Exploration Scores for Order and Stimulus – Group 1

Order	HHS	HHC1	HHC2	HVS	VHC1	VHC2	
1	3.45	3.20	3.14	3.48	3.23	3.17	3.28
2	3.68	3.37	3.34	3.60	3.28	3.22	3.42
3	3.62	3.31	3.26	3.57	3.21	3.13	3.35
4	3.50	3.23	3.16	3.54	3.17	3.16	3.29

Table 7

Mean Haptic Exploration Scores for Sex and Stimulus – Group 1

Sex	HHS	HHC1	HHC2	HVS	VHC1	VHC2	
Boy	3.57	3.29	3.23	3.57	3.23	3.18	3.35
Girl	3.56	3.26	3.22	3.53	3.21	3.16	3.32

Table 8

Analysis of Variance for Exploration Strategy Scores -- Group 1

Stimuli	Factors and Pairwise Comparisons Reaching Significance
HHS, HHC1, HHC2, HVS, VHC1, VHC2	Stimuli (p < .0001) Grade (p < .0001) HHS (p < .0001) HHC1 (p < .0001) HHC2 (p < .001) HVS (p < .0001) VHC1 (p < .0003) VHC2 (p < .0002)
HHS versus HHC1 + HHC2	Stimuli (p < .0001) Grade (p < .011)
HHS versus HHC1	Stimuli (p < .0001) Grade (p < .027)
HHS versus HHC2	Stimuli (p < .0001) Grade (p < .005)
HHS versus HVS	Grade x Sex x Order (p < .018)
HHC1 versus HHC2	Stimuli (p < .0001) Grade (p < .003)
VHC1 versus VHC2	Stimuli (p < .001)
HHC1 + HHC2 versus VHC1 + VHC2	Stimuli (p < .040)
HHC1 versus VHC1	--------------

Table 8 Cont'd

HHC2 versus VHC2	--------------
HHS versus VHC1 + VHC2	Stimuli ($p < .0001$) Grade ($p < .019$)
HHS versus VHC1	Stimuli ($p < .0001$) Grade ($p < .020$)
HHS verus VHC2	Stimuli ($p < .0001$)
HVS versus VHC1 + VHC2	Stimuli ($p < .0001$)
HVS versus VHC1	Stimuli ($p < .0001$)
HVS versus VHC2	Stimuli ($p < .0001$)

[a] Stimuli is a comparison of the specific stimuli.

exploration score (i.e. strategy scores across all stimuli), mean strategy scores increasing from 3.15 at first grade level to 3.54 at sixth grade. (See the right-most column in Table 5.) Multivariate analyses of variance (Table 8) indicate a significant main effect for grade across all haptic stimuli together, reflecting developmental improvement in haptic exploration strategy scores. Since multivariate analyses indicated a significant main effect for grade, univariate analyses for the individual stimuli were then examined. Examination of these univariate analyses

(Table 8) indicates that the effect for grade reached significance for each haptically explored stimulus, indicating that exploration strategy scores improved significantly for each stimulus with increasing grade level.

Order of presentation of conditions was not significant for haptic exploration scores.

No sex differences in exploration scores were evident.

Analyses of variance for the comparison of exploration scores of individual haptic stimuli (Table 8) in conjunction with Table 5 reveals:

- In the HH condition, the exploration scores of the standard stimulus were significantly higher than the scores of the comparison stimuli. This difference was reflected in significantly higher exploration scores for the S (3.57) as opposed to C1 (3.28) and the S as opposed to C2 (3.23).
- No significant differences were evident in exploration strategy scores for the HHS stimulus (3.57) and the HVS stimulus (3.55).
- In both the HH and VH conditions, exploration scores were significantly higher for the C1 stimulus than for the C2 stimulus (HHC1 -- 3.28, HHC2 -- 3.23; VHC1-- 3.22, VHC2 -- 3.19).
- There was a significant difference in the haptic exploration scores of the two comparison items in the HH condition and the scores of the two comparison items in the VH condition (i.e. HHC1 + HHC2 versus VHC1 + VHC2), exploration scores being higher for the HH comparison stimuli.
- The exploration strategy scores of the HHS stimulus were significantly higher than those of the VH comparison stimuli, this difference being reflected in significantly higher scores for the HHS (3.57) than for either VHC1 (3.22) or VHC2 (3.19).

• The exploration strategy scores of the HVS stimulus were significantly higher than those used for the VH comparison stimuli. This difference was reflected in significantly higher strategy scores for HVS (3.55) than for VHC1 (3.22) or VHC2 (3.19).

Exploration Times [17]

As evident from Tables 10 and 13, there was a significant difference in the exploration times for haptic and visual stimuli, exploration times being shorter for visual stimuli. Calculations based on Table 10 reveal that the mean exploration times for haptic and visual stimuli were 5.38 and 3.60 respectively, a difference of 1.78 seconds.

Analysis of exploration times for each condition (i.e. exploration time for S + C1 + C2 in each condition) indicates that exploration times for the

Table 9
Mean Exploration Time for Condition [a] – Group 1

Condition			
HH	HV	VH	VV
15.38	15.11	15.05	8.32

[a] Exploration times are represented in seconds.

[17] Exploration times measured in seconds (to the hundredth of a second.)

Table 10

Mean Exploration Time for Stimulus and Grade -- Group 1

	Stimulus												
Grade	HHS	HHC1	HHC2	HVS	HVC1	HVC2	VHS	VHC1	VHC2	VVS	VVC1	VVC2	
1	5.89	4.15	3.89	6.26	4.30	4.05	5.74	4.92	4.30	3.19	2.64	2.78	4.34
2	6.99	4.61	4.11	7.31	4.54	3.36	5.55	5.09	4.51	3.34	2.52	2.70	4.55
4	6.89	4.61	4.14	7.34	4.16	3.09	5.28	5.03	4.59	3.07	2.34	2.43	4.41
6	7.17	4.73	4.36	8.23	4.56	3.25	5.23	5.48	4.49	3.40	2.44	2.43	4.65
	6.74	4.52	4.12	7.29	4.39	3.43	5.45	5.13	4.47	3.25	2.48	2.59	

Table 11

Mean Exploration Time for Stimulus and Order -- Group 1

	Stimulus												
Order	HHS	HHC1	HHC2	HVS	HVC1	HVC2	VHS	VHC1	VHC2	VVS	VVC1	VVC2	
1	5.70	4.11	3.53	6.40	4.11	3.26	5.05	4.88	4.13	3.31	2.41	2.45	4.11
2	7.11	4.64	4.28	8.64	4.89	4.16	5.93	5.60	5.08	3.33	2.56	2.55	4.90
3	6.82	4.42	4.19	7.29	4.36	3.32	5.64	5.17	4.58	3.18	2.46	2.62	4.50
4	7.32	4.92	4.50	6.82	4.20	2.96	5.18	4.87	4.09	3.18	2.51	2.72	4.44

Table 12

Mean Exploration Time for Stimulus and Sex -- Group 1

	Stimulus												
Sex	HHS	HHC1	HHC2	HVS	HVC1	HVC2	VHS	VHC1	VHC2	VVS	VVC1	VVC2	
Boy	6.68	4.44	4.07	7.44	4.47	3.57	5.72	5.16	4.36	3.35	2.43	2.60	**4.52**
Girl	6.68	4.63	4.21	7.21	4.33	3.28	5.19	5.13	4.60	3.17	2.53	2.57	**4.46**

Table 13

Analysis of Variance for Haptic Exploration Times – Group 1

Stimuli	Factors and Pairwise Comparison Reaching Significance
HHS, HHC1, HHC2, HVS, VHC1, VHC2 versus HVC1, HVC2, VHS, VVS, VVC1, VVC2	Stimuli ($p < .0001$)[a] Grade ($p < .0006$)
HHS, HHC1, HHC2, HVS, VHC1, VHC2	Stimuli ($p < .001$) Order ($p < .011$)
HVC1, HVC2, VHS, VVS, VVC1, VVC2	Stimuli ($p < .0001$) Grade x Order ($p < .038$)
HHS	Order ($p < .018$)
HHC1	-------------
HHC2	Order ($p<.012$)
HVS	Grade ($p < .024$) Order ($p < .004$) Grade x Order ($p <.025$)
HVC1	-------------
HVC2	-------------
VHS	-------------
VHC1	-------------
VHC2	Order ($p < .012$)

Table 13 Cont'd

VVS	-------------
VVC1	-------------
VVC2	Grade ($p < .012$)
HHS + HHC1 + HHC2 versus HVS + HVC1 + HVC2	Order ($p < .011$)
HHS + HHC1 + HHC2 versus VHS + VHC1 + VHC2	Order ($p < .007$)
HHS + HHC1 + HHC2 versus VVS + VVC1 + VVC2	Stimuli ($p < .0001$) Grade ($p < .033$) Order ($p < .015$)
HVS + HVC1 + HVC2 versus VHS + VHC1 + VHC2	Grade x Order ($p < .046$) Grade x Sex x Order ($p < .050$)
HVS + HVC1 + HVC2 versus VVS + VVC1 + VVC2	Stimuli ($p < .0001$) Order ($p < .018$)
VHS + VHC1 + VHC2 versus VVS + VVC1 + VVC2	Stimuli ($p < .0001$) Order ($p < .024$)
HHS versus HHC1 + HHC2	Stimuli ($p < .0001$)
HHS versus HHC1	Stimuli ($p < .0001$) Order ($p < .018$)

Table 13 Cont'd

HHS versus HHC2	Stimuli ($p < .0001$)
VVS versus VVC1 + VVC2	Stimuli ($p < .0001$)
VVS versus VVC1	Stimuli ($p < .0001$) Grade x Order ($p < .045$)
VVS versus VVC2	Stimuli ($p < .0001$)
HHS versus HVS	Stimuli ($p < .013$) Order ($p < .015$)
VHS versus VVS	Stimuli ($p < .0001$)
HHC1 versus HHC2	Stimuli ($p < .0001$)
VHC1 versus VHC2	Stimuli ($p < .0001$)
HHC1 + HHC2 versus VHC1 + VHC2	Stimuli ($p < .0001$) Order ($p < .002$)
HHC1 versus VHC1	Stimuli ($p < .003$) Order ($p < .002$)
HHC2 versus VHC2	Stimuli ($p < .003$) Order ($p < .002$)
HVC1 versus HVC2	Stimuli ($p < .0001$) Grade ($p < .006$)
VVC1 versus VVC2	Stimuli ($p < .008$) Sex ($p < .010$)
HVC1 + HVC2 versus VVC1 + VVC2	Stimuli ($p < .0001$)

Table 13 Cont'd

HVC2 versus VVC2	Stimuli ($p < .0001$) Order ($p < .035$)
HHS versus VHC1 + VHC2	Stimuli ($p < .0001$) Order ($p < .010$)
HHS versus VHC1	Stimuli ($p < .0001$) Order ($p < .010$)
HHS versus VHC2	Stimuli ($p < .0001$) Order ($p < .019$)
HVS versus VHC1 + VHC2	Stimuli ($p < .0001$) Sex x Order ($p < .015$) Grade x Sex x Order ($p < .023$)
HVS versus VHC1	Stimuli ($p < .0001$) Sex x Order ($p < .012$)
HVS versus VHC2	Stimuli ($p < .0001$) Grade ($p < .049$) Sex x Order ($p < .025$) Grade x Sex x Order ($p < .026$)
VHS versus VVC1 + VVC2	Stimuli ($p < .0001$)
VHS versus VVC1	Stimuli ($p < .0001$)
VHS versus VVC2	Stimuli ($p < .0001$) Sex ($p < .014$)

[a] Stimuli is the difference between the stimuli.

VV condition were significantly shorter than for any other condition (HH condition -- 15.38, HV condition -- 15.11, VH condition -- 15.05, VV condition -- 8.32). (See Tables 9 and 13.) No significant differences between exploration times for any of the conditions involving a haptic component (HH, HV, VH) were apparent.

There was no significant grade effect for exploration times of either the haptic or visual stimuli.

There was a significant main effect for order of presentation of conditions for the haptic stimuli, but not for the visual stimuli.

No sex differences were evident in exploration times of either the haptically or the visually explored stimuli.

Examination of the analyses of variance comparing the exploration times of individual stimuli (Table 13) in conjunction with Table 10 reveals:

- In the HH condition, there was a significant difference in the exploration times for the standard as opposed to the comparison stimuli; the exploration time for HHS being significantly longer than the exploration time for the HHC1 and HHC2. This difference was reflected in significantly longer exploration time for the S (6.74) as opposed to C1 (4.52) and the S as opposed to C2 (4.12). A similar pattern was evident for the VV condition. Exploration times were significantly longer for VVS than for either of the comparison stimuli, the mean exploration time for VVS being 3.25, for VVC1 -- 2.48 and for VVC2 -- 2.59.
- There was a significant difference in the exploration times of the HHS (6.74) and the HVS (7.29), exploration times being shorter for the HHS.
- There was a significant difference in exploration times of the VHS (5.45) and the VVS (3.25), exploration times being shorter for the VVS.

• In both the HH and VH conditions, the C1 stimulus was explored significantly longer than the C2 stimulus (HHC1 -- 4.52, HHC2 -- 4.12 and VHC1 -- 5.13, VHC2 -- 4.47).

• There was a significant difference in the exploration times of the comparison stimuli in the HH condition (HHC1 -- 4.52, HHC2 - 4.12) and the comparison stimuli in the VH condition (VHC1 -- 5.13, VHC2 -- 4.47), exploration times being shorter for the HH comparison stimuli than the VH comparison stimuli.

• In the HV condition, the C1 stimlus was explored significantly longer than the C2 stimulus (HVC1 - 4.39, HVC2 -- 3.43). The opposite trend was evident in the VV condition, the VVC2 being explored significantly longer (2.59) than the VVC1 (2.48).

• There was a significant difference in the exploration times of the comparison stimuli in the HV condition (HVC1 -- 4.39, HVC2 -- 3.43) and the comparison stimuli in the VV condition (VVC1 -- 2.48, VVC2 -- 2.59), exploration times being shorter for the comparison stimuli in the VV condition.

• There was a significant difference in the exploration times of the HHS and the two comparison items in the VH condition, this difference being reflected in significantly longer exploration times for the HHS (6.74) than for either VHC1 (5.13) or VHC2 (4.47).

• There was a significant difference in the exploration times of the HVS and the two comparison stimuli in the VH condition, this difference being reflected in significantly longer exploration times for HVS (7.29) than for either VHC1 (5.13) or VHC2 (4.47).

• There was a significant difference in the exploration times of VHS and the two comparison stimuli in the VV condition; this difference being reflected in significantly longer exploration times for the VHS (5.45) than for either VVC1 (2.48) or VVC2 (2.59).

Discussion

Accuracy

Significant developmental improvements in accuracy scores are evident in all conditions (Tables 1 and 4), the greatest improvement between grades one and six occurring on the HV condition. A steady improvement in accuracy with each grade level is evident in this condition. By sixth grade level, accuracy scores on the three conditions involving a haptic component are very close (HH=18.59; HV=18.38; VH=18.56) and are all well below ceiling, indicating that there is still room for improvement on the conditions involving a haptic component.

Jones (1981) proposed that the patterns of accuracy (for subjects of the age group included in this research) among conditions of intra- and inter-modal haptic and visual processing would be VV>VH>HV>HH. In this sample of able readers, spanning first through sixth grade, the pattern postulated by Jones is not confirmed. However, three points are noteworthy in relation to Jones' theory:

1. As predicted by Jones, accuracy is highest on the VV condition at all grade levels.

2. Jones (1981) and other researchers (e.g. Derevensky, 1976, Goodnow, 1971c) postulated that accuracy on VH tasks would be higher than accuracy on HV tasks. In fact, this pattern was found at every grade level,

although the difference in accuracy scores of the VH and HV conditions did not reach significance at any grade level.

3. The HH condition does not follow the pattern suggested by Jones. At the fourth grade level, accuracy scores on the HH condition were significantly higher than accuracy scores on the HV condition, and at sixth grade there were no significant differences in the accuracy scores of the three conditions involving a haptic component, although accuracy scores were highest on the HH condition.

It is further interesting to note that Jones postulated that the ordering of conditions would become VV>HH=VH=HV (essentially the ordering found in the sixth grade sample of the present research) with increasing age, although he specifically postulated that this pattern would not occur if the stimuli were nonsense forms, as used in this study. Furthermore, it is noteworthy that the results of this investigation do confirm the theories proposed by a number of researchers (e.g. Derevensky, 1976; Goodnow, 1971c; Jones, 1981; Petrushka, 1978) that information gathered by hand is less stable than information gathered by eye.

Haptic Exploration Scores

Turning to haptic exploration scores, the significant main effect for grade across all haptic stimuli is reflected in small but consistent increases in exploration scores with increasing grade level for all haptic stimuli. The mean haptic exploration scores for each stimulus range from 3.08 to 3.83 between first and sixth grade. These means reflect the preponderant use of haptic exporation strategies at levels 2 and 3 by subjects in the younger grades, and of more general use of strategies at levels 3 and 4 by sixth grade.

Two patterns are clearly evident in haptic exploration strategy scores (Tables 5 and 8):

1. Exploration scores were significantly higher for a standard stimulus than for comparison stimuli (HHS>HHC1; HHS>HHC2; HHS>VHC1; HHS>VHC2; HVS>VHC1; HVS>VHC2).

2. Exploration scores were higher for C1 than for C2 stimuli (HHC1>HHC2; VHC1>VHC2).

Subjects apparently found it necessary to explore a standard stimulus most thoroughly, a C1 stimulus a lot less thoroughly, and a C2 stimulus less thoroughly again. These findings largely confirm the results reported by Derevensky (1976) and Petrushka (1978). Both reported developmental improvements in haptic exploration strategies used by children, strategy scores being measured on a similar scale to the one used in this research. Petrushka further noted that subjects had higher exploration strategy scores for standard stimuli than for comparison stimuli, on a task involving a paired comparison technique which involved only one comparison stimulus. Her finding that subjects tended to use higher haptic exploration strategies on inter-modal conditions than intra-modal conditions was not confirmed by this study.

Exploration Times

As would be expected, exploration times for visual stimuli are significantly shorter than exploration times for haptic stimuli, a finding reported by a number of other researchers (e.g. Butter and Bjorklund, 1973, 1976; Davidson, 1974; Derevensky, 1976; Petrushka, 1978). For example, comparing the individual stimuli on the two intra-modal conditions, the mean exploration times for the HH condition are as follows: HHS -- 6.74 seconds, HHC1-- 4.52 seconds, HHC2 -- 4.12 seconds; and for the VV condition: VVS -- 3.25 seconds, VVC1 -- 2.48 seconds, VVC2 -- 2.59 seconds (Table 10). While there was no significant grade effect for exploration times of either the haptic or the visual stimuli, a fairly consistent trend of increasing exploration times for haptic stimuli with increasing grade level is noteworthy (Tables 10 and 13). For example: HHS; grade one -- 5. 89 seconds, grade six --7.17 seconds; VHC1; grade one -- 4.92 seconds, grade six -- 5.48 seconds.

With respect to the exploration times for the different conditions, it is not surprising that exploration times would be significantly shorter for the VV condition (S + C1 + C2) than for any of the other conditions (Table 13), mean exploration time for the HH condition being 15.38, the HV condition 15.11, the VH condition 15.05, and the VV condition 8.32 (Table 9). It is somewhat surprising, however, that there are no significant differences in the exploration times of any of the conditions involving a haptic component. As exploration times were shorter for visual stimuli than for haptic stimuli, it might have been expected that exploration times for conditions involving a visual component (especially the HV condition in which the two comparison stimuli were presented visually) would be shorter than exploration times for the intra-modal haptic condition (which involved haptic exploration of all three stimuli). The fact that there were no significant differences in exploration times between these three conditions (HH, HV and VH) would seem to indicate that subjects explored the stimuli longer when the task involved translation between one sensory modality and another. Ittyerah and Broota (1983) have proposed that inter-modal processing takes longer due to the added demand of transforming the original information regarding the standard, so that it can be matched with input pertaining to comparisons coming from the other modality.

Examination of the exploration times for individual stimuli reveal parallel trends to those found for haptic exploration scores (Tables 10 and 13):

1. Longer exploration times for standard stimuli than for comparison stimuli presented to the same modality (HHS>HHC1; HHS>HHC2; HHS>VHC1, HHS>VHC2; VVS>VVC1; VVS>VVC2; HVS>VHC1, HVS>VHC2; VHS>VVC1, VHS>VVC2).

2. In the two conditions involving haptic comparison stimuli (HH and VH), exploration times were longer for C1 than C2 stimuli. The opposite pattern was evident in the HV and VV conditions.

It can therefore be concluded that subjects found it necessary to explore a standard stimulus much longer than comparison stimuli in the same modality, and examined a haptic C1 stimulus longer than a haptic C2 stimulus. In addition, examination of "equivalent stimuli"[18] reveals that subjects explored stimuli longer if a cross-modal comparison was required than if an intra-modal comparison was required. For example, the HVS

18 "Equivalent stimuli" are stimuli that are of the same classification (S, C1 or C2) and presented to the same sensory modality (either haptic or visual) but in different conditions. As such, HHS and HVS are labelled "equivalent stimuli" as they are both standard stimuli presented to the haptic modality.

was explored longer than HHS; VHS was explored longer than VVS; the comparison stimuli in the VH condition were explored longer than the comparison stimuli in the HH condition; and the comparison stimuli in the HV condition were explored longer than the comparison stimuli in the VV condition. This finding confirms the suggestion made above that subjects explored stimuli longer when they knew that a task involved translation between sensory modalities than when they knew the task was intra-modal.

The significant effect for order of presentation of conditions on exploration times of haptic stimuli seems to reflect the shorter exploration times for haptic stimuli for order 1 than for the other orders. Subjects receiving the HH condition first evidently spent less time exploring haptic stimuli than subjects receiving the HV, VH, or VV condition before other conditions.

Summary

In summary, this sample of able readers, allowed unrestricted exploration times for stimuli in intra- and inter-modal haptic and visual matching tasks, showed: (a) developmental trends of increasing accuracy in each condition; (b) superior accuracy on the VV condition compared to the other conditions; (c) developmental improvements in haptic exploration strategy scores; (d) higher haptic exploration scores for standard stimuli than for comparison stimuli, and higher scores for C1 stimuli than C2 stimuli; (e) longer exploration times for standard stimuli than for comparison stimuli (presented to the same modality) and for C1 than C2 stimuli (except for the VV condition); and (f) longer exploration times for stimuli in cross-modal conditions than for the "equivalent" stimuli in intra-modal conditions.

This sample of able readers, with development, evidently relied on two "methods" of improving performance on conditions requiring a haptic component: using more thorough haptic exploration strategies, and using longer exploration times for haptic stimuli. In addition, they took longer to explore stimuli when a cross-modal comparison was involved than when the match was intra-modal.

CHAPTER VI

STUDY 2

The population sample included in Study 2 were able learners, matched in terms of number, socio-economic status, grade level and sex to the subject sample in Study 1 (Group 1). As in Study 1, four tasks of intra- and inter-modal haptic and visual processing were administered. The only difference in experimental procedure in this study was that the exploration times for the individual haptic and visual stimuli were "fixed" (i.e. the amount of time each stimulus was to be explored was determined in advance, and subjects were required to examine the stimuli for exactly this amount of time). The purpose of Study 2 was to examine the effects of imposing "fixed" exploration times for haptic stimuli, these exploration times being substantially longer than the exploration times for visual stimuli, and also longer than the time haptic stimuli would be spontaneously examined (as determined by the pilot study and Study 1) on: a) accuracy scores on each of the four conditions, and b) method of exploration for each stimulus presented for haptic exploration (haptic exploration score).

Method

Subjects

The subject sample consisted of 128 children drawn from two schools in a suburb of Monteal. This sample will henceforth be referred to as Group 2. Subjects in this sample were matched in terms of number, grade and sex with the subjects comprising Group 1. As in Study 1, all children were considered able learners by their classroom teachers, and were in the appropriate grade for their chronological age. All subjects were right-handed. The average ages of the children at each grade at the beginning of testing was as follows: grade one -- 6 years, 11 months; grade two -- 7 years, 10 months; grade four -- 9 years, 9 months; and grade six -- 11 years, 9 months. It should be noted that subjects in this population are consistently a little older at each grade level than subjects in Group 1. This may have been due to the different cut-off dates for entry into school in Quebec and Ontario (September 30 and December 31 respectively).

Materials

The same experimental equipment was used as in Study 1 except that the apparatus which timed the length of exposure of the visual stimuli on the screen was not needed. Instead, two small apparatuses were used to regulate the amount of time the haptic and visual stimuli respectively were presented to the subject for exploraton. (See Appendix L for details.) The stimuli used were the same as those used in Study 1. (See Appendix B.)

Experimental Conditions

As in Study 1, experimental condition was the within-subjects factor in a repeated measures experimental design. The same experimental conditions existed as in Study 1, except that fixed exploration times were imposed for exploration of the haptic and visual stimuli. These exploration times were established based on the results of the pilot study and Study 1, careful pretesting, and on other research findings. Results of the pilot study, previous research (Petrushka, 1978) and careful pre-testing of this study indicated longer exploration times for the standard stimuli than for the comparison stimuli. Exploration times (in seconds) for each stimulus – standard (S), comparison 1 (C1) and comparison 2 (C2) in each condition were set as follows :[19]

Condition	S	C1	C2
Haptic-Haptic	9	6	6
Haptic-Visual	9	2	2
Visual-Haptic	3	6	6
Visual-Visual	3	2	2

The research assistant depressed a lever with her arm simultaneously with the presentation of the shape in the subject's hand, thus activating the reaction timer. One second before the allotted exploration time was up a red light flashed. At this time the research assistant began reaching for the shape to remove it from the subject's upturned hand. The light flashed a second time when the allotted exploration time was up, enabling the research assistant to determine that she was removing the object from the subject's hand at the right time. The experimenter recorded the haptic exploration scores for each haptically presented stimulus. For visually presented shapes, the child depressed a button, thus projecting the slide of the appropriate stimulus onto the screen for the allotted amount of time.

19 It is to be noted that these exploration times for haptic stimuli are much shorter than the 30 seconds of haptic exploration that Butter and Bjorklund (1973) suggested was comparable to 2 seconds of visual exploration. However, Butter and Bjorklund used an adult population of subjects. Carefuly pre-testing for this research indicated that children of the age range included in this study could not tolerate a 30 second exploration time. It was further determined during pilot testing that subjects of this age could not manage an exploration time of less than 3 seconds for a visual standard stimulus.

Procedure

As in the pilot study and Study 1, classroom teachers had been requested to identify only right-handed children in their classrooms to participate in the research. Handedness was verified by the experimenter by asking the child to print or write his/her name on a piece of paper. All of the identifications of the teachers were verified.

As in the pilot study and Study 1, familiarization procedures were adopted before testing began. Four practice items were administered to ensure that the child understood the concept and procedure involved. (See Appendix M for instructions given to the subjects.) Emphasis was placed on the fact that stimuli should be explored for the whole time allowed. If the child seemed confused about operating the projector, the practice items were readministered until he/she felt comfortable with the procedure. Children were thanked for their participation at the end of each session.

Statement of Hypotheses

A number of specific hypotheses are presented for Study 2. These hypotheses are listed for accuracy and haptic exploration strategy scores only, as exploration times were fixed. Questions relating to the study are listed after the hypotheses.

Accuracy

Hypotheses

• Developmental improvement would be evident in all conditions, especially the conditions involving a haptic component (HH, HV, VH conditions).

• Performance would be most accurate on the VV condition. No specific hypotheses are proposed concerning the effect of fixed exploration times on the relative accuracy on the three conditions involving a haptic component.

• No effects for order of presentation of conditions would be evident in accuracy scores.

• No sex differences would be evident in accuracy scores.

• This subject sample would show superior accuracy scores compared to Group 1 on all conditions involving a haptic component (HH, HV, VH), but no differences in accuracy scores would exist between the two groups on the VV condition.

• No grade or sex differences would be evident in mean accuracy scores of the Group 2 and the Group 1 subject samples (i.e. no population by grade or population by sex interactions).

Question

• What pattern of accuracy at each grade level on the conditions involving a haptic component (i.e. the HH, HV and VH conditions) would be evident?

Haptic Exploration Strategy Scores: Hypotheses

• Developmental improvement in haptic exploration scores would be evident.

• No effects for order of presentation of conditions would be evident in haptic exploration strategy scores.

• No sex differences would be evident in haptic exploration scores.

• The patterns of haptic exploration strategy scores for individual stimuli would be the same as those found in Group 1.

• The haptic exploration scores of this subject sample would be higher than the haptic exploration scores of Group 1.

• There would be no differences in sex or grade in the haptic exploration scores of the Group 2 and Group 1 subject samples (i.e. no population by sex or population by grade interactions).

Results

Experimental Design

The experimental design will be described again at this point, as comprehension of the design is essential to understanding the manner in which the results are presented. There were two dependent variables in Study 2: accuracy scores, and haptic exploration scores. Study 2 involved a repeated measures design, with three between-subjects factors and one within-subjects factor, and can be represented as follows: S (A x B x C) x E, where S stands for Subject, A for Grade, B for Sex, and C for Order. In the case of accuracy scores, E stands for condition; in terms of haptic exploration scores, E stands for Stimuli. Study 2 also involved comparison of the data collected for Group 2 with the data collected for Group 1. Therefore, an extra between-subjects factor is added to the experimental design, which can be represented as follows: S (A x B x C x D) x E, where S stands for Subject, A for Grade, B for Sex, C for Order, D for Population (Group 1 versus Group 2), and E for Condition (for accuracy scores) or Stimuli (for haptic exploration scores). The analyses of variance were carried out using the MANOVA subprogram of SPSSX (1986).

Presentation of Data

Accuracy and haptic exploration scores were examined separately. Due to the number of tables required to present this data, the tables included in this chapter provide the relevant means for the above dependent variables, but only a summary of the factors reaching significance for the analyses of variance for each independent variable.[20] Complete tables for the analyses of variance are provided in Appendix N.

Mean accuracy scores for Group 2 are presented in Tables 14 through 16. The accuracy scores reflect the mean number of items correct out of 24 in each condition. Tables 17 and 18 present a summary of the analyses of variance for accuracy scores, these analyses relating directly to the hypotheses and questions proposed earlier (pages 141-142).

Mean haptic exploration scores (delineating the level of exploratory movement for each haptic stimulus) for Group 2 are presented in Tables 19 through 21. These scores reflect the mean exploration score over the 24 items for each haptically explored stimulus (HHS, HHC1, HHC2, HVS, VHC1, VHC2). Tables 22 and 23 present a summary of the analyses of variance for haptic exploration scores. These analyses relate directly to the hypotheses advanced earlier (pages 142 - 143).

Accuracy Scores

Table 14 indicates a steady increase in accuracy scores with increasing grade level for each condition (HH, HV, VH, and VV), and likewise an increase in mean accuracy (accuracy scores across all conditions), which increases from 17.54 at first grade level to 20.66 at sixth grade level. These

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20 The .05 level of significance was adopted.

Table 14
Mean Accuracy Scores for Grade and Condition – Group 2

	Condition				
Grade	HH	HV	VH	VV	
1	16.19	16.03	15.49	22.44	17.54
2	17.44	17.00	16.91	22.31	18.42
4	17.91	18.91	17.88	22.91	19.40
6	18.50	20.31	20.31	23.50	20.66
	17.51	18.06	17.65	22.79	

Table 15
Mean Accuracy Scores for Order and Condition – Group 2

	Condition				
Order	HH	HV	VH	VV	
1	17.31	17.22	18.10	22.91	18.89
2	17.44	17.22	17.81	22.88	18.84
3	17.88	18.84	16.79	22.66	19.04
4	17.41	18.47	17.88	22.72	19.12

Table 16
Mean Accuracy Scores for Sex and Condition – Group 2

	Condition				
Sex	HH	HV	VH	VV	
Boy	17.69	18.42	17.72	22.64	19.12
Girl	17.33	17.03	17.56	22.94	1872

patterns are reflected in a significant grade effect for mean acccuracy (i.e. accuracy across all conditions) and for accuracy scores for each individual condition (Table 17). Since the omnibus test for grade was significant, the decision was made to analyze the various single degree contrasts for grade analytically, using the methods described by Keppel (1982, Chapters 6, 13, 14, and 18). The comparisons between individual grades are presented in Table 17.

Analyses of variance were performed to test for significance of difference in accuracy scores of the different conditions at each grade level[21]. Results indicate the following pattern:[22]

Grade 1	VV>HH=HV=VH
Grade 2	VV>HH=HV=VH
Grade 4	VV>HV>HH=VH
Grade 6	VV>HV=VH>HH

At each grade level, there was a significant difference in accuracy scores for the VV condition compared to the accuracy scores of any condition involving a haptic component (HH, HV, VH). At grades one and two there were no significant differences in the accuracy scores of the three conditions involving a haptic component; at grade four, accuracy scores were significantly higher on the HV condition than on the HH or VH condition

21 These analyses of variance were pairwise comparisons, of the conditions, after splitting the subject population by grade. These analyses are presented in Tables 12 through 15 in Appendix N.

22 Conditions were ordered from highest to lowest (left to right) even when this ordering was not reflected in significant differences (.05 level) between the conditions.

Table 17
Analysis of Variance for Accuracy Scores -- Group 2

Condition	Factors and Pairwise Comparison Reaching Significance
Mean Accuracy (i.e. accuracy scores across conditions)	Grade ($p < .000$)
	1 vs. 2 ($p < .01$)
	1 vs. 4 ($p < .01$)
	1 vs. 6 ($p < .01$)
	2 vs. 4 ($p < .01$)
	2 vs. 6 ($p < .01$)
	4 vs. 6 ($p < .01$)
Haptic - Haptic	Grade ($p < .001$)
	1 vs. 2 ($p < .05$)
	1 vs. 4 ($p < .01$)
	1 vs. 6 ($p < .01$)
	2 vs. 4 N.S.
	2 vs. 4 N.S.
	4 vs. 6 N.S.
	Grade x Sex ($p < .020$)
Haptic - Visual	Grade ($p < .000$)
	1 vs. 2 N.S.
	1 vs. 4 ($p < .01$)
	1 vs. 6 ($p < .01$)
	2 vs. 4 ($p < .01$)
	2 vs. 6 ($p < .01$)
	4 vs. 6 ($p < .05$)
	Order ($p < .016$)
	1 vs. 2 N.S.
	1 vs. 3 ($p < .05$)
	1 vs. 4 N.S.
	2 vs. 3 ($p < .01$)
	2 vs. 4 ($p < .05$)
	3 vs. 4 N.S.

Table 17 (Cont'd)

Visual - Haptic	Grade ($p < .000$) 1 vs. 2 ($p < .01$) 1 vs. 4 ($p < .01$) 1 vs. 6 ($p < .01$) 2 vs. 4 ($p < .05$) 2 vs. 6 ($p < .01$) 4 vs. 6 ($p < .01$)
Visual - Visual	Grade ($p < .001$) 1 vs. 2 N.S. 1 vs. 4 N.S. 1 vs. 6 ($p < .05$) 2 vs. 4 N.S. 2 vs. 6 ($p < .05$) 4 vs. 6 N.S.
Haptic - Haptic versus Haptic - Visual	Condition ($p < .016$)[a] Grade ($p < .002$) Grade x Sex ($p < .035$)
Haptic - Haptic versus Visual - Haptic	Grade ($p < .005$)
Haptic - Haptic versus Visual - Visual	Condition ($p < .000$)
Haptic - Visual versus Visual - Haptic	Order ($p < .001$)
Haptic - Visual versus Visual - Visual	Grade ($p < .000$) Condition ($p < .000$) Order ($p < .012$) Sex ($p < .020$)
Visual - Haptic versus Visual - Visual	Condition ($p < .000$) Grade ($p < .000$)

[a] Condition is a comparison of the conditions.

and at grade six, accuracy scores on the HV and VH conditions were higher than acccuracy scores on the HH condition.

Referring again to Table 17, the pairwise comparisons of conditions reveals that across all grade levels, the pattern of accuracy in the different conditions is VV>HV=VH=HH (accuracy scores on the HV condition being higher than accuracy scores on the HH condition), indicating: a) accuracy scores were significantly higher for the VV condition than for any of the conditions involving a haptic component, and b) accuracy scores were significantly higher on the HV than on the HH condition.

There was no significant effect for order of presentation of conditions on mean accuracy. However, examination of the individual conditions reveals a significant effect for order of presentation of conditions on accuracy scores for the HV condition. The significant differences of accuracy scores between individual orders of presentation for the HV condition are presented in Table 17.

There were no sex differences in the accuracy scores of the Group 2 subject sample.

A comparison of the mean accuracy scores of Group 2 and Group 1 (Table 18) indicates a significant difference between the mean accuracy scores of the two population samples, indicating the superior accuracy scores of Group 2 compared to Group 1 (mean accuracy scores for Group 2 -- 19.00 and for Group 1 -- 18.28). Examination of the analyses of variance for the individual conditions reveals significant differences in the accuracy scores of the two groups on the HV and VV conditions only (Group 1 : HV condition -- 16.63, VV condition -- 22.37; Group 2 : -- HV condition --18.06, VV condition -- 22.79).

Table 18
Analysis of Variance for Accuracy Scores – Group 1 versus Group 2

Condition	Factors Reaching Significance[a]
Mean Accuracy (i.e. accuracy scores across conditions)	Group 1/Group 2 ($p < .000$)
Haptic - Haptic	--------------
Haptic - Visual	Group 1/Group 2 ($p < .000$)
Visual - Haptic	Group 1/Group 2 x Grade ($p < .029$) Group 1/Group 2 x Order ($p < .033$)
Visual - Visual	Group 1/ Group 2 ($p < .015$) Group 1/Group 2 x Grade ($p < .001$)

[a] Only the significant effects involving the two population samples i.e. Group 1 versus Group 2 are reported, as only these effects are meaningful in the present analyses.

There were no significant grade by population (Group 1/Group 2), or sex by population interactions for mean accuracy.

