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A DEVELOPMENTAL ANALYSIS OF HAND AND VISUAL HEMIFIELD DIFFERENCES FOR LETTER IDENTIFICATION: EFFECTS OF MODALITY OF PRESENTATION AND LETTER TYPEFACE CHARACTERISTICS

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By

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ABSTRACT

A DEVELOPMENTAL ANALYSIS OF HAND AND VISUAL HEMIFIELD DIFFERENCES FOR LETTER IDENTIFICATION: EFFECTS OF MODALITY OF PRESENTATION AND LETTER TYPEFACE CHARACTERISTICS

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This study investigated how relative participation of the two cerebral hemispheres in letter recognition varied with typeface complexity, presentation modality (visual or tactual), and age. Bryden and Allard (1976) suggested that complex typefaces require preliminary analysis of spatial configuration by the right hemisphere. Also, more spatial integration is needed with tactual vs. visual presentation. Thus, it was hypothesized that right hemisphere participation (relative performance for left visual field and left hand) would increase with: (1) increasing typeface complexity, and (2) tactual vs. visual presentation.

Subjects were 48 fourth- and ninth-graders and college undergraduates--16 of each grade. All were right-handed males. They orally identified single capital letters in eight typefaces of varying complexity (defined by ratings on scriptlikeness, confusability, and difficulty). In the visual condition, letters were tachistoscopically projected about 2 degrees to either side of a central fixation digit.

In the tactual condition, subjects felt raised letters with two fingers of either hand. Presentation time was adjusted independently for each visual field (hand) to maintain 50% accuracy on each side. The dependent measure was the difference between median presentation times for the two sides for each typeface.

With visual presentation, Hypothesis 1 was supported for all grades. A right field advantage was found for the simplest typeface and a left field advantage for two complex typefaces. However, overall degree of right hemisphere participation was significantly greater for undergraduates than for fourth- and ninth-graders. No hand difference was found for any tactually-presented typeface, thereby failing to support Hypothesis 2.

Another grade difference appeared in regression analyses relating complexity characteristics to average visual field differences for the typefaces. Scriptlikeness and confusability were predictors of field differences for undergraduates, but no combination of predictors was significant for fourth- and ninth-graders. In children, then, the balance of processing was shifted more toward left-hemisphere analysis and responded to different stimulus characteristics.

These findings suggest that both for children and adults the processes used to recognize visually-presented complex letters are different from those used for printlike letters. Tactually-presented letters might require processing in both hemispheres regardless of complexity.

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Bryden, M. P., & Allard, F. Visual hemifield differences depend on typeface. _Brain and Language_, 1976, _3_, 191-200.

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INTRODUCTION

Background

The ability to recognize letters is generally regarded as a fundamental prerequisite for reading (Gibson, Gibson, Pick, & Osser, 1962; Vernon, 1957). Yet, despite the importance of understanding the process of letter identification (considered here to include all the separate phases, such as perception and encoding, that might be involved in the total process) and the great volume of research in the area, the process is still poorly understood. Even the general nature of letter identification cannot be agreed upon. Some researchers stress feature extraction and analysis as a critical step in the process (e.g., Gibson, 1969; Estes, 1975), while others find that it can be explained as a template matching process (e.g., Holbrook, 1975).

In their attempt to better understand letter identification, researchers have analyzed the process with respect to a wide variety of factors. One is modality of letter presentation. In addition to studies of visual and auditory letter presentations, there have been studies of tactile presentations, including braille, embossed, and vibrotactile letters (for review, see Kirman, 1973). A second factor is letter qualities, such as letter typeface (Corcoran & Rouse, 1970) and symmetry (Fudin, Garcia, & Solomon, 1975). Researchers also have investigated certain task variables, such as whether subjects are asked to identify one letter or to categorize two letters as the same or different (e.g., Cohen, 1972), or whether letters are presented alone or in groups (Estes, 1975). In addition, some studies have investigated the letter identification process with respect to the factor of cerebral hemisphere specialization (for review, see White, 1969, 1972) in conjunction with several factors mentioned.

In a broad sense, the purpose of this dissertation is to further examine the letter identification process by determining whether and how it is affected by variation of some of these factors alone and in combination with each other.

In a narrower sense, the purpose is to answer specific questions that arose from a series of studies of hand differences in braille letter learning (Wagner, 1976; Harris, Wagner, & Wilkinson, 1976a, 1976b; Harris, Wagner, Wilkinson, & Feinberg, 1976c). Therefore, this section on background material for the ideas in this dissertation will consist of a brief description of the main braille learning study (Wagner, 1976) and the analysis of results that led to the questions currently being considered.

Description of the Main Braille Learning Study

The purpose of the main braille learning study was to explore possible cerebral hemisphere specialization for braille analysis. Assuming stronger contralateral than ipsilateral connections between hand and cerebral cortex, hemisphere advantage was inferred from hand advantage in learning braille letters. Braille letters are groups of one to five raised dots arranged in designated combinations of the six possible positions in a three by two cell. On the one hand, it was supposed that these letters could be analyzed and recalled as symbols of verbal material, like Roman letters for sighted individuals. Consequently, for right-handers, a right hand (left hemisphere) superiority for braille letter learning would be expected, paralleling the right visual hemifield (RVF) advantage for recognition of tachistoscopically projected Roman letters (e.g., Bryden, 1965).

Contrarily, it was supposed that braille letters might be processed primarily spatially as complex patterns distinguished from one another by the number, location, and spatial configuration of their dots. In this case, a left-hand advantage would be expected, as has been found for the tactile perception of line orientation (Benton, Levin, & Varney, 1973; Varney & Benton, 1975) and irregular, presumably non-labelable shapes (Witelson, 1974, 1976). Left-hand superiority also would be consistent with the left visual hemifield (LVF) superiority found for dot enumeration (Kimura, 1966; Young & Bion, 1979) and dot localization (Kimura, 1969).

To examine hand differences in braille letter discrimination, sighted, right-handed children and adults learned a different set of braille-like letters with each hand. Hand testing order and braille letter set assigned to hand were counterbalanced within each age by sex group. The letters were presented repeatedly in a semi-random order. Subjects were told the names of the letters while they first felt each one, and then had to guess the names on subsequent presentations lasting several second each. Subjects could see neither their hands nor the braille cards.

As measured by the percentage of correct letter identifications with each hand, the group scores revealed a significantly better left-hand than right-hand performance. Although it is this overall result that is important for the purpose of this background section, it should be noted that the extent, and even direction, of hand difference was related to hand testing order and the age and sex of the subject. These variables will be considered later.

The overall left-hand advantage was consistent with earlier studies of blind adults and children (e.g., Hermelin & O'Connor, 1971), sighted adults (Smith, 1929, 1934; Harriman & Castell, 1979), and sighted older children (Rudel, Denckla, & Spalten, 1974). Hermelin and O'Connor (1971) suggested an explanation of the hand differences in terms of cortical specialization. They proposed that braille configurations are treated as spatial stimuli and thus are analyzed more efficiently by the right hemisphere before or during verbal identification and naming by the left hemisphere, resulting in an advantage for the left hand.

Discussion of the Results of the Braille Learning Study

What is still unclear is why the spatial requirements should overshadow the linguistic nature of the stimuli in the case of braille, while the reverse has been found in the case of our Roman letters presented visually. One reason may be that braille letters are more difficult to discriminate than Roman ones, inasmuch as the braille dots require differentiation of minute differences in orientation and spacing of dots separated by a distance just beyond the minimum two-point threshold.

The possibility that the superiority of right hemisphere processing for braille learning stems from the greater difficulty of discriminating braille compared to Roman letters is related to the findings of Bryden and Allard (1976). They showed college students tachistoscopically-projected single letters in ten different typefaces. Subjects had to orally identify the letter shown. The result was a typeface by visual field interaction. The majority of typefaces showed a RVF (left hemisphere) advantage, but two typefaces, which were more "scriptlike" and more difficult to recognize than the others, showed a LVF (right hemisphere) advantage. Bryden and Allard explained these results in terms of hemisphere processing differences. They supposed that the right hemisphere is more efficient at certain global preprocessing operations carried out prior to letter naming, while the left hemisphere is better at the more analytical identification and naming stages. The more scriptlike typefaces probably required more initial preprocessing "to normalize the stimulus and to focus attention on the relevant characteristics of the target" (p. 198). The greater global preprocessing capacity of the right hemisphere therefore became critical, leading to a right hemisphere advantage. Presumably, then, braille letters, like the more scriptlike Roman alphabet letters, could require much "preprocessing" by the right hemisphere prior to letter identification and naming by the left hemisphere.

According to this account, right hand (left hemisphere) superiority would be expected for the tactual discrimination of Roman alphabet letters printed in a simple block form. However, studies of tactual discrimination of Roman letters have suggested greater right hemisphere involvement than generally has been found in visual presentation studies. Of eight studies reviewed, two suggested a left hand (right hemisphere) advantage (Gardner, 1942; Cioffi & Kandel, 1979, for boys), two found a marginal right-hand (left hemisphere) advantage (Witelson, 1977a, for boys; Oscar-Berman, Rehbein, Porfert, & Goodglass, 1978), and four found no hand difference (Witelson, 1974; LaBreche, Manning, Goble, & Markman, 1977; Klein & Rosenfield, 1980; Manning, 1980).

From these findings another possibility is suggested--that left hand superiority on the braille task is related to the special nature of the tactual modality. Perhaps the way most tactile information is detected or processed necessitates a greater degree of integration and, therefore, greater right hemisphere involvement than the same information presented visually.

Main Question to be Addressed in This Dissertation

The basic hypothesis of this dissertation is that hemisphere specialization for letter identification (as reflected in hand and visual field asymmetries) will be influenced systematically by both stimulus characteristics (such as discrimination difficulty and scriptlikeness) and presentation modality. When letters varying in general complexity are presented both visually and tactually, it is expected that left hemisphere advantage (right hand or RVF advantage), if any, will decrease and right hemisphere advantage (left hand or LVF advantage) will gradually appear as the degree of complexity is increased (see Figure 1). However, the point along the continuum of complexity at which a left hemisphere advantage will change to a right hemisphere advantage is expected to differ for the two modalities because of their different natures. Left-hand advantage is expected to begin at a more moderate degree of complexity than that required for a LVF advantage.

One main question to be addressed in this dissertation is whether age of subject and concomitant variation in familiarity with cursive and manuscript letters will modify the hypothesized effects of modality and letter typeface on hemisphere specialization for letter stimuli. Students about to enter fourth and ninth grades and college students will be tested. The fourth-graders should have just begun to learn cursive writing within the past two years. Therefore, although the fourth-graders should be able to recognize cursive letters, they will be relatively inexperienced with them. Ninth-graders will represent an intermediate degree of familiarity with cursive letters and with linguistic stimuli in general, whereas college students should be highly practiced with this type of material.