Haptic Exploration Strategy Scores

Table 19 indicates a small but steady increase in haptic exploration scores for each stimulus (HHS, HHC1, HHC2, HVS, VHC1, VHC2) with increasing grade level. This is paralleled by an increase in mean haptic exploration score (i.e. strategy scores across all stimuli), mean strategy scores increasing from 3.24 at first grade level to 3.70 at sixth grade. (See

Table 19

Mean Haptic Exploration Scores for Grade and Stimulus -- Group 2

	Condition						
Grade	HHS	HHC1	HHC2	HVS	VHC1	VHC2	
1	3.31	3.16	3.11	3.41	3.25	3.18	3.24
2	3.51	3.32	3.22	3.56	3.42	3.32	3.39
4	3.74	3.60	3.49	3.77	3.58	3.45	3.61
6	3.79	3.64	3.53	3.91	3.73	3.60	3.70
	3.59	3.43	3.34	3.66	3.50	3.38	

Table 20

Mean Haptic Exploration Scores for Order and Stimulus – Group 2

	Condition						
Order	HHS	HHC1	HHC2	HVS	VHC1	VHC2	
1	3.59	3.51	3.44	3.68	3.63	3.51	3.56
2	3.63	3.46	3.33	3.61	3.46	3.33	3.47
3	3.58	3.40	3.32	3.66	3.41	3.37	3.46
4	3.54	3.36	3.26	3.70	3.48	3.34	3.45

the right-most column in Table 19.) Multivariate analyses of variance (Table 22) indicate a significant effect for grade across all haptic stimuli together, reflecting developmental improvement in haptic exploration strategy scores. Since multivariate analyses indicated a significant main effect for grade, univariate analyses for the individual stimuli were examined. Examination of these univariate analyses (Table 22) indicates that the effect for grade reached significance for each haptically explored stimulus, indicating that exploration strategy scores improved significantly for each stimulus with increasing grade level.

Order of presentation of conditions was significant for haptic exploration scores. Analysis of the individual haptic stimuli reveals that order of presentation of conditions had a significant effect on exploration strategies for the VHC1 and the VHC2 stimuli (Table 22). It is evident from examination of Table 20 that haptic explorations scores for VHC1 and VHC2 were higher for order 1 than for the other orders of presentation.

No sex differences in haptic exploration scores were evident.

Analysis of variance for the comparison of exploration scores of individual haptic stimuli (Table 22) in conjunction with Table 19 reveals:

- As in Group 1, exploration strategy scores were higher for HHS than for HHC1 and HHC2, this difference being reflected in higher scores for the S (3.59) as opposed to C1 (3.43) and S as opposed to C2 (3.34).
- While in Group 1 there were no significant differences in the exploration scores of the HHS and the HVS, significant differences were evident in Group 2, exploration scores being higher for the HVS (3.66) than for the HHS (3.59).

Table 21

Mean Haptic Exploration Scores for Sex and Stimulus -- Group 2

	Condition						
Sex	HHS	HHC1	HHC2	HVS	VHC1	VHC2	
Boy	3.59	3.44	3.33	3.67	3.49	3.38	3.48
Girl	3.59	3.42	3.34	3.66	3.50	3.39	3.48

Table 22

Analysis of Variance for Exploration Strategy Scores -- Group 2

Stimuli	Factors and Pairwise Comparison Reaching Significance
HHS, HHC1, HHC2, HVS, VHC1, VHC2	Stimuli ($p < .0001$)
	Grade ($p < .001$)
	HHS ($p < .001$)
	HHC1 ($p < .001$)
	HHC2 ($p < .001$)
	HVS ($p < .001$)
	VHC1 ($p < .001$)
	VHC2 ($p < .001$)
	Order ($p < .001$)
	HHS N.S.
	HHC1 N.S.
	HHC2 N.S.
	HVS N.S.
	VHC1 ($p < .001$)
	VHC2 ($p < .001$)

Table 22 Cont'd

	Grade x Order ($p < .005$) HHS N.S. HHC1 N.S. HHC2 N.S. HVS N.S. VHC1 ($p < .003$) VHC2 ($p < .021$)
HHS versus HHC1 + HHC2	Stimuli ($p < .000$)[a] Order ($p < .001$)
HHS versus HHC1	Stimuli ($p < .000$) Order ($p < .003$)
HHS versus HHC2	Stimuli ($p < .000$) Order ($p < .002$)
HHS versus HVS	Stimuli ($p < .001$) Order ($p < .040$)
HHC1 versus HHC2	Stimuli ($p < .000$) Grade ($p < .050$)
VHC1 versus VHC2	Stimuli ($p < .0001$) Order ($p < .016$)
HHC1 + HHC2 versus VHC1 + VHC2	Stimuli ($p < .001$) Grade x Order ($p < .014$)
HHC1 versus VHC1	Stimuli ($p < .004$) Grade x Order ($p < .009$)

Table 22 Cont'd

HHC1 + HHC2 versus VHC1 + VHC2	Stimuli (p < .001) Grade x Order (p < .014)
HHC1 versus VHC1	Stimuli (p < .004) Grade x Order (p < .009)
HHC2 versus VHC2	Stimuli (p < .004) Grade x Order (p < .048)
HHS versus VHC1 + VHC2	Stimuli (p < .001) Order (p < .008) Grade x Order (p < .010)
HHS versus VHC1	Stimuli (p < .0002) Order (p < .005) Grade x Order (p < .014)
HHS versus VHC2	Stimuli (p < .0001) Order (p < .014) Grade x Order (p < .011)
HVS versus VHC1 + VHC2	Stimuli (p < .0001) Order (p < .001) Grade x Order (p < .001)
HVS versus VHC1	Stimuli (p<.0001)
HVS versus VHC2	Stimuli (p<.0001)

[a] Stimuli is a comparison of the specific stimuli.

• As in Group 1, in both the HH and VH conditions, exploration scores were higher for the C1 stimulus than for the C2 stimulus (HHC1 -- 3.43, HHC2 -- 3.34; VHC1 -- 3.50, VHC2 -- 3.38).

• Contrary to Group 1, subjects in Group 2 had significantly higher exploration scores for the VH comparison stimuli (VHC1 -- 3.50, HVC2 -- 3.38) than for the HH comparison stimuli (HHC1 -- 3.43, HHC2 -- 3.34).

• As in Group 1, exploration scores were higher for the HHS (3.59) than for either VHC1 (3.50) or VHC2 (3.38).

• As in Group 1, exploration scores were significantly higher for the HVS (3.66) than for either VHC1 (3.50) or VHC2 (3.38).

There was a significant difference in the exploration scores (across all haptic stimuli) used by the subjects in Group 2 and the subjects in Group 1, reflecting the higher exploration scores of Group 2. (See Table 10 in Chapter V and Tables 19 and 23 in this chapter.) Group 2 had significantly higher exploration scores for the following stimuli: HHS (Group 2 -- 3.59, Group 1 -- 3.57); HHC1 (Group 2 -- 3.43, Group 1 -- 3.28), HHC2 (Group 2 -- 3.34, Group 1 -- 3.23), HVS (Group 2 -- 3.66, Group 1 -- 3.55), VHC1 (Group 2 --3.50, Group 1 -- 3.22).

No significant population (Group1/Group 2) by grade, or population by sex differences were found in exploration scores.

Exploration Times

It is perhaps worthwhile noting that the "fixed" exploration times of the Group 2 subject sample were much longer for haptic stimuli than the exploration times of Group 1. However, for the visual stimuli, the exploration times of Group 1 were slightly longer than the "fixed" exploration times of the Group 2 subjects. (See Table 10 in Chapter V.)

Table 22

Analysis of Variance for Exploration Strategy Scores -- Group 2

Stimuli	Factors and Pairwise Comparison Reaching Significance
HHS, HHC1, HHC2, HVS, VHC1, VHC2	Stimuli (p < .0001)
	Grade (p < .001)
	HHS (p < .001)
	HHC1 (p < .001)
	HHC2 (p < .001)
	HVS (p < .001)
	VHC1 (p < .001)
	VHC2 (p < .001)
	Order (p < .001)
	HHS N.S.
	HHC1 N.S.
	HHC2 N.S.
	HVS N.S.
	VHC1 (p < .001)
	VHC2 (p < .001)
	Grade x Order (p < .005)
	HHS N.S.
	HHC1 N.S.
	HHC2 N.S.
	HVS N.S.
	VHC1 (p < .003)
	VHC2 (p < .021)
HHS versus HHC1 + HHC2	Stimuli (p < .000)[a]
	Order (p < .001)
HHS versus HHC1	Stimuli (p < .000)
	Order (p < .003)

HHS versus HHC2	Stimuli ($p < .000$) Order ($p < .002$)
HHS versus HVS	Stimuli ($p < .001$) Order ($p < .040$)
HHC1 versus HHC2	Stimuli ($p < .000$) Grade ($p < .050$)
VHC1 versus VHC2	Stimuli ($p < .0001$) Order ($p < .016$)
HHC1 + HHC2 versus VHC1 + VHC2	Stimuli ($p < .001$) Grade x Order ($p < .014$)
HHC1 versus VHC1	Stimuli ($p < .004$) Grade x Order ($p < .009$)
HHC2 versus VHC2	Stimuli ($p < .004$) Grade x Order ($p < .048$)
HHS versus VHC1 + VHC2	Stimuli ($p < .001$) Order ($p < .008$) Grade x Order ($p < .010$)
HHS versus VHC1	Stimuli ($p < .0002$) Order ($p < .005$) Grade x Order ($p < .014$)
HHS versus VHC2	Stimuli ($p < .0001$) Order ($p < .014$) Grade x Order ($p < .011$)
HVS versus VHC1 + VHC2	Stimuli ($p < .0001$) Order ($p < .001$) Grade x Order ($p < .001$)

Table 22 (Cont'd)

HVS versus VHC1	Stimuli (p<.0001)
HVS versus VHC2	Stimuli (p<.0001)

[a] Stimuli is a comparison of the specific stimuli.

Table 23
Analysis of Variance for Exploration Strategy Scores -- Group1 versus Group 2

Stimuli	Factors Reaching Significance[a]
HHS, HHC1, HHC2, HVS, VHC1, VHC2	Group 1/Group 2 (p < .0001) Group 1/Group 2 x Order (p < .007)
HHS	Group 1/Group 2 (p < .0001)
HHC1	Group1/Group 2 (p < .0001) Group 1/Group 2 x Grade (p < .037)
HHC2	Group 1/Group 2 (p < .046) Group 1/Group 2 x Grade x Sex x Order (p<.048)
HVS	Group 1/Group 2 (p < .0001)
VHC1	Group 1/Group 2 x Grade x Sex x Order p<.024)
VHC2	Group1/Group2 x Sex x Order (p<.024)

[a] Only significant effects involving a comparison between the populations (i.e. Group 1 versus Group 2) are reported, as only these results are of interest in the present analysis.

Discussion

Accuracy

As in Group 1, significant developmental improvement in accuracy scores are evident in all conditions in the Group 2 subject sample (Tables 14 and 17). This developmental improvement took the form of a steady improvement in accuracy with grade level in each condition; the greatest improvements between grades one and six occurring in the VH condition (15.49 at grade one and 20.31 in grade six) and the HV condition (16.03 in grade one and 20.31 at grade six). By sixth grade level, accuracy scores were close to ceiling level on the VV condition (23.50), while accuracy scores on the other conditions were below ceiling level (HH=18.50, HV=20.31, VH=20.31).

While in Group 1 accuracy scores were almost the same for the three conditions involving a haptic component at sixth grade, in Group 2 a different pattern is evident. While accuracy scores on the three conditions involving a haptic component were fairly close at first grade (HH= 16.19, HV=16.03, VH=15.49), by sixth grade accuracy scores were significantly higher on the HV (20.31) and VH (20.31) conditions than on the HH condition (18.50), seeming to indicate that "fixed" exploration times resulted in relatively greater improvement by sixth grade level on the cross-modal conditions than on the intra-modal haptic condition (accuracy at first grade level for HH condition was 16.19 and for sixth grade 18.50). It could be hypothesized that, by sixth grade, the longer exploration times provided extra information about the haptic stimuli that was useful if one or two stimuli were explored haptically, but that this was not enough to improve performance (relative to Group 1) on the intra-modal haptic condition, which involved haptic exploration of all three stimuli.

Group 2, like Group 1, had highest accuracy scores on the VV condition at all grade levels. However, the pattern of accuracy scores among the conditions at each grade level is different from that of Group 1. Two points are noteworthy:

1. In Group 1, there were no significant differences in the scores on the HH, HV, and VH conditions at any grade level; whereas in Group 2 accuracy scores were higher on the HV condition than on the HH condition at grades four and six.

2. In Group 2, a consistent trend toward lower accuracy scores on the VH condition than on the HV condition is evident (reaching significance at grade four only) at grades one, two, and four, and at sixth grade, accuracy scores on the two cross-modal conditions is equal and significantly higher than accuracy scores on the HH condition. No such pattern is evident in Group 1. As mentioned above, in Group 1 there were no significant differences in the scores on the HH, HV, and VH conditions at any grade level.

It is difficult to explain why the "fixed" exploration times would have resulted in higher accuracy scores on the HV condition relative to the VH condition in Group 2. Jones (1981) suggested that cross-modal matches starting from a visual standard are easier than cross-modal matches starting from a haptic standard because the standard is examined in the more efficient modality in a VH task, providing the subject with adequate information about the standard stimulus to enable him/her to know what to look for in the comparison items. It is possible that imposition of longer exploration times for haptic stimuli than would have been used spontaneously (i.e. exploration times of haptic stimuli used by Group 1) provided sufficient information about the standard in the HV condition (in which only one shape was explored haptically) to make this task easier than the VH condition, which involved haptic examination of the two comparison items. Two other factors, both due to experimental artifact, may have influenced the relative performance of the two subject samples (Group 1 and Group 2) on the inter-modal conditions:

1. The exploration times of Group 1 were consistently longer for VHS than the exploration times of Group 2, giving Group 1 an advantage that may have resulted in superior accuracy scores on the VH condition.

2. Due to the experimental procedure used with Group 2 (presenting stimuli for fixed exploration times), the visual stimuli were presented "automatically" i.e. the subject had no equipment to operate; whereas subjects in Group 1 had to push a button to advance a slide (visual stimulus) and push the button a second time when finished examining the stimulus. This factor in itself may have made conditions relying extensively on visual stimuli (HV and VV) easier for subjects in Group 2.

Significant differences in the mean accuracy scores (i.e. accuracy across all conditions) of the Group 1 sample and the Group 2 sample reflect the superior accuracy scores of Group 2. However, in terms of the individual conditions, significant differences between the populations are found only on the HV and VV conditions. While the difference in accuracy scores of the two populations on the VH condition does not reach significance ($p<.062$), examination of Table 1 (Chapter V) and Table 14 indicates a large difference in the accuracy scores of sixth grade subjects in the two population samples on this condition. The average accuracy score of sixth grade subjects in Group 2 on the VH condition was 20.31, while the mean score on this condition for the sixth graders in Group 1 was 18.56. In fact, by sixth grade, the largest difference in accuracy scores between the two populations is on the two cross-modal conditions.

Haptic Exploration Scores

Examination of the haptic exploration strategy scores reveals that, as in Group 1, developmental improvements are evident in haptic exploration scores, this effect reaching significance for each haptic stimulus. Small but consistent increases in exploration scores for each stimulus with increasing grade level are evident. In terms of the haptic exploration scores for individual stimuli, the patterns are similar to those found in Group 1, with two exceptions:

1. There was a significant difference in exploration scores for the HHS and HVS, exploration scores being higher for the HVS.

2. In comparing the exploration scores for the VH comparison stimuli and the HH comparison stimuli, scores were significantly higher for the VH comparison stimuli, whereas in Group 1, the opposite pattern was apparent.

The same two "patterns" of haptic exploration strategy scores as were evident in Group 1 are found in Group 2:

1. Exploration scores were significantly higher for a standard stimulus than for comparison stimuli.

2. Exploration scores were higher for C1 than for C2 stimuli.

These "patterns" suggest a customary approach to exploration strategies that occurs spontaneously whether subjects are allowed "free" exploration times or whether "fixed" exploration times are imposed: a tendency to explore a standard stimulus most thoroughly, a C1 stimulus much less thoroughly, and a C2 stimulus less thoroughly again.

The haptic exploration scores of Group 2 were significantly higher than the scores of Group 1, a finding which would seem to indicate that fixed exploration times resulted in more thorough haptic exploration strategies. While mean exploration scores were higher in Group 2, the range of exploration scores is similar (3.1 to 3.9), reflecting the predominant use of strategies at the 2 and 3 levels by children at grades one and two, and the more general use of strategies at the 3 and 4 levels at grades four and six.

Summary

In summary, it was found that Group 2, with "fixed" exploration times for stimuli in intra- and inter-modal haptic and visual tasks showed: (a) developmental improvements in accuracy scores for each condition; (b) significantly higher accuracy scores than Group 1 on the HV and VV conditions; (c) developmental improvements in exploration scores; (d) similar patterns of haptic exploration scores for the different haptic stimuli as Group 1, the two differences in this population being that exploration scores were higher for HVS than for HHS and higher for the VH comparison stimuli than for the HH comparison stimuli; and (e) higher haptic exploration scores than Group 1.

Because the mean accuracy scores of the Group 2 subject sample were significantly higher than the mean accuracy scores of Group 1, it is tempting to conclude that in this sample of average learners, imposing "fixed" exploration times for haptic and visual stimuli (these exploration times being much longer for haptic stimuli than for visual stimuli, and also longer those used by Group 1) resulted in higher accuracy. However, the fact that only on the HV and VV conditions were the accuracy scores of Group 2 significantly higher makes such an interpretation unlikely. These are the two conditions that rely most strongly on the visual modality -- the VV condition being exclusively visual and the HV condition requiring haptic inspection of the standard stimulus only. It is also noteworthy that exploration times of Group 2 for all three stimuli in the VV condition and the comparison stimuli in the HV condition were actually shorter than those of Group 1. Therefore, it seems that although imposing "fixed" exploration times on Group 2 produced more thorough haptic exploration strategies, this did not seem to result in an improvement in accuracy on the two conditions relying most heavily on the use of haptic information - the HH and VH conditions. It would seem more reasonable to try to explain the superior accuracy scores of Group 2 on the conditions relying most heavily on the visual modality -- the HV and VV conditions. One possible reason, involving experimental artifact, was advanced earlier: the visual stimuli were presented "automatically" to Group 2, which may have made conditions involving more than one visual stimulus (HV and VV) easier for this population. Another factor which must be considered is the average age of the subjects in the two population samples. Group 2 was about three months older than Group 1 at every grade level, a factor which could explain the superior accuracy of Group 2 on all conditions. However, this does not explain their significantly higher performance relative to Group 1 on two (VV and HV) of the four conditions.

The only other possibility is that the beneficial effects of fixed exploration times on accuracy scores on conditions involving a haptic component are only apparent at the highest grade level studied. As mentioned earlier, comparing the accuracy scores of the sixth grade subjects in Group 1 and Group 2, it is evident that their scores were almost identical on the HH and VV conditions; however, on the HV and VH conditions the scores of Group 2 are much higher than the scores of Group 1. It seems possible that, by sixth grade, the fixed exploration times resulted in either superior accuracy in cross-modal processing, or on tasks which involved haptic exploration of only one or two stimuli. Analyses of the exploration times of Group 1 revealed that subjects found it necessary to explore stimuli in cross-modal conditions longer than the "equivalent" stimuli in intra-modal conditions. It therefore seems plausible that imposing fixed exploration times (which were longer than the exploration times used by Group 1 for individual haptic stimuli) resulted, by sixth grade, in greater relative improvement in accuracy on the two cross-modal conditions.

CHAPTER VII

STUDY 3

Study 3 involved administering the same experimental conditions as used in Study 1 (four tasks of intra- and inter-modal haptic and visual processing with unrestricted exploration times) to a subject sample of reading disabled children spanning the elementary school grades. The aim was to compare this sample of poor readers with the sample of able readers in Study 1 in terms of: a) accuracy scores on each of the four conditions, b) method of exploration for each stimulus presented for haptic exploration (haptic exploration score), and c) exploration times for the individual haptic and visual stimuli.

Method

Subjects

Due to the special definition of this subject sample, the number of children involved in this study is much smaller than the numbers included in the subject samples in groups 1 and 2. A total of 53 children drawn from five elementary schools under the Ottawa Board of Education were included in this study. This population sample will henceforth be referred to as Group 3. Grade placement for these children spanned first grade through sixth grade. However, for the purposes of analyses, each child was categorized according to the grade level that he/she should have been in for his/her chronological age, as some of the children in this sample had repeated a grade due to their reading problems. Only the subjects who fell into grades one, two, four, and six in this manner of classification were included in the data analysis. This decision was made in order to match subjects as closely as possible in terms of age to subjects in Group 1. The number of subjects included in the analyses was thus reduced to 35.

The subject population was selected by screening children who were currently receiving, who had previously received, or who were on the referral lists for, remedial reading instruction. Children referrred for remedial reading under the Ottawa Board of Education were considered, after screening by the school board, to be of average intelligence but to have specific problems in reading.

Screening procedures for the purposes of this research included individual administration of the Oral Reading, the Word Recognition and Word Analysis sections of the Durrell Analysis of Reading Difficulty (1955). Only children who scored a specified level below their expected grade level (i.e. the grade level they should be placed in according to their age) on the above three measures of the Durrell were included in the research. Specific criteria for inclusion in this sample based on the Durrell Analysis of Reading Difficulty scores were as follows. For grade one, subjects scored lower than the 1L (low grade one) level on the Oral Reading, Word Recognition and Word Analysis subtests. (Subjects were in the second half of grade one at the time of testing.) For grades two, four, and six, subjects scored at least one year below the child's expected grade level (i.e. the grade the child should be in for his/her age) on the Oral Reading, Word Recognition and Word Analysis subtests.

The distribution of subjects by sex according to expected grade level[23] was as follows: grade one -- 4 subjects (2 boys, 2 girls), grade two -- 13

23 Expected grade level based on chronological age.

subjects (9 boys, 4 girls), grade four -- 7 subjects (5 boys, 2 girls), and grade six -- 11 subjects (8 boys, 3 girls), for a total of 24 boys and 11 girls.

All subjects were right-handed. The average age (in years and months) of subjects at each grade was as follows: grade one -- 6 years, 7 months; grade two -- 7 years, 8 months; grade four -- 9 years, 9 months; and grade six -- 11 years, 10 months.

Materials, Experimental Conditions, and Procedure

The experimental materials, experimental conditions and experimental procedure were the same as in Study 1.

Statement of Hypotheses

Previous research investigating intra- and inter-sensory haptic and visual processing abilities of reading disabled children is so scant that few specific hypotheses are advanced concerning this study. However, it is to be kept in mind that the two major purposes of this study were to determine: a) whether the patterns of accuracy scores of this population would support the inter-sensory deficit theory of reading disabilities, and b) whether this subject sample applied the same "task strategies" (in terms of exploration times of individual stimuli and strategies used to explore individual haptic stimuli) as their able learning peers. Questions relating to the study are listed after the hypotheses.

Accuracy

Hypothesis

• Developmental improvement in accuracy scores would be evident in all conditions.

Questions

• This sample included many more boys than girls, reflecting the larger percentange of boys who have difficulty learning to read. Were sex differences evident in the accuracy scores of this subject sample?

• How does the pattern of accuracy scores compare to that found in Group 1 (i.e. ordering of conditions in terms of accuracy at each grade level)?

• Were differences in the accuracy scores evident between this sample and Group 1?

• Were grade or sex differences evident in accuracy scores of Group 3 and Group 1 (i.e. population by grade and/or population by sex interactions)? If so, in which conditions are these interactions evident?

Haptic Exploration Strategy Scores

Hypothesis

• Developmental improvement in haptic exploration scores would be evident.

Questions

• Were sex differences evident in the exploration strategy scores of this sample?

• How does the pattern of exploration scores for different stimuli compare to the patterns found in Group 1?

• Is there a difference in the exploration scores of Group 3 and Group 1? If so:

- For which haptically explored stimuli do differences exist between the two samples?

- Were these differences between populations reflected in grade and/or sex differences (i.e. population by grade or population by sex interactions)?

Exploration Times

Hypotheses

- Exploration times would be shorter for visual than for haptic stimuli.
- Exploration times would be shorter for the VV condition than for any other condition.

Questions

- Were the same developmental trends in exploration times evident in Group 3 as in the Group 1 subject sample?
- Were sex differences evident in the exploration times of this subject sample?
- How do the patterns of exploration times for individual stimuli compare to the patterns found in Group 1?
- Are there differences between the Group 3 subject sample and Group 1 in terms of the exploration times for the haptically explored stimuli (HHS, HHC1, HHC2, HVS, VHC1, VHC2) ? If so:

- For which haptically explored stimuli do differences in exploration times exist between the samples?

- Were these differences reflected in grade and/or sex differences (i.e. population by grade or population by sex interactions)?

- Are there differences between Group 3 and Group 1 in terms of the exploration times for the visually explored stimuli (HVC1, HVC2, VHS, VVS, VVC1, VVC2)? If so:

- For which visually explored stimuli do differences in exploration times exist between the samples?
- Were these differences reflected in grade and/or sex differences (i.e. population by grade or population by sex interactions)?

Results

Experimental Design

The experimental design will be described again at this point, as comprehension of the design is essential to understanding the manner in which the results are presented. There were three dependent variables in Study 3: accuracy scores, haptic exploration scores, and exploration times. Study 3 involved a repeated measures design, with two between-subjects factors and one within-subjects factor, and can be represented as follows: S (A x B) x E[24], where S stands for Subject, A for Grade, and B for Sex. In the case of accuracy scores, E stands for condition; in terms of haptic exploration strategies and exploration times, E stands for Stimuli. Study 3 also involved comparison of the data collected for Group 3 with the data collected for Group 1. Consequently, an extra between-subjects factor is added to the experimental design, which can be represented as follows: S (A x B x D) x E, where S stands for Subject, A for Grade, B for Sex, D for Population (Group1 versus Group 3), and E for Condition (for accuracy scores) or Stimuli (for haptic exploration scores and exploration times).

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24 While order of presentation of conditions was counterbalanced as closely as possible within each grade level, order was not included as a between-subjects factor in the analyses, as this would have resulted in unequal n's in the various cells and small n's in the cells.

The analyses of variance were carried out using the MANOVA subprogram of SPSSX (1986).

Presentation of Data

Accuracy, haptic exploration scores and exploration times were examined separately. Due to the number of tables required to present this data, the tables included in this chapter provide the relevant means for the above dependent variables, but only a summary of the factors reaching significance for the analyses of variance for each independent variable.[25] Complete tables for the analyses of variance are provided in Appendix N.

Mean accuracy scores for Group 3 are presented in Tables 24 and 25. The accuracy scores reflect the mean number of items correct out of 24 in each condition. Tables 26 through 28 present a summary of the analyses of variance for accuracy scores, these analyses relating directly to the hypotheses and questions proposed earlier (pages 170-171).

Mean haptic exploration scores (delineating the level of exploratory movement for each haptic stimulus) for Group 3 are presented in Tables 29 and 30. These scores reflect the mean exploration score over the 24 items for each haptically explored stimulus (HHS, HHC1, HHC2, HVS, VHC1, VHC2). Tables 31 and 32 present a summary of the analyses of variance for haptic exploration scores. These analyses related directly to the hypotheses and questions advanced earlier (pages 171-172).

Mean exploration times for Group 3 are provided in Tables 33 through 35. These scores reflect the mean exploration time, measured in 1/100 seconds, over the 24 items for each stimulus. Tables 36 and 37 present a

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25 The .05 level of significance was adopted.

summary of the analyses of variance for exploration times. These analyses related directly to the hypotheses and questions proposed earlier (pages 172 - 173).

Accuracy Scores

Table 24 indicates developmental improvement between grades one and six in every condition (HH, HV, VH, VV), and likewise an increase in mean accuracy (accuracy across conditions) which increases from 14.81 at first grade level to 17.65 at sixth grade level in this subject sample of poor readers. Examination of Table 26 indicates a significant main effect for grade for mean accuracy (i.e. accuracy across all conditions). The analyses of variance for individual conditions (Table 26) reveals a significant main effect for grade for the HH and HV conditions only. Since the omnibus test for grade was significant, the decision was made to analyze the various single degree contrasts for grade analytically, using the methods suggested by Keppel (1982 , Chapters 6, 13, 14, and 18). Examination of these comparisons between different grades (Table 26) reveals a significant improvement in mean accuracy scores between first and second grade, but that beyond second grade there is no significant improvement in accuracy scores. Due to the fact that the largest differences in mean accuracy occurred between grades one and two, and also that there were only four subjects in first grade, analyses of variance for accuracy scores including subjects in grades two, four and six only (i.e. without grade one subjects) were performed. (See Table 27.) It is evident that, without the grade one subjects, the effect for grade is not significant for mean accuracy or for any individual condition.

Table 24

Mean Accuracy Scores for Grade and Condition – Group 3

	Condition				
Grade	HH	HV	VH	VV	
1	13.50	11.25	14.50	20.00	14.81
2	17.21	15.43	14.93	22.93	17.63
4	17.28	15.29	16.00	21.43	17.50
6	16.00	16.90	15.50	22.20	17.65
	16.42	15.39	15.27	22.07	

Table 25

Mean Accuracy Scores for Sex and Condition – Group 3

	Condition				
Sex	HH	HV	VH	VV	
Boy	15.67	14.50	14.58	21.33	16.52
Girl	16.87	15.78	15.61	21.26	17.38

Table 26

Analysis of Variance for Accuracy Scores -- Group 3

Condition	Factors and Pairwise Comparison Reaching Significance
Mean Accuracy (i.e. accuracy scores across conditions)	Grade ($p < .0002$) 1 vs. 2 ($p < .01$) 1 vs. 4 ($p < .01$) 1 vs. 6 ($p < .01$) 2 vs. 4 N.S. 2 vs. 6 N.S. 4 vs. 6 N.S.
Haptic - Haptic	Grade ($p < .015$) 1 vs. 2 ($p < .010$) 1 vs. 4 ($p < .01$) 1 vs. 6 ($p < .01$) 2 vs. 4 N. S. 2 vs. 6 ($p < .05$) 4 vs. 6 ($p < .05$)
Haptic - Visual	Grade ($p < .013$) 1 vs. 2 ($p < .01$) 1 vs. 4 ($p < .01$) 1 vs. 6 ($p < .01$) 2 vs. 4 N.S. 2 vs. 6 ($p < .05$) 4 vs. 6 ($p < .05$)
Visual - Haptic	-------------
Visual - Visual	-------------
Haptic - Haptic versus Haptic - Visual	Condition ($p < .000$)[a]

Table 26 (Cont'd)

Haptic - Haptic versus Visual - Haptic	Condition ($p < .023$)
Haptic - Haptic versus Visual - Visual	Condition ($p < .000$) Grade ($p < .005$)
Haptic - Visual versus Visual -Haptic	--------------
Haptic - Visual versus Visual - Visual	Condition ($p < .000$)
Visual - Haptic versus Visual - Visual	Condition ($p < .000$)

[a] Condition is a comparison of the conditions.

Table 27

Analysis of Variance for Accuracy Scores -- Group 3 (without Grade 1 subjects)

Condition	Factors and Pairwise Comparison Reaching Significance
Mean Accuracy (i.e. accuracy scores across conditions)	-------------
Haptic - Haptic	------------
Haptic - Visual	------------
Visual - Haptic	-----------
Visual - Visual	-----------
Haptic - Haptic versus Haptic - Visual	Condition ($p < .000$)[a]
Haptic - Haptic versus Visual - Haptic	Condition ($p < .023$)

Table 27 Cont'd

Haptic - Haptic versus Visual - Visual	Condition ($p < .000$)
Haptic - Visual versus Visual - Haptic	------------
Haptic - Visual versus Visual - Visual	Condition ($p < .000$)
Visual - Haptic versus Visual - Visual	Condition ($p < .000$) Sex ($p < .019$)

[a] Condition is a comparison of the conditions.

Analyses of variance were performed to test for significance of difference in accuracy scores of the different conditions at each grade level. Results indicate the following pattern:[26]

Grade two	VV>HH>HV=VH
Grade four	VV>HH=VH=HV (where accuracy scores on the HH condition were significantly higher than accuracy scores on the HV condition)
Grade six	VV>HV=HH=VH

26 These analyses of variance were pairwise comparisons, of the conditions, after splitting the subject population by grade. These analyses are presented in Tables 12 through 15 in Appendix N. Analysis of variance could not be performed comparing the accuracy of the four conditions for the grade one population, due to the small number of subjects at this grade level (too few degrees of freedom).

At each grade level (two, four, and six) accuracy scores were significantly higher for the VV condition than for any condition involving a haptic component. At grade two, accuracy scores were significantly higher on the HH condition than on the two inter-modal conditions and at grade four accuracy scores were significantly higher on the HH than the HV condition. At sixth grade level there was no significant difference between any of the conditions involving a haptic component.

Referring again to Table 26, the pairwise comparisons of conditions reveals that across grade levels, the pattern of accuracy in the different conditions is VV>HH>HV=VH, indicating: a) accuracy scores across all grade levels were higher for the VV condition than for any other condition, and b) accuracy scores were significantly higher for the HH condition than for the cross-modal conditions (VH and HV).

There were no sex differences in the accuracy scores of the Group 3 subject sample.

A comparison of the mean accuracy scores of the Group 3 and Group 1 subject samples (Table 28) indicates a significant difference between the mean accuracy scores of the samples, reflecting the superior overall accuracy scores of Group 1 compared to Group 3 (mean accuracy scores for Group 1 -- 18.28 and for Group 3 -- 17.29). Examination of the analyses of variance for the individual conditions reveals that Group 1 scored significantly higher accuracy scores on all four conditions than Group 3. (See Table 1 in Chapter V and Tables 24 and 28 in this chapter.)

There were no significant grade by population (Group 3 versus Group 1) or sex by population interactions for mean accuracy.

Table 28

Analysis of Variance for Accuracy Scores – Group 1 versus Group 3

Condition	Factors and Pairwise Comparisons Reaching Significance [a]
Mean Accuracy (i.e. accuracy scores across conditions)	Group 1/Group 3 ($p < .000$)
Haptic - Haptic	Group 1 / Group 3 ($p < .025$) Group 1/Group 3 x Grade ($p < .004$)
Haptic - Visual	Group 1/Group 3 ($p < .000$)
Visual - Haptic	Group 1/Group 3 ($p<.000$)
Visual - Visual	Group 1/ Group 3 ($p < .002$)

[a] Only the significant effects involving a comparison between the populations (i.e. Group 1 versus Group 3) are reported, as only these results are of interest in the present analysis..

Haptic Exploration Strategy Scores

Multivariate analyses of variance for exploration scores of haptic stimuli indicate no significant main effect for grade (Table 31), indicating no significant developmental improvements in exploration scores in this sample of poor readers.

No significant sex differences in exploration scores were evident.

Analyses of variance for the comparison of individual haptic stimuli (Table 31) in conjunction with Table 24 reveals:

- As in Group 1, exploration strategy scores were higher for the HHS than

Table 29

Mean Haptic Exploration Scores for Grade and Stimulus -- Group 3

	Condition						
Grade	HHS	HHC1	HHC2	HVS	VHC1	VHC2	
1	2.98	2.89	2.86	3.01	2.69	2.70	2.85
2	3.32	3.12	3.12	3.29	3.16	3.11	3.19
4	3.27	3.15	3.16	3.45	3.10	3.09	3.20
6	3.58	3.42	3.39	3.63	3.16	3.16	3.39
	3.35	3.19	3.18	3.40	3.09	3.07	

Table 30

Mean Haptic Exploration Scores for Sex and Stimulus -- Group 3

	Condition						
Sex	HHS	HHC1	HHC2	HVS	VHC1	VHC2	
Boy	3.59	3.44	3.33	3.67	3.49	3.38	10.45
Girl	3.59	3.42	3.34	3.66	3.50	3.39	10.45

Table 31

Analysis of Variance for Haptic Exploration Strategy Scores -- Group 3

Stimuli	Factors and Pairwise Comparison Reaching Significance
HHS, HHC1, HHC2,HVS, VHC1, VHC2	Stimuli ($p < .0001$)[a]
HHS versus HHC1 + HHC2	Stimuli ($p < .0001$)
HHS versus HHC1	Stimuli ($p < .0001$) Sex ($p < .035$)
HHS versus HHC2	Stimuli ($p < .0001$) Sex ($p < .035$)
HHS versus HVS	------------
HHC1 versus HHC2	------------
VHC1 versus VHC2	Stimuli ($p < .022$)
HHC1 + HHC2 versus VHC1 + VHC2	-------------
HHC1 versus VHC1	-------------
HHC2 versus VHC2	-------------
HHS versus VHC1 + VHC2	Stimuli ($p < .0001$)
HHS versus VHC1	Stimuli ($p < .0002$)
HHS versus VHC2	Stimuli ($p < .0001$)

Table 31 Cont'd

HVS versus VHC1 + VHC2	Stimuli ($p < .0001$) Sex ($p < .020$)
HVS versus VHC1	Stimuli ($p < .002$)
HVS versus VHC2	Stimuli ($p < .0001$)

[a] Stimuli is a comparison of the specific stimuli.

for HHC1 and HHC2, this difference being reflected in higher scores for the S (3.35) as opposed to C1 (3.19) and S as opposed to C2 (3.18).

- While exploration scores were higher for HVS (3.40) than HHS (3.35), this effect did not reach significance.
- As in Group 1, exploration scores were significantly higher for the VHC1 (3.09) than for VHC2 (3.07). However, in the HH condition the trend toward higher exploration scores for HHC1 (3.19) than HHC2 (3.18) failed to reach significance.
- A trend toward higher exploration scores for the HH comparison stimuli (HHC1 -- 3.19, HHC2 -- 3.18) compared to the exploration scores of the VH comparison stimuli (VHC1 -- 3.09, VHC2 -- 3.07) was evident in Group 3, but failed to reach significance ($p < .059$).
- As in Group 1, exploration scores were significantly higher for the HHS (3.35) than for either VHC1 (3.09) or VHC2 (3.07).
- As in Group 1, exploration scores were significantly higher for the HVS than for the VH comparison stimuli, reflected in higher scores for HVS (3.40) than for either VHC1 (3.09) or VHC2 (3.07).

A comparison of the mean exploration strategy scores (across all stimuli) for Group 3 and Group 1 (Table 32) indicates a significant difference in the exploration scores of the two samples, reflecting the higher scores of Group 1. The exploration scores of Group 1 were significantly higher for the following stimuli: HHS (Group 1 -- 3.57,

Table 32

Analysis of Variance for Haptic Exploration Strategy Scores -- Group 1 versus Group 3

Stimuli	Factors and Pairwise Comparisons Reaching Significance [a]
HHS, HHC1, HHC2, HVS, VHC1,VHC2	Group 1/Group 3 ($p < .0001$)
HHS	Group 1/Group 3 ($p < .0002$) Group 1/Group 3 x Sex ($p < .002$)
HHC1	Group 1/Group 3 ($p < .0002$) Group 1/Group 3 x Sex ($p < .013$)
HHC2	Group 1/Group 3 x Sex ($p < .010$)
HVS	Group 1/Group 3 ($p < .003$)
VHC1	Group 1/Group 3 ($p < .024$) Group 1/ Group 3 x Sex ($p < .046$)
VHC2	Group 1/Group 3 x Sex ($p < .042$)

[a] Only significant differences involving a comparison between the populations (i.e. Group 1 versus Group 3) are reported, as only these results are of interest in the present analysis.

Group 3 -- 3.35), HHC1 (Group 1 -- 3.28, Group 3 -- 3.19), HVS (Group 1 -- 3.55, Group 3 -- 3.40), VHC1 (Group 1-- 3.22, Group 3 -- 3.09).

No grade by population (Group 1 versus Group 3) or sex by population interactions are evident in mean haptic exploration scores.

Exploration Times

As evident from Tables 34 and 36, there was a significant difference in the exploration times for haptic and visual stimuli, exploration times being shorter for visual stimuli. Calculations based on Table 34 reveal that the mean exploration times for haptic and visual stimuli were 5.07 and 3.58 seconds respectively, a difference of 1.49 seconds.

Analysis of the exploration times for each condition (i.e. exploration time for S + C1 + C2 in each condition) indicates that, as in Group 1, exploration times were significantly shorter for the VV condition than for any other condition (HH condition --14.99, HV condition--14.07, VH condition--13.90, VV condition--9.03). (See Tables 33 and 36.) Similar to Group 1, no significant differences in exploration times for any of the

Table 33

Mean Exploration Time for Condition - - Group 3[a]

Condition			
HH	HV	VH	VV
14.99	14.07	13.90	9.03

[a] Note that exploration times were measured in 1/100th seconds.

Table 34

Mean Exploration Time for Stimulus and Grade -- Group 3

	Stimulus												
Grade	HHS	HHC1	HHC2	HVS	HVC1	HVC2	VHS	VHC1	VHC2	VVS	VVC1	VVC2	
1	4.03	3.25	2.90	4.69	3.90	3.69	4.45	3.63	3.61	3.30	3.10	2.85	3.66
2	7.78	4.85	3.86	6.81	4.46	3.54	5.83	5.18	4.04	4.06	3.13	3.12	4.72
4	5.67	3.80	3.38	6.42	3.98	3.01	4.00	4.12	3.63	2.63	2.36	2.44	3.79
6	7.06	4.87	4.39	6.95	4.16	3.13	4.83	5.22	4.65	3.28	2.40	2.40	4.45
	6.70	4.46	3.82	6.54	4.20	3.33	5.00	4.81	4.10	3.50	2.74	2.73	

Table 35

Mean Exploration Time for Stimulus and Grade -- Group 3

	Stimulus												
Grade	HHS	HHC1	HHC2	HVS	HVC1	HVC2	VHS	VHC1	VHC2	VVS	VVC1	VVC2	
Boy	5.05	4.14	7.18	4.41	3.48	3.48	5.04	4.88	4.09	3.64	2.86	2.79	4.63
Girl	4.48	3.16	5.37	3.83	3.06	3.06	4.98	4.64	4.06	3.30	2.58	2.66	3.79

Table 36

Analysis of Variance for Exploration Times -- Group 3

Stimuli	Factors and Pairwise Comparison Reaching Significance
HHS, HHC1, HHC2, HVS, VHC1, VHC2 versus HVC1, HVC2, VHS, VVS, VVC1, VVC2	Stimuli ($p < .0001$)[a] Grade ($p < .007$) Sex ($p < .009$)
HHS, HHC1, HHC2, HVS, VHC1, VHC2	Stimuli ($p < .0001$) Grade ($p < .049$) Sex ($p < .004$)
HVC1, HVC2, VHS, VVS, VVC1, VVC2	Stimuli ($p < .0001$)
HHS	Sex ($p < .002$)
HHC1	Sex ($p < .002$)
HHC2	Grade ($p < .041$) Sex ($p < .030$)
HVS	Sex ($p < .037$)
HVC1	------------
HVC2	Sex ($p < .021$)
VHS	-------------
VHC1	-------------
VHC2	-------------

Table 36 Cont'd

VVS	Grade ($p < .003$)
VVC1	Grade ($p < .041$)
VVC2	-------------
HHS + HHC1 + HHC2 versus HVS + HVC1 + HVC2	-------------
HHS + HHC1 + HHC2 versus VHS + VHC1 + VHC2	Sex ($p < .001$)
HHS + HHC1 + HHC2 versus VVS + VVC1 + VVC2	Stimuli ($p < .0001$) Grade ($p < .016$) Sex ($p < .001$)
HVS + HVC1 + HVC2 versus VHS + VHC1 + VHC2	-------------
HVS + HVC1 + HVC2 versus VVS + VVC1 + VVC2	Stimuli ($p < .0001$)
VHS + VHC1 + VHC2 versus VVS + VVC1 + VVC2	Stimuli ($p < .0001$)
HHS versus HHC1 + HHC2	Stimuli ($p < .0001$) Sex ($p < .008$)
HHS versus HHC1	Stimuli ($p < .0001$) Sex ($p < .008$)

Table 36 Cont'd

HHS versus HHC2	Stimuli ($p < .0001$) Sex ($p < .006$)
VVS versus VVC1 + VVC2	Stimuli ($p < .0001$)
VVS versus VVC1	Stimuli ($p < .0001$)
VVS versus VVC2	Stimuli ($p < .0001$)
HHS versus HVS	--------------
VHS versus VVS	Stimuli ($p < .0001$)
HHC1 versus HHC2	Stimuli ($p < .0001$) Sex ($p < .048$)
VHC1 versus VHC2	Stimuli ($p < .0002$)
HHC1 + HHC2 versus VHC1 + VHC2	Stimuli ($p < .044$)
HHC1 versus VHC1	Sex ($p < .042$)
HHC2 versus VHC2	Sex ($p < .043$)
HVC1 versus HVC2	Stimuli ($p < .0001$)
VVC1 versus VVC2	--------------
HVC1 + HVC2 versus VVC1 + VVC2	Stimuli ($p < .0001$)
HVC1 versus VVC1	Stimuli ($p < .0001$)
HVC2 versus VVC2	Stimuli ($p < .0001$) Grade ($p < .042$)

Table 36 Cont'd

HHS versus VHC1 + VHC2	Stimuli ($p < .0001$) Sex ($p < .0003$)
HHS versus VHC1	Stimuli ($p < .0001$) Sex ($p < .004$)
HHS versus VHC2	Stimuli ($p < .0001$) Sex ($p < .002$)
HVS versus VHC1 + VHC2	Stimuli ($p < .0001$)
HVS versus VHC1	Stimuli ($p < .0001$)
HVS versus VHC2	Stimuli ($p < .0001$) Sex ($p < .043$)
VHS versus VVC1 + VVC2	Stimuli ($p < .0001$)
VHS versus VVC1	Stimuli ($p < .0001$)
VHS versus VVC2	Stimuli ($p < .0001$) Sex ($p < .032$)

[a] Stimuli is the difference between specific stimuli.

conditions involving a haptic component (HH, HV, VH) were apparent.

Significant main effects for grade and sex are evident in exploration times of the haptic stimuli, but not of the visual stimuli.

Examination of the analyses of variance for the comparison of exploration times of individual stimuli (Table 36) in conjunction with Table 34 reveals:

• As in Group 1, there was a significant difference in the exploration times used for the standard as opposed to the comparison stimuli. This was reflected in significantly longer exploration times for HHS (6.70) than for either HHC1 (4.46) or HHC2 (3.82). As in Group 1, a similar pattern was found for the VV condition, exploration times being longer for VVS (3.50) than for either VVC1 (2.74) or VVC2 (2.73).

• The pattern of shorter exploration times for HHS than for HVS that was significant in Group 1 was not evident in Group 3, a nonsignificant trend toward longer exploration times for HHS (6.70) than for HVS (6.54) being evident in this sample.

• As in Group 1, there was a significant difference in the exploration times for VHS (5.00) and VVS (3.50), exploration times being shorter for VVS.

• As in Group 1, the C1 stimulus was explored significantly longer than the C2 stimulus in both the HH and VH conditions (HHC1 - 4.46, HHC2 - 3.82, VHC1 -- 4.81, VHC2 -- 4.10).

• As in Group 1, there was a significant difference in the exploration times of the comparison stimuli in the HH condition (HHC1 -- 4.46, HHC2 -- 3.82) and the comparison stimuli in the VH condition (VHC1 -- 4.81, VHC2 -- 4.10), exploration times being shorter for the HH comparison stimuli.

• Contrary to Group 1, in the HV condition, the C1 stimulus (4.20) was explored significantly longer than the C2 stimulus (3.33); however there were not significant differences in the exploration times for VVC1 (2.74) and VVC2 (2.73).

• As in Group 1, there was a significant difference in the exploration times of the comparison stimuli in the HV condition (HVC1 -- 4.20, HVC2 -- 3.33) and the comparison stimuli in the VV condition (VVC1 -- 2.74, VVC2 -- 2.73), exploration times being shorter for the comparison stimuli in the VV condition.

• As in Group 1, there was a significant difference in the exploration times of the HHS and the two comparison stimuli in the VH condition, this difference being reflected in significantly longer exploration times for the HHS (6.70) than for either VHC1 (4.81) or VHC2 (4.10).

• As in Group 1, there was a significant difference in the exploration times of the HVS and the two comparison stimuli in the VH condition, this difference being reflected in significantly longer exploration times for the HVS (6.54) than for either VHC1 (4.81) or VHC2 (4.10).

• As in Group 1, there was a significant difference in the exploration times of VHS and the the comparison stimuli in the VV condition; this difference being reflected in significantly longer exploration times for the VHS (5.00) than for either VVC1 (2.74) or VVC2 (2.73).

There were no significant differences in the exploration times of the Group 1 subject sample and the Group 3 subject sample for either the haptic or visual stimuli (Table 37). However, there was a significant population (Group 1 versus Group 3) by sex interaction for exploration times of the haptic stimuli.

Table 37

Analysis of Variance for Exploration Times -- Group 1 versus Group 3

Stimuli	Factors and Pairwise Comparisons Reaching Significance [a]
HHS, HHC1, HHC2,HVS, VHC1, VHC2 versus HVC1, HVC2, VHS, VVS, VVC1, VVC2	Group 1/Group 3 x Sex ($p < .007$)
HHS, HHC1, HHC2, HVS, VHC1, VHC2	Group 1/Group 3 x Sex ($p < .011$)
HVC1, HVC2, VHS, VVS, VVC1, VVC2	---------
HHS	Group 1/Group 3 x Sex ($p < .000$)
HHC1	Group 1/Group 3 x Sex ($p < .000$)
HHC2	Group 1/Group 3 x Sex ($p < .039$)
HVS	--------------
HVC1	--------------
HVC2	-------------
VHS	-------------
VHC1	------------
VHC2	-------------

Table 37 Cont'd

VVS	Group 1/Group 3 x Grade ($p < .027$)
VVC1	Group 1/ Group 3 ($p < .014$) Group 1/Group 3 x Grade ($p < .050$)
VVC2	-------------

[a] Only significant effects involving a comparison between the populations (i.e. Group 1 versus Group 3) are reported, as only these results are of interest in the present anlyses.

Discussion

Accuracy

While a significant effect for grade on mean accuracy (i.e. accuracy across all conditions) was evident in this group of poor readers, the main "jump" (improvement) in accuracy scores for each condition occurred between grades one and two, a finding difficult to explain due to the small number of subjects in grade one of this sample (4 subjects). Grade was not a significant effect in any condition when the grade one subjects were eliminated from the analyses. Accuracy scores on the individual conditions do not show the patterns of steady improvement evident in Group 1. In each condition, accuracy scores increased between grades one and two, as mentioned earlier, but beyond grade two, accuracy scores on the different conditions were unstable. For the HH condition, accuracy scores remain stable between second grade (17.21) and fourth grade (17.28), and then fall at sixth grade level (16.00). In the HV condition, accuracy scores dip slightly between second grade (15.43) and fourth grade (15.29) and are higher at sixth grade (16.90). The performance of subjects on the VH condition increased between second (14.93) and fourth grades (16.00) and then dipped slightly at sixth grade (15.50). On the VV condition, accuracy is highest at second grade level (22.93), dipping at fourth grade (21.43), and then rising at sixth grade (22.20).

By sixth grade, accuracy scores are fairly close to ceiling on the VV condition (22.20) . Accuracy scores on the three conditions involving a haptic component are much lower than the scores of Group 1 and are far below ceiling level (HH=16.00, HV=16.90 and VH=15.50).

As in Group 1, accuracy scores were higher on the VV condition than on any other condition. No consistent pattern of relative accuracy on the other conditions is apparent. At the second grade level, accuracy scores are significantly higher on the HH condition than on the two inter-modal conditions; at fourth grade level, there is no significant difference in accuracy scores of the two inter-modal conditions, but accuracy scores were significantly higher on the HH condition than on the HV condition; at sixth grade level there is no significant difference between accuracy scores on any of the conditions involving a haptic component.

Significant differences in the mean accuracy scores of the Group 1 and Group 3 subject samples reflect the superior performance of Group 1. Accuracy scores of Group 1 were significantly higher than scores of Group 3 on every condition. The "gap" in the accuracy scores of Group 3 and Group 1 is most marked among first and sixth graders. Comparing the scores of the sixth graders in the two samples, the following gaps in scores between the two population samples are evident:

	Group 1	Group 3	Difference in Scores
HH	18.59	16.00	2.59
HV	18.38	16.90	1.74
VH	18.58	15.50	3.06
VV	23.50	22.20	1.30

The gap between the first grade subjects in the two populations samples is difficult to interpret. It is possible that subjects who were three-quarters of the way through first grade and did not possess even pre-primer level reading skills were more severely "disabled" readers than the subjects in the other grades of this sample, and hence had extreme difficulty on these tasks. Again, it must be kept in mind that the small number of subjects at this grade level in Group 3 (n=4) weakens the validity of any interpretations or conclusions based on this sample. The gap between the population samples at sixth grade makes it seem unlikely that Group 3 will "catch up" to the performance of average readers on these tasks. It is further interesting to note, that at sixth grade level, the largest gap between the two populations is on the HH and VH conditions, the two conditions relying most heavily on the haptic modality.

There are then, three patterns evident in the accuracy scores of this subject sample of poor readers compared to their able reading peers: a) overall depressed accuracy on all conditions among Group 3; b) a "gap" in the accuracy scores of the two subject samples that seems to be widening rather than narrowing at sixth grade; and c) by sixth grade level, Group 3 experienced greatest relative difficulty on the two conditions relying most extensively on processing of haptic information (HH and VH). These patterns indicate a general problem in sensory processing among this population of poor readers (rather than a specific inter-modality deficit), and suggests also that older reading disabled children in particular may have specific problems processing information from the haptic modality.

Haptic Exploration Scores

While a trend toward developmental improvement in haptic exploration strategy scores is evident in Group 3, this trend is much less even and less consistent than that found in Group 1, and the effect for grade did not reach significance. Looking at the "patterns" of exploration strategy scores for different stimuli, it is evident that, like Group 1, Group 3 had higher scores for standard stimuli than for comparison stimuli. Exploration scores were higher for VHC1 than VHC2, although this pattern did not hold true for the HH comparison stimuli. Haptic exploration scores of Group 1 were significantly higher than those of Group 3 for every haptic stimulus except the HHC2 and VHC2.

Exploration Times

There is a significant effect for grade for the exploration times of the haptic stimuli. However, examination of the mean exploration times indicates that while differences in exploration times for the individual haptic stimuli are evident, no consistent trend toward longer or shorter exploration times with increasing grade level is obvious, exploration times jumping between grades one and two, then dipping at the grade four level and being longer again at the grade six level.

Examination of the exploration times of individual stimuli reveal the same patterns as found in Group 1, revealing that, like Group 1, Group 3: (a) used longer exploration times for S stimuli than comparison stimuli;

(b) used longer exploration times for C1 than C2 stimuli (presented to the haptic modality) (c) generally used longer exploration times for stimuli in cross-modal conditions than for "equivalent" stimuli in intra-modal conditions (the exception being for the HHS and HVS, exploration times being longer for the former). It is interesting to note that there were no significant differences in exploration times of Group 1 and Group 3 for either the haptic or visual stimuli.

Summary

In summary, it is evident that:

1. Disabled readers, such as the sample in this population, seem to have difficulty relative to able readers on tasks of intra- *and* inter-modal processing.

2. Whereas the able readers showed consistent developmental improvement on all conditions, no significant developmental improvements in accuracy scores were evident in the disabled readers between grades two and six, resulting in a widening gap between accuracy scores of the two groups.

3. Subjects at the highest grade level sampled (grade six) had greatest relative difficulty compared to Group 1 on the two tasks relying most heavily on the haptic modality (HH and VH).

4. While the disabled readers had lower haptic exploration scores than the able readers and did not show any significant pattern of developmental improvement in exploration scores, they showed similar patterns of haptic exploration strategy scores for individual stimuli as used by Group 1.

5. In terms of exploration times, there were no significant differences between Group 3 and Group 1, and the disabled readers generally relied on

the same patterns of exploration times for individual stimuli as the able readers.

These findings are particularly pertinent in relation to the two main purposes of this study. The first major goal was to investigate the validity of the inter-sensory deficit theory of reading disablities. This theory is not supported by the results of this study. It appears that the reading disabled children included in the present study have a general problem or "deficit" in sensory processing, rather than a specific inter-sensory processing deficit, and that at older ages (sixth grade) a specific problem in processing information from the haptic modality seems likely.

The second major goal of Study 3 was to analyze the "task strategies" (in terms of exploration strategies used for individual haptic stimuli, and exploration times used for individual haptic and visual stimuli) used by the poor readers in comparison to those used by the able readers. It has been suggested by a number of researchers that children with learning problems often do not apply the efficient task strategies employed by their peers to the task at hand. This hypothesis is only partially confirmed by the present research. The poor readers generally employed lower level (less sophisticated) haptic exploration strategy scores than the able readers. However, in other aspects of the task, they did apply the same task strategies. In terms of haptic exploration strategies, the disabled readers applied essentially the same patterns of strategies for individual haptic stimuli as the good readers; in terms of exploration times, they used essentially the same time to explore individual haptic and visual stimuli, and the same patterns of exploration times for individual stimuli, as the able readers.

CHAPTER VIII

GENERAL DISCUSSION AND CONCLUSION

Historically, touch was considered a very important sense, although it has received comparatively little research attention in recent years. Interest has shifted to the more efficient and more acute sense, that of vision. Nevertheless, touch has retained an important place in aspects of both early childhood training and special education -- incorporating the efforts of such educational reformers as Froebel and Montessori, and reformers cum practitioners as Seguin and Fernald.

Work on haptic perception in the last forty years, dating from the efforts of Piaget and Inhelder, and being triggered to some extent by the research of Birch et al. has focused on its relationship with visual perception -- i.e. the relative efficiency and accuracy of the two modalities, relative developmental patterns in the two modalities, and ability to process, integrate and organize information from the haptic and visual modalities (inter-modal integration).

The inter-sensory deficit theory, originally proposed by Birch (1962), has been of great interest to educators. This theory postulates that children with reading problems have difficulty integrating information from different sensory modalities. It has held great intuitive appeal since the process of reading involves the ability to transform visual patterns of perception into auditory patterns of response.

Review of the relevant research literature led to the definition of a number of problems for investigation, some of which are of general interest involving intra- and inter-modal haptic and visual processing in able learners, and others of a more educational importance, relating to inter-modal processing in poor readers. The main investigation consisted of three studies.

The main purposes of Study 1 were to examine: (a) accuracy scores on the four matching tasks, (b) the strategies used by subjects to explore individual stimuli presented to the haptic modality, and (c) the time taken to explore individual stimuli presented to the haptic and visual modalities. These measures (accuracy, haptic exploration strategies, and exploration times) provided more thorough and detailed information about intra- and inter-modal haptic and visual processing than had been reported by other researchers in the field, making it possible to analyze relative performance on the four tasks, and the "techniques" (haptic exploration strategies and exploration times) children applied when presented with these tasks. Study 1 further provided a "baseline" against which the data collected in Study 2 and Study 3 were compared. Study 2 differed from Study 1 in terms of the experimental procedure. Study 3 differed from Study 1 in terms of the definition of the population.

Study 2 involved imposition of fixed exploration times for examination of individual stimuli, exploration times for haptic stimuli being substantially longer than the exploration times allowed for visual stimuli and also longer than the times spontaneously used to explore haptic stimuli. The main purpose of Study 2 was to determine whether imposition of fixed exploration times for examination of individual stimuli resulted in any improvement in accuracy scores on the conditions involving a haptic component, and/or on the strategies used to explore haptic stimuli.

The main purpose of Study 3 was to examine how children with reading problems compare to their able learning peers in terms of performance on tasks of intra- and inter-modal processing, in terms of: (a) accuracy scores, (b) haptic exploration scores, and (c) exploration times of individual haptic and visual stimuli. Once again, data from this study were only meaningful when compared to the data obtained for Study 1.

The present research sought to apply a more refined experimental design and more sophisticated statistical analyses than had been used in previous research investigating intra- and inter-sensory processing in "normal" and "disabled" readers. In terms of experimental design, it was attempted to: (a) use a sufficiently large number of subjects in each population sample involved in the research; (b) sample the population spanning the elementary school grades; (c) use a repeated measures design, making it possible to measure performance of the same subjects on tasks of intra- and inter-modal haptic and visual processing; (d) apply a rigorous quantitative and qualitative method of recording the strategies used to explore each stimulus presented for haptic examination; and (e) develop a rigorous and accurate method of recording the time taken to explore each haptic and visual stimulus.

The most important and interesting results of the research will be briefly discussed, along with indications for future research. Following discussion of the main results, a few more general issues, which do not relate specifically to the hypotheses presented for the present research, will be discussed.

A general finding that should not be overlooked is the confirmation by the present research that information gathered by hand is less stable than information gathered by eye. At every grade level sampled, subjects showed significantly higher accuracy on the intra-modal visual condition than on any of the conditions involving a haptic component. This pattern was evident in samples of able readers (Study 1) and poor readers (Study 3). Even under conditions which attempted to equate the amount of information acquired by the two modalities (Study 2), by requiring subjects to explore haptic stimuli for a much longer time than they explored visual stimuli, and for a longer time than they would spontaneously explore haptic stimuli, information gathered by hand was less effective in a match-to-sample task, either because the information was not as effectively abstracted from the haptic stimulus and/or because memory for information acquired haptically was less well retained. These results add strength to the growing evidence that the empiricist assumption that visual perception is based on the prior development of the haptic system is incorrect.

Turning to look at the individual studies included in the research, it is perhaps useful to consider accuracy scores and the "task strategies" (i.e. haptic exploration scores and exploration times) as two different factors. Study 1 will be discussed first, as the results of this study were interesting both in terms of relating to findings and hypotheses reported by other researchers in the area, and also in terms of providing a kind of "baseline" against which the results of Study 2 and Study 3 were compared.

While Study 1 found evidence of developmental improvement in all conditions, absolute increases in each condition between grades one and six are small (the largest improvement being in the VH condition, of 2.91 between grades one and six). At the sixth grade, accuracy scores were still well below ceiling level on all conditions involving a haptic component; while accuracy scores on the intra-modal visual condition were close to ceiling at sixth grade. Two points are noteworthy in this regard:

1. It is fairly widely accepted (e.g. Abravanel, 1973; Goodnow, 1971a) that effective haptic matching of complex shapes is difficult for young children, the age at which children can perform matches based on haptic information being about five and a half. The present research indicates that on a successive presentation match-to-sample task with two comparison stimuli, the age at which subjects can successfully perform matches based on haptic information is slightly higher. Most of the kindergarten children involved in the pilot study (average age 5 years, 10 months) found an intra-modal matching task involving successive presentation of a standard and two comparison stimuli too difficult. By contrast, the grade one subjects in Study 1 (average age 6 years, 8 months), performed above chance level on all conditions involving a haptic component.

2. A number of researchers have suggested that visual sensitivity has reached its maximum by about five years of age. For example, Butter and Zung (1970) concluded that visual performance on matching tasks had stabilized by five and a half years of age; Gliner, Pick, Pick and Hales (1969) found that visual sensitivity had reached its maximum by five years of age, and Goodnow (1971a) reported that children were capable of fairly accurate (90%) visual matching by the age of 5;0. Study 1 found a slightly lower level of accuracy on an intra-modal visual task (87%) at 6 years, 8 months than the level suggested by Goodnow (1971a); accuracy on the visual matching task being close to ceiling level (23.50, or 98%) at sixth grade level. The poorer performance of subjects at the lowest age level in this research on tasks of intra-modal visual matching compared to the findings of other studies is, once again, probably attributable to specific characteristics of the tasks administered (successive presentation match-

to-sample , with two comparison stimuli). Goodnow's (1971a) research, by comparison, used a matching task which involved inspecting five Greek and Russian letters, one at a time, either haptically or visually, and then identifying the letters inspected from a set of ten letters.

It is perhaps worthwhile noting that while there were no significant differences in the accuracy scores on the three conditions involving a haptic component at any of the grade levels sampled, a trend toward higher accuracy scores on the VH condition than the HV condition at all grade levels is evident. This non-significant trend indicates that the findings reported by a number of other researchers (e.g. Derevensky, 1976, Goodnow 1971c, Jones, 1981) that cross-modal matches starting from a haptic standard are more difficult than cross-modal matches starting from a visual standard for younger age groups (probably because an HV matching task requires examining the standard stimulus in the weaker modality) is not robust in this population sample.

Imposing exploration times that were substantially longer for haptic stimuli than visual stimuli (Study 2) did result in higher accuracy scores than were evident under conditions of "free" exploration times (Study 1), but curiously enough not on the conditions that relied most heavily on haptic information (HH and VH). However, examination of the accuracy scores at each grade level indicates that at sixth grade level, the largest gap between subjects in Study 1 (free exploration times) and subjects in Study 2 (fixed exploration times) in accuracy scores is on the two inter-modal conditions (HV and VH). It therefore seems that, at the oldest age level sampled in the present research, longer exploration of haptic stimuli did result in higher accuracy scores on conditions relying on one or two haptic stimuli; however the extra haptic information (or better memory for information) derived from the increased exploration times was not sufficient to improve performance on a task which involved haptic exploration of all three stimuli (HH condition). Further research including older subjects would be required to determine whether this trend is in fact stable, and whether the increased exploration times for haptic stimuli would result in improved accuracy scores on an intra-modal haptic task at higher grade levels.

While a number of researchers have provided descriptive information about the haptic exploration strategies used by children of various ages (e.g. Abravanel, 1968; Davidson, 1972; Kleinman, 1979; Locher, 1982; Piaget and Inhelder, 1948, 1956; Vliestra, 1980; Zaporozhets, 1965, 1969), research documenting haptic strategies, as a score, for individual haptic stimuli is lacking, particularly over the age range included in this research. Examination of the haptic exploration strategy scores of the subjects in Study 1 reveals a consistent and significant trend toward developmental improvements in haptic exploration scores for each haptic stimulus, confirming the results of previous research which has documented developmental trends toward use of more comprehensive or thorough haptic exploration strategies. While subjects in grades one and two tended to use strategies at level 2 (minimal, global and haphazard explorations of the object) and level 3 (active manipulation of the objects with incomplete motions), subjects at fourth and sixth grade levels showed more general use of stategies at level 3 and level 4 (active acquaintance and manipulation). However, increases in haptic exploration scores were small, the mean exploration score being 3.15 at first grade level, and 3.54 at sixth grade level, and examination of the scores indicates that even at sixth grade level, there is no evidence of prepondent use of level 4 strategies. While there was a significant difference in the haptic exploration strategy scores of subjects in Study 2 as compared to the scores of subjects in Study 1, reflecting the use of more sophisticated or thorough strategies under experimental conditions of longer exploration times for haptic stimuli, the absolute differences in the haptic exploration scores of the two subject samples is small, the mean exploration scores being 3.34 for subjects in Study 1 and 3.49 for subjects in Study 2. Again, research including older subjects would be necessary to determine whether subjects above the age of twelve years engage in more thorough haptic exploration (as reflected in higher haptic exploration scores) and whether the gap between haptic exploration strategy scores under conditions of fixed exploration times and free exploration times widens in an older age group.

The most interesting findings in terms of haptic exploration scores concern the patterns of scores for the different individual stimuli, revealing that under conditions of free or fixed exploration times, subjects explored a standard stimulus more thoroughly than comparison stimuli. This pattern confirms the pattern reported by Derevensky (1976) and Petrushka (1978) for a match-to-sample task, and suggests that subjects examine the standard stimulus very thoroughly, and then examine the comparison stimuli looking for "critical features" which either match the standard stimulus or distinguish the comparison stimulus from the standard. For instance, a subject at sixth grade level might engage in active acquaintance and manipulation of all the features of the standard stimulus (level 4), and then actively search the comparson stimuli for significant cues (level 3 exploration) that would either match the standard, or distinguish it as different from the standard. Looking at the developmental improvements in haptic exploration scores for individual stimuli, it is evident that, in Study 1, there is a greater increase in haptic exploration scores between grades one and six for standard stimuli (HHS and HVS) than for comparison stimuli (HHC1, HHC2, VHC1, VHC2), indicating that this "technique" of exploring a standard stimulus more thoroughly than comparison stimuli was stronger among the older age groups sampled. This pattern was not as strong in Study 2.

It was not surprising to find that exploration times were longer for haptic than for visual stimuli under conditions of free exploration times (Study 1), confirming the relative efficiency of the visual system in terms of scanning and any "rehearsal" techniques that may be spontaneously used by subjects as memory aids on a match-to-sample task.

The developmental trend evident in Study 1, of increasing exploration times for haptic stimuli, is interesting. The "serial processing" required by haptic exploration is obviously slower than visual scanning, and, as Butter and Bjorklund (1976) suggest, probably imposes constraints on the subject's memory. With increasing age, subjects spontaneously relied on both more thorough exploration strategies for examination of haptic stimuli and use of longer exploration times, both these techniques probably being effective methods of obtaining "more" information about haptic stimuli, or information more likely to be retained. The fact that parallel trends were found for exploration times of individual stimuli as for haptic exploration strategy scores (longer exploration of standard than of comparison stimuli) indicates more thorough examination of standard than comparison stimuli in the visual as well as the haptic modality -- through use of longer exploration times.

The other finding of particular interest in terms of exploration times of subjects in Study 1, is the use of longer exploration times for individual stimuli when an inter-modal match was required than when an intra-modal match was required, indicating that if the subject knew that a "switch" in modalities was required, he/she explored each stimulus longer. However, it is not clear whether these longer exploration times for stimuli in inter-modal conditions reflect extra time taken by the subject to "transform" information to the other modality, or whether subjects examined stimuli on inter-modal tasks longer for some other reason, such as to gather "more" information about the stimulus, or to facilitate memory for the individual stimuli. The latter hypothesis appears more likely, as both standard and comparison stimuli were explored longer in cross-modal tasks. If subjects were involved in a translation of information, as suggested by Ittyerah and Broota (1983), it would be expected that this process would be reflected in longer exploration times of either the standard or the comparison stimuli (whichever was being "translated"), but not both.

In terms of the population of poor readers (Study 3), there are two major findings concerning accuracy scores which are of particular interest. Firstly, the finding that this population of poor readers had difficulty relative to able readers on tasks of intra- and inter-sensory processing would seem to negate the inter-sensory deficit theory proposed by Birch (1962) and others (e.g. Beery, 1967; Birch and Belmont, 1964; Hatchette and Evans, 1983; Kahn and Birch, 1968; Muehl and Kremenak, 1966; Rae, 1977; Sterritt and Rudnick, 1966). The results of the present research rather indicate that this particular sample of children with reading problems experienced difficulty on tasks of intra- and inter-sensory haptic and visual processing due to some other factor -- indicating either a problem processing information from the haptic and visual modalities per se (intra-modal processing), or due to some more general deficit, as suggested by Bryden (1972). A number of studies which used auditory and visual tasks (e.g. Bryden, 1972; Vande Voort and Senf, 1973; Vande Voort, Senf and Benton, 1972; Zendel and Pihl, 1983) found that poor readers had difficulty on intra-modal and cross-modal auditory and visual processing compared to their able reading counterparts. The results of the present research suggest that this phenomenon is more general, applying to the haptic and visual modalities as well, and lends support to a general perceptual deficit theory. It is perhaps worthwhile reflecting on the fact that the poor readers were deficient relative to their able reading school mates even on the intra-modal visual condition -- a task relying exclusively on information from the relatively efficient visual modality, and not requiring any "switch" between modalities.

A second finding relating to the accuracy scores of the poor readers is their failure to show the clear pattern of developmental improvement on tasks of intra- and inter-modal processing that is so clearly evident in the population of able readers. This lack of developmental improvement in accuracy scores resulted in a widening gap between the able readers and the poor readers at the higher grade levels. While it is not possible, on the basis of this research, to determine whether this pattern would be sustained at higher age levels, the fact that the gap between the two populations is wider at sixth grade level than at second and fourth grade levels (in other words, the disabled readers show no indication of "catching up") would seem to indicate support for a "deficit" model (e.g. Benton, 1975; Geschwind, 1968; Spreen, 1976) rather than a "developmental delay" model (e.g. Satz and Sparrow, 1970; Satz and Van Nostrand, 1973).

Satz and his colleagues specifically hypothesized that disabled readers have a lag in the maturation of the left hemisphere, affecting skills in primary ascendancy at a given age, the pattern of disorders changing with age. According to this theory, younger disabled readers should be more delayed in skills which develop ontogenetically earlier (visual-motor and cross-modal sensory integration), wheras older disabled children would show delays in skills which develop at a slower rate during childhood (conceptual-linguistic skills). The present research finds disabled readers weak in intra- and inter-sensory processing, and finds no indications that the disabled readers are "catching up" to their able learning age mates at sixth grade level. Once again, further research, including larger samples of reading disabled children, and extending to higher ages, would be necessary to determine whether, in fact, poor readers do catch up to their able learning peers on these tasks. As Wong (1979) has pointed out, the weakness in the theory proposed by Satz and his colleagues lies in the interpretation of the age-dependent relationships (i.e. the developmental factors). More specifically, it is difficult to procure data making it possible to judge the appropriateness of the age-dependent relationships in a "deficit" or "difference" perspective. It must be considered, also, that one of the major problems in this area of research is the identification of, definition of, and access to, a sufficiently large disabled population.

A major purpose of the present research was to attempt to determine whether the task strategies used by poor readers (i.e. the techniques they used to approach the specific tasks) differ from the task strategies used by able readers, both in terms of the ways subjects explored the individual haptic stimuli, as well as the time taken to explore the individual haptic and visual stimuli. In terms of haptic exploration strategy scores, the results point to two interesting patterns for the poor readers. The fact that their exploration strategy scores are lower than the scores of able readers indicates that this sample of poor readers was probably not abstracting as much information about the individual haptic stimuli as were the able readers, which likely put them at a distinct disadvantage in terms of being able to make a correct choice on the matching tasks involving a haptic component. However, the poor readers used some of the "patterns" of haptic exploration for individual stimuli (for instance, exploring a haptic standard more thoroughly than haptic comparison stimuli). Moreover, they showed the same patterns as evident in the subject sample in Study 1, of greater increase in haptic exploration scores between grades one and six for standard stimuli (HHS and HVS) than for comparison stimuli (HHC1, HHC2, VHC1, VHC2), indicating that older subjects in this reading disabled population relied more strongly on this technique of exploring a standard stimulus more thoroughly than comparison stimuli than did younger subjects. In other words, the sample of poor readers showed a similar "approach" in terms of exploration of the individual haptic stimuli, although generally exploring each stimulus presented to the haptic modality less thoroughly. The finding that the disabled readers failed to show the patterns of developmental improvement in haptic exploration scores that were so clearly evident in the population of able readers seems, once again, to throw doubt on the possiblity that these readers will "catch up" to their able reading counterparts on this skill.

While it might have been expected that the poor readers' lower haptic exploration scores would be mirrored by lower exploration times for haptic stimuli, this was not the case. There were no significant differences between the able and poor readers in exploration times for either the haptic or the visual stimuli. Moreover, the patterns of exploration times for individual stimuli were almost identical in the two populations, indicating that the poor readers in Study 3 showed a similar "approach" to their normal reading counterparts, both in terms of exploration strategies used for different haptic stimuli, and in the time taken to explore the different haptic and visual stimuli.

Turning to more general issues, a significant effect for order was evident in a number of places in the analyses. Order was included as a factor in the analyses of variance, not because it related in any way to the specific hypotheses for the research, but rather because if the order of presentation of conditions had a strong effect on any of the dependent variables, this effect should be noted. Order of presentation of conditions did have a significant effect on specific dependent variables, particularly on accuracy scores and exploration times in Study 1, and on haptic exploration scores in Study 2. These order effects were unexpected, as both Derevensky (1976) and Petrushka (1978) reported no significant differences resulting from a partially randomized order of presentation of conditions. In the present research, the inclusion of an intra-modal visual condition (not used by Derevensky and Petrushka) may have partially contributed to the order effects that appeared. It is also to be noted that this effect (for order of presentation of conditions) may be a problem inherent in a repeated measures design for research of this nature. It must also be considered that these effects for order may have masked other more general trends. Any future research in this area should consider this issue carefully.