In summary, the general purpose of this dissertation is to clarify further the process of letter identification. Specifically, it is

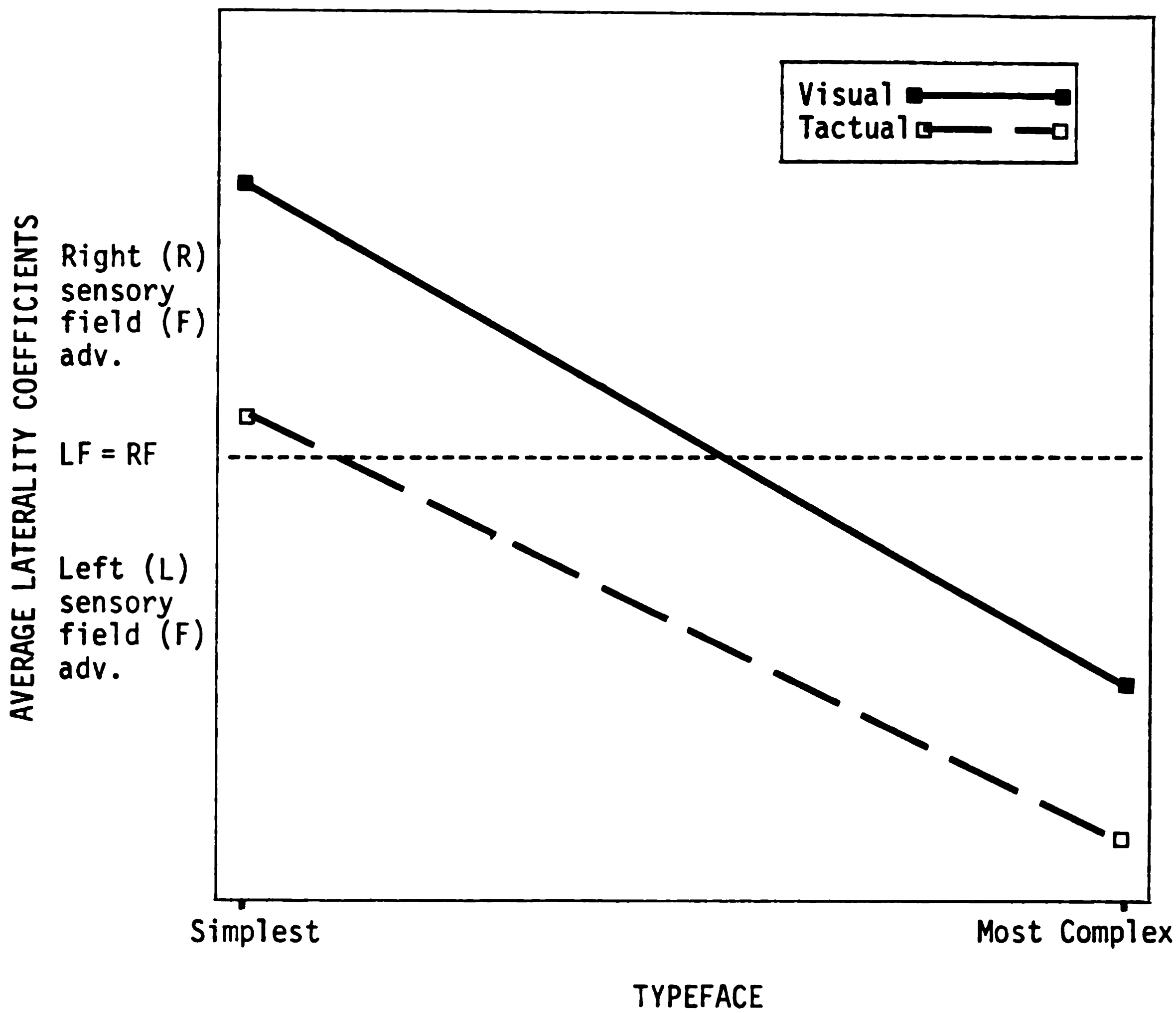

Fig. 1. Hypothesized relation between typeface characteristics and hemisphere specialization for the visual and tactual modalities.

hypothesized that hemisphere specialization for letter identification depends on the interaction of modality of presentation and letter typeface characteristics, and that this relationship varies with the subject's age. The rest of the introduction is divided into two main sections: first, a discussion of presentation modality; second, a discussion of stimulus characteristics. Each section will begin with a consideration of some apparently important aspects of the factor, followed by evidence for the effects of these aspects on hemisphere specialization for letter identification. Finally, specific predictions about the interaction of the two factors will be summarized.

Presentation Modality

Modality versus Non-modality Approach to Form Perception

The main question about modality to be addressed in this dissertation is whether it critically affects the accuracy and process of letter identification. The first step in dealing with this question will be to address the issue of the influence of modality on form perception in general. This more global issue has been considered by Goodnow (1971a). She assumed that an object could be explored in many different ways, and with different modalities, and that on any two inspections a person might have difficulty deciding whether he was dealing with one and the same object (Goodnow, 1971a, p. 4). Goodnow supposed, however, that the difficulty could not be attributed to presentation of the object in different perceptual modalities. Instead, she suggested an approach emphasizing differences in exploratory behavior, or in memory or encoding processes, that would cut across modalities.

Comparison of scanning patterns. This non-modality approach is reflected in other research that has stressed the nature of scanning and exploratory processes, some of which Goodnow cited. Vurpillot (1976), Gibson (1966), Piaget (1956), and many of the Soviet researchers in the area of learning and perception in children (see review by Pick, 1963; Zaporozhets, 1965) have related children's increasingly accurate perceptual judgments to increasingly thorough exploratory movements of eye and hand. In general, for Vurpillot, and for the Soviet researchers (Zaporozhets, 1965), thorough exploratory movements enable the observer to form an accurate model, or image, of the object being explored. From Gibson's point of view, the emphasis should be more on the importance of the movements for facilitating the abstraction of critical stimulus features. Piaget (1956, 1961) emphasized the importance of the movements for creating "decentration" or more uniform distribution of attention across the object. Despite slightly different ideas about the function of the exploratory movements, all of these researchers have noted the similarity of the development of these movements in the tactual and visual modalities. In both modalities, development proceeds through stages in which the movements become progressively more systematic and more consistent with the stimulus outline. Although the emergence of systematic movements occurs earlier in the visual modality, movements in both perceptual modalities reach a fairly mature stage by at least nine years of age (Vurpillot, 1976; Zaporozhets, 1965). This work therefore emphasizes fundamental similarities in the character of the two modalities, thereby supporting the non-modality approach advocated by Goodnow.

Comparison of relative saliency of different properties. Other evidence Goodnow related to the non-modality approach is not so strongly suggestive of inter-modal similarities, and might even be reinterpreted to support a strict modality approach. One type of evidence consists of the comparison of stimulus characteristics most salient to the hand and to the eye. To make this comparison, Goodnow (1969) tested children on a match-to-sample task in which the stimuli were examined either tactually or visually. On each trial, the child was given a standard and two comparison stimuli, which would vary from the standard in size, orientation, curvature of line, or number of lines. In general, a stimulus that varied in curvature was most often judged different from the standard when the stimuli were looked at, while a stimulus that varied in orientation resulted in the strongest sense of difference from the standard when the stimuli were felt.

According to Goodnow (1971a), part of the difficulty in judging whether an object that is felt is the same as one that is seen thus can be explained in terms of differential sampling of stimulus properties rather than in terms of modalities per se. Further support for this explanation comes from studies (Pick & Pick, 1966; Gibson et al., 1962) in which children were presented with letter-like standard forms followed by a series of transformations of these forms and at least one duplicate of the standard. The children then were asked to select the forms that were the same as the standard. With visual presentation, Gibson et al. found that the line to curve transformations and orientation transformations were of about equal difficulty. In contrast, Pick and Pick found orientation transformations to be very easy tactual discriminations, compared with line to curve and other transformations. Therefore, whether the measure is disciminability or preferred basis of similarity, orientation seems to be relatively more salient for the tactual modality, while curvature is relatively more salient for the visual modality.

The question that follows from Goodnow's explanation in terms of sampling method is, which factor--modality or sampling method--should be considered more fundamental? If it is sampling method, this implies that a given modality could be easily trained in the stimulus sampling procedures characteristic of another modality. In this case, Goodnow's use of the evidence pertaining to the relative salience of stimulus properties to support the non-modality approach seems justified. However, if sampling method is inherent in or a natural product of the special nature of the modality, then the critical factor is still modality. The difference in sampling procedure might even be considered to enhance the difference between modalities. In any case, it seems just as reasonable to suppose that the nature of the modality gives rise to its typical sampling method as to suppose that sampling differences override fundamental modality differences.

Comparison of recall accuracy. A second type of evidence used by Goodnow to support the non-modality approach involves research on the role of memory in cross-modal matching. To test for the effects of memory demand, Goodnow (1971b) likened the effects of increasing the time delay between presentation of standard and comparison objects to increasing the number of comparison objects. Both manipulations would make it harder to remember the object presented first. Goodnow presented adults with one, three, or five comparison objects after a standard first inspected by eye or hand. In general, errors increased with the number of comparison objects when inspection of the standard was by hand, but errors remained constant when inspection of the standard was visual. These results are consistent with those of a previous study (Posner, 1967) which found that memory for kinesthetically perceived distances decayed more during an unfilled time interval than did memory for visually perceived distances. A greater decrease in recall for conditions involving a tactual component compared to those with only visual components also has been found for children by increasing the number of comparison items (Davidson, Cambardella, Stenerson, & Carney, 1974a), and for adults by increasing the retention intervals (Abravanel, 1973).

The general conclusion from these findings is that increased memory demand had a different effect on stimulus recall, depending on whether the stimulus was perceived by hand or by eye. This conclusion assumes that information acquisition was equal in the two modalities or, at least, that the accuracy of information acquisition did not affect the retention curves. Again, Goodnow (1971a) rejected an explanation in terms of intrinsic modality differences and, instead, attributed the weakness of memory for tactually perceived stimuli to the inexperience of normally sighted subjects at gathering information by that means. She cited evidence from work with blind subjects to support her point of view. Subsequent research on tactual scanning strategies (Davidson, Barnes, & Mullen, 1974b; see Davidson, 1976, for review) has reinforced Goodnow's view by showing that individuals with extensive tactual experience (e.g., blind people) are not so seriously affected by memory demand as less experienced persons, at least partly because of the experienced individuals' more efficient ways of exploring the stimulus.