Prevous research investigating intra-modal and cross-modal haptic and visual processing in "normal" populations is fairly consistent in terms of reporting no significant sex differences. Therefore, the fact that no significant sex differences were evident in studies 1 and 2 confirms previous research findings. A number of the research studies investigating intra- and inter-modal processing in reading disabled populations restricted their population samples to boys (e.g. Ford, 1967, Kahn, 1965, Katz and Deutsch, 1963, Lawton and Seim, 1973; Vande Voort and Senf, 1973, Vande Voort, Senf and Benton, 1982), probably due in part to the higher incidence of boys in such a population. The fact that no sex differences in any of the measures analyzed in the research were evident in the subject sample of poor readers suggests that while sex differences occur in the incidence of reading problems, that within a strictly defined population of reading disabled children, no sex differences in intra- and inter-modal haptic and visual processing are evident. However, the fact that the population of disabled readers included so few girls precludes any firm conclusions.

A most interesting avenue for further research would be investigation in a more thorough manner of the intra- and inter-sensory processing skills of reading disabled children. Such research should definitely include a larger subject sample of disabled readers than the sample included in the present research, and should extend the subject sample to include older subjects. In this case, it would also be necessary to extend the age sample of "able readers" to include subjects at higher grades, in order to determine whether the trends evident at the sixth grade level of the present research (Study 1) were in fact maintained at older ages, and to make comparison of the disabled readers to their peers of the same chronological age possible. Such a research design would make it possible to assess possible sensory processing problems in reading disabled children more thoroughly, and also to assess more thoroughly the validity of a developmental delay theory in relation to sensory processing. Inclusion of older subjects in the reading disabled and "able reading" control samples would make it possible to determine whether the gap evident between the able and disabled readers in the present research remains stable, or alternatively widens or closes at higher grade levels.

An alternate approach that would provide similar information would be a longitudinal study -- identifying a population of disabled readers spanning the elementary school grades, and monitoring both their reading performance and their performance on intra- and inter-modal haptic and visual matching tasks at specified intervals. Such an approach, while much more difficult to implement, would make it possible to gather other types of information, such as differences within the population which might develop over the specified age range i.e. whether the reading disabled group is fairly homogeneous, or whether different "subgroups" are evident within the population. A longitudinal approach would enable consideration of the following research questions:

1. Do some poor readers "outgrow" their reading problem. In this case, do they also outgrow problems (relative to their able-reading peers) of intra- and inter-modal processing?

2. Is it possible to identify, on the basis of their performance on sensory processing tasks, which children will outgrow a reading problem?

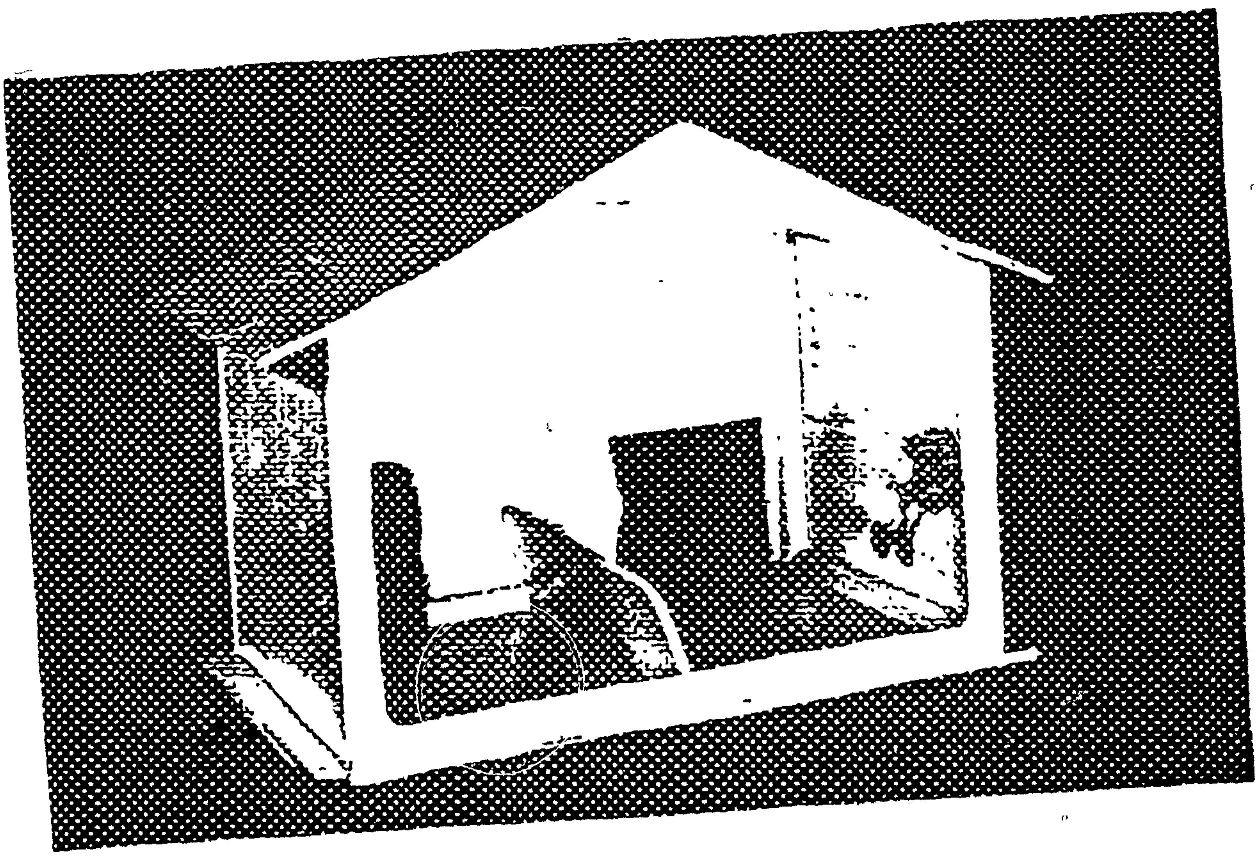
3. If it is found that some children outgrow both the reading problem and the sensory processing problem, would training on such tasks improve reading ability?

APPENDICES

Appendix A

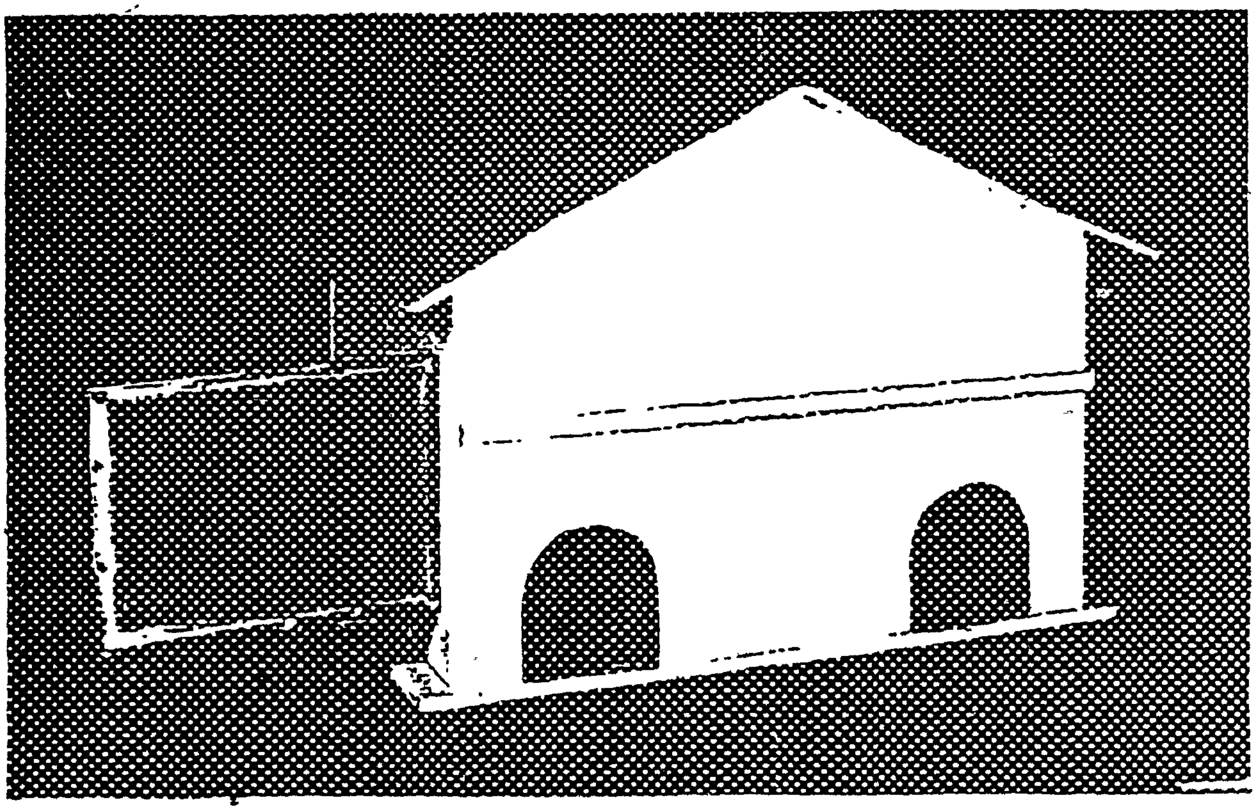
Haptic Perception Box

The haptic perception box was constructed of plywood and painted light blue. The depth of the apparatus was 31 cm., the width 47 cm., and the height at its maximum point, 40 cm. On the front (child's side) of the box there were two openings, each 10 cm. in diameter and 12 cm. in height. Two pieces of blue felt material with a slit up the centre covered the openings and allowed easy positioning of the child's hands while restricting any visual information about the tactual stimuli.



Rear View

Appendix A Cont'd



Front View

Appendix B

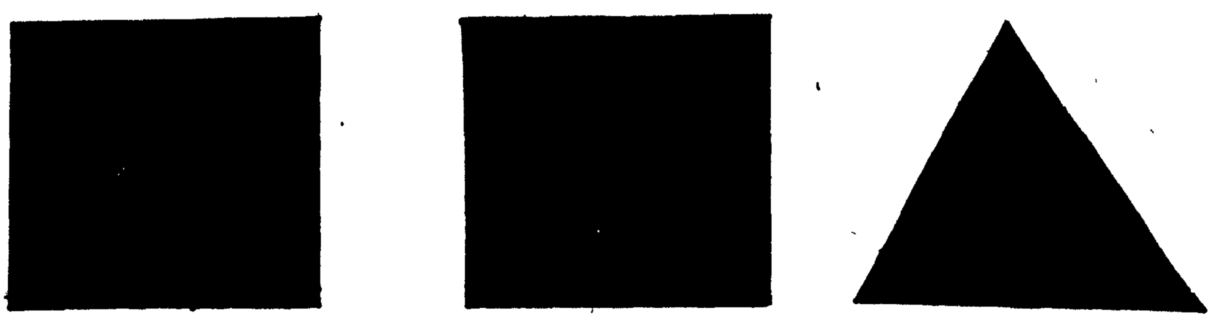
Stimuli

There were four practice items, 1 and 3 being rectilinear, 2 and 4 curvilinear in outline. The twenty-four experimental items were arranged as follows: a - m curvilinear and n - x rectilinear. Within the practice items, C1 was the correct choice for items 1 and 4; for the experimental items C1 was the correct choice for half the curvilinear items a - f and half the rectilinear items m - r.

NOTE: All shapes have been reduced to 50% of their original size.

Practice Items

1



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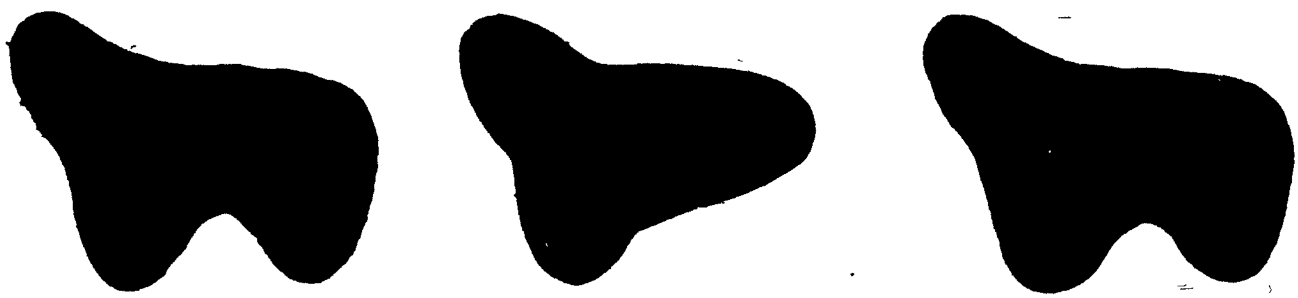

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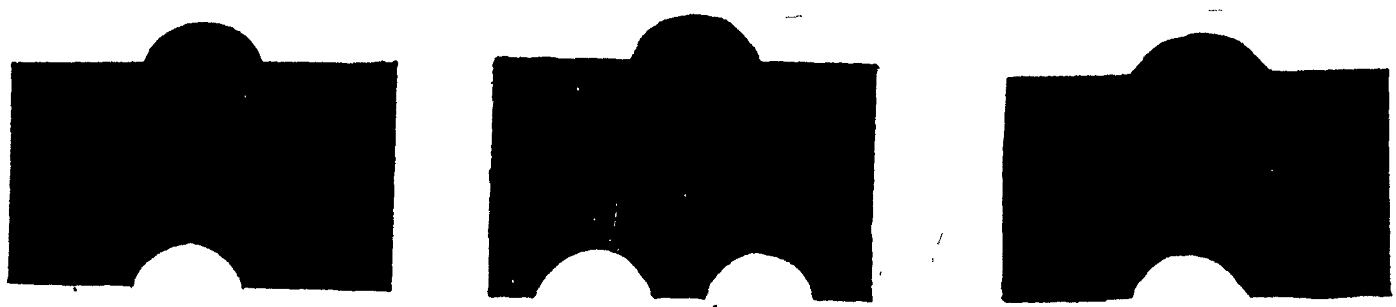

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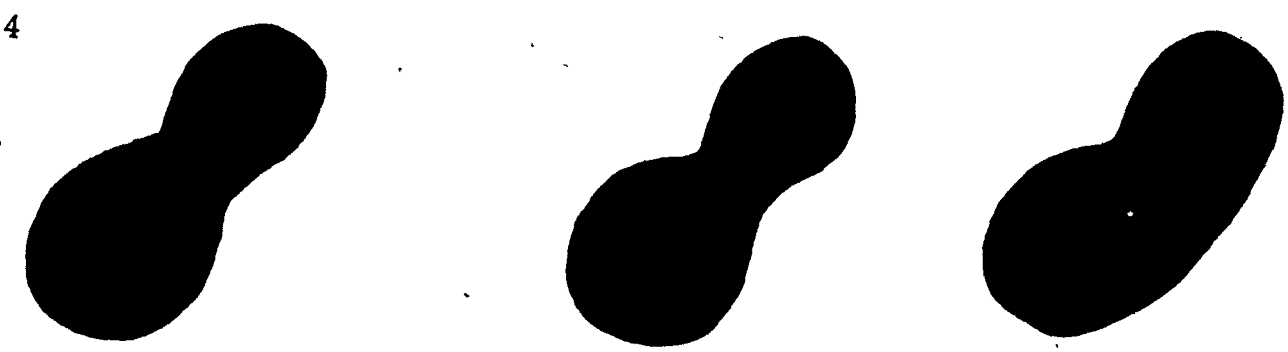
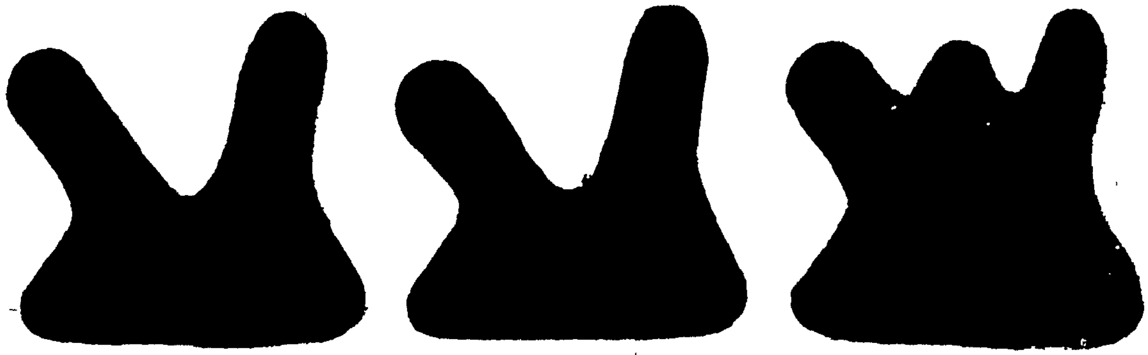


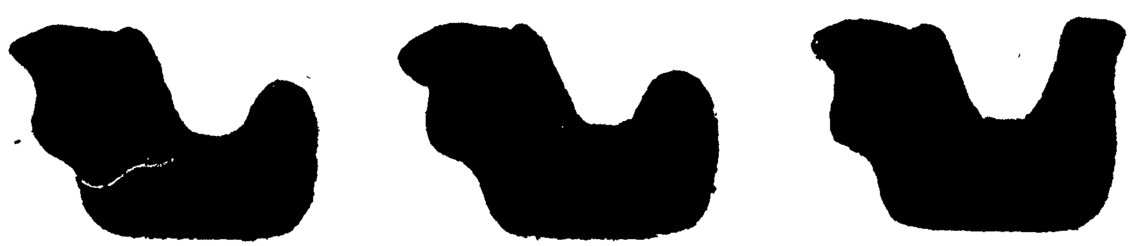
Experimental Items

a



b

c



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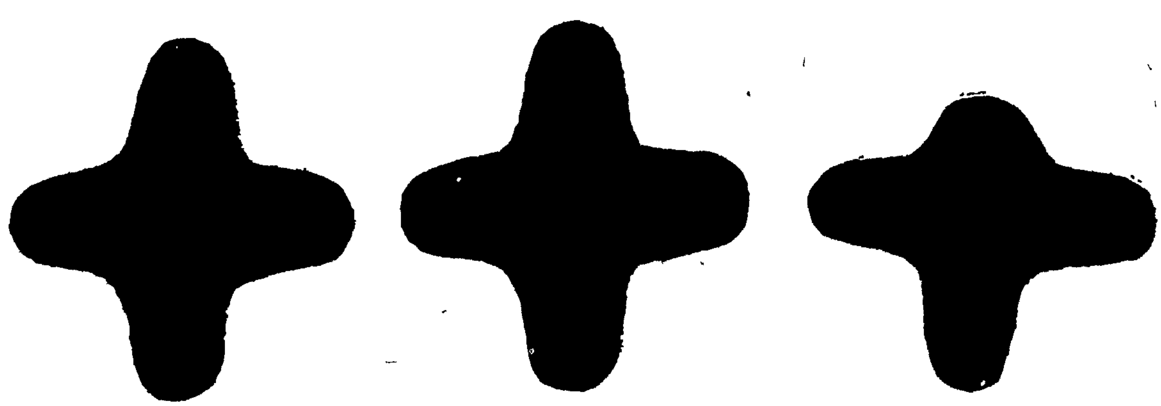

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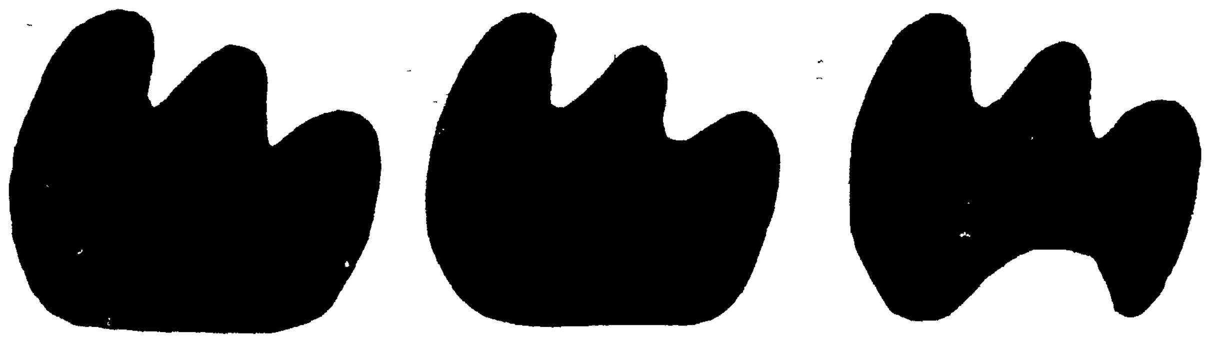
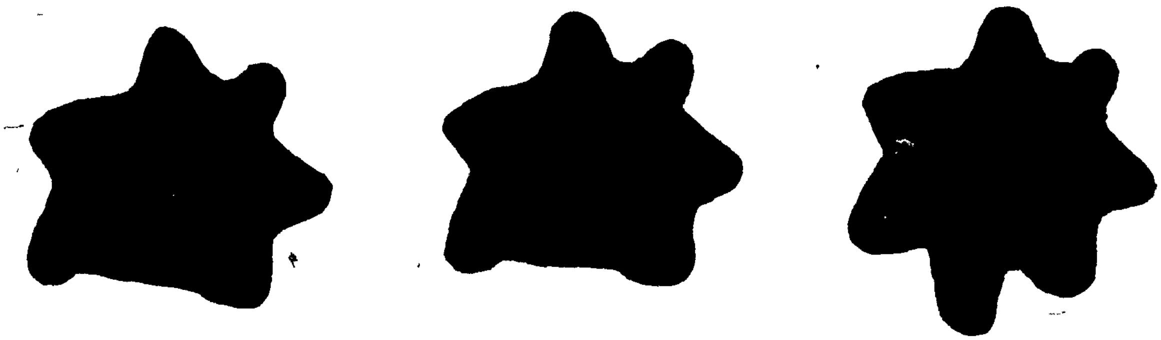


f



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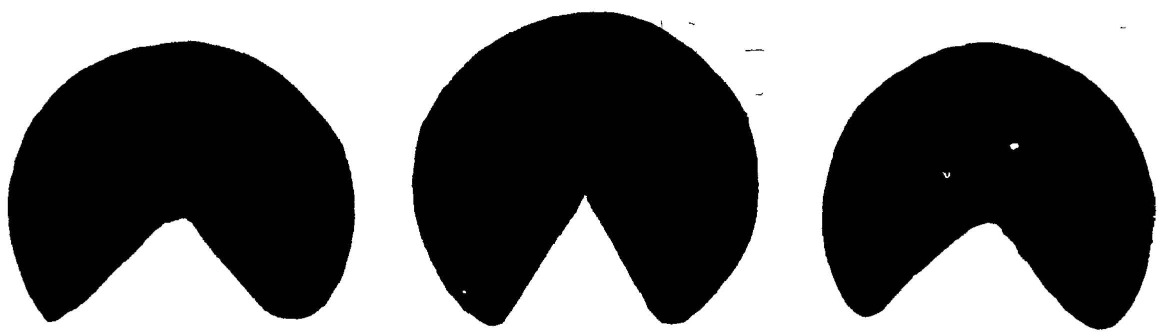

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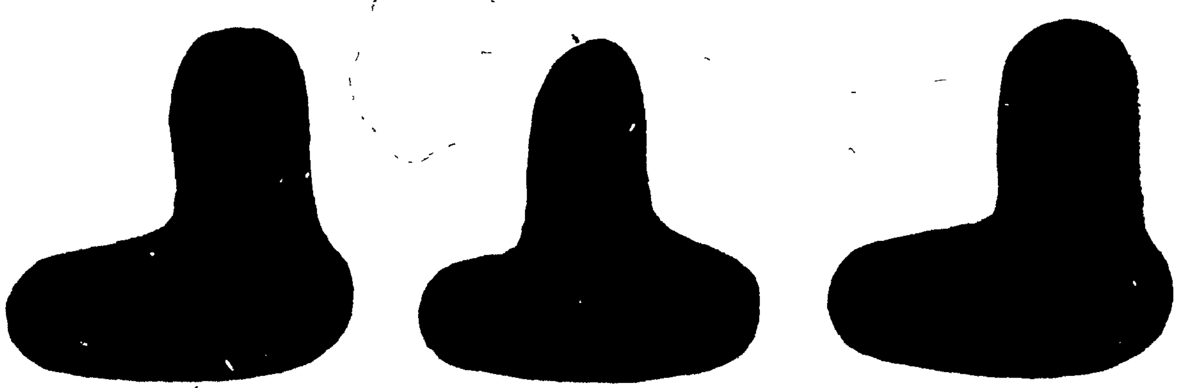

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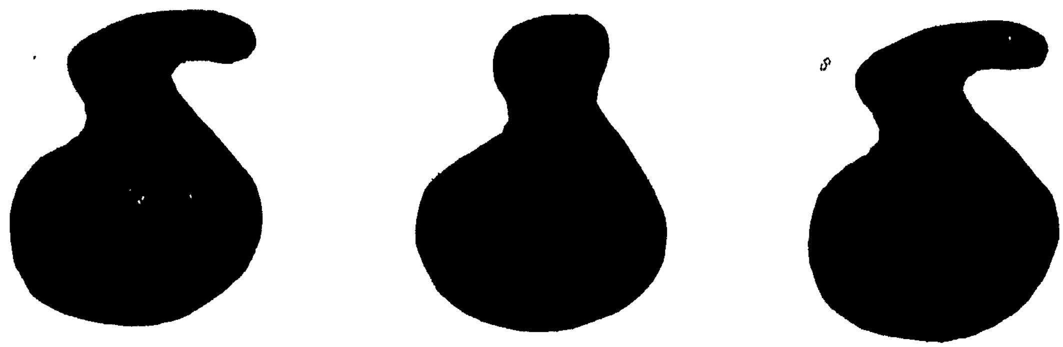

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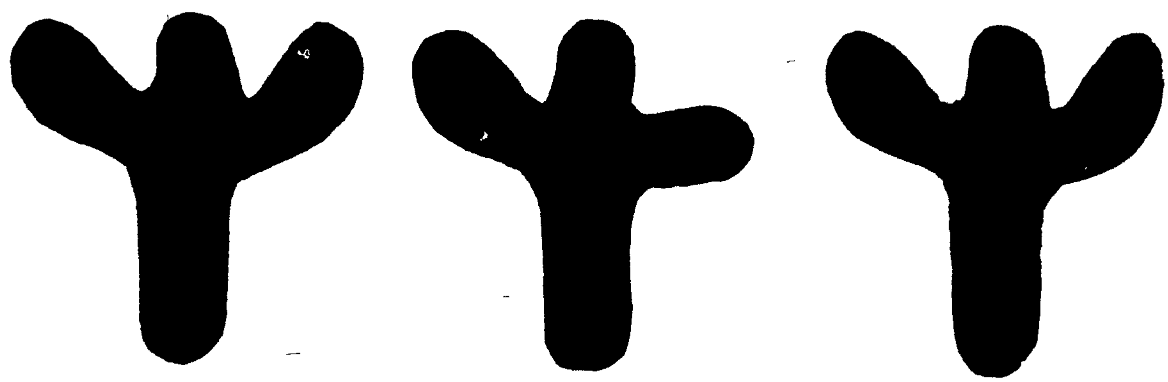

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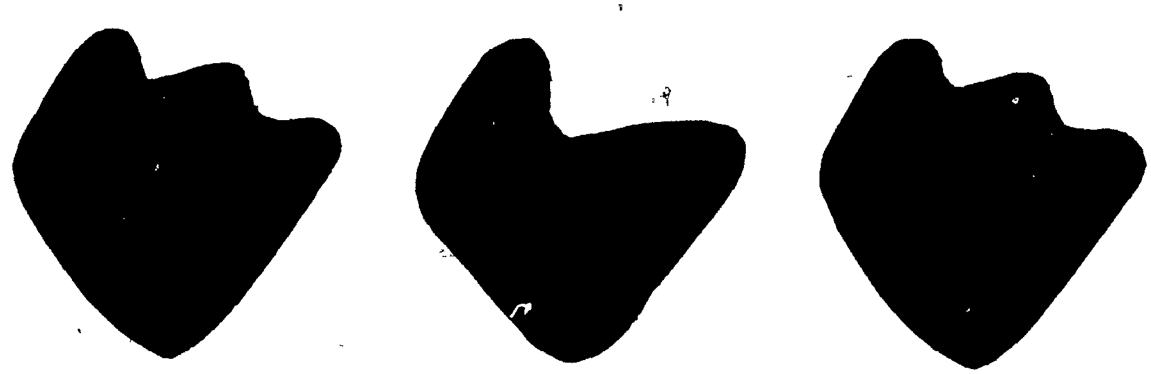

l

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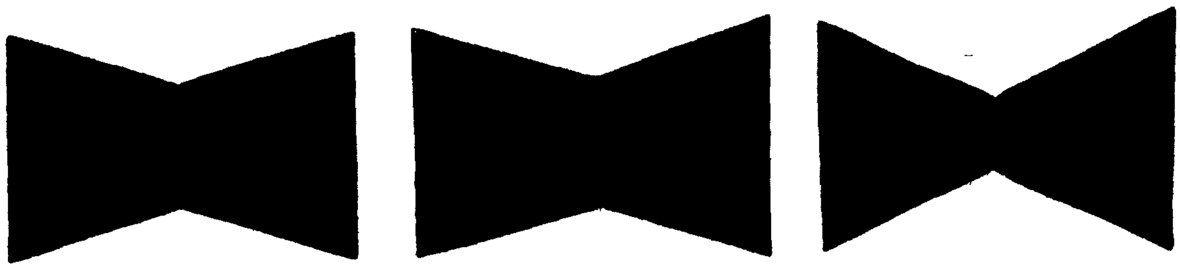

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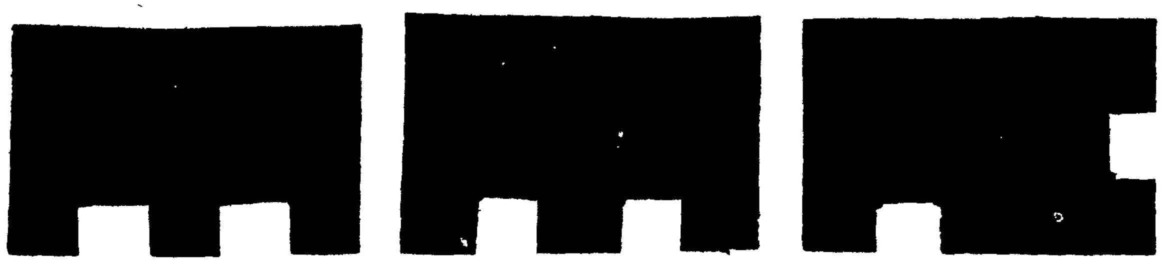
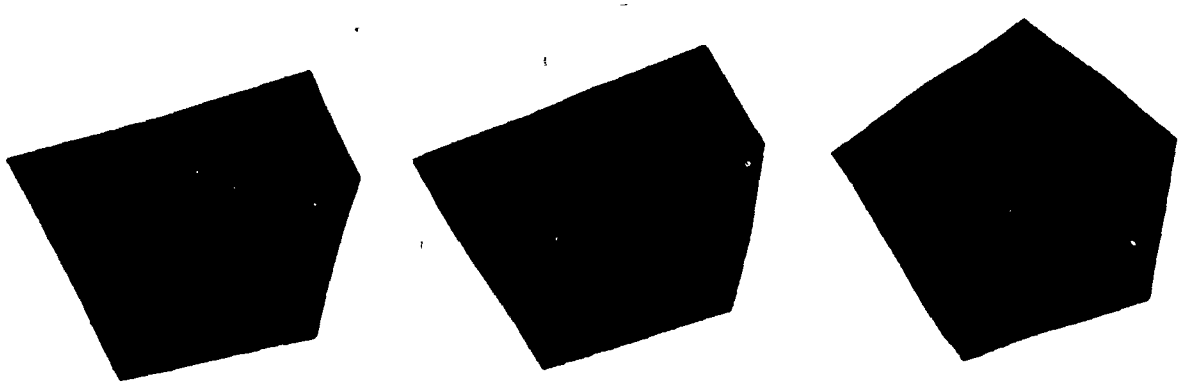


o



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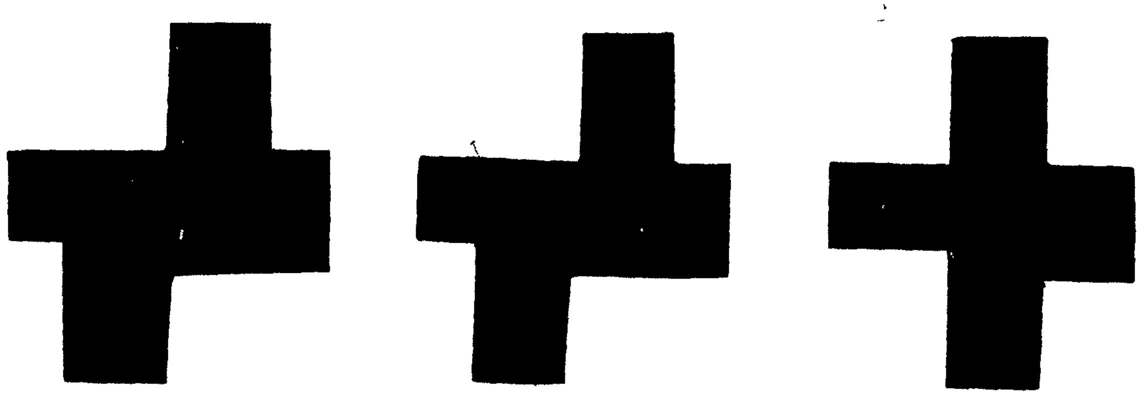

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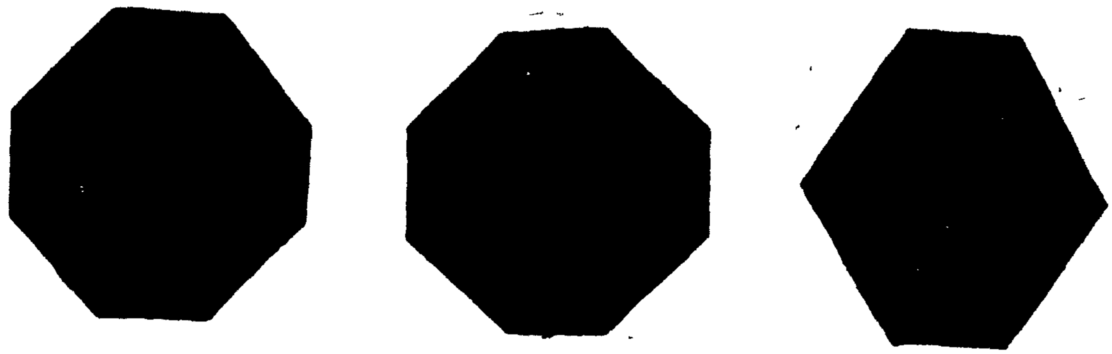

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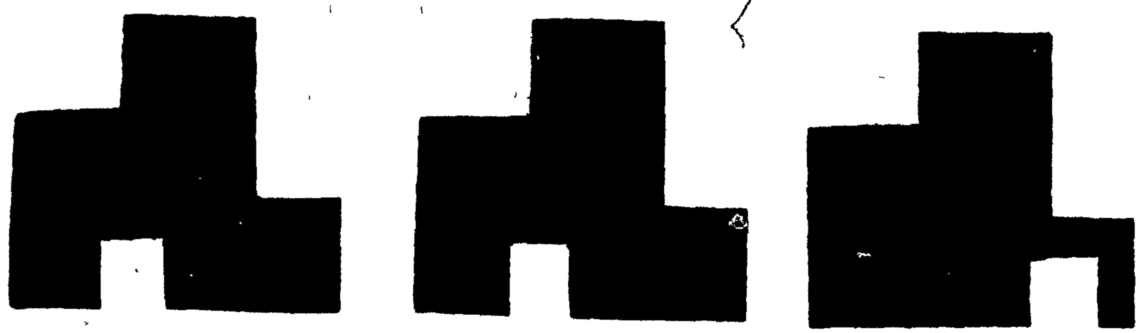
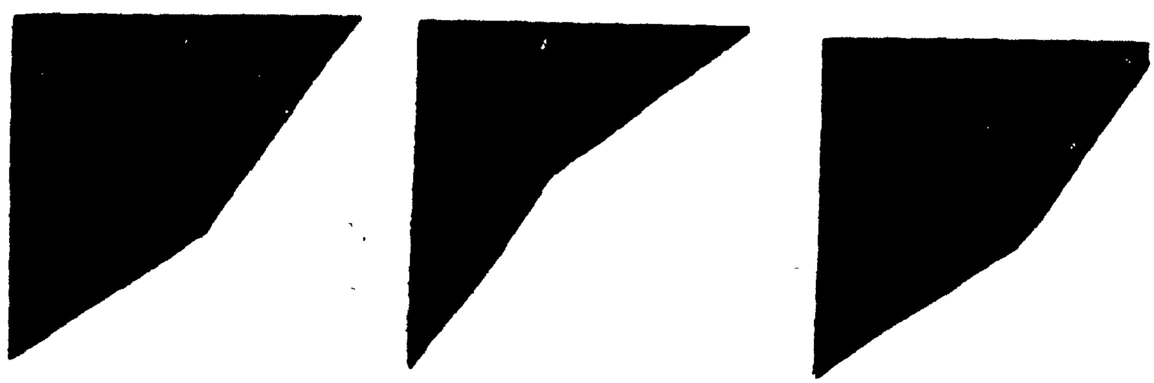
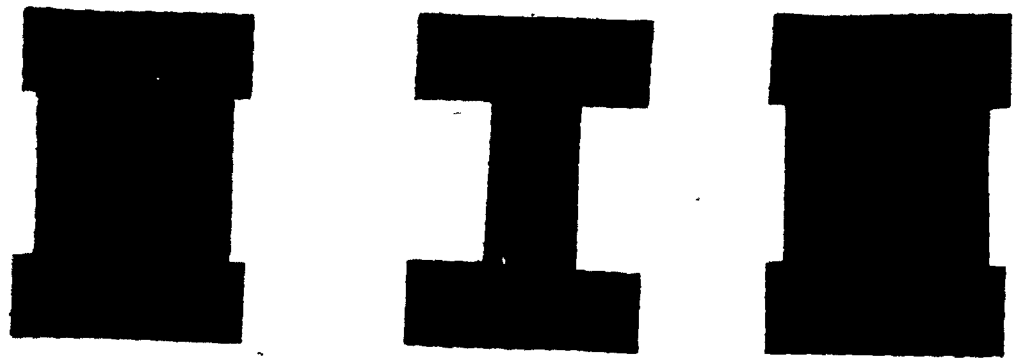


s



t

u



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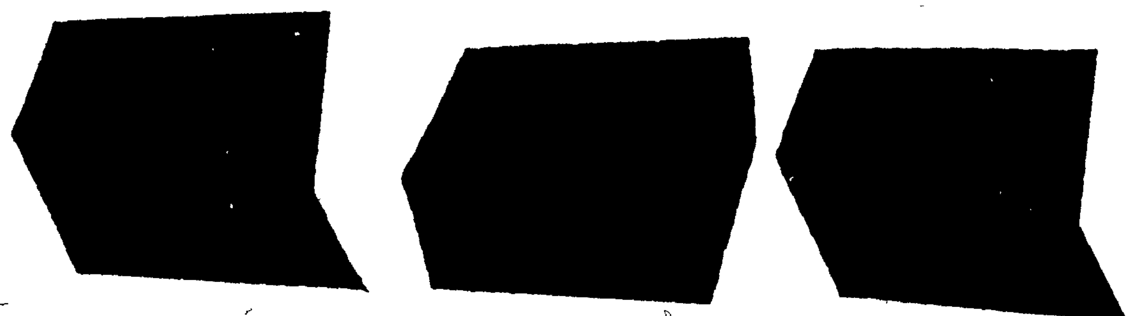

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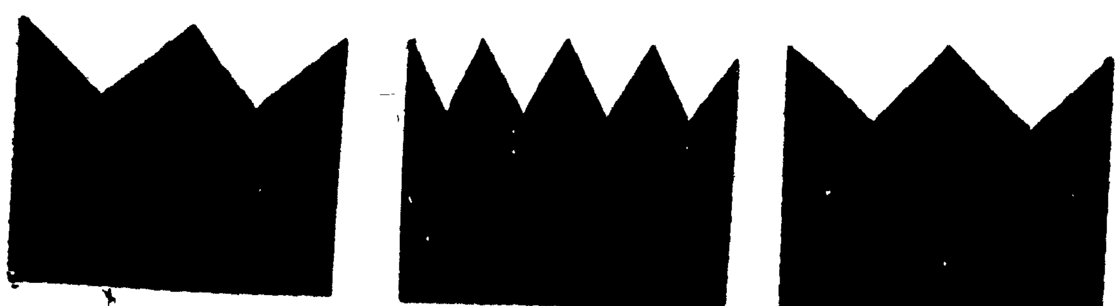

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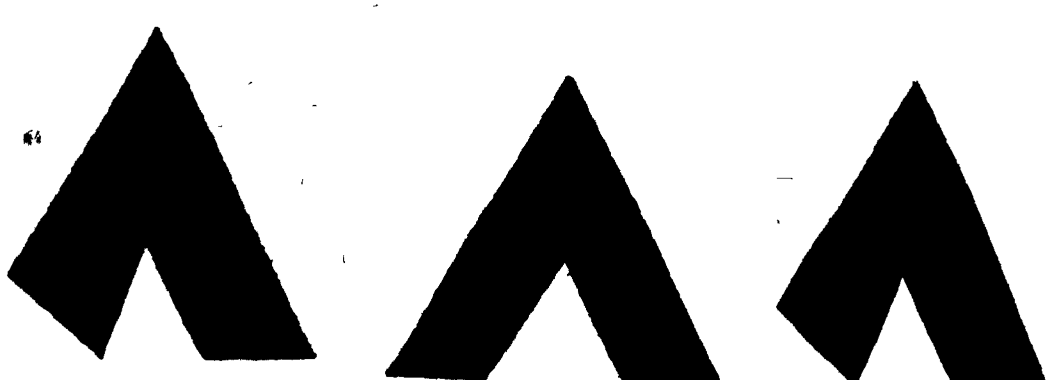

Appendix C

Haptic Scoring Sheet for One-Handed Explorations

1. One point is given for minimal movements. The child is to demonstrate at least one of the following:

a) Putting hand on the outside surface of the object as if wearing mittens; such as holding a ball in fist (but not exploring the edges of object with palm of hand or surfaces of fingers).

b) Feeling the surface of the edge with the palm of the hand (but not feeling the edges of object with the palm or active finger motions).

c) Discovering a special characteristic of an object by chance, such as a handle or a hole in a topological form (but not actively searching for specific clues).

d) Grasping object and turning it round and round (but not feeling the edges).

e) Touching across diameter of object.