While this research suggests that memory for tactually perceived stimuli can be improved through experience, this mainly holds for extensive long-term experience, like that received by a congenitally blind individual. There is, moreover, no evidence that the level of retention of tactual information achieved is equivalent to the retention of the analogous visual information by sighted persons. Thus, for each modality, there might be a range of retention accuracy according to the degree of experience at information gathering through that channel. These ranges might overlap slightly at the extremes, but the fundamental memory difference between modalities will still apply.

<u>Comparison of memory encoding processes</u>. In addition to considering recall accuracy, it is important to consider whether the

actual encoding process differs for stimuli presented in the two modalities. Millar (1975) has argued that both blind and sighted children show both tactual and verbal encoding of tactually presented common objects. It also has been shown that adults possess a short-term tactual storage for non-verbal materials (Bliss, Crane, Mansfield, & Townsend, 1966). This short-term tactual store presumably means that the characteristic features of the way an object feels can be stored in memory beyond brief iconic persistence and can be used to aid recall even a minute or two after presentation. Thus, tactual information apparently can survive perception and can affect recall, just as visual information can (Millar, 1972).

While both modalities have their own characteristic memory store, the storage of tactually perceived spatial or form information seems to be more flexible than the storage of visual information, and, in many cases, can even involve visual encoding (Attneave & Benson, 1969; Freides, 1974; Pick, 1970). For example, visual imagery seems to play a large role in cross-modal matching studies, even in the intra-modal (tactual-tactual matching) control condition (Cairns & Coll, 1977; Jackson, 1973). Researchers who have hypothesized visual storage of tactual information have generally stressed the qualitatively different facilities for data handling possessed by different modalities and the tendency for sensory information to be transferred to the modality most adept at processing and storing it. Therefore, the range and type of strategies available for memory storage appear to be different for the two modalities, even if the modality difference in recall accuracy does diminish with extensive practice at gathering information tactually.

Comparison of the need for spatial integration in the visual and tactual modalities. After considering some other possible interpretations of Goodnow's arguments for a non-modality approach to form perception, it seems that care must be taken not to underemphasize the importance of modality. Though it is possible to treat stimulus sampling method and practice at encoding a stimulus in memory as alternatives to modality explanations and as reasons for modality differences, these factors also can be dealt with as consequences of a difference in the basic natures of the visual and tactual modalities. A comparison of these basic natures must be based in large part on speculations and observations, because empirical questions about this problem are difficult to formulate.

The main idea of many of the theorists who have compared the two modalities is that tactual perception necessitates more integration from separate points in time and space. For instance, Revesz (1950) has stated that tactual perceptions are more sums of separate parts than are their visual equivalents. Similarly, Vurpillot (1976) observed that "the visual receptor system permits the simultaneous experience of multiple data, while the tactile system only provides limited data in succession" (p. 273). Even though Gibson (1962) emphasized the similarity between visual and tactual information gathering, he also observed that visual perception is based on "the figure-ground phenomenon, the simultaneous registering of the whole contour, whereas the unity of the tactual perception has to be based on either cutaneously separate impressions or on successive impressions" (p. 488).

Another way of viewing this extra demand on the tactual modality is to consider that the tactual modality may be especially suited for the analysis of spatiotemporal displays. These spatiotemporal displays require the integration of points separated in time and space. Transforming a spatial display into a spatiotemporal one by the addition of movement generally impedes perception of qualities by the eye, yet facilitates perception by hand (Kirman, 1973). One example mentioned by Kirman (1973, p. 66) deals with the perception of moving letters by hand and eye. Visually, the moving print is experienced as a blur at relatively low rates of movement. Yet such movement is exactly what is needed to aid the hand in reading braille or embossed Roman letters.

Kirman's view is consistent with Kasajima's (1974) comparison of the function of pauses and movements in visual and braille reading. According to Kasajima, "movements of the eye are so rapid that no perception of words or letters occurs during them; but in braille reading, perception occurs only during movement" (p. 54). Thus, the integration of successively perceived points is both a requirement and a special ability of the tactual modality.

Comparison of information-gathering tempo in the visual and tactual modalities. In general, the hand is slower than the eye at gathering information. The limited tempo of tactual information gathering in combination with the serial nature of tactual exploration determine to a large degree the significantly poorer performance in the tactual-tactual matching condition compared to the visual-visual matching condition in most cross-modal studies of form perception (e.g., Abravanel, 1973, with adults; Jackson, 1973; Cronin, 1973; Davidson et al., 1974a). In such studies, there have been attempts to control for the slower information gathering capabilities of the tactual modality by using a longer presentation period for the tactual stimuli than for the visual stimuli. Davidson, Abbott, and Gershenfield (1974c) found that the accuracy of form matching in the visual and tactual intra-modal conditions did not differ significantly with 16-sec. exposure times for tactual stimuli against four-sec. times for visual, although the tactual scores were still lower.

Other attempts have not been successful and have found a significant difference between intramodal conditions even when the tactual stimuli were explored for 30 sec. compared to five sec. for the visual stimuli (Cairns & Coll, 1977; Butter & Bjorklund, 1973). This difference became non-significant in one of the studies (Butter & Bjorklund, 1973) only when visual exploration time was reduced to two sec. Jackson (1973) attempted to control for the modality difference in information gathering tempo and in the serial nature of exploration by having children in the visual condition follow a dot of light as it moved around the contour of the form. Errors were still significantly greater in the tactual intramodal condition. The results of these attempts to control for exploration pace and manner demonstrate the much longer exploration time needed in the tactual modality to attain parity in accuracy to that in the visual modality. The findings also indicate that even with controls, visual performance surpasses tactual performance, suggesting that other fundamental differences between modalities remain.

Comparison of the spatial resolving power of the tactual and visual modalities. Another possible critical difference between vision and touch with respect to the question at hand is in their spatial resolving power. Evidence for the poorer spatial resolving power of the skin has come mainly from studies of simultaneous masking (see Kirman, 1973, for review). For instance, Loomis and Apkarian-Stielau (1976) looked at the effects of simultaneous lateral masking on tactile and blurred visual letter recognition. They attempted to control for the different spatial resolving powers of the skin and eye by changing the spacing and size of their visual and vibrotactile arrays. Even with this control, tactile recognition was worse in all masking conditions. Also, when the accuracy scores for each letter perceived visually were correlated with the accuracy scores for letters perceived by touch, the correlation was only .68 for the no-mask condition. Thus, the spatial resolving power of the skin is poorer than that of the eye, but even when this factor is controlled, other fundamental modality differences affect the accuracy and quality of performance.

In conclusion, in some instances, especially when developmental progression is of main concern, the nature and function of exploratory processes are similar in the visual and tactual modalities, and, in many ways, are more critical than modality considerations. However, the importance of considering the sensory modality in which a stimulus is perceived should not be overlooked. Differences between the visual and tactual modalities in relative saliency of various stimulus dimensions and in memory strength and encoding processes can be thought of as reflections of a fundamental difference in the natures of the two modalities. These natures are determined by such factors as spatial resolving power, information gathering tempo, and the need for spatial and temporal integration. While most previous studies of modality differences have been concerned with form perception in general, there is limited evidence to suggest that letter identification may also vary systematically with modality of presentation.

Relationship of Modality Differences and Hemisphere Specialization

Assuming fundamental differences between the visual and tactual modalities, the next step in developing the hypotheses of this dissertation is to examine whether these differences are related to hemisphere specialization. First, consideration will be given to possible reasons for expecting an association between hemisphere and modality on the basis of previously discussed modality differences. Then, evidence from past research on visual field asymmetries will be compared to evidence pertaining to hand differences on similar tasks. If there is a modality difference in direction or degree of asymmetry, then a relationship between modality and cerebral hemisphere might be expected. For the purposes of this dissertation, the emphasis will be on letter and word identification tasks. Finally, several studies that have examined the correlations between left-right asymmetry on a dichotic listening task and a visual field test will be considered. While these studies do not directly compare tactile and visual asymmetry, they do address the general issue of the effect of modality of presentation on hemisphere specialization.

Expectations based on previously discussed modality differences. One modality difference previously discussed is the difference in relative saliency of curvature (greater for vision) and orientation (greater for touch). An association of modality with cerebral hemisphere would be indicated if it could be shown that each hemisphere is specialized for the judgment of one of these characteristics, or if hemisphere specialization is found for one of the characteristics or one of the presentation modalities, but not the other. In general, for both visual and tactual presentations, the right hemisphere seems to be specialized for the analysis of line orientation, as long as the difference between lines is small (Umilta, Rizzolatti, Marzi, Zamboni, Franzini, Camarada, & Berlucchi, 1974, for vision; Varney & Benton, 1975; Benton, Levin, & Varney, 1973; Benton, Varney, & Hamsher, 1978, for touch). With a difference between lines of 45 degress or more, a right visual field (RVF), or left hemisphere, advantage has been found (Umilta et al., 1974; White, 1971). However, it is possible that this left hemisphere advantage indicates only that the easier discriminations are more available to linguistic analysis.

A tendency toward right hemisphere specialization for the judgment of arc curvature also has been indicated (Longden, Ellis, & Iversen, 1976, for vision; Nebes, 1971a, for touch). Longden et al. found a left visual field advantage (right hemisphere) in reaction time for judgments of whether two arcs differed in curvature. Using commissurotomized patients, Nebes showed that the right hemisphere was superior to the left in matching tactually perceived arcs to their corresponding circles. With normal subjects, a right hemisphere advantage on a modified arc-circle matching test was found by Fagan-Dubin (1978), although no hand difference has been observed by others (Nebes, 1971b; Kutas, McCarthy, & Donchin, 1975). If the perception of the orientation and curvature of forms can be related to the perception of simple line orientation and arc curvature, then the modality difference in relative saliency of these two characteristics does not seem to be a reason for expecting an association between modality and cerebral hemisphere.

A second modality difference is that for sighted subjects, the image of a tactually perceived object, compared to the image of a visually perceived object, is more susceptible to temporal decay and more likely to be stored at least partly in another modality (vision). There is no clear evidence that memory strength is related to cerebral hemisphere. A LVF superiority for the recognition of complex, random shapes has been found to increase with the length of recall interval, becoming significant at the 10 and 20 sec. intervals (Dee & Fontenot, 1973). This finding might suggest an association of greater memory strength with the right hemisphere, but it is more likely that short-term memory demands merely enhance the existing factors (perceptual and others) affecting hemisphere specialization. Then, greater memory demands would also be expected to increase RVF superiority for verbal stimuli. Rosen, Curcio, MacKavey, and Hebert (1975) investigated this hypothesis by presenting subjects with bilateral columns of four letters and asking them to report only one column in each trial. Based on their finding that the largest visual field asymmetry occurred for letters in the fourth position, they concluded that short-term memory demands contributed to the observed asymmetry.