2. Two points are given for minimal, global and haphazard explorations of the object. The child is to demonstrate at least one of the following:

a) Exploring haphazardly the edges of objects with the palm of the hand and surfaces of fingers (but not systematically exploring the edges and specific features with the surfaces of fingers or finger tips.)

b) Taking hold of a least two extremities to establish a relationship between the two; such as grasping the points of a triangle with two fingers (but not exploring the recessess of the edges).

3. Three points are given for active manipulation of the object with incomplete motions. The child is to demonstrate at least one of the following:

a) Searching actively for significant clues of objects such as curves, straight lines and angles with incomplete motions (but not following through on the entire object or carefully examining specific clues).

b) Turning the object over and over in one direction, feeling the edges simultaneously.

4. Four points are given for active acquaintance and manipulation. The child is to demonstrate at least one of the following:

a) Carefully examining all specific clues; such as putting finger(s) in and around the edges of a hole.

b) Locating extremities of objects and exploring recesses of edges; such as feeling both the points and inner angles of a star.

c) Exploring the whole contour or edges with one finger tip.

d) Moving finger tips or surfaces of fingers around the edges and into the specific features.

Appendix D

Haptic Scoring Sheet for Two-Handed Explorations

1. One point is given for minimal movements using either one or both hands. The child is to demonstrate at least one of the following:

a) Putting hand(s) on the outside surface of the object as if wearing mittens; such as holding a ball in fist (but not exploring the edges of object with palm(s) of hand(s) or surfaces of fingers).

b) Feeling the surface of the edge with the palm(s) of the hand(s) (but not feeling the edges of object with the palm or active finger motions).

c) Discovering a special characteristic of an object by chance, such as a handle or a hole in a topological form (but not actively searching for specific clues).

d) Grasping object and turning it round and round (but not feeling the edges).

e) Touching across diameter of object.

2. Two points are given for minimal, global and haphazard explorations of the object with either one or both hands. The child must demonstrate at least one of the following:

a) Exploring haphazardly the edges of objects with the palm(s) of the hand(s) and surfaces of fingers (but not systematically exploring the edges and specific features with the surfaces of fingers or finger tips.)

b) Taking hold of a least two extremities to establish a relationship between the two; such as grasping the points of a triangle with two fingers (but not exploring the recessess of the edges).

3. Three points are given for active manipulation of the object with incomplete motions either with one or both hands. The child is to demonstrate at least one of the following:

a) Searching actively for significant clues of objects such as curves, straight lines and angles with incomplete motions (but not following through on the entire object or carefully examining specific clues).

b) Turning the object over and over in one direction, feeling the edges simultaneously.

4. Four points are given for active acquaintance and manipulation, either using one or both hands. The child is to demonstrate at least one of the following:

a) Carefully examining all specific clues; such as putting finger(s) in and around the edges of a hole.

b) Locating extremities of objects and exploring recesses of edges; such as feeling both the points and inner angles of a star.

c) Exploring the whole contour or edges with one finger tip.

d) Moving finger tips or surfaces of fingers around the edges and into the specific features.

Appendix E

Randomized Orders of Presentation of Items within Condition (Pilot Study)

Condition 1 (One-handed haptic exploration)

Order 1

Trial	Stimulus Item
1	A
2	S
3	B
4	T
5	U
6	G
7	C
8	V
9	M
10	N
11	D
12	H
13	W
14	E
15	O
16	F
17	I
18	J
19	P
20	K
21	X
22	Q
23	L
24	R

Order 2

Trial	Stimulus Item
1	X
2	R
3	H
4	B
5	O
6	D
7	J
8	V
9	E
10	M
11	W
12	K
13	S
14	F
15	Q
16	G
17	U
18	N
19	I
20	L
21	C
22	P
23	T
24	A

Appendix E (Cont'd)

Condition 2 (Two-handed haptic exploration)

Order 1

Trial	Stimulus Item
1	C
2	L
3	F
4	I
5	U
6	T
7	R
8	H
9	K
10	Q
11	A
12	P
13	S
14	G
15	B
16	E
17	D
18	V
19	W
20	N
21	J
22	O
23	X
24	M

Order 2

Trial	Stimulus Item
1	P
2	M
3	I
4	C
5	L
6	N
7	A
8	S
9	U
10	O
11	B
12	T
13	Q
14	H
15	G
16	R
17	K
18	J
19	X
20	F
21	V
22	E
23	D
24	W

Appendix F

<u>Distribution of Subjects According to Order of Presentation of Conditions and Item Order Within Condition</u>

Subjects Receiving Condition 1 followed by Condition2

		Condition 1	Condition 2
Kindergarten	2 boys 3 girls	order 1	order 2
	2 boys 3 girls	order 2	order 1
Grade 2	4 boys 3 girls	order 1	order 2
	3 boys 2 girls	order 2	order 1
Grade 4	3 boys 2 girls	order 1	order 2
	3 boys 3 girls	order 2	order 1

Appendix F Cont'd

Subjects Receiving Condition 2 followed by Condition 1

		Condition 2	Condition 1
Kindergarten	2 boys 3 girls	order 1	order 2
	2 boys 3 girls	order 2	order 1
Grade 2	3 boys 3 girls	order 1	order 2
	3 boys 3 girls	order 2	order 1
Grade 4	3 boys 2 girls	order 1	order 2
	4 boys 2 girls	order 2	order 1

Appendix G

Procedural Instructions for Pilot Study

Condition 1 (One-handed exploration)
Condition 2 (Two-handed exploration)

Instructions for practice items

This is a feeling game. You are going to feel shapes with your hand(s). First, though, I'll show you how to play the game using your eyes. Look at this shape. We'll call it "number 1", just to give it a name. (Experimenter put the standard shape on the table in front of the child.) Here's another shape. We'll call it "A". (Experimenter placed comparison 1 shape to the right of the standard shape leaving approximately a 10 cm. gap between the two shapes). This shape is called "B". (Experimenter placed comparison 2 shape close beside, and to the right of comparison 1). Which shape is the same shape as "number 1", "A" or "B". (Experimenter pointed to the standard, comparison1 and comparison 2 respectively, as she named the shapes.) Good. Now let's try the same game using your hand(s) to feel the shapes. Put your hand(s) in the box like this. (In condition 1, the experimenter placed the child's right hand (palm up) through the slot of the haptic perception box. In condition 2, the experimenter placed both hands, palms up, through the corresponding slots of the haptic perception box.) This shape is "number 1". (Experimenter placed the standard shape in child's upturned palm(s)). Feel it carefully, and when you have finished feeling it say "O.K." (Experimenter removed the shape from the child's hand(s)). This is "A". Feel it carefully and say "O.K." when you have finished. (Experimenter placed object in subject's hand(s) and removed it at appropriate time). This is "B". Feel it carefully and say "O.K." when you have finished. (Once again, experimenter placed object in subject's hand(s) and removed it at appropriate times). Which is the same shape as "number 1", "A" or "B"?

For the 24 experimental items the instructions were abbreviated as follows:

This is "number 1" (Experimenter placed standard shape in child's upturned palm(s) and removed it when child had finished exploring it.). This is "A". (Experimenter placed comparison 1 shape in child's hand(s) and removed it when the child had finished exploring it), and this is "B". (Experimenter placed comparison 2 shape in child's palm and removed it when the child had finished exploring it.) Which shape is the same as "number 1", "A" or "B"?

Appendix H

Experimental Apparatus for Studies 1 and 3

The haptic perception box was placed on a table of appropriate height for the child to reach his/her hands into the box. The reverse mirror screen was mounted on the left side (from the front view) of the box, and could be adjusted to the child's eye level. The slide projector was placed behind the box (i.e. on the experimenter's side) to prevent the child from obscuring the visual image with body position or body movement. The clock/counter measured 1/1,000 seconds. An electronic timer (approximate size 7.5 cm. x 12.5 cm. x 4.50 cm.), connected to the clock/counter and the slide projector, activated and disabled the timer when the child pushed the remote control button for the projector. Both the clock/counter and the electronic timer were placed on the experimenter's side of the box, out of the child's view.

Appendix I

Order of Presentation of Stimulus Items (Phases I, 2 and 3)

Haptic-Haptic Condition

Order 1

Trial	Stimulus Item
1	A
2	S
3	B
4	T
5	U
6	G
7	C
8	V
9	M
10	N
11	D
12	H
13	W
14	E
15	O
16	F
17	I
18	J
19	P
20	K
21	X
22	Q
23	L
24	R

Order 2

Trial	Stimulus Item
1	X
2	R
3	H
4	B
5	O
6	D
7	J
8	V
9	E
10	M
11	W
12	K
13	S
14	F
15	Q
16	G
17	U
18	N
19	I
20	L
21	C
22	P
23	T
24	A

Appendix I (Cont'd)

Haptic-Visual Condition

Order 1

Trial	Stimulus Item
1	C
2	L
3	F
4	I
5	U
6	T
7	R
8	H
9	K
10	Q
11	A
12	P
13	S
14	G
15	B
16	E
17	A
18	V
19	W
20	N
21	J
22	O
23	X
24	M

Order 2

Trial	Stimulus Item
1	P
2	M
3	I
4	C
5	L
6	N
7	A
8	S
9	U
10	O
11	B
12	T
13	Q
14	H
15	G
16	R
17	K
18	J
19	X
20	F
21	V
22	E
23	D
24	W

Appendix I (Cont'd)

Visual-Haptic Condition

Order 1

Trial	Stimulus Item
1	K
2	A
3	F
4	T
5	C
6	M
7	O
8	L
9	D
10	P
11	U
12	V
13	X
14	Q
15	N
16	B
17	W
18	R
19	J
20	E
21	I
22	H
23	G
24	S

Order 2

Trial	Stimulus Item
1	U
2	I
3	O
4	X
5	B
6	H
7	E
8	F
9	J
10	N
11	K
12	V
13	A
14	W
15	Q
16	C
17	M
18	L
19	D
20	S
21	T
22	G
23	R
24	P

Appendix I (Cont'd)

Visual-Visual Condition

Order 1

Trial	Stimulus Item
1	Q
2	B
3	I
4	H
5	C
6	W
7	N
8	X
9	R
10	F
11	M
12	U
13	A
14	E
15	L
16	G
17	K
18	D
19	T
20	O
21	S
22	V
23	P
24	J

Order 2

Trial	Stimulus Item
1	R
2	S
3	C
4	X
5	G
6	M
7	Q
8	V
9	N
10	E
11	P
12	T
13	I
14	F
15	L
16	W
17	K
18	O
19	U
20	J
21	A
22	D
23	H
24	B

Appendix J

Order of Presentation of Stimulus Items[27] within each order of presentation of conditions

Condition	Subjects within each Grade[28]	
Haptic-Haptic	2 boys order 1 2 girls order 1	2 boys order 2 2 girls order 2
Haptic-Visual	2 boys order 1 2 girls order 1	2 boys order 2 2 girls order 2
Visual-Haptic	2 boys order 1 2 girls order 1	2 boys order 2 2 girls order 2
Visual-Visual	2 boys order 1 2 girls order 1	2 boys order 2 2 girls order 2

27 For randomized orders of presentation of items within condition, see Appendix I.

28 8 subjects (4 boys, 4 girls) at each grade level received each of the four orders of presentation of conditions.

Appendix K

Procedural Instructions for Study 1 and Study 3

Haptic-Haptic Condition

Instructions for practice items

This is a game with shapes. You are going to feel shapes with your hand. First, though, I'll show you how to play the game using your eyes. Look at this shape. We'll call it "number 1", just to give it a name. (Experimenter put the standard shape on the table in front of the child.) Here's another shape. We'll call it "A". (Experimenter placed comparison 1 shape to the right of the standard shape leaving approximately a 10 cm. gap between the two shapes). This shape is called "B". (Experimenter placed comparison 2 shape close beside, and to the right of comparison 1). Which shape is the same shape as "number 1", "A" or "B". (Experimenter pointed to the standard, comparison1 and comparison 2 respectively, as she named the shapes.) Good. Now let's try the same game using your hand to feel the shapes. Put your right hand in the box like this. (Experimenter placed the child's right hand, palm up, in the right slot of the haptic perception box.) This shape is "number 1". (Experimenter placed the standard shape in child's upturned palm). Feel it carefully, and when you have finished feeling it say "O.K." (Experimenter removed the shape from the child's hand). This is "A". Feel it carefully and say "O.K." when you have finished. (Experimenter placed object in subject's hand and removed it at appropriate time). This is "B". Feel it carefully and say "O.K." when you have finished. (Once again, experimenter placed object in subject's hand and removed it at appropriate time). Which is the same shape as "number 1", "A" or "B"?

For the 24 experimental items the instructions were abbreviated as follows:

This is "number 1" (Experimenter placed standard shape in child's upturned palm and removed it when child had finished exploring it.). This is "A". (Experimenter placed comparison 1 shape in child's hand and removed it when the child had finished exploring it), and this is "B". (Experimenter placed comparison 2 shape in child's hand and removed it when the child had finished exploring it.) Which shape is the same as "number 1", "A" or "B"?

Appendix K (Cont'd)

Haptic-Visual Condition

Instructions for practice items

This is a game with shapes. You are going to feel some shapes with your hand and look at other shapes with your eyes. First, though, I'll show you how to play the game using your eyes. Look at this shape. We'll call it "number 1", just to give it a name. (Experimenter put the standard shape on the table in front of the child.) Here's another shape. We'll call it "A". (Experimenter placed comparison 1 shape to the right of the standard shape leaving approximately a 10 cm. gap between the two shapes). This shape is called "B". (Experimenter placed comparison 2 shape close beside, and to the right of comparison 1). Which shape is the same shape as "number 1", "A" or "B". (Experimenter pointed to the standard, comparison1 and comparison 2 respectively, as she named the shapes.) Good. Now let's try the same game using your hand to feel the shape called number 1 and your eyes to look at "A" and "B". (Experimenter pointed at the screen.) Put your right hand in the box like this. (Experimenter placed the child's right hand, palm up, in the right slot of the haptic perception box.) Put your other hand on this board. (Experimenter placed child's left hand, palm down on board with remote control button for the projector, with the child's forefinger extended and close to the button.) This shape is "number 1". (Experimenter placed the standard shape in child's upturned palm). Feel it carefully, and when you have finished feeling it say "O.K." (Experimenter removed the shape from the child's hand). Now press the button once. This is "A" (pointing at shape projected on screen). Look at it carefully. When you have finished, press the button again. Now, press the button again. (A blank slide was projected on the screen.)[29] This is "B" (pointing to the shape on the screen). Look at it carefully. When you have finished, press the button. (A blank slide was projected on the screen.) Which is the same shape as "number 1", "A" or "B"?

[29] The blank slide referred to here was actually a piece of cardboard. This procedure was adopted to prevent the light from flashing onto the screen.

Appendix K (Cont'd)

For the 24 experimental items the instructions were abbreviated as follows:

This is "number 1". (Experimenter placed standard shape in child's upturned palm and removed it when child had finished exploring it.) Press the button to see "A".[30] (If necessary, the experimenter reminded the subject to press the button again when finished looking at the shape.) Now press the button to see "B". (If necessary, the experimenter reminded the subject to press the button again when finished looking at the shape.) Which shape is the same as "number 1", "A" or "B"?

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30 Usually, after the first few trials, the child automatically pressed the button to advance the slide to see each comparison shape, and again when finished viewing the shape. In this case, the experimenter simply said:

This is "A", and this is "B". Which shape is the same as "number 1", "A" or "B".

Appendix K (Cont'd)

Visual-Haptic Condition

Instructions for practice items

This is a game with shapes. You are going to to look at some shapes with your eyes and feel other shapes with your hand. First, though, I'll show you how to play the game using your eyes. Look at this shape. We'll call it "number 1", just to give it a name. (Experimenter put the standard shape on the table in front of the child.) Here's another shape. We'll call it "A". (Experimenter placed comparison 1 shape to the right of the standard shape leaving approximately a 10 cm. gap between the two shapes). This shape is called "B". (Experimenter placed comparison 2 shape close beside, and to the right of comparison 1). Which shape is the same shape as "number 1", "A" or "B". (Experimenter pointed to the standard, comparison1 and comparison 2 respectively, as she named the shapes.) Good. Now let's try the same game using your eyes to look at "number 1" and your hands to feel "A" and "B". First, put your right hand in the box, like this. (Experimenter placed the child's right hand, palm up, in the right slot of the haptic perception box.) Put your other hand on this board. (Experimenter placed child's left hand, palm down on board with remote control button for the projector, with the child's forefinger extended and close to the button.) This shape is "number 1". Now press the button once. This is "number 1". (Experimenter pointed to shape on the screen.) Look at it carefully and when you have finished looking at it press the button again. (A blank slide was projected on the screen.) This is "A". (Experimenter placed shape in subject's hand.) Feel it carefully, and say "O.K." when you have finished. (Experimenter placed object in subjects hand and removed it at appropriate time. This is "B". Feel it carefully and say "O.K." when you have finished. (Once again, experimenter placed object in subject's hand and removed it at appropriate time). Which is the same shape as "number 1", "A" or "B"?

Appendix K (Cont'd)

For the 24 experimental items the instructions were abbreviated as follows:

Press the button. This is "number 1" (If necesssary, the experimenter reminded the subject to press the button again when finished looking at it. This is "A". (Experimenter placed comparison 1 shape in child's hand and removed it when the child had finished exploring it), and this is "B". (Experimenter placed comparison 2 shape in child's hand and removed it when the child had finished exploring it.) Which shape is the same as "number 1", "A" or "B"?

Appendix K (Cont'd)

Visual-Visual Condition

Instructions for practice items

This is a game with shapes. You are going to look at shapes with your eyes. Look at this shape. We'll call it "number 1", just to give it a name. (Experimenter put the standard shape on the table in front of the child.) Here's another shape. We'll call it "A". (Experimenter placed comparison 1 shape to the right of the standard shape leaving approximately a 10 cm. gap between the two shapes). This shape is called "B". (Experimenter placed comparison 2 shape close beside, and to the right of comparison 1). Which shape is the same shape as "number 1, "A' or "B". (Experimenter pointed to the standard, comparison1 and comparison 2 respectively, as she named the shapes.) Good. Now let's try the same game using the projector. Put your left hand on this board. (Experimenter placed child's left hand, palm down on board with remote control button for the projector, with the child's forefinger extended and close to the button.) Press the button once. This is "number 1". Look at it carefully, and when you have finished looking at it press the button again. (A blank slide was projected on the screen.) Press the button again. This is "A". Look at it carefully. When you have finished, press the button again. (A blank slide was projected on the screen.) Press the button. This is "B". Look at it carefully. Press the button when you have finished. (A blank slide was projected on the screen.) Now, which is the same shape as "number 1", "A" or "B"?

For the 24 experimental items the instructions were abbreviated as follows:

Press the button. This is "number 1" (If necessary, the experimenter reminded the subject to press the button again when finished looking at it.). Press the button again. This is "A". (If necessary, the experimenter reminded the subject to press the button again when finished looking at it.). Press the button. "This is "B". (If necessary, the experimenter reminded the subject to press the button again when finished looking at it.). Which shape is the same as "number 1", "A" or "B"?[31]

31 Usually, the subjects operated the projector without prompting after the first few trials. In this case, the experimenter simply named each shape as it appeared on the screen, and when the subject had finished viewing the three shapes, asked which shape was the same as "number 1" (standard), the "A" (comparison 1) or the "B" (comparison 2) shape.

Appendix L

Experimental Apparatus for Studies 1 and 3

The haptic perception box was placed on a table of appropriate height for the child to reach his/her hands into the box. The reverse mirror screen was mounted on the left side (from the front view) of the box, and could be adjusted to the child's eye level. The slide projector was placed behind the box (i.e. on the experimenter's side) to prevent the child from obscuring the visual image with body position or body movement. The clock/counter measured 1/1,000 seconds. An electronic interval timer (approximate size 7.5 cm. x 12.5 cm. x 4.50 cm.), projected slides on the screen for the set amount of time (seconds). A second apparatus attached to the clock/counter enabled the experimenter to verify exactness of timing of exploration of haptic stimuli by flashing a small red light one second before termination of set exploration time and again at the set time. The clock/counter and the electronic timers were placed on the experimenter's side of the box, out of the child's view.

Appendix M

Instructions for Study 2

Haptic-Haptic Condition

Instructions for practice items

This is a game with shapes. You are going to feel shapes with your hand. First, though, I'll show you how to play the game using your eyes. Look at this shape. We'll call it "number 1", just to give it a name. (Experimenter put the standard shape on the table in front of the child.) Here's another shape. We'll call it "A". (Experimenter placed comparison 1 shape to the right of the standard shape leaving approximately a 10 cm. gap between the two shapes). This shape is called "B". (Experimenter placed comparison 2 shape close beside, and to the right of comparison 1). Which shape is the same shape as "number 1", "A" or "B". (Experimenter pointed to the standard, comparison1 and comparison 2 respectively, as she named the shapes.) Good. Now let's try the same game using your hand to feel the shapes. Put your right hand in the box like this. (Experimenter placed the child's right hand, palm up, in the right slot of the haptic perception box.) This shape is "number 1". (Experimenter placed the standard shape in child's upturned palm). Feel it carefully. Keep feeling it until I tell you to put it down. (If subject tried to put the shape down or stopped exploration of the shape before the allotted time was up, the Experimenter reminded the subject to keep feeling the shape.) (Experimenter said "O.K." and removed the shape from the child's hand when the allotted time was up). This is "A". Feel it carefully and keep feeling it until I tell you to put it down. (Experimenter placed object in subject's hand and removed it at appropriate time). This is "B". Feel it carefully keep feeling it until I tell you to put it down. (Once again, experimenter placed object in subject's hand and removed it at appropriate time). Now, which is the same shape as "number 1", "A" or "B"?

For the 24 experimental items the instructions were abbreviated as follows:

This is "number 1". (Experimenter placed standard shape in child's upturned palm and removed it at appropriate time.)[32] This is "A". (Experimenter placed comparison 1 shape in child's hand and removed it at appropriate time), and this is "B". (Experimenter placed comparison 2 shape in child's hand and removed it at appropriate time.) Which shape is the same as "number 1", "A" or "B"?

32 Throughout the 24 experimental items, the child was reminded of the importance of exploring the shapes for the whole time allotted.

Appendix M (Cont'd)

Haptic-Visual Condition

Instructions for practice items

This is a game with shapes. You are going to feel some shapes with your hand and look at other shapes with your eyes. First, though, I'll show you how to play the game using your eyes. Look at this shape. We'll call it "number 1", just to give it a name. (Experimenter put the standard shape on the table in front of the child.) Here's another shape. We'll call it "A". (Experimenter placed comparison 1 shape to the right of the standard shape leaving approximately a 10 cm. gap between the two shapes). This shape is called "B". (Experimenter placed comparison 2 shape close beside, and to the right of comparison 1). Which shape is the same shape as "number 1, "A' or "B". (Experimenter pointed to the standard, comparison1 and comparison 2 respectively, as she named the shapes.) Good. Now let's try the same game using your hand to feel the shape called number 1 and your eyes to look at "A" and "B". (Experimenter pointed at the screen.) Put your right hand in the box like this. (Experimenter placed the child's right hand, palm up, in the right slot of the haptic perception box.) Put your other hand on this board here. (Experimenter placed child's left hand, palm down on board with remote control button for the projector, with the child's forefinger extended and close to the button.) This shape is "number 1". (Experimenter placed the standard shape in child's upturned palm). Feel it carefully, and keep feeling it until I tell you to put it down. (If subject tried to put the shape down or stopped exploration of the shape before the allotted time was up, the Experimenter reminded the subject to keep feeling the shape.) (Experimenter said "O.K." and removed the shape from the child's hand when the allotted time was up.) Now press this button once. This is "A" (pointing at shape projected on screen). Look at it carefully and keep looking at it until it disappears.[33] (When the slide disappeared, a blank slide was projected on the screen.) Now, press the button again. This is "B" (pointing to the shape on the screen). Look at it carefully and keep looking at it until it disappears. (When the slide disappeared, a blank slide was

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33 The blank slide referred to here was actually a piece of cardboard. This procedure was adopted to prevent the light from flashing onto the screen.

projected onto the screen.) Which is the same shape as "number 1", "A" or "B"?

For the 24 experimental items the instructions were abbreviated as follows:

This is "number 1". (Experimenter placed standard shape in child's upturned palm and removed it when the allotted time was up.)[34] Press the button to see "A". Now press the button to see "B". Which shape is the same as "number 1", "A" or "B"?

34 Usually, after the first few trials, the child automatically pressed the button to advance the slide to see each comparison shape, and again when fiinished viewing the shape. In this case, the experimenter simply said:

This is "A", and this is "B". Which shape is the same as "number 1", "A" or "B".

Appendix M (Cont'd)

Visual-Haptic Condition

Instructions for practice items

This is a game with shapes. You are going to to look at some shapes with your eyes and feel other shapes with your hand. First, though, I'll show you how to play the game using your eyes. Look at this shape. We'll call it "number 1", just to give it a name. (Experimenter put the standard shape on the table in front of the child.) Here's another shape. We'll call it "A". (Experimenter placed comparison 1 shape to the right of the standard shape leaving approximately a 10 cm. gap between the two shapes). This shape is called "B". (Experimenter placed comparison 2 shape close beside, and to the right of comparison 1). Which shape is the same shape as "number 1, "A' or "B". (Experimenter pointed to the standard, comparison1 and comparison 2 respectively, as she named the shapes.) Good. Now let's try the same game using your eyes to look at "number 1" and your hands to feel "A" and "B". First, put your right hand in the box like this. (Experimenter placed the child's right hand, palm up, in the right slot of the haptic perception box.) Put your other hand on this board. (Experimenter placed child's left hand, palm down on board with remote control button for the projector, with the child's forefinger extended and close to the button.) This shape is "number 1". Now press the button once. This is "number 1". (Experimenter pointed to shape on the screen.) Look at it carefully and keep looking at it until it disappears. (When the slide disappeared a blank slide was projected onto the screen.) This is "A". (Experimenter placed shape in subject's hand.) Feel it carefully, and keep feeling it until I tell you to put it down. (Experimenter said "O.K." and removed the shape from the child's hand when the allotted time was up.) This is "B". Feel it carefully and keep feeling it until I tell you to put it down. (Once again, experimenter placed object in subject's hand and removed it at appropriate time). Now, which is the same shape as "number 1", "A" or "B"?

For the 24 experimental items the instructions were abbreviated as follows:

Press the button. This is "number 1" This is "A", (experimenter placed comparison 1 shape in child's hand and removed it when allotted-time was up), and this is "B". (Experimenter placed comparison 2 shape in child's hand and removed it when allotted time was up.) Which shape is the same as "number 1", "A" or "B"?

Appendix M (Cont'd)

Visual-Visual Condition

Instructions for practice items

This is a game with shapes. You are going to look at shapes with your eyes. Look at this shape. We'll call it "number 1", just to give it a name. (Experimenter put the standard shape on the table in front of the child.) Here's another shape. We'll call it "A". (Experimenter placed comparison 1 shape to the right of the standard shape leaving approximately a 10 cm. gap between the two shapes). This shape is called "B". (Experimenter placed comparison 2 shape close beside, and to the right of comparison 1). Which shape is the same shape as "number 1, "A' or "B". (Experimenter pointed to the standard, comparison1 and comparison 2 respectively, as she named the shapes.) Good. Now let's try the same game using the projector. Put your left hand on this board. (Experimenter placed child's left hand, palm down on the board with remote control button for the projector, with the child's forefinger extended and close to the button.) Press the button once. This is "number 1". Look at it carefully, and keep looking at it until it disappears. (When the slide disappeared, a blank slide was projected onto the screen.) Press the button again. This is "A". Look at it carefully and keep looking at it until it disappears. (When the slide disappeared, a blank slide was projected on the screen.) Press the button again. This is "B". Look at it carefully and keep looking at it until it disappears. (A blank slide appeared on the screen.) Now, which is the same shape as "number 1", "A" or "B"?

For the 24 experimental items the instructions were abbreviated as follows:

Press the button. This is "number 1". Press the button again. This is "A". Press the button. "This is "B". Which shape is the same as "number 1", "A" or "B"?[35]

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35 Usually, the subjects operated the projector without prompting after the first few trials. In this case, the experimenter simply named each shape as it appeared on the screen, and when the subject had finished viewing the three shapes, asked which shape was the same as "number 1" (standard), the "A" (comparison 1) or the "B" (comparison 2) shape.

APPENDIX N

Analyses of Variance Tables

for Study 1, Study 2, and Study 3

Note that the table numbers correspond for the different populations, facilitating comparisons between populations.

Note the use of the following terms in these tables:

Condition is the comparison of the specific conditions.

Stimuli is the comparison of the specific stimuli.

Gp1/2 is the comparison of the Group 1 subject sample and the Group 2 subject sample.

Gp1/3 is the comparison of the Group 1 subject sample and the Group 2 subject sample.

Analyses of Variance For Study 1

<u>Group 1–Table 1</u> Analysis of Variance for Accuracy Scores (Mean Accuracy Scores i.e. mean accuracy across conditions)

Source	DF	MS	F	Sig. of F
Grade	3	44.980	21.174	0.0
1 vs. 2	1	3.165	1.49	NS
1 vs. 4	1	39.443	18.57	.01
1 vs. 6	1	806.780	379.84	.01
2 vs. 4	1	20.242	9.53	.01
2 vs. 6	1	708.843	333.73	.01
4 vs. 6	1	489.476	230.45	.01
Sex	1	.633	.298	.586
Order	3	2.514	1.184	.320
Grade x Sex	3	4.72	2.222	.091
Sex x Order	3	.765	.360	.782
Grade x Order	9	.797	.375	.944
Grade x Sex x Order	9	4.452	2.096	.037
Error	96	2.124		

Group 1--Table 2 **Analysis of Variance for Accuracy Scores for the Haptic-Haptic Condition**

Source	DF	MS	F	Sig. of F
Grade	3	65.352	12.247	.000
1 vs. 2	1	2.668	.50	NS
1 vs. 4	1	50.745	9.51	.01
1 vs. 6	1	102.504	19.21	.01
2 vs. 4	1	76.572	14.45	.01
2 vs. 6	1	138.096	25.88	.01
4 vs. 6	1	9.018	1.69	NS
Sex	1	1.320	2.474	.620
Order	3	7.195	1.384	.236
Grade x Sex	3	6.549	1.227	.304
Sex x Order	3	32.654	.497	.685
Grade x Order	9	98.674	1.626	.119
Grade x Sex x Order	9	9.133	.712	.097
Error	96	5.336		

Group 1--Table 3 **Analysis of Variance for Accuracy Scores for the Haptic-Visual Condition**

Source	DF	MS	F	Sig. of F
Grade	3	52.599	9.911	.000
1 vs. 2	1	4.551	.85	NS
1 vs. 4	1	22.555	4.25	<.05
1 vs. 6	1	135.116	25.46	<.01
2 vs. 4	1	6.899	1.30	NS
2 vs. 6	1	90.272	17.01	<.01
4 vs. 6	1	47.285	8.91	<.01
Sex	1	5.281	.995	.321
Order	3	7.195	1.348	.263
Grade x Sex	3	12.177	2.294	.083
Sex x Order	3	1.052	.198	.897
Grade x Order	9	2.958	.557	.829
Grade x Sex x Order	9	9.337	1.759	.086
Error	96		5.307	

Group 1–Table 4 Analysis of Variance for Accuracy Scores for the Visual-Haptic Condition

Source	DF	MS	F	Sig. of F
Grade	3	37.389	7.820	.000
1 vs. 2	1	4.016	.84	NS
1 vs. 4	1	17.020	3.56	NS
1 vs. 6	1	97.532	20.40	<.01
2 vs. 4	1	4.494	.94	NS
2 vs. 6	1	62.010	12.97	<.01
4 vs. 6	1	3.308	6.92	<.01
Sex	1	.781	.163	.806
Order	3	5.875	1.229	.304
Grade x Sex	3	7.719	1.614	.191
Sex x Order	3	4.281	.895	.447
Grade x Order	9	2.799	.585	.687
Grade x Sex x Order	9	9.246	1.934	.056
Error	96	4.781		

Group 1–Table 5 Analysis of Variance for Accuracy Scores for the Visual-Visual Condition

Source	DF	MS	F	Sig. of F
Grade	3	46.487	20.685	.000
1 vs. 2	1	21.391	9.52	<.01
1 vs. 4	1	83.251	37.05	<.01
1 vs. 6	1	112.867	50.23	<.01
2 vs. 4	1	20.245	9.01	<.01
2 vs. 6	1	35.997	16.02	<.01
4 vs. 6	1	2.247	1.00	NS
Sex	1	1.320	.587	.445
Order	3	7.195	1.348	.263
Grade x Sex	3	.654	.291	.832
Sex x Order	3	3.924	1.746	.163
Grade x Order	9	1.140	.507	.866
Grade x Sex x Order	9	2.369	1.054	.404
Error	96	2.247		

Group 1--Table 6 **Analysis of Variance for Accuracy Scores for the Haptic-Haptic vs. Haptic-Visual Conditions**

Source	DF	MS	F	Sig. of F
Condition	1	21.945	3.808	.054
Grade	3	13.258	2.301	.082
Sex	1	11.883	2.062	.154
Order	3	18.570	3.222	.026
Grade x Sex	3	3.445	.598	.618
Sex x Order	3	6.758	1.173	.324
Grade x Order	9	13.244	2.298	.022
Grade x Sex x Order	9	5.848	1.015	.434
Error	96	5.763		

Group 1--Table 7 **Analysis of Variance for Accuracy Scores Haptic-Haptic vs. Visual-Haptic Conditions**

Source	DF	MS	F	Sig. of F
Condition	1	.383	.054	.817
Grade	3	14.779	2.075	.109
Sex	1	4.133	.580	.448
Order	3	9.008	1.265	.291
Grade x Sex	3	2.570	.361	.781
Sex x Order	3	10.924	1.534	.211
Grade x Order	9	13.709	1.925	.057
Grade x Sex x Order	9	9.723	1.365	.215
Error	96	7.122		

Group 1--Table 8 **Analysis of Variance for Accuracy Scores for the Haptic-Haptic vs. Visual-Visual Conditions**

Source	DF	MS	F	Sig. of F
Condition	1	3633.781	590.259	0.0
Grade	3	16.115	2.618	.055
Sex	1	5.281	.858	.357
Order	3	8.531	1.386	.252
Grade x Sex	3	5.865	.953	.418
Sex x Order	3	12.615	2.049	.122
Grade x Order	9	7.865	1.278	.259
Grade x Sex x Order	9	10.198	1.657	.110
Error	96	6.156		

Group 1–Table 9 Analysis of Variance for Accuracy Scores for the Haptic-Visual vs. Visual-Haptic Conditions

Source	DF	MS	F	Sig. of F
Condition	1	28.125	5.033	.027
Grade	3	1.271	.227	.877
Sex	1	2.000	.358	.551
Order	3	1.854	.332	.802
Grade x Sex	3	5.354	.958	.416
Sex x Order	3	2.188	.391	.759
Grade x Order	9	7.111	1.272	.262
Grade x Sex x Order	9	3.931	.703	.704
Error	96	5.810		

Group 1–Table 10 Analysis of Variance for Accuracy Scores for the Haptic-Visual vs. Visual-Visual Conditions

Source	DF	MS	F	Sig. of F
Condition	1	4220.508	674.438	0.0
Grade	3	11.841	1.892	.136
Sex	1	1.320	.211	.647
Order	3	21.320	3.407	.021
Grade x Sex	3	8.529	1.363	.259
Sex x Order	3	.925	.148	.931
Grade x Order	9	2.904	.464	.895
Grade x Sex x Order	9	10.272	1.641	.144
Error	96	6.258		

Group 1–Table 11 Analysis of Variance for Accuracy Scores Visual-Haptic vs. Visual-Visual Conditions

Source	DF	MS	F	Sig. of F
Condition	1	3559.570	612.674	0.0
Grade	3	9.945	1.712	.170
Sex	1	.070	.012	.913
Order	3	12.633	2.174	.096
Grade x Sex	3	7.112	1.224	.305
Sex x Order	3	2.008	.346	.792
Grade x Order	9	4.702	.809	.609
Grade x Sex x Order	9	9.133	1.572	.135
Error	96	5.810		

Group 1–Table 12 **Analysis of Variance for Accuracy Scores (Split by Grade)**

Grade 1

Comparison	DF	MS	Error MS	F	Sig. of F
HH vs. HV	1,31	11.281	7.346	1.536	.225
HH vs. VH	1,31	.031	8.483	.004	.952
HH vs. VV	1,31	731.531	8.951	81.730	.000
HV vs. VH	1,31	12.500	6.952	1.798	.190
HV vs. VV	1,31	924.500	8.242	112.170	.000
VH vs. VV	1,31	722.000	6.581	109.716	.000

Group 1–Table 13 **Analysis of Variance for Accuracy Scores (Split by Grade)**

Grade 2

Comparison	DF	MS	Error MS	F	Sig. of F
HH vs. HV	1,31	3.781	5.136	.736	.397
HH vs. VH	1,31	28.125	7.415	3.793	.061
HH vs. VV	1,31	1287.781	7.910	162.798	.000
HV vs. VH	1,31	11.281	3.797	2.971	.095
HV vs. VV	1,31	1152.000	4.903	234.947	.000
VH vs. VV	1,31	935.281	4.959	188.615	.000

Group 1–Table 14 Analysis of Variance for Accuracy Scores (Split by Grade)

Grade 4

Comparison	DF	MS	Error MS	F	Sig. of F
HH vs. HV	1,31	45.125	5.125	8.805	.006
HH vs. VH	1,31	16.531	6.531	2.531	.122
HH vs. VV	1,31	89.531	4.596	194.207	.000
HV vs. VH	1,31	5.031	266.143	1.677	.205
HV vs. VV	1,31	1339.031	5.031	266.143	.000
VH vs. VV	1,31	1152.000	6.129	187.958	.000

Group 1–Table 15 Analysis of Variance for Accuracy Scores (Split by Grade)

Grade 6

Comparison	DF	MS	Error MS	F	Sig. of F
HH vs. HV	1,31	1.531	8.951	.171	.682
HH vs. VH	1,31	.031	8.741	.004	.953
HH vs. VV	1,31	770.281	5.636	136.669	.000
HV vs. VH	1,31	1.125	6.544	.172	.681
HV vs. VV	1,31	840.500	8.048	104.431	.000
VH vs. VV	1,31	780.125	6.448	120.995	.000

Group 1–Table 16 Analysis of Variance for Exploration Strategy Scores

Dependent Variables:
HHS
HHC1
HHC2
HVS
VHC1
VHC2

Factor	DF	F	Sig. of F
Stimuli	6,91	5933.003	.0001
Grade	18,258	4.773	.0001
Sex	6,91	.439	.851
Order	18,258	1.511	.086
Grade x Sex	18,258	.453	.974
Sex x Order	18,258	.473	.968
Grade x Order	54,469	1.214	.151
Grade x Sex x Order	54,469	1.031	.491

Univariate Analyses for the factor Grade

Factor	DF	MS	F	Sig. of F
Variable: HHS				
Grade	3	1.882	24.224	.0001
Error	96	.066		
Variable: HHC1				
Grade	3	1.311	19.935	.0001
Error	96	.058		
Variable HHC2				
Grade	3	1.278	20.619	.0001
Error	96	.062		
Variable HVS				
Grade	3	1.250	20.727	.0001
Error	96	.060		

Variable VHC1

Grade	3	.627	6.906	.0003
Error	96	.091		

Variable VHC2

Grade	3	.593	7.336	.0002
Error	96	.081		

Group 1–Table 17-C Analysis of Variance for Exploration Strategy Scores

Dependent Variables: HHS vs. HHC1 + HHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	12.566	406.199	.0001
Grade	3	.120	3.888	.011
Sex	1	.000	.001	.974
Order	3	.020	.637	.593
Grade x Sex	3	.007	.231	.875
Sex x Order	3	.001	.030	.993
Grade x Order	9	.044	1.430	.186
Grade x Sex x Order	9	.013	.414	.925
Error	96	.015		

Group 1–Table 18 Analysis of Variance for Exploration Strategy Scores

Dependent Variables: HHS vs. HHC1

Factor	DF	MS	F	Sig. of F
Stimuli	1	10.597	372.136	.0001
Grade	3	.091	3.179	.027
Sex	1	.004	.138	.711
Order	3	.026	.900	.444
Grade x Sex	3	.002	.083	.969
Sex x Order	3	.000	.006	.999
Grade x Order	9	.048	1.672	.106
Grade x Sex x Order	9	.015	.513	.862
Error	96	.028		

Group 1–Table 19 **Analysis of Variance for Exploration Strategy Scores**

Dependent Variables: HHS vs. HHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	14.702	398.309	.0001
Grade	3	.167	4.534	.005
Sex	1	.003	.071	.790
Order	3	.016	.447	.720
Grade x Sex	3	.015	.398	.755
Sex x Order	3	.003	.072	.975
Grade x Order	9	.046	1.233	.284
Grade x Sex x Order	9	.014	.374	.945
Error	96	.037		

Group 1–Table 20 **Analysis of Variance for Exploration Strategy Scores**

Dependent Variables: HHS vs. HVS

Factor	DF	MS	F	Sig. of F
Stimuli	1	.037	.557	.457
Grade	3	.074	1.135	.339
Sex	1	.013	.196	.659
Order	3	.110	1.674	.178
Grade x Sex	3	.050	.770	.514
Sex x Order	3	.054	.817	.488
Grade x Order	9	.083	1.261	.268
Grade x Sex x Order	9	.156	2.379	.018
Error	96	.065		

Group 1–Table 21 **Analysis of Variance for Exploration Strategy Scores**

Dependent Variables: HHC1 vs. HHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	.335	47.643	.0001
Grade	3	.036	5.068	.003
Sex	1	.031	1.848	.177
Order	3	.005	.768	.515
Grade x Sex	3	.006	.780	.508
Sex x Order	3	.002	.270	.847
Grade x Order	9	.009	1.318	.238
Grade x Sex x Order	9	.006	.805	.613
Error	96	.007		

Group 1–Table 22 **Analysis of Variance for Exploration Strategy Scores**

Dependent Variables: VHC1 vs. VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	.403	26.957	.001
Grade	3	.024	1.607	.193
Sex	1	.000	.002	.966
Order	3	.026	1.705	.171
Grade x Sex	3	.004	.277	.842
Sex x Order	3	.007	.440	.725
Grade x Order	9	.023	.849	.573
Grade x Sex x Order	9	.010	.657	.746
Error	96	.015		

Group 1–Table 23 Analysis of Variance for Exploration Strategy Scores

Dependent Variables: HHC1 + HHC2 vs. VHC1 + VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	1.609	4.334	.040
Grade	3	.457	1.230	.303
Sex	1	.000	.001	.978
Order	3	.590	1.590	.197
Grade x Sex	3	.242	.652	.584
Sex x Order	3	.110	.294	.828
Grade x Order	9	.474	1.277	.259
Grade x Sex x Order	9	.622	1.676	.105
Error	96	.371		

Group 1–Table 24 Analysis of Variance for Exploration Strategy Scores

Dependent Variables: HHC1 vs. VHC1

Factor	DF	MS	F	Sig. of F
Stimuli	1	.368	3.421	.068
Grade	3	.193	1.792	.154
Sex	1	.003	.025	.876
Order	3	.108	1.009	.392
Grade x Sex	3	.068	.631	.597
Sex x Order	3	.021	.199	.897
Grade x Order	9	.136	1.270	.264
Grade x Sex x Order	9	.184	1.713	.096
Error	96	.107		

Group 1–Table 25 **Analysis of Variance for Exploration Strategy Scores**

Dependent Variables: HHC2 vs. VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	.438	4.937	.068
Grade	3	.057	.641	.591
Sex	1	.005	.052	.820
Order	3	.208	2.339	.078
Grade x Sex	3	.061	.685	.564
Sex x Order	3	.038	.428	.734
Grade x Order	9	.111	1.224	.278
Grade x Sex x Order	9	.136	1.527	.149
Error	96	.089		

Group 1–Table 26 **Analysis of Variance for Exploration Strategy Scores**

Dependent Variables: HHS vs. VHC1 + VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	17.464	158.019	.0001
Grade	3	.381	3.473	.019
Sex	1	.000	.002	.966
Order	3	.273	2.484	.066
Grade x Sex	3	.058	.524	.667
Sex x Order	3	.028	.255	.858
Grade x Order	9	.156	1.420	.190
Grade x Sex x Order	9	.167	1.524	.150
Error	96	.110		

Group 1–Table 27 Analysis of Variance for Exploration Strategy Scores

Dependent Variables: HHS vs. VHC1

Factor	DF	MS	F	Sig. of F
Stimuli	1	14.913	126.512	.0001
Grade	3	.407	3.450	.020
Sex	1	.000	.001	.973
Order	3	.236	2.006	.118
Grade x Sex	3	.070	.596	.619
Sex x Order	9	.148	1.252	.274
Grade x Sex x Order	9	.173	1.470	.170
Error	96	.118		

Group 1–Table 28 Analysis of Variance for Exploration Strategy Scores

Dependent Variables: HHS vs. VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	18.536	210.635	.0001
Grade	3	.123	1.398	.248
Sex	1	.009	.106	.746
Order	3	.099	1.119	.345
Grade x Sex	3	.071	.808	.493
Sex x Order	3	.034	.386	.763
Grade x Order	9	.129	1.463	.173
Grade x Sex x Order	9	.080	.905	.525
Error	96	.088		

Group 1--Table 29 Analysis of Variance for Exploration Strategy Scores

Dependent Variables: HVS vs. VHC1 + VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	15.905	176.189	.0001
Grade	3	.122	1.354	.262
Sex	1	.010	.109	.743
Order	3	.089	.975	.408
Grade x Sex	3	.071	.789	.503
Sex x Order	3	.031	.344	.793
Grade x Order	9	.118	1.301	.246
Grade x Sex x Order	9	.073	.812	.607
Error	96	.118		

Group 1--Table 30 Analysis of Variance for Exploration Strategy Scores

Dependent Variables: HVS vs. VHC1

Factor	DF	MS	F	Sig. of F
Stimuli	1	13.475	134.732	.0001
Grade	3	.134	1.335	.268
Sex	1	.010	.103	.749
Order	3	.090	.903	.443
Grade x Sex	3	.074	.735	.534
Sex x Order	3	.032	.315	.815
Grade x Order	9	.113	1.126	.353
Grade x Sex x Order	9	.072	.718	.691
Error	96	.100		

Group 1–Table 31 **Analysis of Variance for Exploration Strategy Scores**

Dependent Variables: HVS vs. VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	18.536	210.635	.0001
Grade	3	.123	1.398	.248
Sex	1	.009	.106	.746
Order	3	.009	1.119	.345
Grade x Sex	3	.071	.808	.493
Sex x Order	3	.034	.386	.763
Grade x Order	9	.129	1.463	.173
Grade x Sex x Order	9	.080	.905	.525
Error	96	.088		

Group 1–Table 38 Analysis of Variance for Exploration Times

Dependent Variables:
HHS + HHC1 + HHC2 + HVS + VHC1 + VHC2
versus HVC1 + HVC2 + VHS + VVS + VVC1 + VVC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	14622.445	367.238	.0001
Grade	3	255.656	6.421	.0006
Sex	1	94.251	2.367	.127
Order	3	97.295	2.444	.069
Grade x Sex	3	30.203	.759	.520
Sex x Order	3	29.773	.748	.523
Grade x Order	9	59.851	1.503	.158
Grade x Sex x Order	9	45.500	1.143	.341
Error	96	39.817		

Group 1– Table 39 **Analysis of Variance for Exploration Times**

Dependent Variables:
HHS + HHC1 + HHC2
versus HVS + HVC1 +HVC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	10.335	.363	.584
Grade	3	15.710	.552	.648
Sex	1	43.351	1.524	.220
Order	3	110.657	3.890	.011
Grade x Sex	3	47.896	1.680	.177
Grade x Order	9	47.796	1.684	.104
Grade x Sex x Order	9	33.191	1.167	.325
Error	96	28.450		

Group 1–Table 40 **Analysis of Variance for Exploration Times**

Dependent Variables:
HHS + HHC1 + HHC2
versus VHS + VHC1 + VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	14.174	.802	.373
Grade	3	27.707	1.569	.202
Sex	1	23.424	1.326	.252
Order	3	75.716	4.286	.007
Grade x Sex	3	15.030	.851	.470
Sex x Order	3	17.859	1.011	.437
Grade x Order	9	6.854	.388	.762
Grade x Sex x Order	9	29.848	1.690	.102
Error	96	17.664		

Group 1--Table 41 Analysis of Variance for Exploration Times

Dependent Variables:
HHS + HHC1 + HHC2
versus VVS + VVC1 +VVC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	6385.997	404.167	.0001
Grade	3	47.825	3.027	.033
Sex	1	15.489	.980	.325
Order	3	58.429	3.698	.015
Grade x Sex	3	1.216	.077	.927
Sex x Order	3	17.195	1.088	.379
Grade x Order	9	12.560	.795	.500
Grade x Sex x Order	9	22.662	1.434	.184
Error	96	15.800		

Group 1--Table 42 Analysis of Variance for Exploration Times

Dependent Variables:
HVS + HVC1 + HVC2
versus VHS + VHC1 + VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	.303	.009	.923
Grade	3	9.958	.307	.821
Sex	1	3.043	.094	.760
Order	3	15.396	.474	.701
Grade x Sex	3	30.109	.927	.431
Sex x Order	3	31.713	.976	.465
Grade x Order	9	89.991	2.771	.046
Grade x Sex x Order	9	64.235	1.978	.050
Error	96	32.481		

Group 1–Table 43 **Analysis of Variance for Exploration Times**

Dependent Variables:
HVS + HVC1 + HVC2
versus VVS + VVC1 +VVC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	5882.532	218.264	.0001
Grade	3	18.037	.669	.573
Sex	1	7.015	.260	.611
Order	3	94.828	3.519	.018
Grade x Sex	3	9.865	.366	.778
Sex x Order	3	41.156	1.526	.150
Grade x Order	9	69.843	2.591	.057
Grade x Sex x Order	9	36.449	1.352	.221
Error	96	26.951		

Group 1–Table 44 **Analysis of Variance for Exploration Times**

Dependent Variables:
VHS + VHC1 + VHC2
versus VVS + VVC1 +VVC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	8798.460	457.931	.0001
Grade	3	3.427	.271	.847
Sex	1	.818	.065	.800
Order	3	41.565	3.283	.024
Grade x Sex	3	22.622	1.787	.155
Sex x Order	3	22.701	1.793	.079
Grade x Order	9	12.129	.958	.416
Grade x Sex x Order	9	18.380	1.452	.177
Error	96	12.662		

Group 1–Table 45-C **Analysis of Variance for Exploration Times**

Dependent Variables:
HHS vs. HHC1 + HHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	44.990	416.980	.0001
Grade	3	4.266	2.388	.074
Sex	1	.003	.001	.970
Order	3	4.043	2.263	.086
Grade x Sex	3	.104	.058	.982
Sex x Order	3	.371	.208	.891
Grade x Order	9	3.046	1.705	.098
Grade x Sex x Order	9	2.357	1.319	.237
Error	96	1.787		

Group 1–Table 46 **Analysis of Variance for Exploration Times**

Dependent Variables:
HHS vs. HHC1

Factor	DF	MS	F	Sig. of F
Stimuli	1	626.407	404.692	.0001
Grade	3	3.253	2.102	.105
Sex	1	.007	.005	.964
Order	3	5.481	3.541	.018
Grade x Sex	3	.203	.131	.942
Sex x Order	3	.607	.392	.759
Grade x Order	9	2.660	1.719	.095
Grade x Sex x Order	9	2.433	1.572	.135
Error	96	1.548		

Group 1–Table 47 Analysis of Variance for Exploration Times

Dependent Variables:
HHS vs. HHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	873.845	383.854	.0001
Grade	3	5.478	2.406	.072
Sex	1	.035	.015	.902
Order	3	2.937	1.290	.282
Grade x Sex	3	.462	.203	.894
Sex x Order	3	.217	.095	.963
Grade x Order	9	3.798	1.668	.107
Grade x Sex x Order	9	2.510	1.103	.369
Error	96	2.277		

Group 1–Table 48 Analysis of Variance for Exploration Times

Dependent Variables:
VVS vs. VVC1 + VVC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	65.545	100.172	.0001
Grade	3	1.238	1.817	.136
Sex	1	1.218	1.861	.176
Order	3	.652	.981	.405
Grade x Sex	3	.069	.105	.957
Sex x Order	3	.163	.249	.862
Grade x Order	9	1.207	1.845	.070
Grade x Sex x Order	9	1.088	1.663	.109
Error	96	1.209		

Group 1–Table 49 **Analysis of Variance for Exploration Times**

Dependent Variables:
VVS vs. VVC1

Factor	DF	MS	F	Sig. of F
Stimuli	1	75.468	125.616	.0001
Grade	3	.916	1.525	.213
Sex	1	2.410	3.562	.062
Order	3	.330	.550	.650
Grade x Sex	3	.187	.312	.817
Sex x Order	3	.091	.152	.928
Grade x Order	9	1.215	2.023	.045
Grade x Sex x Order	9	.948	1.587	.133
Error	96	.601		

Group 1–Table 50 **Analysis of Variance for Exploration Times**

Dependent Variables:
VVS vs. VVC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	56.321	70.275	.0001
Grade	3	1.676	2.091	.107
Sex	1	.554	.691	.408
Order	3	1.121	1.398	.248
Grade x Sex	3	.045	.056	.982
Sex x Order	3	.259	.324	.808
Grade x Order	9	1.340	1.672	.107
Grade x Sex x Order	9	1.326	1.655	.111
Error	96	.801		

Group 1--Table 51 **Analysis of Variance for Exploration Times**

Dependent Variables:
HHS, HHC1, HHC2, HVS, VHC1, VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	133294.462	2245.977	.0001
Grade	3	141.323	2.381	.074
Sex	1	15.297	.258	.613
Order	3	234.945	3.959	.011
Grade x Sex	3	23.713	.400	.754
Sex x Order	3	88.264	1.487	.223
Grade x Order	9	112.504	1.896	.062
Grade x Sex x Order	9	82.287	1.387	.205
Error	96	18.484		

Group 1--Table 52 **Analysis of Variance for Exploration Times**

Dependent Variables:
HVC1, HVC2, VVS, VVC1, VVC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	59619. 897	2562.470	.0001
Grade	3	30.488	1.310	.276
Sex	1	33.607	1.444	.232
Order	3	54.471	2.341	.078
Grade x Sex	3	5.759	.248	.863
Sex x Order	3	33.015	1.419	.242
Grade x Order	9	48.388	2.080	.039
Grade x Sex x Order	9	34.341	1.476	.168
Error	96	27.154		

Group 1--Table 53 **Analysis of Variance for Exploration Times**

Dependent Variable: HHS

Factor	DF	MS	F	Sig. of F
Grade	3	1063.992	2.271	.085
Sex	1	133.764	.268	.594
Order	3	1648.105	3.577	.018
Grade x Sex	3	15.836	.034	.992
Sex x Order	3	379.050	.809	.492
Grade x Order	9	613.419	1.309	.242
Grade x Sex x Order	9	698.804	1.491	.162
Error	96	468.568		

Group 1--Table 54 **Analysis of Variance for Exploration Times**

Dependent Variable: HHC1

Factor	DF	MS	F	Sig. of F
Grade	3	214.615	1.469	.228
Sex	1	154.177	1.055	.307
Order	3	375.370	2.569	.059
Grade x Sex	3	24.837	.170	.917
Sex x Order	3	239.550	1.645	.184
Grade x Order	9	194.503	1.331	.231
Grade x Sex x Order	9	141.810	.971	.469
Error	96	146.125		

Group 1--Table 55 Analysis of Variance for Exploration Times

Dependent Variable: HHC2

Factor	DF	MS	F	Sig. of F
Grade	3	115.250	.731	.502
Sex	1	94.119	.646	.424
Order	3	564.267	3.874	.012
Grade x Sex	3	29.429	.202	895
Sex x Order	3	239.550	1 645	.184
Grade x Order	9	191.073	1 312	.241
Grade x Sex x Order	9	206.155	1 415	192
Error	96	145.652		

Group 1--Table 56 Analysis of Variance for Exploration Times

Dependent Variable: HVS

Factor	DF	MS	F	Sig. of F
Grade	3	2081.355	3.299	.024
Sex	1	83.835	.133	.716
Order	3	3026.151	4.796	.004
Grade x Sex	3	416.217	.660	.579
Sex x Order	3	1675.240	2.655	.053
Grade x Order	9	1418.642	2.248	.025
Grade x Sex x Order	9	1117.799	1.772	.084
Error	96	630.950		

Group 1--Table 57 **Analysis of Variance for Exploration Times**

Dependent Variable: HVC1

Factor	DF	MS	F	Sig. of F
Grade	3	117.468	.387	.763
Sex	1	48.229	.159	.691
Order	3	392.419	1.293	.282
Grade x Sex	3	28.033	.092	.964
Sex x Order	3	697.226	2.297	.083
Grade x Order	9	467.384	1.540	.145
Grade x Sex x Order	9	328.344	1.082	.384
Error	96	303.586		

Group 1--Table 58 **Analysis of Variance for Exploration Times**

Dependent Variable: HVC2

Factor	DF	MS	F	Sig. of F
Grade	3	520.666	1.546	.208
Sex	1	257.815	.766	.384
Order	3	842.472	2.502	.064
Grade x Sex	3	232.175	.690	.561
Sex x Order	3	437.267	1.299	.279
Grade x Order	9	324.444	.964	.475
Grade x Sex x Order	9	275.057	.817	.602
Error	96	336.688		

Group 1--Table 59 **Analysis of Variance for Exploration Times**

Dependent Variable: VHS

Factor	DF	MS	F	Sig. of F
Grade	3	176.821	.469	.704
Sex	1	858.378	2.279	.135
Order	3	535.045	1.420	.242
Grade x Sex	3	435.190	1.155	.331
Sex x Order	3	448.157	1.190	.386
Grade x Order	9	677.521	1.799	.078
Grade x Sex x Order	9	691.074	1.835	.072
Error	96	376.685		

Group 1--Table 60 **Analysis of Variance for Exploration Times**

Dependent Variable: VHC1

Factor	DF	MS	F	Sig. of F
Grade	3	188.590	.851	.470
Sex	1	.121	.001	.981
Order	3	373.279	1.684	.176
Grade x Sex	3	359.951	1.624	.189
Sex x Order	3	226.641	1.022	.386
Grade x Order	9	408.654	1.843	.070
Grade x Sex x Order	9	214.402	.967	472
Error	96	221.687		

Group 1--Table 61 **Analysis of Variance for Exploration Times**

Dependent Variable: VHC2

Factor	DF	MS	F	Sig. of F
Grade	3	48.962	.276	.842
Sex	1	222.974	1.258	.265
Order	3	688.522	3.886	.012
Grade x Sex	3	199.652	1.127	.342
Sex x Order	3	287.308	1.621	.190
Grade x Order	9	271.757	1.534	.147
Grade x Sex x Order	9	223.820	1.263	.267
Error	96	177.203		

Group 1--Table 62 **Analysis of Variance for Exploration Times**

Dependent Variable: VVS

Factor	DF	MS	F	Sig. of F
Grade	3	69.804	.901	.444
Sex	1	85.511	1.103	.296
Order	3	22.387	.289	.833
Grade x Sex	3	35.815	.462	.710
Sex x Order	3	62.220	.803	.496
Grade x Order	9	138.580	1.788	.080
Grade x Sex x Order	9	135.389	1.747	.089
Error	96	77.520		

Group 1–Table 63 **Analysis of Variance for Exploration Times**

Dependent Variable: VVC1

Factor	DF	MS	F	Sig. of F
Grade	3	49.071	1.751	.162
Sex	1	28.966	1.033	.312
Order	3	14.697	.524	.667
Grade x Sex	3	7.759	.277	.842
Sex x Order	3	39.992	1.427	.240
Grade x Order	9	32.925	1.175	.320
Grade x Sex x Order	9	27.074	.966	.473
Error	96	28.030		

Group 1–Table 64 **Analysis of Variance for Exploration Times**

Dependent Variable: VVC2

Factor	DF	MS	F	Sig. of F
Grade	3	108.834	3.820	.012
Sex	1	3.264	.115	.736
Order	3	40.113	1.408	.245
Grade x Sex	3	32.202	1.130	.341
Sex x Order	3	32.564	1.143	.336
Grade x Order	9	32.462	1.139	.343
Grade x Sex x Order	9	13.200	.463	.896
Error	96	28.490		

Group 1--Table 65 **Analysis of Variance for Exploration Times**

Dependent Variables:
HHS vs. HVS

Factor	DF	MS	F	Sig. of F
Stimuli	1	38.839	6.485	.013
Grade	3	3.739	.624	.601
Sex	1	4.294	.717	.399
Order	3	22.120	3.693	.015
Grade x Sex	3	4.618	.771	.513
Sex x Order	3	14.425	2.408	.072
Grade x Order	9	7.466	1.247	.277
Grade x Sex x Order	9	5.564	.299	.504
Error	96	5.990		

Group 1--Table 66 **Analysis of Variance for Exploration Times**

Dependent Variables:
VHS vs. VVS

Factor	DF	MS	F	Sig. of F
Stimuli	1	619.419	240.590	.0001
Grade	3	2.656	1.032	.382
Sex	1	4.020	1.562	.215
Order	3	5.108	1.984	.122
Grade x Sex	3	7.009	2.723	.059
Sex x Order	3	2.488	.996	.412
Grade x Order	9	3.126	1.214	.295
Grade x Sex x Order	9	3.029	1.177	.319
Error	96	2.575		

Group 1–Table 67 **Analysis of Variance for Exploration Times**

Dependent Variables:
HHC1 vs. HHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	20.546	40.912	.0001
Grade	3	.399	.794	.501
Sex	1	.074	.147	.703
Order	3	.665	1.323	.271
Grade x Sex	3	.915	1.821	.149
Sex x Order	3	.163	.325	.808
Grade x Order	9	.734	1.461	.174
Grade x Sex x Order	9	.459	.915	.516
Error	96	.502		

Group 1--Table 68 **Analysis of Variance for Exploration Times**

Dependent Variables:
VHC1 vs. VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	55.910	46.246	.0001
Grade	3	1.744	1.443	.235
Sex	1	2.335	1.931	.168
Order	3	.508	.420	.739
Grade x Sex	3	.275	.228	.877
Sex x Order	3	.537	.444	.722
Grade x Order	9	.887	.733	.678
Grade x Sex x Order	9	.672	.556	.830
Error	96	1.209		

Group 1--Table 69 **Analysis of Variance for Exploration Times**

Dependent Variables:
HHC1 + HHC2 vs. VHC1 + VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	116.285	20.533	.0001
Grade	3	.735	.130	.942
Sex	1	.568	.100	.752
Order	3	30.325	5.355	.002
Grade x Sex	3	8.810	1.556	.205
Sex x Order	3	2.585	.466	.072
Grade x Order	9	8.147	1.439	.183
Grade x Sex x Order	9	6.538	1.154	.333
Error	96	5.663		

Group 1--Table 70 **Analysis of Variance for Exploration Times**

Dependent Variables:
HHC1 vs. VHC1

Factor	DF	MS	F	Sig. of F
Stimuli	1	15.362	9.232	.003
Grade	3	.659	.396	.756
Sex	1	.274	.164	.686
Order	3	9.005	5.411	.002
Grade x Sex	3	2.482	1.492	.222
Sex x Order	3	.830	.499	.684
Grade x Order	9	2.058	1.237	.282
Grade x Sex x Order	9	1.885	1.133	.348
Error	96	1.664		

Group 1–Table 71 **Analysis of Variance for Exploration Times**

Dependent Variables:
HHC2 vs. VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	15.362	9.232	.003
Grade	3	.659	.396	.756
Sex	1	.274	.164	.686
Order	3	9.005	5.441	.002
Grade x Sex	3	2.482	1.492	.222
Sex x Order	3	.830	.499	.684
Grade x Order	9	2.058	1.237	.282
Grade x Sex x Order	9	1.885	1.133	.348
Error	96	1.664		

Group 1–Table 72 **Analysis of Variance for Exploration Times**

Dependent Variables:
HVC1 vs. HVC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	119.179	76.990	.0001
Grade	3	6.755	4.364	.006
Sex	1	.830	.536	.466
Order	3	1.594	1.030	.383
Grade x Sex	3	1.633	1.055	.372
Sex x Order	3	3.611	2.333	.079
Grade x Order	9	1.598	1.032	.420
Grade x Sex x Order	9	.821	.531	.849
Error	96	1.548		

Group 1–Table 73 **Analysis of Variance for Exploration Times**

Dependent Variables:
VVC1 vs. VVC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	1.398	7.472	.008
Grade	3	.233	1.247	.297
Sex	1	.517	2.761	.010
Order	3	.335	1.792	.154
Grade x Sex	3	.190	1.017	.389
Sex x Order	3	.050	.268	.848
Grade x Order	9	.281	1.501	.159
Grade x Sex x Order	9	.196	1.046	.410
Error	96	.187		

Group 1--Table 74 **Analysis of Variance for Exploration Times**

Dependent Variables:
HVC1 + HVC2 vs. VVC1 + VVC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	962.804	82.697	.0001
Grade	3	1.388	.119	.949
Sex	1	7.063	.607	.438
Order	3	22.813	1.960	.125
Grade x Sex	3	6.069	.521	.669
Sex x Order	3	20.259	1.740	.164
Grade x Order	9	12.008	1.031	.421
Grade x Sex x Order	9	10.471	.899	.529
Error	96	11.643		

Group 1--Table 75 Analysis of Variance for Exploration Times

Dependent Variables:
HVC1 vs. VVC1

Factor	DF	MS	F	Sig. of F
Stimuli	1	465.018	144.575	.0001
Grade	3	1.357	.422	.738
Sex	1	1.520	.472	.494
Order	3	2.824	.878	.456
Grade x Sex	3	.541	.168	.918
Sex x Order	3	8.001	2.488	.065
Grade x Order	9	3.694	1.149	.337
Grade x Sex x Order	9	3.497	1.087	.380
Error	96	3.216		

Group 1--Table 76 Analysis of Variance for Exploration Times

Dependent Variables:
HVC2 vs. VVC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	89.583	26.112	.0001
Grade	3	2.278	.644	.576
Sex	1	2.031	.592	.444
Order	3	10.265	2.992	.035
Grade x Sex	3	3.622	1.056	.372
Sex x Order	3	4.348	1.267	.290
Grade x Order	9	3.318	.967	.472
Grade x Sex x Order	9	2.260	.659	.744
Error	96	3.431		

Group 1–Table 77 **Analysis of Variance for Exploration Times**

Dependent Variables:
HHS vs. VHC1 + VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	479.729	130.464	.0001
Grade	3	6.186	1.682	.176
Sex	1	.183	.050	.824
Order	3	14.612	3.974	.010
Grade x Sex	3	1.832	.498	.685
Sex x Order	3	.774	.211	.889
Grade x Order	9	3.191	.868	.557
Grade x Sex x Order	9	6.286	1.705	.098
Error	96	3.677		

Group 1–Table 78 **Analysis of Variance for Exploration Times**

Dependent Variables:
HHS vs. VHC1

Factor	DF	MS	F	Sig. of F
Stimuli	1	329.934	94.035	.0001
Grade	3	6.057	1.726	.167
Sex	1	1.419	.405	.526
Order	3	14.051	4.005	.010
Grade x Sex	3	2.556	.728	.538
Sex x Order	3	1.066	.304	.823
Grade x Order	9	3.150	.898	.531
Grade x Sex x Order	9	5.840	1.664	.108
Error	96	3.509		

Group 1--Table 79 **Analysis of Variance for Exploration Times**

Dependent Variables:
HHS vs. VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	657.480	147.746	.0001
Grade	3	7.188	1.615	.191
Sex	1	.113	.026	.874
Order	3	15.427	3.467	.019
Grade x Sex	3	1.254	.280	.840
Sex x Order	9	.750	.169	.917
Grade x Order	9	3.676	.826	.594
Grade x Sex x Order	9	7.033	1.580	.132
Error	96	4 450		

Group 1--Table 80 **Analysis of Variance for Exploration Times**

Dependent Variables:
HVS vs. VHC1 + VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	791.567	146.563	.0001
Grade	3	13.658	2.529	.062
Sex	1	2.705	.501	.481
Order	3	11.092	2.054	.112
Grade x Sex	3	5.449	1.009	.392
Sex x Order	3	19.895	3.684	.015
Grade x Order	9	7.431	1.376	.210
Grade x Sex x Order	9	12.348	2.286	.023
Error	96	5.401		

Group 1--Table 81 **Analysis of Variance for Exploration Times**

Dependent Variables:
HVS vs. VHC1

Factor	DF	MS	F	Sig. of F
Stimuli	1	559.172	115.306	.0001
Grade	3	11.253	2.180	.095
Sex	1	.776	.150	.700
Order	3	13.180	2.553	.060
Grade x Sex	3	5.753	1.145	.347
Sex x Order	3	19.735	3.823	.012
Grade x Order	9	6.563	1.272	.262
Grade x Sex x Order	9			
Error	96	5.162		

Group 1--Table 82 **Analysis of Variance for Exploration Times**

Dependent Variables:
HVS vs. VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	1015.917	162.694	.0001
Grade	3	16.935	2.712	.049
Sex	1	5.803	.929	.338
Order	3	9.258	1.483	.224
Grade x Sex	3	5.282	.846	.472
Sex x Order	3	20.324	3.255	.025
Grade x Order	9	8.741	1.400	.199
Grade x Sex x Order	9	13.995	2.241	.026
Error	96	5.244		

Group 1--Table 83 **Analysis of Variance for Exploration Times**

Dependent Variables:
VHS vs. VVC1 + VVC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	1087.951	313.622	.0001
Grade	3	.282	.081	970
Sex	1	9.663	2.786	098
Order	3	4.819	1.389	.251
Grade x Sex	3	5.772	1.664	180
Sex x Order	3	2.370	.683	.565
Grade x Order	9	5.668	1.634	.116
Grade x Sex x Order	9	6.306	1.818	.075
Error	27	3.469		

Group 1--Table 84 **Analysis of Variance for Exploration Times**

Dependent Variables:
VHS vs. VVC1

Factor	DF	MS	F	Sig. of F
Stimuli	1	1127.306	339.120	.0001
Grade	3	.553	.166	.919
Sex	1	12.027	3.618	.060
Order	3	4.249	1.278	.286
Grade x Sex	3	5.253	1.580	199
Sex x Order	3	2.326	.700	.555
Grade x Order	9	5.885	1.770	.084
Grade x Sex x Order	9	5.945	1.788	.080
Error	96	3.324		

Group 1–Table 85 **Analysis of Variance for Exploration Times**

Dependent Variables:
VHS vs. VVC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	123.056	39.210	.0001
Grade	3	3.735	1.980	.318
Sex	1	19.563	6.234	.014
Order	3	.416	.014	.234
Grade x Sex	3	4.681	1.492	.222
Sex x Order	3	.564	.174	.914
Grade x Order	9	3.300	1.052	.406
Grade x Sex x Order	9	3.883	1.237	.282
Error	96	3.138		