There is also no direct evidence available to associate with either hemisphere the transfer of tactual information to a visual image. However, the left parietal region has been associated with tactile-visual matching (Butters, Barton, & Brody, 1970), which might suggest a left hemisphere advantage for the transfer from a tactile to visual image. Overall, evidence about the association of memory factors with hemisphere differences is weak and requires many inferences. No general association of modality and cerebral hemisphere is apparent.

A third difference between the hand and the eye is concerned with the degree to which information from successively perceived points must be integrated during stimulus exploration. Since the hand must integrate information from separate points to a much greater degree than the eye, it might be expected that the tactual modality would be associated with the serial processing attributed to the left hemisphere (Cohen, 1973).

However, more critically, it seems that the tactual integration of separate points requires active construction and manipulation of increasingly more complete images. This active process of construction involves thinking in a "spatial" way, which has been categorized as a right hemisphere process (e.g., Kimura, 1973). The integration of separate points required by the tactual modality also seems to depend on what Broadbent (1974) has described as "a stored representation of the world that retains its features in parallel for quite long periods of time" (p. 40). In other words, recently perceived stimulus points can be integrated with less recently perceived points only if the previously gathered information is retained. These processes that involve sustaining the continuing representations of the environment are characterized by Broadbent (1974, p. 40) as right hemisphere processes. Contrarily, left hemisphere processes would involve categorizing changes in the environment. Thus, intuitive consideration of the fundamental nature of the modalities might lead to an association between right hemisphere processing and the tactual modality.

Expectations based on past research: previous studies of visual field asymmetry. In general, past studies of visual field asymmetry have shown a RVF advantage for the recognition of verbal stimuli (see reviews by White, 1969, 1972). A RVF superiority in adults has been found for: (1) recognition of single letters presented along the horizontal meridian (Bryden, 1965, 1966, 1973; Bryden & Rainey, 1963; Worall & Coles, 1976; Fennell, Bowers, &

Satz, 1977; Schmuller, 1979) and, especially, the encoding phase of letter identification (Cohen, 1976); (2) time taken to judge whether two letters have the same name (Cohen, 1972; Geffen, Bradshaw, & Nettleton, 1972); (3) recognition of single letters presented in groups (Bryden, 1966; Kimura, 1966); and (4) word recognition (Fontenot, 1973).

These studies that have found a RVF advantage typically have employed a successive unilateral presentation technique with binocular viewing and a verbal identification response. The two major problems with this technique are the possible confounding of the hemisphere specialization effect with trace scanning tendencies and with response factors (White, 1969, 1972). However, since at least some of the studies reporting a RVF advantage used methods or stimuli that minimized the effects of these possible confounding factors, we can conclude that a hemisphere difference in processing is at least one important reason for the RVF advantage. First, trace scanning refers to the scanning of the iconic image that persists briefly following stimulus presentation. While the general tendency to scan the post-exposural stimulus trace in a left to right direction would lead to a RVF superiority for unilaterally presented stimuli, this trace scanning should not have been a critical factor when only single letters were presented. Second, although the RVF advantage in some of the studies might have been partly the result of left hemisphere control of the identification response, this should not have been the case in other studies, especially those requiring a rapid "same" or "different" response. In summary, the RVF advantage for verbal stimuli can be attributed largely to an asymmetry in hemispheric processing.

Effects of age on visual field asymmetry for the recognition of verbal stimuli. While a RVF advantage for the recognition of verbal stimuli generally has been found for seven- to 13-year-old children who are normal readers, the findings are not as clear as those for adults. Some developmental studies of visual field asymmetry for word identification have found a significant RVF advantage for the one age group tested (McKeever & Huling, 1970; Marcel, Katz, & Smith, 1974; Marcel & Rajan, 1975) or a constant RVF advantage across all ages tested (Olson, 1973). Other similar studies have found a significant RVF advantage for children older than 10 or 12 years of age, but not for the youngest age groups tested (Forgays, 1953; Miller & Turner, 1973; Turner & Miller, 1975, only under certain conditions of word length and post-exposure field; Reitsma, 1975, cited by Witelson, 1977b; Carmon, Nachshon, & Starinsky, 1976; Tomlinson-Keasey, Kelly, & Burton, 1978, for same-different judgments of sequentially presented words).

Since all these studies involved unilateral presentation of horizontally arranged words, one question is whether the effects are due to hemisphere specialization or to left to right scanning of the post-exposural stimulus trace. This question was addressed in two studies that included conditions for which the two factors would predict opposite results. Olson (1973) used a bilateral presentation condition. According to trace scanning theory, scanning should begin at the left most point of the image, and thus the left field word should be reported more accurately. Carmon et al. (1976) used Hebrew words, which are scanned right to left and therefore should elicit a LVF advantage when presented unilaterally. Since a RVF (left hemisphere) advantage was found in both instances, hemisphere specialization is most likely the dominant factor.

It should be cautioned, however, that while the weight of the evidence supports the conclusion of left hemisphere specialization in children for visually presented linguistic stimuli, not all studies are in agreement. Yeni-Komshian, Isenberg, and Goldberg (1975), for example, found no field asymmetry in 10- to 13-year olds for vertically arranged digit names. In addition, following the predictions of trace scanning theory, Daves and Werzberger (1971) found a <u>LVF</u> advantage for children in grades one to seven for the identification of strings of six letters presented bilaterally.

A second question about the developmental results is whether the pattern of asymmetry changes significantly with age. Of the studies of word identification cited above, over half failed to find a RVF advantage for the youngest age groups tested. While this age trend should be considered tentative because of the lack of controls for changing task difficulty across age groups, further support may be found in several studies of asymmetry for letter discrimination. Reynolds and Jeeves (1978) measured choice reaction time to single lateralized letters. There were four possible letters. Subjects were instructed to press one button if either of two specified letters appeared and to press the other button if either of the other two letters appeared. A RVF advantage was found for 13- and 14-year-olds and adults, but not for seven- and eight-year-olds. Using a similar task with lateralized letter pairs as stimuli, Broman (1978) found a slight RVF advantage for 13-year-olds and adults, a slight LVF advantage for 10-year-olds, and a significant LVF advantage for seven-year-olds. An identical age pattern was found by Carmon et al. (1976) for the identification of single lateralized Hebrew letters. There was no significant field asymmetry at any age except for a LVF advantage for seven-year-olds.

Explanations for this increasing RVF advantage with age focused on the ideas of either increasing specialization of the left hemisphere for processing the printed word (Tomlinson-Keasey et al., 1978) or, as is more likely the case, a change in strategy with age. For instance, Carmon et al. (1976) suggested that sequential (left hemisphere) processing of verbal materials becomes more accentuated with age. Similarly Broman (1978) argued that the "configurational" approach may be the more primitive and the "naming" approach the more advanced manner of perceiving alphabetical material.

In summary, children, as well as adults, have shown a RVF (left hemisphere) advantage for the processing of linguistic stimuli. If there is a change with age in the relative participation of the two hemispheres in the recognition of printed material, the evidence suggests that it is in the direction of increasing left hemisphere participation with increasing age. Therefore, it there is an age difference in asymmetry in this dissertation, it can be predicted that the effect will be a smaller RVF advantage for fourth-graders compared to ninth-graders and college students.

Expectations based on past research: previous studies of hand asymmetry. The eight studies of hand asymmetry for Roman letters that were reviewed can be grouped according to two procedural variables: (1) whether the presentation was dichhaptic (different letters presented simultaneously to the two hands) or unilateral (letters presented to one hand at a time); and (2) whether exploration was active (subjects moved their fingertips over the letter) or passive (subjects held their hands stationary while letters were drawn on them). Results were inconsistent, even within groups of studies using similar procedures.

The procedure used by five of the studies involved dichhaptic presentation with active exploration. Witelson (1974, 1977a & c) conducted two studies with six- to 14-year-old boys. Her stimuli were twenty styrofoam upper-case letters, excluding five of the total of nine laterally symmetrical letters of the alphabet.[1] On a given trial, two pairs of letters were presented for two seconds each, and the subject's task was to report orally the names of the four letters he had just felt. No hand asymmetry was found in the first study, while a marginally significant ($p < .10$) right hand (left hemisphere) advantage was found for boys[2] in the second. However, since the verbal identification response probably necessitated left hemisphere involvement, one possible interpretation of the

findings is that right hemisphere superiority in processing was masked by the left hemisphere's control of the response mode.

To avoid this confounding of response and processing modes, LaBreche et al. (1977) used a left hand and a right hand fingerspelling letter identification response as well as a written response. While hemisphere specialization for fingerspelling has not been clearly established, the evidence suggests either a bilateral representation of manual linguistic stimuli or a tendency toward right hemisphere dependency.[3] Therefore, use of the fingerspelling response might, if anything, tend to enhance any right hemisphere superiority in processing. Despite this change in response method, LaBreche et al. (1977) found no hand differences for deaf and hearing adolescents.

Klein and Rosenfield (1980) used still a different, supposedly "neutral" response method with a similar dichhaptic procedure. They had third-graders point to their response choices using a "double-handed" pointer in the shape of a divining rod. Again, no hand difference was found.

In the fifth related study, Cioffi and Kandel (1979) also used a pointing response, but presented pairs of two consonants (consonant bigrams) rather than single letters. They found a left hand (right hemisphere) advantage for six- to 14-year-old boys. One question raised by this study, though, is whether letters or short sequences of letters are adequate linguistic stimuli. This question was suggested by the results of another condition in which two letter words were presented. A right hand advantage was found for these presumably more adequate linguistic stimuli. One problem with these findings is that, if anything, sequences of two letters should be closer to word stimuli than single letters. Therefore, if right hand advantage increased as the linguistic characteristics of the stimulus increased, consonant bigrams would be more likely than single letters to result in no hand advantage or a trend toward right hand advantage.

There was only one study that combined a dichhaptic technique with a passive procedure, where the experimenter controlled delivery of the stimuli (Oscar-Berman et al., 1978). Following the presentation of one pair of single capital consonants, the adult subjects' task was to report the letter names orally in the order then designated by the experimenter. A marginal ($p < .06$) right hand (left hemisphere) advantage was found, not only for the hand reported second. According to the authors, asymmetry was enhanced for the hand reported second because a greater memory demand was involved.

Finally, stimulus presentation was unilateral in two studies, one with a passive procedure and one with active exploration. Both studies used strings of letters and an oral identification response, and both tested adult subjects. Manning (1980) had subjects hold their hands stationary while the experimenter drew sequences of six capital letters on the palm. There was no hand asymmetry in the number of letters remembered.

Using a different exploration technique, Gardner (1942) had 30 students read nonsense syllables with the fingers in both a left

to right and a right to left direction. The syllables consisted of laterally symmetrical letters made of cord stitched upon cardboard. Performance in both reading directions was faster and more accurate for the left hand than for the right. Summed across the two reading directions, the time difference between the hands was about 5.5 seconds (with 67% of the sample faster with the left hand), and the difference in number of errors was about .7. No statistical tests were performed, but at the least, a trend toward left hand superiority for the recognition of Roman letters was demonstrated. If these findings can be interpreted in terms of cerebral asymmetry, then even tasks requiring the linguistic processing involved in reading, when presented through the tactual system, seem to require some degree of spatial, "right-hemisphere" analysis.

In summary, of the eight studies of hand asymmetry for Roman letter recognition, only four found a significant hand advantage, two in favor of the right hand and two in favor of the left. One of the studies that showed a right hand advantage used a dichhaptic, active presentation technique and the other used a dichhaptic, passive procedure with a moderate memory demand. However, the three other studies using a dichhaptic, active procedure failed to find a hand asymmetry, as did another study using a passive procedure combined with an even greater memory demand. Also, in both studies that showed a right hand advantage, the letters were named orally. Possibly, then, these results were related mainly to a left hemisphere advantage for the spoken response and not to a hemispheric asymmetry for letter perception and processing.

Although the asymmetry was stronger in the two studies that found a left hand advantage, there again were some unanswered questions. No statistical tests were performed in one study, and the left hand advantage switched to a right hand advantage in the other study when two-letter words as opposed to consonant bigrams were used as sitmuli. All in all, the results show that it is difficult to elicit an asymmetry for the tactual perception of Roman letters, possibly indicating that both hemispheres contribute importantly to the letter processing.

The findings of a left hand advantage for reading nonsense syllables and bigrams are consistent with some of the more recent reports of hand asymmetry for braille reading and letter recognition mentioned in the first section. With blind adult subjects, Hermelin and O'Connor (1971) found a left hand advantage in the accuracy with which vertical columns of braille letters were read. With blind children, they found that sentences were read faster and more accurately with the left hand than with the right. Thus, even when a tactile alphabet becomes so familiar a linguistic system as to be almost second-nature, the very fact that it is perceived tactually might induce a certain degree of right hemisphere analysis.

Research with sighted subjects has supported the conclusion that this left hand advantage at least partly represents a hemisphere processing difference and not just a bias resulting from different amounts and types of experience with braille reading for the two hands. As stated in the first section, an overall left hand advantage for braille letter identification also has been found for sighted subjects. This pattern of left hand advantage, however, was influenced by the order in which the hands were tested.

The main effect of hand testing order was an enhancement of left hand performance when it followed the right. Rudel et al. (1974) tested children with a paired associate learning method similar to the procedure of the braille learning study described in the first section (Wagner, 1976). They found that girls did about as well with their right hand whether it was tested first or second, but their left hand scores were much better than the right when tested second, and worse when tested first. To explain this order effect, Rudel et al. suggested that prior training with the right hand helps or "prepares" the left, possibly because right hand use activates verbal strategies tended to be relied on by young girls (Harris, 1977).

Wagner (1976) also found that left hand performance was enhanced when it followed the right. Although scores were generally higher for the second hand tested, the difference between hand scores was greater when the left hand was tested second than when the right hand was second. These findings could be explained in terms of an interaction of the factors of practice and hemisphere specialization, but they also might indicate that part of the left hand superiority depends on prior preparation through left hemisphere strategies.

The latter interpretation is consistent with Kinsbourne's (1973) discussion of lateral asymmetries in terms of "attentional sets" induced by the nature of the task or response method. When the task or response method favors the processing in one hemisphere, that hemisphere is then activated, turning attention toward the opposite side, and, at the same time, inhibiting activation of the other hemisphere. Thus, in a braille learning task, it might be easier initially to establish a left-hemisphere, verbal "set," but once the verbal aspects of the task are mastered, a right-hemisphere, spatial "set" would become effective. Hence, the right-hand-first testing order would be the most advantageous.

One way to eliminate the effects of hand testing order is to present letters to the left and right hands in simple alternation, with a different group of letters being presented to each hand. This alternating hand method has been used by Feinberg and by Harris and Wagner (both studies described in Harris et al., 1976c), and significant left hand advantage was found for right-handed adults. Thus, while the order effect may be important, it is not crucial for the emergence of a left hand advantage. To obtain clearer results, an alternating hand method will be proposed for this dissertation.

Effects of age on hand asymmetry for recognition of verbal stimuli. In general, the age of the subject has not been shown to influence the pattern of hand asymmetry for the recognition of Roman letters. In all three studies that included more than one age group, no significant effect of age on hand asymmetry was found in six- to 14-year-olds. In addition, both for the two studies that found a left hand advantage and for the two that found a right hand advantage, the subjects were children in one case and adults in the other. Therefore, both within and between studies, there was no association of age and degree or direction of asymmetry. It should be noted that while sex differences in asymmetry were reported in two instances (Witelson, 1977a; Cioffi & Kandel, 1979), there was no sex by age interaction.

Contrarily, the age and sex of subject have been found to be related to the pattern of hand advantage for braille letter learning shown by sighted subjects. The general findings were a later emergence of left hand advantage in females than in males, and a tendency toward right hand superiority in younger children. In the developmental study of braille letter learning described in the first section, a definite left hand advantage was found by age nine for males, but not until college age for females (Wagner, 1976). The nine-, 11-, and 14-year-old girls tested by Wagner showed no hand difference. Using a similar paired associate letter learning method with children seven to 14 years of age, Rudel et al. (1974) found a left hand advantage by age 11 for boys, but only by age 13 for girls. In this case, though, the younger girls showed a right hand advantage. In addition, Rudel, Denckla, and Hirsch (1977) tested children and adults on a task requiring same-different judgments of two braille letters examined sequentially by one hand. Left hand superiority was found by the same ages for boys and girls as in the previous study, but a right hand advantage was found for both nine-year-old girls and boys.

These findings could be interpreted to mean that young girls, and maybe even young boys, processed the braille letters as verbal stimuli, and they did so even when the letters did not have to be identified verbally or even have to be known as letters. Thus, when the task involves both spatial and linguistic components, as is thought to be the case for braille letter discrimination, the verbal aspects of the task may be more critical for children below the age of 11 years.

Expectations based on past research: comparison of previous studies on visual field and hand asymmetry for verbal material. The findings of visual field differences in the recognition of verbal stimuli seem to contrast sharply with the findings pertaining to hand differences in the recognition of similar material. Among the visual field studies reviewed by White (1972), none reported a LVF superiority for the recognition of single letters, and nine of 12 studies reported a RVF superiority. Among the studies of hand differences in the recognition of Roman and braille letters summarized in the last section, nearly all reported a left hand superiority or no hand asymmetry. The question now is whether this different pattern of results for the two modalities is evidence for a systematic relationship between modality and hemisphere specialization.

One possible interpretation of the findings is that they do not warrant the assumption that, given similar stimuli, tactual presentation is more likely than visual presentation to induce a right hemisphere advantage. The different patterns of asymmetry for the two modalities instead might be attributed to simple task variables. For instance, it may be more difficult to show an asymmetry in either direction in the tactual modality, so that more complex stimuli would have to be used. This idea is related to LaBreche et al.'s suggestion that their failure to find a hand difference for the recognition of Roman letters indicates that "the task demands associated with each of the letters conditions were not sufficiently complex to tax the spatial and linguistic resources of each hemisphere" (p. 193).

This lack of sufficient complexity in the tactual stimuli, then, would explain why four out of eight studies of hand differences, but only three out of 12 comparable visual field studies, failed to find an asymmetry for Roman letter recognition. The "lack of complexity" hypothesis might also explain the fragile nature of the left hand advantage for braille letter learning, reflected in the fluctuation of results with such variables as age, sex, and hand testing order, and the fact that a left visual field, but not a left hand, superiority was found for dot enumeration (Myers, 1976). While this interpretation in terms of task variables is possible, there is no apparent explanation as to why tactually presented stimuli should need to be more complex for an asymmetry to be shown.

Another possible interpretation of the different pattern of results for the two modalities is that, given similar stimuli, a right hemisphere advantage would be more likely to occur with a tactual presentation method than with a visual presentation method. This hypothesized association between modality and cerebral hemisphere, at least for verbal stimuli, was implicit in Witelson's (1974) explanation for her failure to find a hand difference in the recognition of Roman letters. She suggested that "within the tactual system, linguistic information is analyzed first in a spatial code and then translated into a linguistic code, with spatial analysis more readily processed in the right hemisphere and linguistic analysis in the left hemisphere" (p. 14). Thus, presentation of letters in the tactual modality increases the spatial nature of the identification task, and therefore induces right hemisphere processing. Witelson's description of letter identification in the tactual system is consistent with Hermelin and O'Connor's (1971) description of braille letter recognition as a two-stage coding process. It is difficult to talk about modality differences in the case of braille, however, since no evidence is available on hemisphere specialization for the recognition of braille letters presented visually.

An even stronger association between right hemisphere processing and a tactual presentation method seems to be advocated by Rudel et al. (1977). They suggest that one of the main reasons for the left hand advantage in braille letter recognition is the fact that naive sighted subjects and blind subjects cannot visualize the braille letters. Similarly, they argue that much of the evidence for right hemisphere superiority comes from experiments where vision is excluded. One bit of evidence from the clinical literature might also support this idea of a strong association between the tactual modality and right hemisphere processing. Boll (1974) administered tests of tactile-perceptual ability, including a form recognition task, to patients with right or left hemisphere brain damage. The results showed that the performance of patients with right hemisphere damage was more impaired on the ipsilateral and contralateral sides of the body than for patients with left hemisphere damage. These findings were interpreted as demonstrating the "pre-eminence" of the right hemisphere in subserving tactile perception.

Whether or not this almost exclusive association of the tactual modality with right hemisphere superiority is warranted is not clear. However, there does appear to be some tendency for a systematic increase in the need for right hemisphere analysis when the presentation modality is tactual instead of visual.

Expectations based on cross-modal reliability of laterality tests. A third basis for forming expectations about possible associations between modality and cerebral hemisphere is evidence concerning the correlation of left-right asymmetries found in different modalities. If the asymmetries found in different modalities are highly correlated, it might be predicted that the cerebral hemispheres develop specialization for certain functions independent of the modality in which they are performed. On the other hand, if the asymmetries in different modalities are not even moderately correlated, or are negatively correlated, a dissociation of laterality effects in different modalities might be predicted, and a systematic variation in laterality effects across modalities would be unlikely.