Analyses of Variance for Study 2

Group 2—Table 1 Analysis of Variance for Accuracy Scores* (Mean Accuracy Scores i.e. mean accuracy across conditions)

Source	DF	MS	F	Sig. of F
Grade	3	57.626	36.495	.000
1 vs. 2	1	12.443	7.88	<.01
1 vs. 4	1	55.707	35.28	<.01
1 vs. 6	1	156.259	98.96	<.01
2 vs. 4	1	15.490	9.81	<.01
2 vs. 6	1	80.497	50.98	<.01
4 vs. 6	1	25.359	16.06	<.01
Sex	1	1.758	1.113	.259
Order	3	.451	.285	.836
Grade x Sex	3	1.462	.926	.431
Sex x Order	3	1.187	.752	.524
Grade x Order	9	1.216	.770	.644
Grade x Sex x Order	9	.906	.574	.816
Error	96	1.579	—	

Group 2--Table 2 **Analysis of Variance for Accuracy Scores for the Haptic-Haptic Condition**

Source	DF	MS	F	Sig. of F
Grade	3	30.841	6.33	.001
1 vs. 2	1	24.933	5.13	<.05
1 vs. 4	1	47.210	9.69	<.01
1 vs. 6	1	85.504	17.55	<.01
2 vs. 4	1	3.508	.72	NS
2 vs. 6	1	18.026	3.70	NS
4 vs. 6	1	5.649	1.16	NS
Sex	1	4.133	.849	.359
Order	3	2.008	.412	.745
Grade x Sex	3	16.674	3.422	.020
Sex x Order	3	6.091	1.250	.296
Grade x Order	9	2.230	.458	.899
Grade x Sex x Order	9	7.022	1.411	.182
Error	96	4.872		

Group 2--Table 3 **Analysis of Variance for Accuracy Scores for the Haptic-Visual Condition**

Source	DF	MS	F	Sig. of F
Grade	3	117.646	24.932	.000
1 vs. 2	1	9.957	2.11	NS
1 vs. 4	1	87.821	18.61	<.01
1 vs. 6	1	194.800	41.28	<.01
2 vs. 4	1	38.601	8.18	<.01
2 vs. 6	1	116.606	24.71	<.01
4 vs. 6	1	21.047	4.46	<.05
Sex	1	16.531	3.503	.064
Order	3	17.125	3.629	.016
1 vs. 2	1	4.011	.85	NS
1 vs. 3	1	20.245	4.29	<.05
1 vs. 4	1	9.013	1.91	NS
2 vs. 3	1	42.235	8.95	<.01
2 vs. 4	1	25.010	5.30	<.05
3 vs. 4	1	2.265	.48	NS
Grade x Sex	3	.510	.108	.955
Sex x Order	3	5.865	1.243	.299
Grade x Order	9	2.576	.546	.836
Grade x Sex x Order	9	3.483	.738	.673
Error	96	4.719		

Group 2–Table 4 Analysis of Variance for Accuracy Scores for the Visual-Haptic Condition

Source	DF	MS	F	Sig. of F
Grade	3	132.802	23.719	.000
1 vs. 2	1	81.969	14.64	<.01
1 vs. 4	1	229.738	41.04	<.01
1 vs. 6	1	931.338	166.34	<.01
2 vs. 4	1	37.289	6.66	<.05
2 vs. 6	1	464.101	82.89	<.01
4 vs. 6	1	232.942	42.14	<.01
Sex	1	.781	.140	.710
Order	3	10.969	1.959	.125
Grade x Sex	3	3.052	.545	.653
Sex x Order	3	3.594	.642	.590
Grade x Order	9	8.628	1.541	.145
Grade x Sex x Order	9	2.476	.442	.909
Error	96	5.599		

Group 2–Table 5 Analysis of Variance for Accuracy Scores for the Visual-Visual Condition

Source	DF	MS	F	Sig. of F
Grade	3	9.279	5.968	.001
1 vs. 2	1	.109	.07	NS
1 vs. 4	1	1.555	1.00	NS
1 vs. 6	1	8.093	5.17	<.05
2 vs. 4	1	2.504	1.61	NS
2 vs. 6	1	10.045	6.46	<.05
4 vs. 6	1	2.519	1.62	NS
Sex	1	2.820	1.555	.181
Order	3	.446	.300	.825
Grade x Sex	3	.070	.045	.987
Sex x Order	3	1.049	.675	.569
Grade x Order	9	1.716	1.104	.368
Grade x Sex x Order	9	1.688	1.086	.380
Error	96	1.555		

Group 2--Table 6 **Analysis of Variance for Accuracy Scores for the Haptic-Haptic vs. Haptic-Visual Conditions**

Source	DF	MS	F	Sig. of F
Condition	1	39.383	6.047	.016
Grade	3	34.883	5.356	.002
Sex	1	4.133	.635	.428
Order	3	11.195	1.719	.186
Grade x Sex	3	19.466	2.988	.035
Sex x Order	3	9.404	1.444	.235
Grade x Order	9	6.445	.990	.454
Grade x Sex x Order	9	7.043	1.081	.384
Error	96	6.513		

Group 2--Table 7 **Analysis of Variance for Accuracy Scores for the Haptic-Haptic vs. Visual-Haptic Condtions**

Source	DF	MS	F	Sig. of F
Condition	1	2.258	.241	.625
Grade	3	42.820	4.561	.005
Sex	1	1.320	.141	.708
Order	3	7.208	.285	.836
Grade x Sex	3	17.341	1.847	.144
Sex x Order	3	19.000	.752	.524
Grade x Order	9	9.230	.983	.459
Grade x Sex x Order	9	15.431	1.644	.114
Error	96	9.388		

Group 2--Table 8 **Analysis of Variance for Accuracy Scores for the Haptic-Haptic vs. Visual-Visual Conditions**

Source	DF	MS	F	Sig. of F
Condition	1	3918.113	597.312	.000
Grade	3	13.458	2.031	.115
Sex	1	13.781	2.081	.152
Order	3	3.979	.601	.616
Grade x Sex	3	16.031	2.420	.071
Sex x Order	3	10.844	1.637	.186
Grade x Order	9	2.424	.366	.949
Grade x Sex x Order	9	10.372	1.566	.137
Error	96	6.625		

Group 2--Table 9 Analysis of Variance for Accuracy Scores for the Haptic-Visual vs. Visual-Haptic Conditions

Source	DF	MS	F	Sig. of F
Condition	1	22.781	3.059	.084
Grade	3	7.219	.969	.411
Sex	1	10.125	1.359	.247
Order	3	46.802	6.284	.001
Grade x Sex	3	1.938	.260	.854
Sex x Order	3	3.563	.478	.698
Grade x Order	9	7.488	1.282	.257
Grade x Sex x Order	9	5.736	.771	.644
Error	96	7.448		

Group 2--Table 10 Analysis of Variance for Accuracy Scores for the Haptic-Visual vs. Visual-Visual Conditions

Source	DF	MS	F	Sig. of F
Condition	1	2534.283	431.246	.000
Grade	3	64.654	10.990	.000
Sex	1	33.008	5.611	.020
Order	3	22.820	3.879	.012
Grade x Sex	3	.591	.100	.960
Sex x Order	3	6.091	1.035	.381
Grade x Order	9	6.265	1.065	.396
Grade x Sex x Order	9	2.536	.43	.915
Error	96	5.883		

Group 2--Table 11 Analysis of Variance for Accuracy Scores for the Visual-Haptic vs. Visual-Visual Conditions

Source	DF	MS	F	Sig. of F
Condition	1	3392.820	579.299	.000
Grade	3	77.216	13.184	.000
Sex	1	6.570	1.122	.292
Order	3	7.904	1.349	.263
Grade x Sex	3	2.466	.421	.738
Sex x Order	3	3.279	.560	.643
Grade x Order	9	7.244	1.237	.282
Grade x Sex x Order	9	3.063	.523	.855
Error	96	5.857		

Group 2–Table 12 **Analysis of Variance for Accuracy Scores (Split by Grade)**

Grade 1

Comparison	DF	MS	Error MS	F	Sig. of F
HH vs. HV	1,31	.781	10.846	.072	.790
HH vs. VH	1,31	16.531	11.370	1.454	.273
HH vs. VV	1,31	1250.000	6.968	179.398	.000
HV vs. VH	1,31	10.125	6.770	1.496	.231
HV vs. VV	1,31	1313.281	6.055	216.876	.000
VH vs. VV	1,31	1554.031	4.805	323.390	.000

Group 2–Table 13 **Analysis of Variance for Accuracy Scores (Split by Grade)**

Grade 2

Comparison	DF	MS	Error MS	F	Sig. of F
HH vs. HV	1,31	6.125	7.092	.864	.397
HH vs. VH	1,31	9.031	10.257	.880	.355
HH vs. VV	1,31	760.500	9.145	83.159	.000
HV vs. VH	1,31	.281	8.668	.032	.858
HV vs. VV	1,31	903.125	9.770	92.437	.000
VH vs. VV	1,31	935.281	5.475	170.834	.000

Group 2–Table 14 **Analysis of Variance for Accuracy Scores (Split by Grade)**

Grade 4

Comparison	DF	MS	Error MS	F	Sig. of F
HH vs. HV	1,31	32.000	4.129	7.750	.009
HH vs. VH	1,31	.031	10.289	.003	.956
HH vs. VV	1,31	800.000	2.645	302.439	.000
HV vs. VH	1,31	34.031	3.094	10.999	.008
HV vs. VV	1,31	512.000	5.032	101.744	.000
VH vs. VV	1,31	810.031	8.225	98.487	.000

Group 2–Table 15 **Analysis of Variance for Accuracy Scores (Split by Grade)**

Grade 6

Comparison	DF	MS	Error MS	F	Sig. of F
HH vs. HV	1,31	105.125	6.028	17.439	.000
HH vs. VH	1,31	105.125	9.577	10.977	.002
HH vs. VV	1,31	800.000	8.903	89.855	.000
HV vs. VH	1,31	.000	6.452	.000	1.000
HV vs. VV	1,31	325.125	3.835	84.785	.000
VH vs. VV	1,31	325.125	4.157	78.207	.000

Group 1 versus Group 2--Table 1 Analysis of Variance for Accuracy Scores (Mean Accuracy Scores i.e. mean accuracy across conditions)

Source	DF	MS	F	Sig. of F
Gp1/2	1	32.963	17.884	.000
Grade	3	101.703	55.178	0.0
Sex	1	2.277	1.235	.268
Order	3	1.894	1.027	.382
Gp1/2x Grade	3	.814	.442	.723
Gp1/2 x Sex	1	.117	.064	.801
Grade x Sex	3	4.273	2.318	.077
Gp1/2x Order	3	1.292	.701	.552
Grade x Order	9	1.345	.730	.681
Sex x Order	3	1.346	.730	.535
Gp1/2 x Grade x Sex	3	1.820	.987	.400
Gp1/2 x Grade x Order	9	.777	.422	.923
Gp1/2 x Sex x Order	3	.759	.412	.745
Grade x Sex x Order	9	2.599	1.410	.186
Gp1/2 x Grade x Sex x Order	9	2.777	1.507	.148
Error	192	1.845		

Group 1 versus Group 2–Table 2 Analysis of Variance for Accuracy Scores for the Haptic-Haptic Condition

Source	DF	MS	F	Sig. of F
Gp1/2	1	12.754	2.525	.114
Grade	3	79.381	15.716	.000
Sex	1	.639	.126	.723
Order	3	5.862	1.161	.326
Gp1/2x Grade	3	12.729	2.520	.059
Gp1/2 x Sex	1	4.297	.851	.358
Grade x Sex	3	12.431	2.461	.064
Gp1/2x Order	3	1.573	.311	.817
Grade x Order	9	5.954	1.179	.311
Sex x Order	3	4.047	.801	.495
Gp1/2 x Grade x Sex	3	9.903	1.961	.121
Gp1/2 x Grade x Order	9	6.251	1.238	.274
Gp1/2 x Sex x Order	3	4.687	.928	.428
Grade x Sex x Order	9	6.454	1.278	.251
Gp1/2 x Grade x Sex x Order	9	9.505	1.882	.057
Error	192	5.051		

Group 1 versus Group 2–Table 3 Analysis of Variance for the Haptic-Visual Condition

Source	DF	MS	F	Sig. of F
Gp1/2	1	127.707	25.655	.000
Grade	3	155.210	31.180	.000
Sex	1	21.927	4.405	.037
Order	3	29.453	5.917	.001
Gp1/2x Grade	3	10.829	2.175	.092
Gp1/2 x Sex	1	1.127	.226	.635
Grade x Sex	3	7.879	1.583	.195
Gp1/2x Order	3	.819	.165	.920
Grade x Order	9	1.168	.235	.989
Sex x Order	3	4.001	.804	.493
Gp1/2 x Grade x Sex	3	3.765	.756	.520
Gp1/2 x Grade x Order	9	4.286	.861	.561
Gp1/2 x Sex x Order	3	3.116	.626	.599
Grade x Sex x Order	9	5.720	1.149	.330
Gp1/2x Grade x Sex x Order	9	7.219	1.450	.169
Error	192	4.978		

Group 1 versus Group 2–Table 4 Analysis of Variance for Accuracy Scores for the Visual-Haptic Condition

Source	DF	MS	F	Sig. of F
Gp1/2	1	18.416	3.537	.062
Grade	3	151.830	29.163	.000
Sex	1	1.763	.339	.561
Order	3	1.138	.219	.883
Gp1/2x Grade	3	15.995	3.072	.029
Gp1/2 x Sex	1	.006	.001	.972
Grade x Sex	3	9.183	1.764	.155
Gp1/2 x Order	3	15.446	2.967	.033
Grade x Order	9	3.267	.628	.773
Sex x Order	3	1.251	.240	.868
Gp1/2 x Grade x Sex	3	1.500	.288	.834
Gp1/2 x Grade x Order	9	8.508	1.634	.108
Gp1/2 x Sex x Order	3	6.391	1.227	.301
Grade x Sex x Order	9	8.383	1.610	.115
Gp1/2 x Grade x Sex x Order	9	2.912	.599	.829
Error	192	5.206		

Group 1 versus Group 2–Table 5 Analysis of Variance for Accuracy Scores for the Visual-Visual Condition

Source	DF	MS	F	Sig. of F
Gp1/2	1	11.479	6.041	.015
Grade	3	44.771	23.559	.000
Sex	1	.153	.081	.777
Order	3	2.056	1.082	.358
Gp1/2 x Grade	3	10.569	5.562	.001
Gp1/2 x Sex	1	3.925	2.066	.152
Grade x Sex	3	.265	.139	.936
Gp1/2 x Order	3	.892	.470	.704
Grade x Order	9	1.387	.730	.681
Sex x Order	3	2.933	1.543	.205
Gp1/2 x Grade x Sex	3	.472	.248	.863
Gp1/2 x Grade x Order	9	1.495	.786	.629
Gp1/2 x Sex x Order	3	2.046	1.076	.360
Grade x Sex x Order	9	1.054	.555	.833
Gp1/2 x Grade x Sex x Order	9	2.996	1.576	.125
Error	192	1.900		

Group 2–Table 16 **Analysis of Variance for Exploration Strategy Scores**

Dependent Variables:
HHS
HHC1
HHC2
HVS
VHC1
VHC2

Factor	DF	F	Sig. of F
Stimuli	6,91	11175.55	.001
Grade	18,258	7.407	.001
Sex	6,91	.375	.893
Order	18,258	3.002	.001
Grade x Sex	18,258	.839	.654
Sex x Order	18,258	.854	.635
Grade x Order	54,469	1.619	.005
Grade x Sex x Order	54,49	1.013	.454
Error			

Univariate Analyses for the factors: Grade, Order, Grade x Order

Variable: HHS

Factor	DF	MS	F	Sig. of F
Grade	3	1.566	28.727	.001
Order	3	.038	.694	.558
Grade x Order	3	.062	1.133	.347
Error	96	.055		

Variable HHC1

Factor	DF	MS	F	Sig. of F
Grade	3	1.687	28.889	.001
Order	3	.133	2.277	.085
Grade x Order	9	.104	1.781	.082
Error	96	.058		

Variable HHC2

Factor	DF	MS	F	Sig. of F
Grade	3	1.329	22.674	.001
Order	3	.171	2.919	.038
Grade x Order	9	.080	1.359	.218
Error	96	.059		

Variable HVS

Grade	3	1.599	40.210	.001
Order	3	.048	2.201	.314
Grade x Order	9	.030	.747	.665
Error	96	.040		

Variable VHC1

Grade	3	1.321	35.891	.001
Order	3	.293	7.969	.001
Grade x Order	9	.112	3.037	.003
Error	96	.037		

Variable VHC2

Grade	3	1.045	29.682	.001
Order	3	.223	6.326	.001
Grade x Order	9	.082	2.315	.021
Error	96	.035		

Group 2–Table 17 Analysis of Variance for Exploration Strategy Scores

Dependent Variables: HHS vs. HHC1 + HHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	5.234	349.162	.0001
Grade	3	.023	1.502	.219
Sex	1	.002	.122	.727
Order	3	.091	6.086	.001
Grade x Sex	3	.016	1.070	.366
Sex x Order	3	.023	1.549	.207
Grade x Order	9	.029	1.909	.060
Grade x Sex x Order	9	.019	1.284	.256
Error	96	.015		

Group 2–Table 18 Analysis of Variance for Exploration Strategy Scores

Dependent Variables: HHS vs. HHC1

Factor	DF	MS	F	Sig. of F
Stimuli	1	3.088	228.686	.000
Grade	3	.012	.879	.455
Sex	1	.011	.779	.380
Order	3	.067	4.968	.003
Grade x Sex	3	.017	1.270	.289
Sex x Order	3	.019	1.394	.294
Grade x Order	9	.023	1.718	.095
Grade x Sex x Order	9	.023	1.699	.100
Error	96	.014		

Group 2--Table 19 **Analysis of Variance for Exploration Strategy Scores**

Dependent Variables: HHS vs. HHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	7.965	349.827	.000
Grade	3	.050	2.200	.093
Sex	1	.001	.012	.912
Order	3	.123	5.397	.002
Grade x Sex	3	.020	.887	.451
Sex x Order	3	.031	1.363	.259
Grade x Order	9	.044	1.942	.055
Grade x Sex x Order	9	.019	.845	.577
Error	96	.023		

Group 2--Table 20 **Analysis of Variance for Exploration Strategy Scores**

Dependent Variables: HHS vs. HVS

Factor	DF	MS	F	Sig. of F
Stimuli	1	.743	13.402	.001
Grade	3	.051	.924	.433
Sex	1	.010	.180	.672
Order	3	.160	2.882	.040
Grade x Sex	3	.009	.155	.926
Sex x Order	3	.006	.111	.954
Grade x Order	9	.071	1.272	.262
Grade x Sex x Order	9	.078	1.407	.196
Error	96	.055		

Group 2--Table 21 Analysis of Variance for Exploration Strategy Scores

Dependent Variables: HHC1 vs. HHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	30.088	90.901	.000
Grade	3	.034	2.701	.050
Sex	1	.014	1.141	.289
Order	3	.014	1.150	.333
Grade x Sex	3	.010	.836	.478
Sex x Order	3	.007	.533	.661
Grade x Order	9	.020	1.614	.122
Grade x Sex x Order	9	.007	.581	.810
Error	96	.012		

Group 2--Table 22 Analysis of Variance for Exploration Strategy Scores

Dependent Variables: VHC1 vs. VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	1.578	98.064	.0001
Grade	3	.019	1.185	.320
Sex	1	.004	.231	.632
Order	3	.058	3.630	.016
Grade x Sex	3	.001	.030	.993
Sex x Order	3	.014	.894	.447
Grade x Order	9	.017	1.073	.390
Grade x Sex x Order	9	.010	1.100	.371
Error	96	.016		

Group 2–Table 23 **Analysis of Variance for Exploration Strategy Scores**

Dependent Variables: HHC1 + HHC2 vs. VHC1 + VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	1.571	7.921	.001
Grade	3	.424	2.139	.101
Sex	1	.028	.142	.707
Order	3	.322	1.624	.189
Grade x Sex	3	.202	1.019	.388
Sex x Order	3	.319	1.610	.192
Grade x Order	9	.491	2.473	.014
Grade x Sex x Order	9	.281	1.100	.371
Error	96	.198		

Group 2–Table 24 **Analysis of Variance for Exploration Strategy Scores**

Dependent Variables: HHC1 vs. VHC1

Factor	DF	MS	F	Sig. of F
Stimuli	1	.522	8.709	.004
Grade	3	.092	1.539	.209
Sex	1	.030	.506	.479
Order	3	.146	2.438	.069
Grade x Sex	3	.034	.573	.634
Sex x Order	3	.077	1.292	.282
Grade x Order	9	.158	2.639	.009
Grade x Sex x Order	9	.050	1.244	.278
Error	96	.060		

Group 2–Table 25 Analysis of Variance for Exploration Strategy Scores

Dependent Variables: HHC2 vs. VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	.282	8.710	.004
Grade	3	.124	2.340	.078
Sex	1	.000	.001	.979
Order	3	.864	.472	.088
Grade x Sex	3	.074	1.392	.250
Sex x Order	3	.095	1.793	.154
Grade x Order	9	.106	1.995	.048
Grade x Sex x Order	9	.066	1.244	.278
Error	96	.053		

Group 2 -Table 26 Analysis of Variance for Exploration Strategy Scores

Dependent Variables: HHS vs. VHC1 + VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	2.766	44.135	.001
Grade	3	.098	1.559	.204
Sex	1	.002	.027	.870
Order	3	.265	4.221	.008
Grade x Sex	3	.053	.840	.476
Sex x Order	3	.075	1.193	.317
Grade x Order	9	.164	2.618	.010
Grade x Sex x Order	9	.883	1.410	.195
Error	96	.063		

Group 2–Table 27 **Analysis of Variance for Exploration Strategy Scores**

Dependent Variables: HHS vs. VHC1

Factor	DF	MS	F	Sig. of F
Stimuli	1	1.071	15.730	.0002
Grade	3	.071	1.036	.380
Sex	1	.005	.075	.785
Order	3	.316	4.639	.005
Grade x Sex	3	.048	.702	.553
Sex x Order	9	.074	1.093	.356
Grade x Order	9	.168	2.472	.014
Grade x Sex x Order	9	.084	1.230	.286
Error	96	.068		

Group 2–Table 28 **Analysis of Variance for Exploration Strategy Scores**

Dependent Variables: HHS vs. VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	5.248	80.423	.0001
Grade	3	1.134	2.059	.111
Sex	1	.000	.002	.976
Order	3	.242	3.710	.014
Grade x Sex	3	.058	.884	.453
Sex x Order	3	.082	1.260	.293
Grade x Order	9	.168	2.579	.001
Grade x Sex x Order	9	.098	1.496	.160
Error	96	.065		

Group 2--Table 29 **Analysis of Variance for Exploration Strategy Scores**

Dependent Variables: HVS vs. VHC1 + VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	6.375	176.621	.0001
Grade	3	.041	1.149	.334
Sex	1	.020	.551	.460
Order	3	.208	5.773	.001
Grade x Sex	3	.045	1.241	.299
Sex x Order	3	.039	1.083	.360
Grade x Order	9	.132	3.658	.001
Grade x Sex x Order	9	.043	1.187	.312
Error	96	.036		

Group1 versus Group 2–Table 12 **Analysis of Variance for Haptic Exploration Strategy Scores**

Dependent Variables:

HHS
HHC1
HHC2
HVS
VHC1
VHC2

Factor	DF	F	Sig. of F
Stimuli	6,187	15349.773	.0001
Gp1/2	6,187	21.834	.0001
Grade	18,529	10.650	.0001
Sex	6,187	.601	.729
Order	18,529	2.108	.005
Gp1/2 x Grade	18,529	1.090	.358
Gp1/2 x Sex	6,187	.071	.999
Grade x Sex	18,402	.429	.983
Gp1/2 x Order	18,529	2.049	.007
Grade x Order	54,958	1.696	.002
Sex x Order	13,529	.905	.573
Gp1/2 x Grade x Sex	54,958	.797	.705
Gp1/2 x Grade x Order	18,529	1.021	.435
Gp1/2 x Sex x Order	18,529	.330	.996
Grade x Sex x Order	54,958	1.005	.466
Gp1/2 x Grade x Sex x Order	54,958	1.003	.470

Group1 versus Group 2–Table 32 **Analysis of Variance for Haptic Exploration Strategy Scores**

Dependent Variables: HHS

Factor	DF	MS	F	Sig. of F
Gp1/2	1	.788	34.363	.0001
Grade	3	.041	3.741	.012
Sex	1	.001	.026	.872
Order	3	.091	3.986	.009
Gp1/2 x Grade	3	.054	2.440	.066
Gp1/2 x Sex	1	.002	.072	.789
Grade x Sex	3	.008	.366	.778
Gp1/2 x Order	3	.021	.909	.438
Grade x Order	9	.050	2.163	.026
Sex x Order	3	.011	.475	.700
Gp1/2 x Grade x Sex	3	.017	.746	.526
Gp1/2 x Grade x Order	9	.022	.969	.468
Gp1/2 x Sex x Order	3	.014	.592	.621
Grade x Sex x Order	9	.016	.707	.702
Gp1/2 x Grade x Sex x Order	9	.017	.753	.660
Error	192	.023		

Group1 versus Group 2–Table 33 **Analysis of Variance for Haptic Exploration Strategy Scores**

Dependent Variable: HHC1

Factor	DF	MS	F	Sig. of F
Gp1/2	1	1.122	53.688	.0001
Grade	3	.041	1.978	.119
Sex	1	.010	.496	.482
Order	3	.079	3.792	.011
Gp1/2 x Grade	3	.060	2.886	.037
Gp1/2 x Sex	1	.002	.105	.746
Grade x Sex	3	.100	.464	.708
Gp1/2 x Order	3	.053	.606	.612
Grade x Order	3,	.046	2.186	.025
Sex x Order	9	.009	.051	.717
Gp1/2 x Grade x Sex	3	.012	.553	.647
Gp1/2 x Grade x Order	9	.025	1.175	.313
Gp1/2 x Sex x Order	3	.100	.473	.702
Grade x Sex x Order	9	.023	1.100	.365
Gp1/2 x Grade x Sex x Order	9	.016	.753	.660
Error	192	.021		

Group1 versus Group 2--Table 34 **Analysis of Variance for Haptic Exploration Strategy Scores**

Dependent Variables: HHC2

Factor	DF	MS	F	Sig. of F
Gp1/2	1	2.432	28.059	.0001
Grade	3	.398	4.590	.004
Sex	1	.001	.009	.926
Order	3	.514	5.935	.001
Gp1/2 x Grade	3	.103	1.192	.314
Gp1/2 x Sex	1	.002	.026	.871
Grade x Sex	3	.054	.625	.599
Gp1/2 x Order	3	.053	.606	.612
Grade x Order	9	.242	2.789	.004
Sex x Order	3	.118	1.366	.255
Gp1/2 x Grade x Sex	3	.100	1.152	.329
Gp1/2 x Grade x Order	9	.095	1.101	.364
Gp1/2 x Sex x Order	3	.016	.188	.904
Grade x Sex x Order	9	.088	1.015	.430
Gp1/2 x Grade x Sex x Order	9	.169	1.945	.048
Error	192	.087		

Group1 versus Group 2--Table 35 Analysis of Variance for Haptic Exploration Strategy Scores

Dependent Variables: HVS

Factor	DF	MS	F	Sig. of F
Gp1/2	1	3.165	36.950	.0001
Grade	3	.350	4.081	.008
Sex	1	.006	.075	.784
Order	3	.529	6.177	.001
Gp1/2 x Grade	3	.128	1.492	.218
Gp1/2 x Sex	1	.001	.009	.923
Grade x Sex	3	.061	.714	.545
Gp1/2 x Order	3	.011	.126	.945
Grade x Order	9	.205	2.393	.014
Sex x Order	3	.089	1.043	.374
Gp1/2 x Grade x Sex	3	.104	1.215	.305
Gp1/2 x Grade x Order	9	.113	1.314	.213
Gp1/2 x Sex x Order	3	.024	.275	.844
Grade x Sex x Order	9	.087	1.012	.432
Gp1/2 x Grade x Sex x Order	9	.161	1.88	.057
Error	192	.086		

Group1 versus Group 2--Table 36 **Analysis of Variance for Haptic Exploration Strategy Scores**

Dependent Variable: VHC1

Factor	DF	MS	F	Sig. of F
Gp1/2	1	6.335	88.219	.0001
Grade	3	2.571	35.798	.0001
Sex	1	.016	.224	.637
Order	3	.142	1.980	.119
Gp1/2 x Grade	3	.072	.997	.396
Gp1/2 x Sex	1	.007	.090	.765
Grade x Sex	3	.069	.965	.411
Gp1/2 x Order	3	.114	1.588	.194
Grade x Order	9	.127	1.768	.077
Sex x Order	3	.062	.867	.459
Gp1/2 x Grade x Sex	3	.157	2.182	.092
Gp1/2 x Grade x Order	9	.066	.915	.514
Gp1/2 x Sex x Order	3	.018	.250	.862
Grade x Sex x Order	9	.042	.582	.811
Gp1/2 x Grade x Sex x Order	9	.134	2.201	.024
Error	192	.072		

Group1 versus Group 2--Table 37 **Analysis of Variance for Haptic Exploration Strategy Scores**

Dependent Variables: VHC2

Factor	DF	MS	F	Sig. of F
Gp1/2	1	.099	1.624	.204
Grade	3	.015	.238	.870
Sex	1	.001	.014	.908
Order	3	.236	3.854	.011
Gp1/2 x Grade	3	.067	1.103	.349
Gp1/2 x Sex	1	.002	.025	.874
Grade x Sex	3	.037	.597	.618
Gp1/2 x Order	3	.049	.798	.496
Grade x Order	9	.151	2.465	.011
Sex x Order	3	.073	1.199	.311
Gp1/2 x Grade x Sex	3	.025	.404	.751
Gp1/2 x Grade x Order	9	.048	.778	.631
Gp1/2 x Sex x Order	3	.003	.054	.984
Grade x Sex x Order	9	.072	1.178	.311
Gp1/2 x Grade x Sex x Order	9	.135	2.201	.024
Error	192	.062		

Analysis of Variance for Study 3

<u>Group 3–Table 1</u> **Analysis of Variance for Accuracy Scores* (Mean Accuracy Scores i.e. mean accuracy across conditions)**

Source	DF	MS	F	Sig. of F
Grade	3	8.359	6.459	.002
1 vs. 2	1	85.520	66.09	<.01
1 vs. 4	1	115.515	89.27	<.01
1 vs. 6	1	128.779	99.52	<.01
2 vs. 4	1	2.252	1.74	NS
2 vs. 6	1	4.413	3.41	NS
4 vs. 6	1	.362	.28	NS
Sex	1	3.165	2.445	.130
Grade x Sex	3	1.769	1.367	.274
Error	27	1.294		

Group 3–Table 2 Analysis of Variance for Accuracy Scores for the Haptic-Haptic conditions

Source	DF	MS	F	Sig. of F
Grade	3	16.633	4.168	.015
1 vs. 2	1	220.702	55.30	<.01
1 vs. 4	1	229.323	57.47	<.01
1 vs. 6	1	100.015	25.06	<.01
2 vs. 4	1	.080	.02	NS
2 vs. 6	1	23.587	5.91	<.05
4 vs. 6	1	26.460	6.63	<.05
Sex	1	7.544	1.890	.180
Grade x Sex	3	3.165	.793	.508
Error	27	3.991		

Group 3–Table 3 Analysis of Variance for Accuracy Scores for the Haptic-Visual Condition

Source	DF	MS	F	Sig. of F
Grade	3	30.460	4.287	.013
1 vs. 2	1	279.408	39.32	<.01
1 vs. 4	1	260.648	36.68	<.01
1 vs. 6	1	510.779	71.88	<.01
2 vs. 4	1	.335	.05	NS
2 vs. 6	1	34.606	4.87	<.05
4 vs. 6	1	41.712	5.87	<.05
Sex	1	6.174	.869	.360
Grade x Sex	3	6.821	.960	.426
Error	27	7.105		

<u>Group 3--Table 4</u> Analysis of Variance for Accuracy Scores for the Visual-Haptic Condition

Source	DF	MS	F	Sig. of F
Grade	3	2.752	1.220	.322
Sex	1	6.589	2.920	.099
Grade x Sex	3	2.301	1.019	.399
Error	27	2.257		

<u>Group 3--Table 5</u> Analysis of Variance for Accuracy Scores for the Visual-Visual Condition

Source	DF	MS	F	Sig. of F
Grade	3	5.633	1.614	.209
Sex	1	.466	.134	.718
Grade x Sex	3	3.837	1.099	.367
Error	27	3.491		

Group 3–Table 6 **Analysis of Variance for Accuracy Scores for the Haptic-Haptic vs. Haptic-Visual conditions**

Source	DF	MS	F	Sig. of F
Condition	1	43.457	4.050	.000
Grade	3	5.633	1.614	.209
Sex	1	.466	.134	.718
Grade x Sex	3	3.837	1.099	.367
Error	27	3.491		

Group 3–Table 7 **Analysis of Variance for Accuracy Scores for the Haptic-Haptic vs. Visual-Haptic conditions**

Source	DF	MS	F	Sig. of F
Condition	1	50.400	5.785	.023
Grade	3	13.605	1.562	.222
Sex	1	.032	.004	.952
Grade x Sex	3	3.842	.441	.726
Error	27	8.712		

Group 3–Table 8 **Analysis of Variance for Accuracy Scores for the Haptic-Haptic vs. Visual-Visual conditions**

Source	DF	MS	F	Sig. of F
Condition	1	816.029	138.968	.000
Grade	3	16.886	2.886	.005
Sex	1	11.761	2.003	.168
Grade x Sex	3	4.669	.795	.507
Error	27	5.872		

Group 3–Table 9 Analysis of Variance for Accuracy Scores for the Haptic-Visual vs. Visual-Haptic conditions

Source	DF	MS	F	Sig. of F
Condition	1	.257	.027	.871
Grade	3	22.888	2.409	.089
Sex	1	.007	.001	.979
Grade x Sex	3	11.172	1.176	.337
Error	27	9.502		

Group 3–Table 10 Analysis of Variance for Accuracy Scores for the Haptic-Visual vs. Visual-Visual conditions

Source	DF	MS	F	Sig. of F
Condition	1	1236.114	168.558	.000
Grade	3	12.893	1.758	.179
Sex	1	10.034	1.368	.252
Grade x Sex	3	7.333	.326	.807
Error	27	7.333		

Group 3–Table 11 Analysis of Variance for Accuracy Scores for the Visual-Haptic vs. Visual-Visual conditions

Source	DF	MS	F	Sig. of F
Condition	1	1272.029	281.200	.000
Grade	3	10.706	2.367	.093
Sex	1	10.561	2.335	.138
Grade x Sex	3	2.719	.601	.620
Error	27	4.534		

Group 3–Table 13 **Analysis of Variance for Accuracy Scores (Split by Grade)**

Grade 2

Comparison	DF	MS	Error MS	F	Sig. of F
HH vs. HV	1,13	44.643	7.104	6.284	.026
HH vs. VH	1,13	73.143	5.758	12.703	.003
HH vs. VV	1,13	193.143	2.835	68.124	.000
HV vs. VH	1,13	3.500	6.269	.558	.468
HV vs. VV	1,13	423.500	5.962	71.039	.000
VH vs. VV	1,13	504.000	5.692	88.541	.000

Group 3–Table 14 Analysis of Variance for Accuracy Scores (Split by Grade)

Grade 4

Comparison	DF	MS	Error MS	F	Sig. of F
HH vs. HV	1,6	28.000	3.667	7.636	.033
HH vs. VH	1,6	11.571	12.571	.920	.374
HH vs. VV	1,6	120.143	12.810	9.379	.022
HV vs. VH	1,6	3.571	9.905	.361	.570
HV vs. VV	1,6	264.143	9.810	26.927	.002
VH vs. VV	1,6	206.286	10.952	18.835	.005

Group 3–Table 15 Analysis of Variance for Accuracy Scores (Split by Grade)

Grade 6

Comparison	DF	MS	Error MS	F	Sig. of F
HH vs. HV	1,9	3.781	5.136	.736	.397
HH vs. VH	1,9	28.125	7.415	3.793	.061
HH vs. VV	1,9	1287.781	7.910	162.798	.000
HV vs. VH	1,9	11.281	3.797	2.971	.095
HV vs. VV	1,9	1152.000	4.903	234.947	.000
VH vs. VV	1,9	935.281	4.959	188.615	.000

Group 3 --without grade 1--Table 1* Analysis of Variance for Accuracy Scores (Mean Accuracy Scores i.e. mean accuracy across conditions)

Source	DF	MS	F	Sig. of F
Grade	2	1.505	1.165	.328
Sex	1	.669	.518	.478
Grade x Sex	2	1.387	1.074	.357
Error	25		1.291	

Group 3--without grade 1--Table 2* Analysis of Variance for Accuracy Scores for the Haptic-Haptic condition

Source	DF	MS	F	Sig. of F
Grade	2	2.552	.603	.555
Sex	1	3.493	.826	.372
Grade x Sex	2	2.421	.573	.571
Error	25	4.230		

Group 3--without grade 1--Table 3* Analysis of Variance for Accuracy Scores for the Haptic-Visual Condition

Source	DF	MS	F	Sig. of F
Grade	2	10.555	1.596	.223
Sex	1	.179	.027	.871
Grade x Sex	2	2.421	.572	.571
Error	25	4.230		

Group 3--without grade 1--Table 4* Analysis of Variance for Accuracy Scores for the Visual-Haptic Condition

Source	DF	MS	F	Sig. of F
Grade	2	1.298	.580	.567
Sex	1	10.020	4.478	.044
Grade x Sex	2	2.968	1.324	.284
Error	25	2.237		

Group 3--without grade 1--Table 5* Analysis of Variance for Accuracy Scores for the Visual-Visual Condition

Source	DF	MS	F	Sig. of F
Grade	2	5.642	1.635	.215
Sex	1	4.781	1.386	.250
Grade x Sex	2	2.860	.829	.448
Error	25	3.451		