No data on the correlation of asymmetries in the tactual and visual modalities are available, but several studies have looked at the correlation between asymmetries in the visual and auditory modalities. At least four did not find even a moderate positive relationship between modalities. Bryden (1965) and Zurif and Bryden (1969) found only weak positive correlations between asymmetries revealed in a series of dichotic listening and visual field tests. Using a measure of concordance for direction of laterality effect in a dichotic listening test and a visual field test for letter recognition, Bryden (1973) found a relationship the reverse of what he had expected. Those students who showed better left ear performance were more likely to show a RVF superiority. Fennell et al. (1977) also found negative or weak positive correlations between ear and visual field scores within and across testing sessions.

In contrast to those studies, at least two studies have suggested a significant moderate correlation between asymmetries in the two modalities for right handers. Hines and Satz (1974) improved upon the method used in some of the previous studies by computing separate correlations for left and right handers, and by using a visual field testing method that minimized the influence of direction-of-reading. They found significant positive correlations between asymmetries in the two modalities for the right-handed subjects (average uncorrected r = .37). In addition, they found that about 63% of the right handers showed concordance for direction of asymmetry in the two modalities. When Fennell et al. (1977) measured directional concordance rates, instead of correlations between dichotic listening

and visual field scores, they found a moderate agreement between the early testing sessions, and a strong (81.4%) agreement between the third and fourth sessions. In light of these two studies, it seems that a moderate correlation between asymmetries might be expected, and therefore, systematic modality differences in asymmetry would be possible.

One additional issue to be considered when discussing cross-modal reliability is the type of stimuli presented in the different modalities. First, it seems unreasonable to expect that hemisphere specialization for all types of verbal material is a unitary phenomenon (consider Bryden, 1966). Rather, it seems that during development the left hemisphere would come to be specialized for increasingly complex verbal processing "routines," and that each of these routines might be lateralized to a different degree. Therefore, since some of the studies mentioned used different types of stimuli for the visual and auditory tests (Fennell et al., 1977; Bryden, 1973), the basis for their expectation of a strong correlation between asymmetries in the two modalities is unclear.

Second, even in the cases where the stimuli presented in the two modalities were similar (Hines & Satz, 1974), there was no indication that the amount and type of information perceived by each modality were subjectively equal. In conclusion, then, failure to find a strong correlation between asymmetries in the visual and auditory modalities might be partly the result of lack of control over the objective and subjective similarity of the stimuli presented in the two modalities. The importance of stimulus factors will be considered in the next section.

Stimulus Characteristics

Effects of Letter and Typeface Characteristics on the Letter Identification Process

The question of main concern in this section is whether or not systematic variation of letters or their typefaces along selected dimensions would be expected to lead to differences in performance on a letter identification test. Since this dissertation is mainly concerned with hemisphere differences in letter identification, the three dimensions to be discussed are dimensions that Bryden and Allard (1976) have shown to be related to visual field differences. These dimensions are scriptlikeness, difficulty (naming latency), and internal confusability--the extent to which one item in a typeface would be confused with other items in the same typeface. Typeface selection in the current study will be determined by ratings on these three main characteristics.

In addition, ratings will be obtained on two dimensions to be mentioned only briefly in this section--unfamiliarity and superfluity. Unfamiliarity was chosen because Bryden and Allard found it to be moderately, though non-significantly, correlated with visual field differences. Superfluity was chosen because it shared some of the characterisics of scriptlikeness, but might be more appropriate for the type of lettering used both in Bryden and Allard's study and in the current study.

Scriptlikeness. Bryden and Allard evidently used the term "scriptlike" to mean "like handwriting" and that is the way it will be used in the current study. Evidence that this definition of scriptlikeness may be associated with differences in the letter identification process comes from a study by Corcoran and Rouse (1970). These authors suggested that the perceptual system is organized into two "subroutines," one for printing (typing) and one for handwriting. They designed lists of words that were copied in four different ways: (1) lower-case typed letters (TL); (2) upper-case typed letters (TU); (3) handwritten by person 1 (H1); and (4) handwritten by person 2 (H2). These words were then assigned to sets that were either unmixed (all from one list) or mixed (half from one list and half from another). Subjects were shown tachistoscopically projected words from a given set and asked to orally identify them. The data showed that when the mixed set contained H1 and TL words, the mean probability of recognizing the words on the first presentation was significantly lower for the mixed set than for the respective ummixed sets. However, when the mixed set contained either H1 and H2 words, or TL and TU words, there was no difference between the mixed and respective unmixed sets in the mean probability of correct word identification. Thus, Corcoran and Rouse hypothesized that the lower accuracy for sets that contained both typed and handwritten words was caused by the subject's inability to switch to the appropriate processing subroutine before the stimulus was presented.

Given this evidence, then, it would be nice to equate the more scriptlike typefaces used by Bryden and Allard with cursive handwriting. However, it should be noted that, technically and historically, cursive script differs in many respects from the more formal script letters used by Bryden and Allard. The term "script" technically means any handwritten letter or character. Formal script is the polished, calligraphic type of writing system that can be traced back at least as far as the ideograms and phonetic symbols used in ancient Sumeria around 3100 B.C. Contrarily, cursive script can be defined as signs and styles of writing changed in form by everyday use and quickly executed construction (Fairbank, 1970).

Two styles of writing apparent in ancient Egypt can be related to the formal and cursive scripts (Fairbank, 1970). One style, hieratic writing, derived from Egyptian hieroglyphics, which were characters that represented formalized pictures, and also words, syllables, and consonants. The hieratic style was used by priests during the first dynasty (around 2900 B.C.). A second style, demotic writing, was characterized by a rapid, fluent quality which departed greatly from the pictorial quality of the hieroglyphs. This demotic style has not been traced as existing earlier than the seventh century B.C., and probably developed because of the need to write with speed, and consequently to simplify, when writing informally.

This contrast between the formal and cursive styles was also apparent in Roman times (Delpire & Monory, 1961). The bold, polished Roman rustic and unical lettering styles developed at the same time that cursive writing was becoming more popular, possibly because the pen was able to slide on the surface of papyrus. Delpire and Monory noted that "as beautiful as they were legible, the Roman capitals gratify the mind and the eye" (p. 74). Then, in an aside, they noted that "one might assume that capitals in cursive script fatigue the eye" (p. 77). The contrast between formal and cursive scripts was also evident in their observation that "while someone who knows Latin can without much study successfully grapple with rustic or unical inscriptions, he risks being baffled for a long time, if not for good, with the miniscule (lower-case) cursive" (p. 77).

In light of these historical and technical observations, if Bryden and Allard's term "scriptlike" means "like cursive writing," the characteristics of the scriptlike typefaces ought to include: (1) a rapid, fluent quality; (2) possibly more loops and cirlicues; (3) extensions of the letters at the beginning and end, as if to be joined with other letters;[4] and (4) an irregular, even sloppy, quality reflecting the distinctiveness (Gordon & Mock, 1960) and sometimes sloppiness of adult hands. The typefaces used by Bryden and Allard instead are in a precise, formal style. Therefore, variance along a dimension of cursive handwiritng might not be meaningful.

One suggestion for a related dimension that might be more appropriate for Byden and Allard's distinct, precise letters is superfluity, or the degree to which the letter varies from some impression of the "ideal" letter. This dimension could be operationally defined in terms of the number of extra lines, loops, and curlicues added to the basic form of the letter and in terms of the tilt and thickness of the line. To assess the importance of this related dimension, the typefaces in the current study will be rated on both scriptlikeness and superfluity.

Difficulty. The dimension of difficulty also may be important. If this dimension is measured by naming latency (as in Bryden and Allard's study), it probably would be highly related to the dimension of deviation from an ideal. The greater the deviation, the more time it would take to match the perceived letter to the image in memory. When considering the factors that make a letter difficult to recognize, both the characteristics of the letter itself and the characteristics of the typeface appear to be significant. Evidence for a marked variation in the difficulty of perceiving particular letters presented alone was found by Budohoska, Grabowska, and Jablonowska (1975). They asked adults to identify printed Roman alphabet letters presented at a central fixation point for 17 msec. each. The percent of errors ranged from about 60% for T, I, and L, to less than 10% for D and O.

A large variation in the difficulty of recognizing the same letter typed in different scripts also has been shown. Bryden and Allard found that mean recognition times for their different typefaces ranged from 671 msec. to 1183 msec. Reasons for the greater difficulty of some typefaces might be simple explanations based on the clarity of the script or the amount of black and white contrast provided, or they might be more complex explanations based on factors such as amount of deviation from an ideal. In addition, it might be expected that letter and typeface variables would interact with each other to determine difficulty. Some letters, then, would be more difficult to recognize in certain typefaces than in others. For instance, if a given letter was changed in one script by the addition of a loop to the letter's upper part, the most crucial part for letter recognition (Fairbank, 1970, p. 76), the letter might be relatively more difficult to recognize in that typeface than in another where it was changed only slightly or only in the lower part.

Since sensory modality is a primary variable in this dissertation, the possible interaction of modality with these dimensions of letter and typeface difficulty should also be noted. Moderate correlations between visual and tactual presentations have been found for recognition accuracies of letters (Loomis & Apkarian-Stielau, 1976; Craig, 1979) and forms (Birch & Lefford, 1963). Thus it could be expected that relative letter difficulties would be similar, though not identical, in the two modalities. Since there is evidence for a modality difference in the relative ease of line to curve and orientation transformations, typefaces emphasizing orientation changes from the basic form should be relatively easier with tactual presentation, and those emphasizing curvature changes should be relatively easier with visual presentation. Again, the factors of letter and typeface difficulty may interact. For instance, while Goodnow (1969) found that orientation changes yielded a strong sense of difference from most tactually presented standards, this was not true for all tactually presented standards. This finding was presumably related to whether or not the focal point of a particular standard was changed by an orientation transformation. Thus, the modality of presentation, the difficulty of recognizing a given letter, the difficulty of the typeface, and the two- and three-way interactions among these factors are important to consider.

Confusability. Finally, the letter identification process might be influenced by the degree to which the letters in a given typeface are likely to be confused with each other. Again, this dimension is highly related to the others, and especially to difficulty, since confusability is likely to be a main contributor to increased identification times. It seems that a certain degree of confusability is inherent in the nature of typefaces (or scripts). As Fairbank (1947) stated, "family relationships and homogeneity give harmony and readableness to the scripts" (p. 17). Letters in any typeface tend to fit into regular family groups, such as those that wholly enclose space within them (A,B,D), and others that have spaces only partly enclosed (C,F,U,V), or those that are either all curved or all straight. Gibson et al. (1962) have shown that letterlike forms with some of these family characteristics, such as symmetry, possession of a closed loop, and straightness, are less likely to be confused with forms that are close variants of them than are letter-like forms with the opposite family characteristics. In addition, confusability within each family group should be greater than confusability between groups. Thus, it can be predicted that the most confusable typefaces should be those with fewer family groups, more homogeneity within groups and less variance between groups, and a relatively large number of members of the less discriminable groups.

Several formalized methods of measuring interletter similarity were compared by Holbrook (1975). These methods included: (1) The Luce-Choice-model Similarity Measure--a model computed from a tachistoscopic confusion matrix; (2) A Subjective Rating Measure--based on subject's judgments of similarity of letter pairs on a 10-point scale; (3) The Distinctive Feature Measure--a model that considers the number of distinctive features shared by two letters; and (4) The Optimal Distinctive Features Measure--similar to (3) except that each feature is weighted to give an optimal least-squares fit in a regression analysis. The predictions generated by (1) and (2) tended to be very close, and they both were similar to the prediction of a mechanical measure based on the physical overlap of each pair. The distinctive feature measures only moderately correlated with (1). The strength of the correlations improved somewhat when the optimal weights were added, but they still were poorer than the correlations among the other measures. In conclusion, this study provides evidence that a simple subjective rating measure might be a fairly reliable method of determining confusability for a given typeface.

In summary, these three dimensions could all reasonably be expected to have an influence on the letter identification process. Scriptlikeness may be particularly important because there is evidence to show that handwriting and printed material may be processed by different "sub-routines."

Relationship of Stimulus Characteristics and Hemisphere Specialization

The most direct evidence for a relationship between letter typeface characteristics and hemisphere specialization is provided by Bryden and Allard's study of the effect of typeface on visual hemifield differences for letter identification. As described in the first section, a typeface by visual field interaction was found. Of the 10 typefaces, five were recognized better in the RVF (three, significantly better), two were recognized about equally well in both visual fields, and three were recognized better in the LVF (two, significantly better). To verify the stability of the LVF advantage for certain typefaces, Bryden and Allard carried out a second experiment similar to the first, except that individual subjects were shown just one typeface. Only the two typefaces that had yielded a significant LVF advantage in the first experiment were used. Again, these typefaces were recognized more accurately in the LVF, although the visual field difference was not significant in one case. Thus, the LVF advantage for these typefaces was shown to be stable and intrinsic to the lettering style.

In a third experiment, Bryden and Allard investigated the relationship between different typeface characteristics and the visual field asymmetries from Experiment 1. They asked seven additional subjects to rank order the 10 different typefaces on the dimensions of familiarity, scriptlike vs. printlike, and internal confusability. To obtain a measure of the relative difficulty of naming letters in the different typefaces, two of the seven subjects and four additional ones were presented with the stimulus cards from Experiment 1 and were asked to name each letter as quickly as possible. The average naming latency and average ranks on the other three dimensions were recorded for each typeface.

Rank-order correlations and product-moment correlations between the visual field asymmetries and each of these dimensions, except familiarity, were significant. A LVF advantage was associated with greater scriptlikeness, internal confusability, and difficulty and, moderately, with less familiarity. Thus, in general, these dimensions do seem to have an effect on the letter identification process, as measured globally by relative hemisphere advantage for letter recognition. Since most of the dimensions were significantly correlated with visual field asymmetry, and, it appears, with each other, it is difficult to estimate which particular characteristic or combination of characteristics contributed most to the difference in hemisphere advantage. The rank-order correlation was slightly greater for naming latency than for other dimensions, while the product-moment correlation was highest for the scriptlikeness dimension. Multiple correlation procedures revealed that little was added to the predictability of laterality scores by supplementing the scriptlikeness measure, but, again, this could be due to the fact that the dimensions were highly correlated with each other in these particular typefaces.

It should be noted that the rank-order and product-moment correlations are in the direction predicted by studies of visual field and hand asymmetry for discrimination of shapes and line orientations.

Simple geometrical forms (Bryden & Rainey, 1963) and lines differing in orientation by at least 45 degrees (White, 1971) have been found to be discriminated more accurately in the RVF. It would seem that printed letters, also better recognized in the RVF, could be broken down into these simple lines and shapes. Contrarily, more complex forms (Witelson, 1974) and lines close in orientation (Umilta et al., 1974) are better recognized when presented to the left hand or LVF. Scriptlike letters, also better recognized in the LVF, may be thought to be composed of complex shapes, with many loops, and lines differing slightly from the vertical or horizontal. In addition, a LVF advantage for the perception of depth has been shown (Durnford & Kimura, 1970), and some scriptlike typefaces are designed to appear three-dimensional. Thus, the three-dimensionality of the typeface may be another characteristic to consider.

The correlations between typeface dimensions and visual field asymmetries also are consistent with the results of Faglioni, Scotti, and Spinnler's (1969) tests of letter recognition ability in patients with unilateral hemispheric damage. The patients were given four letter identification subtests in which they were shown a letter and had to find it among a series of alternative letters printed with a different type. For all four subtests, the multiple choice letters were printed in a convential form, either block-printed capitals or simple italic small letters. The test letters were printed in a conventional form for Subtests A and B, were incomplete for Subtest C, and were partially hidden, or crossed out, for Subtest D.

Of the posterior brain-damaged patients, those with left hemisphere damage were specifically impaired on Subtests A and B, and those with right hemisphere damage were specifically impaired on Subtests C and D, when the letters were presented in a perceptually difficult way. Faglioni et al., concluded that the contribution of the right hemisphere to the letter identification process becomes critical when the letters are presented in a perceptually complicated form. These perceptually complicated forms are comparable to the more scriptlike, internally confusable, and difficult typefaces used by Bryden and Allard. The partially crossed-out letters (Subtest D) are especially analogous to Bryden and Allard's very scriptlike letters, which typically had several extra loops or lines.

Finally, given that the relative contribution of the two hemispheres to the letter identification process changes when typeface characteristics change, it should be asked how this finding increases understanding of hemisphere differences and of letter identification. In regard to hemisphere differences, the finding that letters are not always more accurately identified in the RVF is inconsistent with a characterization of the hemispheres according to the general type of material they are specialized for dealing with (e.g., verbal vs. spatial). Instead, this finding suggests a characterization of the hemispheres in terms of types of processing (Bryden & Allard). Thus, even verbal material can be better recognized in the LVF if it is complex enough to need much of the preprocessing which can be done more efficiently by the parallel processing (Cohen, 1973), global analysis (Levy, 1969), or diffuse organization (Semmes, 1968) of the right hemisphere.

This dissertation will investigate the specific typeface characteristics that are associated with greater right hemisphere participation. One purpose of this investigation is a further refinement of the characterization of the processing for which each hemisphere is specialized. This dissertation also will investigate whether and to what extent modality of presentation affects the balance of hemispheric processing as typeface complexity varies. It is expected that, contrary to the assumption that hemispheric advantages are independent of modality, the range of processing that can be employed may be limited by the modality in which the information is received.

The finding that visual field asymmetries are associated with typeface characteristics also has implications for our understanding of the letter identification process. It suggests that when the letter cannot be immediately matched to the template or distinctive features stored as part of the letter and word identification system, then a process that is partly separate and partly integrated with this system can be employed. This process acts to break down (or normalize) the letter so that its distinctive characteristics can be attended to easily.

This suggestion that letter identification involves both left and right hemisphere processes is consistent with the conclusions of Kershner (1975) and Pirozzolo and Rayner (1977). In a review of reading and laterality, Kershner (1975) concluded that the perception of single letters is better when both hemispheres are involved. To investigate the relative contribution of the hemispheres to the word recognition process, Pirozzolo and Rayner (1977) presented four-letter words either bilaterally or unilaterally and had the subjects select their response from four choices shown on a response card. More errors occurred for words presented in the LVF, but this effect was especially strong when the errors were visually similar words. Thus, Pirozzolo and Rayner concluded that, in addition to single letter perception, the reading of whole words is also a multi-stage process, with visual feature analysis carried out by the right hemisphere and identification and naming by the left hemisphere.

A comparison of different age groups in this dissertation may have implications for assessing developmental changes in the relative importance of these two processes for letter identification. On the one hand, since children below the age of 11 years have shown a right hand advantage for braille letter learning, and since their RVF scores seem to be more critical for determining reading ability, it might be that they will not employ the right hemisphere normalization process as often as an adult, but will concentrate instead on the verbal aspects of the task. On the other hand, as hypothesized, since even the moderately scriptlike typefaces will be relatively more complex for children than for adults, children might need to employ a greater degree of right hemisphere preprocessing than adults for those typefaces.

In summary, Bryden and Allard found that the dimensions of typeface scriptlikeness, difficulty (naming latency), and confusability we

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were strongly related to visual field asymmetries for letter identification. The relationship between these variables is in the direction predicted by studies of hand and visual field differences for the discrimination of shapes or line orientation and by studies of patients with unilateral hemispheric damage. Bryden and Allard's finding has many implications for the nature of the difference between the hemispheres and for the letter identification process. The purpose of this dissertation is to further understanding of these mechanisms by examining the variables of modality of presentation and age and their interaction with typeface characteristics.

Summary of Hypotheses

Modality of Presentation

Difference in direction of asymmetry. Based on the comparison of previous findings pertaining to hand and visual field asymmetries for letter identification, and on the intuitive idea that tactual perception involves more "spatial integration," the tactual modality seems to have a stronger association with right hemisphere processing than does the visual modality. Therefore, it is hypothesized that a greater right hemisphere (left field) advantage will be shown in the tactual modality than in the visual modality (see Figure 1). The direction of this modality difference is expected to be constant across levels of typeface complexity. The magnitude of the difference, however, might be smaller for the more complex typefaces because the degree of right hemisphere processing required for those typefaces might be large in both modality conditions.

Cross-modal correlations. It is hypothesized that, for a given typeface, the correlation between individual asymmetries in the visual and tactual conditions will be positive and (at least) moderately strong. This prediction is based on the assumptions that: (1) an individual will tend to use a strategy involving more or less right hemisphere processing compared to other individuals regardless of stimulus modality, and (2) hemisphere specialization is based on type of processing, regardless of sensory modality.

Stimulus Characteristics

Interaction of typeface with hand and visual field. Based in part on Bryden and Allard's findings, an interaction of typeface with sensory field is expected. Specifically, LVF and left hand scores should increase relative to RVF and right hand scores as overall complexity of the typeface is increased.