Group 3--without grade 1--Table 6* Analysis of Variance for Accuracy Scores for the Haptic-Haptic vs. Haptic-Visual conditions

Source	DF	MS	F	Sig. of F
Condition	1	7306.846	5657.765	.000
Grade	2	6.334	2.131	.140
Sex	1	2.091	.190	.667
Grade x Sex	2	4.908	.446	.645
Error	25	11.009		

Group 3--without grade 1--Table 7* Analysis of Variance for Accuracy Scores for the Haptic-Haptic vs. Visual-Haptic conditions

Source	DF	MS	F	Sig. of F
Condition	1	52.293	5.883	.023
Grade	2	6.733	.757	.479
Sex	1	1.681	.190	.667
Grade x Sex	2	.815	.090	.913
Error	25	8.890		

Group 3--without grade 1--Table 8* Analysis of Variance for Accuracy Scores for the Haptic-Haptic vs. Visual-Visual conditions

Source	DF	MS	F	Sig. of F
Condition	1	609.100	102.662	.000
Grade	2	14.939	2.514	.101
Sex	1	16.448	2.768	.109
Grade x Sex	2	6.972	1.173	.326
Error	25	5.942		

Group 3--without grade 1--Table 9* Analysis of Variance for Accuracy Scores for the Haptic-Visual vs. Visual-Haptic conditions

Source	DF	MS	F	Sig. of F
Condition	1	10.343	1.255	.273
Grade	2	6.334	.769	.474
Sex	1	7.521	.912	.349
Grade x Sex	2	9.606	1.165	.328
Error	25	8.242		

Group 3--without grade 1--Table 10* Analysis of Variance for Accuracy Scores for the Haptic-Visual vs. Visual-Visual conditions

Source	DF	MS	F	Sig. of F
Condition	1	824.461	120.182	.000
Grade	2	3.034	.442	.647
Sex	1	6.810	.993	.329
Grade x Sex	2	3.510	.516	.606
Error	25	6.860		

Group 3--without grade 1--Table 11* Analysis of Variance for Accuracy Scores for the Visual-Haptic vs. Visual-Visual conditions

Source	DF	MS	F	Sig. of F
Condition	1	1019.497	225.280	.000
Grade	2	1.615	.357	.703
Sex	1	28.644	6.329	.019
Grade x Sex	2	10.296	2.275	.124
Error	25	10.294		

<u>Group 1 versus Group 3–Table 1</u> **Analysis of Variance for Accuracy Scores (Mean Accuracy Scores i.e. mean accuracy across conditions)**

Source	DF	MS	F	Sig. of F
Gp1/3	1	48.752	24.215	.000
Grade	3	45.534	22.617	.000
Sex	1	.429	.213	.645
Gp1/3x Grade	3	4.175	2.074	.106
Grade x Sex	3	5.968	2.964	.034
Gp1/3 x Sex	1	1.156	.574	.450
Gp1/3 x Grade x Sex	3	1.733	.861	.463
Error	147	2.013		

Group 1 versus Group 3–Table 2 **Analysis of Variance for Accuracy Scores for the Haptic-Haptic Condition**

Source	DF	MS	F	Sig. of F
Gp1/3	1	28.127	5.509	.025
Grade	3	25.114	4.559	.004
Sex	1	6.679	1.212	.273
Gp1/3 x Grade	3	25.141	4.564	.004
Grade x Sex	3	4.018	.729	.536
Gp1/3 x Sex	1	12.423	2.255	.135
Gp1/3 x Grade x Sex	3	3.194	.580	.629
Error	147	5.509		

Group 1 versus Group 3–Table 3 **Analysis of Variance for Accuracy Scores for the Haptic-Visual Condition**

Source	DF	MS	F	Sig. of F
Gp1/3	1	77.858	13.422	.000
Grade	3	62.168	10.717	.000
Sex	1	10.652	1.836	.177
Gp1/3 x Grade	3	10.251	1.767	.156
Grade x Sex	3	9.524	1.642	.182
Gp1/3 x Sex	1	1.914	.330	.567
Gp1/3 x Grade x Sex	3	6.283	1.083	.358
Error	147	5.801		

<u>Group 1 versus Group 3–Table 4</u> Analysis of Variance for Accuracy Scores for the Visual-Haptic Condition

Source	DF	MS	F	Sig. of F
Gp1/3	1	90.287	20.146	.000
Grade	3	12.461	2.781	.043
Sex	1	6.735	1.503	.222
Gp1/3 x Grade	3	3.101	.692	.558
Grade x Sex	3	6.138	1.370	.254
Gp1/3 x Sex	1	3.504	.782	.378
Gp1/3 x Grade x Sex	3	.488	.109	.955
Error	147	4.482		

<u>Group 1 versus Group 3–Table 5</u> Analysis of Variance for Accuracy Scores for the Visual-Visual Condition

Source	DF	MS	F	Sig. of F
Gp1/3	1	25.168	10.257	.002
Grade	3	24.422	9.953	.000
Sex	1	.007	.003	.975
Gp1/3 x Grade	3	.113	.046	.987
Grade x Sex	3	3.766	1.535	.208
Gp1/3 x Sex	1	.732	1.274	.286
Error	147	2.454		

Group 3--Table 16 **Analysis of Variance for Exploration Strategy Scores**

Dependent Variables:
HHS
HHC1
HHC2
HVS
VHC1
VHC2

Factor	DF	F	Sig. of F
Stimuli	6,22	1013.616	.0001
Grade	18,63	1.435	.147
Sex	6,22	2.249	.076
Grade x Sex	18,63	1.360	.184

Error

Group 3--Table 17 **Analysis of Variance for Exploration Strategy Scores**

Dependent Variables: HHS vs. HHC1 + HHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	.973	62.810	.0001
Grade	3	.018	1.202	.328
Sex	1	.079	5.133	.032
Grade x Sex	3	.024	1.577	.218
Error	27	.015		

Group 3--Table 18 **Analysis of Variance for Exploration Strategy Scores**

Dependent Variables: HHS vs. HHC1

Factor	DF	MS	F	Sig. of F
Stimuli	1	.915	59.734	.0001
Grade	3	.020	1.277	.302
Sex	1	.071	4.651	.035
Grade x Sex	3	.027	1.749	.226
Error	27	.015		

Group 3--Table 19 **Analysis of Variance for Exploration Strategy Scores**

Dependent Variables: HHS vs. HHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	1.032	57.921	.0001
Grade	3	.019	1.055	.348
Sex	1	.088	4.949	.035
Grade x Sex	3	.028	1.542	.226
Error	96	.018		

Group 3--Table 20 **Analysis of Variance for Exploration Strategy Scores**

Dependent Variables: HHS vs. HVS

Factor	DF	MS	F	Sig. of F
Stimuli	1	.058	.574	.455
Grade	3	.071	.695	.563
Sex	1	.287	2.832	.105
Grade x Sex	3	.060	.589	.627
Error	27	.102		

Group 3--Table 21 Analysis of Variance for Exploration Strategy Scores

Dependent Variables: HHC1 vs. HHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	.004	.808	.377
Grade	3	.002	.532	.666
Sex	1	.001	.208	.652
Grade x Sex	3	.011	2.498	.081
Error	96	.004		

Group 3--Table 22 Analysis of Variance for Exploration Strategy Scores

Dependent Variables: VHC1 vs. VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	.017	5.892	.022
Grade	3	.007	2.559	.073
Sex	1	.002	.779	.385
Grade x Sex	3	.144	1.649	.202
Error	27	.003		

Group 3–Table 23 Analysis of Variance for Exploration Strategy Scores

Dependent Variables: HHC1 + HHC2 vs. VHC1 + VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	.312	3.894	.059
Grade	3	.598	1.767	.177
Sex	1	.079	.235	.632
Grade x Sex	3	.598	1.767	.177
Error	27	.338		

Group 3–Table 24 Analysis of Variance for Exploration Strategy Scores

Dependent Variables: HHC1 vs. VHC1

Factor	DF	MS	F	Sig. of F
Stimuli	1	.291	3.145	.088
Grade	3	.120	2.138	.119
Sex	1	.018	.190	.667
Grade x Sex	3	.166	1.790	.172
Error	27	.092		

Group 3--Table 25 Analysis of Variance for Exploration Strategy Scores

Dependent Variables: HHC2 vs. VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	.370	4.592	.053
Grade	3	.109	1.347	.280
Sex	1	.022	.276	.604
Grade x Sex	3	.144	1.782	.174
Error	27	.081		

Group 3--Table 26 Analysis of Variance for Exploration Strategy Scores (Experimental Dyslexic Population)

Dependent Variables: HHS vs. VHC1 + VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	2.434	22.267	.0001
Grade	3	.136	1.242	.314
Sex	1	.179	1.636	.212
Grade x Sex	3	.184	1.685	.194
Error	27	.109		

Group 3--Table 27 **Analysis of Variance for Exploration Strategy Scores**

Dependent Variables: HHS vs. VHC1

Factor	DF	MS	F	Sig. of F
Stimuli	1	2.237	20.162	.0002
Grade	3	.158	1.430	.256
Sex	1	.160	1.438	.241
Grade x Sex	3	.169	1.522	.231
Error	27	.111		

Group 3--Table 28 **Analysis of Variance for Exploration Strategy Scores**

Dependencent Variables: HHS vs. VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	2.639	24.199	.0001
Grade	3	.116	1.068	.379
Sex	1	.199	1.826	.188
Grade x Sex	3	.202	1.850	.162
Error	27	.109		

Group 3--Table 29 **Analysis of Variance for Exploration Strategy Scores**

Dependent Variables: HVS vs. VHC1+VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	332.640	4062.990	.0001
Grade	3	.234	2.859	.056
Sex	1	.470	5.742	.020
Grade x Sex	3	.159	1.940	.147
Error	27	.082		

Group 3--Table 30 **Analysis of Variance for Exploration Strategy Scores**

Dependent Variables: HVS vs. VHC1

Factor	DF	MS	F	Sig. of F
Stimuli	1	3.019	20.693	.002
Grade	3	.250	1.713	.189
Sex	1	.019	.128	.723
Grade x Sex	3	.160	1.094	.369
Error	27	.146		

Group 3--Table 31 Analysis of Variance for Exploration Strategy Scores

Dependent Variables: HVS vs. VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	3.482	24.674	.0001
Grade	3	.180	1.272	.304
Sex	1	.008	.057	.813
Grade x Sex	3	.166	1.173	.338
Error	27	.141		

Group 1 versus Group 3–Table 12 **Analysis of Variance for Haptic Exploration Strategy Scores**

Dependent Variables:

HHS
HHC1
HHC2
HVS
VHC1
VHC2

Factor	DF	F	Sig. of F
Stimuli	6,142	6664.795	.0001
Gp1/3	6,142	5.175	.0001
Grade	18,402	5.618	.0001
Sex	6,142	.926	.479
Gp1/3 x Grade	18,402	.828	.668
Grade x Sex	18,402	.586	.910
Gp1/3 x Sex	6,142	1.936	.079
Gp1/3 x Grade x Sex	18,402	1.142	.309

<u>Group 1 versus Group 3--Table 32</u> **Analysis of Variance for Haptic Exploration Strategy Scores**

Dependent Variable: HHS

Factor	DF	MS	F	Sig. of F
Gp1/3	1	1.306	14.739	.0002
Grade	3	2.118	23.904	.0001
Sex	1	.354	3.993	.048
Gp1/3 x Grade	3	.146	1.653	.180
Grade x Sex	3	.012	.136	.983
Gp1/3 x Sex	1	.864	9.762	.002
Gp1/3 x Grade x Sex	3	.141	1.595	.193
Error	147	.089		

<u>Group 1 versus Group 3--Table 33</u> **Analysis of Variance for Haptic Exploration Strategy Scores**

Dependent Variable: HHC1

Factor	DF	MS	F	Sig. of F
Gp1/3	1	1.306	14.739	.0002
Grade	3	1.583	22.208	.0001
Sex	1	.272	3.815	.053
Gp1/3 x Grade	3	.045	.634	.594
Grade x Sex	3	.006	.087	.967
Gp1/3 x Sex	1	.455	.387	.013
Gp1/3 x Grade x Sex	3	.054	.758	.520
Error	147	.071		

Group 1 versus Group 3--Table 34 **Analysis of Variance for Haptic Exploration Strategy Scores**

Dependent Variable: HHC2

Factor	DF	MS	F	Sig. of F
Gp1/3	1	.071	1.067	.303
Grade	3	1.217	18.330	.0001
Sex	1	.181	2.726	.101
Gp1/3 x Grade	3	.057	.865	.461
Grade x Sex	3	.012	.184	.907
Gp1/3 x Sex	1	.458	6.901	.010
Gp1/3 x Grade x Sex	3	.042	.629	.600
Error	147	.066		

Group 1 versus Group 3--Table 35 **Analysis of Variance for Haptic Exploration Strategy Scores**

Dependent Variable: HVS

Factor	DF	MS	F	Sig. of F
Gp1/3	1	.706	9.508	.003
Grade	3	1.668	22.469	.0001
Sex	1	.206	2.772	.098
Gp1/3 x Grade	3	.025	.332	.802
Grade x Sex	3	.043	.585	.626
Gp1/3 x Sex	1	.144	1.937	.166
Gp1/3 x Grade x Sex	3	.173	2.333	.077
Error	147	.074		

Group 1 versus Group 3–Table 36 **Analysis of Variance for Haptic Exploration Strategy Scores**

Dependent Variable: VHC1

Factor	DF	MS	F	Sig. of F
Gp1/3	1	.461	5.201	.024
Grade	3	.762	8.604	.0001
Sex	1	.136	1.535	.217
Gp1/3 x Grade	3	.117	1.315	.272
Grade x Sex	3	.067	.754	.522
Gp1/3 x Sex	1	.360	4.059	.046
Gp1/3 x Grade x Sex	3	.202	2.279	.082
Error	147	.089		

Group 1 versus Group 3–Table 37 **Analysis of Variance for Haptic Exploration Strategy Scores**

Dependent Variable: VHC2

Factor	DF	MS	F	Sig. of F
Gp1/3	1	.249	3.181	.077
Grade	3	.698	8.924	.0001
Sex	1	.125	1.595	.209
Gp1/3 x Grade	3	.111	1.418	.240
Grade x Sex	3	.060	.773	.511
Gp1/3 x Sex	1	.331	4.233	.042
Gp1/3 x Grade x Sex	3	.179	2.290	.081
Error	147	.078		

Group 3--Table 38 **Analysis of Variance for Exploration Times**

Dependent Variables:
HHS + HHC1 + HHC2 + HVS + VHC1 + VHC2
vs. HVC1 + HVC2 + VHS + VVS + VVC1 + VVC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	2942.745	77.574	.0001
Grade	3	190.390	5.091	.007
Sex	1	303.856	8.010	.009
Grade x Sex	3	101.039	2.664	.068
Error	27	1.305		

Group 3--Table 39 **Analysis of Variance for Exploration Times**

Dependent Variables:
HHS + HHC1 + HHC2
versus HVS + HVC1 + HVC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	29.096	1.052	.314
Grade	3	24.552	.888	.460
Sex	1	79.942	2.890	.100
Grade x Sex	3	32.035	1.158	.344
Error	27	7.663		

Group 3--Table 40 **Analysis of Variance for Exploration Times**

Dependent Variables:
HHS + HHC1 + HHC2
versus VHS + VHC1 + VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	41.398	2.204	.149
Grade	3	10.614	.565	.643
Sex	1	248.084	13.209	.001
Grade x Sex	3	29.680	1.580	.217
Error	27	18.782		

Group 3--Table 41 **Analysis of Variance for Exploration Times**

Dependent Variables:
HHS + HHC1 + HHC2
versus VVS + VVC1 + VVC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	1242.219	86.019	.0001
Grade	3	58.998	4.085	.016
Sex	1	188.381	13.045	.001
Grade x Sex	3	29.559	2.047	.131
Error	27	14.441		

Group 3--Table 42 **Analysis of Variance for Exploration Times**

Dependent Variables:
HVS + HVC1 + HVC2
versus VHS + VHC1 + VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	1.082	.088	.770
Grade	3	7.505	.608	.616
Sex	1	46.371	3.757	.063
Grade x Sex	3	.057	.005	.999
Error	27	12.344		

Group 3--Table 43 Analysis of Variance for Exploration Times

Dependent Variables:
HVS + HVC1 + HVC2
versus VVS + VVC1 + VVC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	891.083	51.895	.0001
Grade	3	15.934	.928	.441
Sex	1	22.888	1.333	.258
Grade x Sex	3	10.699	.623	.606
Error	27	17.171		

Group 3--Table 44 Analysis of Variance for Exploration Times

Dependent Variables:
VHS + VHC1 + VHC2
versus HVS + HVC1 + HVC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	830.072	56.519	.0001
Grade	3	22.362	1.523	.231
Sex	1	4.103	.279	.602
Grade x Sex	3	9.604	.654	.588
Error	27	14.687		

Group 3--Table 45 Analysis of Variance for Exploration Times

Dependent Variables:
HHS vs. HHC1 + HHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	236.984	71.486	.0001
Grade	3	8.581	2.588	.074
Sex	1	27.151	8.190	.008
Grade x Sex	3	2.876	.868	.470
Error	27	3.315		

Group 3--Table 46 Analysis of Variance for Exploration Times

Dependent Variables:
HHS vs. HHC1

Factor	DF	MS	F	Sig. of F
Stimuli	1	186.837	69.173	.0001
Grade	3	6.192	2.293	.101
Sex	1	17.954	6.647	.008
Grade x Sex	3	2.679	.992	.412
Error	27	2.701		

Group 3–Table 47 **Analysis of Variance for Exploration Times**

Dependent Variables:
HHS vs. HHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	293.087	67.087	.0001
Grade	3	11.552	2.644	.070
Sex	1	38.243	8.754	.006
Grade x Sex	3	3.133	.717	.550
Error	27	4.369		

Group 3–Table 48 **Analysis of Variance for Exploration Times**

Dependent Variables:
VVS vs. VVC1 + VVC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	21.862	45.142	.0001
Grade	3	.969	2.001	.138
Sex	1	.031	.063	.803
Grade x Sex	3	.176	.363	.781
Error	27	.484		

Group 3--Table 49 Analysis of Variance for Exploration Times

Dependent Variables:
VVS vs. VVC1

Factor	DF	MS	F	Sig. of F
Stimuli	1	21.068	49.154	.0001
Grade	3	.859	2.004	.137
Sex	1	.004	.009	.925
Grade x Sex	3	.093	.218	.884
Error	27	.429		

Group 3--Table 50--Analysis of Variance for Exploration Times

Dependent Variables:
VVS vs. VVC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	22.671	36.021	.0001
Grade	3	1.123	1.784	.174
Sex	1	.170	.271	.607
Grade x Sex	3	.413	.657	.586
Error	27	.629		

Group 3–Table 51 Analysis of Variance for Exploration Times

Dependent Variables:
HHS, HHC1, HHC2, HVS, VHC1, VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	32353.383	587.941	.0001
Grade	3	164.283	2.985	.048
Sex	1	461.024	8.378	.004
Grade x Sex	3	72.356	1.315	.290
Error	27	55.023		

Group 3–Table 52 Analysis of Variance for Exploration Times

Dependent Variables:
HVC1, HVC2, VHS, VVS, VVC1, VVC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	16330.896	1289.953	.0001
Grade	3	59.924	4.733	.009
Sex	1	35.888	2.835	.104
Grade x Sex	3	2.611	.206	.891
Error	27	12.660		

Group 3--Table 53 Analysis of Variance for Exploration Times

Dependent Variable: HHS

Factor	DF	MS	F	Sig. of F
Grade	3	20.360	2.875	.055
Sex	1	80.824	11.897	.002
Grade x Sex	3	8.953	1.264	.307
Error	27	7.083		

Group 3--Table 54 Analysis of Variance for Exploration Times

Dependent Variable: HHC1

Factor	DF	MS	F	Sig. of F
Grade	3	5.117	2.695	.066
Sex	1	22.590	11.412	.002
Grade x Sex	3	3.134	1.650	.201
Error	27	1.899		

Group 3--Table 55 **Analysis of Variance for Exploration Times**

Dependent Variable: HHC2

Factor	DF	MS	F	Sig. of F
Grade	3	4.705	3.150	.041
Sex	1	7.874	5.271	.030
Grade x Sex	3	2.199	1.472	.244
Error	27	1.494		

Group 3--Table 56 **Analysis of Variance for Exploration Times**

Dependent Variable: HVS

Factor	DF	MS	F	Sig. of F
Grade	3	5.619	1.274	.303
Sex	1	21.283	4.824	.037
Grade x Sex	3	3.500	.793	.508
Error	27	4.412		

Group 3--Table 57 Analysis of Variance for Exploration Times

Dependent Variable: HVC1

Factor	DF	MS	F	Sig. of F
Grade	3	.466	.517	.674
Sex	1	3.334	3.701	.065
Grade x Sex	3	.229	.254	.858
Error	27	.901		

Group 3--Table 58 Analysis of Variance for Exploration Times

Dependent Variable: HVC2

Factor	DF	MS	F	Sig. of F
Grade	3	.629	1.738	.183
Sex	1	2.166	5.982	.021
Grade x Sex	3	.245	.676	.574
Error	27	.362		

Group 3--Table 59 **Analysis of Variance for Exploration Times**

Dependent Variable: VHS

Factor	DF	MS	F	Sig. of F
Grade	3	6.091	1.938	.174
Sex	1	.016	.005	.944
Grade x Sex	3	1.382	.440	.727
Error	27	3.144		

Group 3--Table 60 **Analysis of Variance for Exploration Times**

Dependent Variable: VHC1

Factor	DF	MS	F	Sig. of F
Grade	3	3.861	1.976	.141
Sex	1	1.475	.755	.393
Grade x Sex	3	1.523	.779	.516
Error	27	1.954		

Group 3--Table 61 **Analysis of Variance for Exploration Times**

Dependent Variable: VHC2

Factor	DF	MS	F	Sig. of F
Grade	3	2.800	2.145	.118
Sex	1	.388	.297	.590
Grade x Sex	3	8.880	.675	.575
Error	27	1.305		

Group 3--Table 62 **Analysis of Variance for Exploration Times**

Dependent Variable: VVS

Factor	DF	MS	F	Sig. of F
Grade	3	4.047	5.993	.003
Sex	1	.692	1.025	.320
Grade x Sex	3	.397	.587	.629
Error	27	.675		

Group 3--Table 63 **Analysis of Variance for Exploration Times**

Dependent Variable: VVC1

Factor	DF	MS	F	Sig. of F
Grade	3	1.737	3.166	.041
Sex	1	.800	1.457	.238
Grade x Sex	3	.633	1.154	.346
Error	27	.549		

Group 3--Table 64 **Analysis of Variance for Exploration Times**

Dependent Variable: VVC2

Factor	DF	MS	F	Sig. of F
Grade	3	1.427	1.625	.207
Sex	1	.176	.200	.659
Grade x Sex	3	.321	.365	.779
Error	27	.878		

Group 3–Table 65 **Analysis of Variance for Exploration Times**

Dependent Variables:
HHS vs. HVS

Factor	DF	MS	F	Sig. of F
Stimuli	1	3.398	.376	.545
Grade	3	7.129	.790	.510
Sex	1	19.157	2.122	.157
Grade x Sex	3	7.306	.809	.500
Error	27	9.029		

Group 3–Table 66 **Analysis of Variance for Exploration Times**

Dependent Variables:
VHS vs. VVS

Factor	DF	MS	F	Sig. of F
Stimuli	1	73.744	28.382	.0001
Grade	3	1.116	.429	.734
Sex	1	.498	.192	.665
Grade x Sex	3	2.393	.921	.444
Error	27	2.598		

Group 3--Table 67 **Analysis of Variance for Exploration Times**

Dependent Variables:
HHC1 vs HHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	11.908	13.549	.0001
Grade	3	1.166	1.327	.268
Sex	1	3.790	4.312	.048
Grade x Sex	3	12.115	.138	.937
Error	27	.879		

Group 3--Table 68 **Analysis of Variance for Exploration Times**

Dependent Variables:
VHC1 vs. VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	15.130	19.800	.0002
Grade	3	1.574	2.060	.129
Sex	1	34 994	.458	.504
Grade x Sex	3	39.150	.512	.677
Error	27	76.414		

Group 3--Table 69 Analysis of Variance for Exploration Times

Dependent Variables:
HHC1 + HHC2 vs. VHC1 + VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	29.975	4.474	.044
Grade	3	16.076	2.400	.090
Sex	1	18.161	2.712	.111
Grade x Sex	3	11.862	1.771	.177
Error	27	6.700		

Group 3--Table 70 Analysis of Variance for Exploration Times

Dependent Variables:
HHC1 vs. VHC1

Factor	DF	MS	F	Sig. of F
Stimuli	1	1.361	1.028	.320
Grade	3	.162	.122	.946
Sex	1	12.521	9.547	.042
Grade x Sex	3	.290	.219	.883
Error	27	1.324		

Group 3--Table 71 Analysis of Variance for Exploration Times

Dependent Variables:
HHC2 vs. VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	.530	.502	.485
Grade	3	.673	.639	.597
Sex	1	4.767	4.519	.043
Grade x Sex	3	.590	.560	.646
Error	27	1.055		

Group 3--Table 72 Analysis of Variance for Exploration Times

Dependent Variables:
HVC1 vs. HVC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	25.615	37.734	.0001
Grade	3	.635	.935	.438
Sex	1	.126	.185	.671
Grade x Sex	3	.662	.976	.419
Error	27	.679		

Group 3--Table 73 **Analysis of Variance for Exploration Times**

Dependent Variables:
VVC1 vs. VVC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	.029	.164	.689
Grade	3	.088	.492	.691
Sex	1	.226	1.263	.271
Grade x Sex	3	.311	1.739	.183
Error	27	17.879		

Group 3--Table 74 **Analysis of Variance for Exploration Times**

Dependent Variables:
HVC1 + HVC2 vs. VVC1 + VVC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	155.275	30.183	.0001
Grade	3	2.528	.491	.691
Sex	1	3.938	.766	.390
Grade x Sex	3	1.940	.377	.770
Error	27	5.144		

Group 3--Table 75 Analysis of Variance for Exploration Times

Dependent Variables:
HVC1 vs. VVC1

Factor	DF	MS	F	Sig. of F
Stimuli	1	75.262	42.239	.0001
Grade	3	1.341	.753	.530
Sex	1	.868	.487	.491
Grade x Sex	3	1.167	.655	.587
Error	27	1.782		

Group 3--Table 76 Analysis of Variance for Exploration Times

Dependent Variables:
HVC2 vs. VVC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	64.897	32.007	.0001
Grade	3	6.339	3.126	.042
Sex	1	.042	.021	.887
Grade x Sex	3	.523	.258	.855
Error	27	2.028		

Group 3--Table 77 **Analysis of Variance for Exploration Times**

Dependent Variables:
HHS vs. VHC1 + VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	208.723	35.656	.0001
Grade	3	12.185	2.080	.126
Sex	1	65.150	11.120	.003
Grade x Sex	3	4.024	.687	.568
Error	27	5.859		

Group 3--Table 78 **Analysis of Variance for Exploration Times**

Dependent Variables:
HHS vs. VHC1

Factor	DF	MS	F	Sig. of F
Stimuli	1	156.309	26.525	.0001
Grade	3	8.290	1.407	.262
Sex	1	60.463	10.260	.004
Grade x Sex	3	4.022	.683	.571
Error	27	5.893		

Group 3–Table 79 Analysis of Variance for Exploration Times

Dependent Variables:
HHS vs. VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	268.701	43.293	.0001
Grade	3	16.867	2.718	.064
Sex	1	70.012	11.280	.002
Grade x Sex	3	4.222	.680	.572
Error	27	5.207		

Group 3–Table 80 Analysis of Variance for Exploration Times

Dependent Variables:
HVS vs. VHC1 + VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	182.976	32.058	.0001
Grade	3	5.001	.876	.466
Sex	1	7.707	1.350	.256
Grade x Sex	3	3.046	.534	.663
Error	27	5.708		

Group 3--Table 81 **Analysis of Variance for Exploration Times**

Dependent Variables:
HVS vs. VHC1

Factor	DF	MS	F	Sig. of F
Stimuli	1	113.613	27.683	.0001
Grade	3	1.376	.335	.800
Sex	1	11.533	2.815	.105
Grade x Sex	3	1.666	.406	.750
Error	27	4.104		

Group 3--Table 82 **Analysis of Variance for Exploration Times**

Dependent Variables:
HVS vs. VHC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	211.663	60.115	.0001
Grade	3	4.157	1.191	.336
Sex	1	15.924	4.523	.043
Grade x Sex	3	2.868	.815	.497
Error	27	3.521		

Group 3–Table 83 **Analysis of Variance for Exploration Times**

Dependent Variables:
VHS vs. VVC1 + VVC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	175.912	47.342	.0001
Grade	3	2.723	.733	.542
Sex	1	.281	.076	.785
Grade x Sex	3	3.091	.832	.488
Error	27	3.716		

Group 3-Table 84 **Analysis of Variance for Exploration Times**

Dependent Variables:
VHS vs. VVC1

Factor	DF	MS	F	Sig. of F
Stimuli	1	173.646	45.994	.0001
Grade	3	2.834	.751	.523
Sex	1	.590	.156	.696
Grade x Sex	3	3.313	.877	.465
Error	27	3.775		

Group 3--Table 85 Analysis of Variance for Exploration Times

Dependent Variables:
VHS vs. VVC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	.973	62.810	.0001
Grade	3	.018	1.202	.328
Sex	1	.079	5.133	.032
Grade x Sex	3	.024	1.577	.218
Error	27	3.745		

Group 1 versus Group 3–Table 34 Analysis of Variance for Exploration Times

Dependent Variables:
HHS + HHC1 + HHC2 + HVS + VHC1 + VHC2
vs. HVC1 + HVC2 + VHS+ VVS + VVC1 + VVC2

Factor	DF	MS	F	Sig. of F
Stimuli	1	17557.501	414.397	.0001
Gp1/3	1	65.163	1.538	.217
Grade	3	389.801	9.200	.001
Sex	1	.018	.0004	.934
Gp1/3 x Grade	3	49.318	1.164	.326
Grade x Sex	3	77.446	1.828	.115
Gp1/3 x Sex	1	315.602	7.449	.007
Gp1/3 x Grade x Sex	3	68.595	1.619	.188
Error	147	42.369		

Group 1 versus Group 3--Table 51 **Analysis of Variance for Exploration Times**

Dependent Variables:
HHS, HHC1, HHC2, HVS, VHC1, VHC2

Factor	DF	MS	F	Sig. of F
Gp1/3	1	95.751	1.422	.235
Grade	3	238.042	3.535	.016
Sex	1	33.374	.525	.470
Gp1/3 x Grade	3	66.545	.988	.400
Grade x Sex	3	47.593	.707	.549
Gp1/3 x Sex	1	446.582	6.633	.011
Gp1/3 x Grade x Sex	3	50.316	.747	.526
Error	147	67.332		

Group 1 versus Group 3--Table 52 **Analysis of Variance for Exploration Times**

Dependent Variables:
HVC1, HVC2, VHS, VVS, VVC1, VVC2

Factor	DF	MS	F	Sig. of F
Gp1/3	1	.009	.0004	.984
Grade	3	64.691	2.641	.052
Sex	1	47.231	1.928	.167
Gp1/3 x Grade	3	26.370	1.077	.361
Grade x Sex	3	3.747	.153	.928
Gp1/3 x Sex	1	10.411	.425	.516
Gp1/3 x Grade x Sex	3	1.755	.072	.975
Error	147	24.496		

Group 1 versus Group 3--Table 53 **Analysis of Variance for Exploration Times**

Dependent Variables:
HHS

Factor	DF	MS	F	Sig. of F
Gp1/3	1	.415	.074	.786
Grade	3	20.971	3.753	.124
Sex	1	9.049	1.622	.205
Gp1/3 x Grade	3	9.734	1.745	.160
Grade x Sex	3	3.894	.698	.555
Gp1/3 x Sex	1	67.357	12.076	.001
Gp1/3 x Grade x Sex	3	7.491	1.343	.263
Error	147	5.578		

Group 1 versus Group 3--Table 54 **Analysis of Variance for Exploration Times**

Dependent Variables:
HHC1

Factor	DF	MS	F	Sig. of F
Gp1/3	1	.017	.010	.919
Grade	3	4 543	2 816	.041
Sex	1	.977	606	.438
Gp1/3 x Grade	3	2.663	1 651	.180
Grade x Sex	3	.859	.532	.661
Gp1/3 x Sex	1	22.027	13.654	.000
Gp1/3 x Grade x Sex	3	2.990	1.854	.140
Error	147	1.613		

Group 1 versus Group 3–Table 55 **Analysis of Variance for Exploration Times**

Dependent Variables:
HHC2

Factor	DF	MS	F	Sig. of F
Gp1/3	1	.687	.421	.518
Grade	3	3.478	2.131	.099
Sex	1	.177	.109	.742
Gp1/3 x Grade	3	2.354	1.442	.233
Grade x Sex	3	1.771	1.085	.358
Gp1/3 x Sex	1	7.089	4.343	.039
Gp1/3 x Grade x Sex	3	1.296	.794	.499
Error	147	1.632		

Group 1 versus Group 3–Table 56 **Analysis of Variance for Exploration Times**

Dependent Variables:
HVS

Factor	DF	MS	F	Sig. of F
Gp1/3	1	15.033	2.021	.157
Grade	3	25.014	3.362	.020
Sex	1	7.347	.988	.322
Gp1/3 x Grade	3	1.332	.179	.911
Grade x Sex	3	8.038	1.080	.360
Gp1/3 x Sex	1	11.101	1.492	.224
Gp1/3 x Grade x Sex	3	1.076	.145	.933
Error	147	7.440		

Group 1 versus Group 3–Table 57 Analysis of Variance for Exploration Times

Dependent Variables:
HVC1

Factor	DF	MS	F	Sig. of F
Gp1/3	1	.763	.267	606
Grade	3	1 537	538	.657
Sex	1	1 687	590	444
Gp1/3 x Grade	3	092	032	.992
Grade x Sex	3	417	146	932
Gp1/3 x Sex	1	1.893	662	417
Gp1/3 x Grade x Sex	3	067	023	995
Error	147	2 860		

Group 1 versus Group 3–Table 58 Analysis of Variance for Exploration Times

Dependent Variables:
HVC2

Factor	DF	MS	F	Sig. of F
Gp1/3	1	090	031	861
Grade	3	5 589	1 924	.128
Sex	1	3.911	1.346	.248
Gp1/3 x Grade	3	.206	071	.975
Grade x Sex	3	1 961	.675	.569
Gp1/3 x Sex	1	759	261	.610
Gp1/3 x Grade x Sex	3	.095	.033	.992
Error	147	2.905		

Group 1 versus Group 3--Table 59 **Analysis of Variance for Exploration Times**

Dependent Variables:
VHS

Factor	DF	MS	F	Sig. of F
Gp1/3	1	6.002	1.462	.229
Grade	3	3.944	.961	.413
Sex	1	6.123	1.492	.224
Gp1/3 x Grade	3	3.806	.927	.430
Grade x Sex	3	4.921	1.199	.313
Gp1/3 x Sex	1	.303	.074	.787
Gp1/3 x Grade x Sex	3	.209	.051	.985
Error	147	4.105		

Group 1 versus Group 3--Table 60 **Analysis of Variance for Exploration Times**

Dependent Variables·
VHC1

Factor	DF	MS	F	Sig. of F
Gp1/3	1	4.072	1.761	.187
Grade	3	3.975	1.719	.166
Sex	1	.476	.206	.651
Gp1/3 x Grade	3	1.733	.750	.524
Grade x Sex	3	3.190	1.380	.251
Gp1/3 x Sex	1	.825	.357	.551
Gp1/3 x Grade x Sex	3	1.945	.841	.473
Error	147	2.312		

Group 1 versus Group 3–Table 61 Analysis of Variance for Exploration Times

Dependent Variables:
VHC2

Factor	DF	MS	F	Sig. of F
Gp1/3	1	4.000	2.111	.148
Grade	3	1.092	.576	.632
Sex	1	1.242	.656	.420
Gp1/3 x Grade	3	2.237	1.181	.319
Grade x Sex	3	1.570	.829	.480
Gp1/3 x Sex	1	1.292	.682	.410
Gp1/3 x Grade x Sex	3	1.535	.810	.490
Error	147	1.895		

Group 1 versus Group 3–Table 62 Analysis of Variance for Exploration Times

Dependent Variables:
VVS

Factor	DF	MS	F	Sig. of F
Gp1/3	1	2.170	2.668	.105
Grade	3	2.236	2.750	.045
Sex	1	.930	1.143	.287
Gp1/3 x Grade	3	2.558	3.145	.027
Grade x Sex	3	.464	.571	.635
Gp1/3 x Sex	1	.067	.082	.775
Gp1/3 x Grade x Sex	3	.524	.644	.588
Error	147	.813		

Group 1 versus Group 3--Table 63 **Analysis of Variance for Exploration Times**

Dependent Variables:
VVC1

Factor	DF	MS	F	Sig. of F
Gp1/3	1	2.048	6.228	.014
Grade	3	1.342	4.082	.008
Sex	1	.065	.198	.657
Gp1/3 x Grade	3	.879	2.672	.050
Grade x Sex	3	.207	.629	.597
Gp1/3 x Sex	1	1.020	3.103	.080
Gp1/3 x Grade x Sex	3	.652	1.983	.119
Error	147	.329		

Group 1 versus Group 3--Table 64 **Analysis of Variance for Exploration Times**

Dependent Variables:
VVC2

Factor	DF	MS	F	Sig. of F
Gp1/3	1	.708	1.627	.204
Grade	3	1.806	4.153	.007
Sex	1	.012	.028	.867
Gp1/3 x Grade	3	.414	.951	.418
Grade x Sex	3	.656	1.509	.215
Gp1/3 x Sex	1	.044	.101	.752
Gp1/3 x Grade x Sex	3	.299	.687	.561
Error	147	.435		

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