In the visual condition, it is hypothesized that there will be a significant RVF advantage for the simplest, printlike typefaces and a significant LVF advantage for the more complex, scriptlike typefaces (as was found by Bryden and Allard). In the tactual condition, it is hypothesized that there will be little or no right hand advantage for the recognition of plain, block-printed letters (as was found by Witelson, 1974; LaBreche et al., 1977). A significant left hand advantage is expected for the recognition of the more complex, scriptlike letters. This prediction is consistent with the left hand superiority found for learning complex braille letters (e.g., Wagner, 1976).

Relative contribution of specific typeface characteristics. If it is possible to select typefaces for which the characteristics of scriptlikeness, difficulty, and confusability are not highly correlated, it is hypothesized that each of these characteristics will be significantly correlated with visual field and hand asymmetries and that their effect will be additive. In addition, it is predicted that scriptlikeness will be the strongest predictor of visual field asymmetries, as was tentatively concluded by Bryden and Allard.

Grade

Greater right hemisphere participation in the tactual condition than in the visual condition is predicted for all grades. Increasing right hemisphere participation with typeface complexity also is predicted for all grades, but the general level of right hemisphere participation is expected to differ across grades. Specifically, the younger grades should show evidence of more right hemisphere participation than the college students, particularly for the moderately complex typefaces.

This prediction of a grade difference is supported by two points. First, developmental studies of visual field asymmetries for verbal material (in simple print) have found either a constant degree of RVF advantage across age (e.g., Olson, 1973; Marcel & Rajan, 1975) or no significant RVF advantage for the youngest ages tested (e.g., Forgays, 1953; Tomlinson-Keasey et al., 1978). Second, right hemisphere participation has been found to increase with increasing typeface difficulty and unfamiliarity. Since the non-printlike typefaces (especially the moderately complex ones) should be relatively more difficult and unfamiliar for the younger grades, greater right hemisphere participation is predicted for those grades.

METHOD: PART I--TYPEFACE SCALING

Scaling for "Difficulty"

Subjects

The subjects were 20 college students--10 males and 10 females--with no reported vision problems. They participated for credit in their Introductory Psychology classes at Michigan State University.

Apparatus

A 3-channel Scientific Prototype Auto-tachistoscope (Model GB) with a split-beam binocular eyepiece was used. Each field was back-lit through the diffusion screen by two standard fluorescent bulbs (GE-FT4-5, with onset time reportedly much less than 1 msec.). Only two fields were used--one for the letter stimuli and one for the fixation point. The fields were set at the same moderate brightness level, and both were modified to obtain more equal left-right half field brightness by inserting a matte white strip of cardboard behind each bulb pair. For the stimulus field, 35mm slides were automatically fed from 100-slide rototrays. For the fixation field, a stationary slot held one slide. The timers for both fields were set at 1.5 msec.

The tachistoscope was wired so that an on-off switch used by the experimenter triggered the onset of the fixation field. Fixation field offset triggered the onset of the stimulus field, and stimulus field offset then triggered the advancement of the rototray. The same switch simultaneously started a reaction timer (Klockcounter), which was stopped by a voice activated relay (VAR) when the subject's response was spoken into a microphone. The "delay" button on the VAR was set to 12 seconds to allow the experimenter to record response time and the response before the relay could be activated again.

Materials

A sample of 22 different typefaces was selected from those available in 60-point Chartpak Velvet Touch transfer lettering (black). The goal of the selection was to obtain as broad a sample of lettering styles as possible, based on the judgment of the experimenter. Selection was made with regard to such characteristics as letter slant and thickness, presence of serifs, and amount of detail, as well as the five general characteristics on which the typefaces were to be scaled.

For each typeface, the following eight letters were used--C, G, O, Q, B, R, F, P. They were chosen for two main reasons. First, the letters could be divided into two groups on the basis of physical similarity. The first four letters were circular or nearly circular. In contrast, the second four letters had a vertical line on the left border, with a curved or straight line extending to the right at its midpoint.[5] Since it was hypothesized that letter characteristics might affect field differences, the selection of letters that could be grouped according to certain primary characteristics was designed to aid in determining which general characteristics were important.

Second, all the letters also were used by Bryden and Allard. Therefore, if the results of the current study differed from Bryden and Allard's findings, the discrepancy could not be attributed to specific letter differences.

Slides of the letter stimuli were made as follows. Each letter was transferred onto the center of a 7.6 cm. square piece of white poster board with matte finish. The typefaces and letters varied slightly in size. Heights ranged from about 1.6 cm. to 2.3 cm. and widths ranged from about 1.1 cm. to 2.1 cm. The small squares then were placed one at a time in the center of a large piece of the same poster board and photographed using Kodak Ektachrome film (ASA 160). Standard 35mm slides were developed and mounted commercially. Each slide was examined to check that the letter was centered on the slide, and if not centered to the nearest .5 mm., the slide was remounted by hand.

Each slide thus contained a single black letter in the center surrounded by a thin black outline of a square. In terms of visual angle subtended when viewed through the tachistoscope, letter heights ranged from .31 to .50 degrees and widths ranged from .21 to .42 degrees.

A fixation slide was made under the same conditions as the letter slides. There was a black dot in the center of the small square of poster board and a small black bracket in each of the four corners of the background poster board. When viewed through the tachistoscope, the diameter of the dot subtended an angle of .18 degrees. The area within the brackets represented the unoccluded part of any stimulus field and permitted the subject to make minor self-centering head adjustments before each trial. This viewing area had an "apparent" viewing distance of 76.2 cm. and projected a visual angle of about 2.9 (height) by 5.25 degrees.

Procedure

Subjects were tested individually in a small laboratory room, where they were seated facing the tachistoscope with their backs to the experimenter. The sequence for each trial was described to them. They were told that upon hearing the click of the experimenter's switch, they should look into the tachistoscope directly at the center dot, while making any minor head adjustments necessary so that all four reference brackets could be seen. After about 1.5 secs., the dot would be replaced by a single capital letter in one of various styles, which they then should identify as quickly and accurately as possible.

Before the experiment began, the room lights were turned off, and subjects were given a brief period to adapt to the brightness level of the fixation field. They also were asked to adjust the interocular separation of the eyepieces so that they had a clear view of the fixation field with both eyes, and they practiced saying letter names loudly and clearly into the microphone.

There were 176 trials in all, with a rest period of about five minutes after half the trials. Stimulus order was random with the following constraints: (1) no letter or typeface was presented on two consecutive trials, and (2) within a group of 44 trials, each typeface was presented twice and each of the eight letters was presented at least five times. The 176 slides were divided into two rototrays of 88 slides each. The order of the rototrays was switched for half of the subjects of each sex.

For each subject, a difficulty rating for a given typeface was determined by taking the median naming latency of the eight letters presented in that typeface. A trial was excluded from the computation of the median (and not replaced) if the response was incorrect ($\bar{X}$ = 7.3%, 0 - 40.6%), exceeded 1.5 secs. ($\bar{X}$ = 0.7%, 0-5.6%), or could not be measured due to equipment problems ($\bar{X}$ = 0.4%, 0-1.9%).[6] If the typeface with the highest error rate was not included, incorrect responses averaged 5.7% (ranging from 0 - 14.4%), and responses over 1.5 secs. averaged 0.5% (ranging from 0 - 2.5%).

Scaling for Scriptlikeness, Confusability, Unfamiliarity, and Superfluity

Subjects

The subjects were 42 college students who participated for credit in their Introductory Psychology classes. There were 35 females and eight males.

Materials

The eight small squares of poster board containing the letters of each typeface were bunched together to make two rows of four overlapping cards (with the letters in the same order for every typeface). Five photocopies were made for each typeface. These sheets were then cut and mounted on poster board to serve as cards for the subjects to sort into piles.

Signs were made to label the endpoints of the four scales. They were as follows:

1	10
most familiar	least familiar (least typically seen or thought of)
1	10
most printlike	most scriptlike (like handwriting)
1	10
letters not easily confusable	letters most confusable
1	10
most basic form of the letter (no extra lines or curves)	farthest removed from basic form

The highest value on each scale was assigned to the end of the continuum expected to be associated with the highest degree of right hemisphere participation.

Procedure

Subjects were tested in small groups of up to five people. They sat at desks widely spaced around a large room and facing the wall. On each desk was a pile of the 22 typeface cards in a random order, the numbers one to ten placed in order, and the labels for the first scale for that group placed above the numbers one and ten. Subjects were instructed to sort the cards into ten ordered and equally spaced groups to represent levels of the characteristic being measured. There was no requirement pertaining to the distribution of the cards in the ten groups, and subjects were allowed to change their placements at any time during the sorting.

Sorting was individually paced. As soon as any subject finished sorting for one scale (usually after 10 to 15 min.) his responses were recorded, the cards reshuffled, and the next characteristic explained to him. A different randomly selected order of the characteristics was used for each small group tested. For each characteristic, the median group placement for a given typeface was used as the rating for that typeface.

METHOD: PART II--MEASUREMENT OF FIELD DIFFERENCES

Visual and Tactual Conditions

Subjects

The subjects were 48 fourth- and ninth-graders and college students--16 in each grade group. All were male, right-handed,[7] and had no reported uncorrected vision problems. The mean ages for the groups, in order, were as follows: 9 yrs., 5 mos. (8 yrs., 11 mos. to 9 yrs., 11 mos.); 14 yrs., 5 mos. (13 yrs., 10 mos. to 15 yrs.); and 20 yrs., 4 mos. (18 yrs., 8 mos. to 27 yrs., 2 mos.). Since the children were tested in the summer or early fall, they were selected on the basis of the grade they were going to enter or had just entered, not on the basis of age or grade just completed.

Most fourth- and ninth-grade subjects were students in a predominantly middle class, suburban community.[8] They were recruited through their schools in the spring and early fall and through a recreational program during the summer. Letters describing the study were sent home with them, and parents were asked to return a postcard giving their name and phone number if they and their child were interested in the study. The children were paid $3 for their participation.

College students again were Introductory Psychology students who received course credit for their participation.

Handedness for fourth-graders was determined by noting the hand used when the children were asked to perform five common actions (Annett, 1970a). A child was considered right-handed if he performed at least four actions with the right hand.

For ninth-graders and college students, handedness was determined by responses to a 12-item handedness questionnaire developed by Annett (1970b) and modified (following Briggs & Nebes, 1975) to include five response categories to distinguish between whether a hand was "always" or "usually" used. To be considered right-handed, it was necessary to "always" write with the right hand and to perform three of the five other primary tasks at least "usually" with the right hand.[9] Numerical scores were computed by assigning number values to response categories, ranging from + 2 for "always" right to - 2 for "always" left. The scores for all subjects were positive. The mean score for college students ($\bar{X}$ = 17.2, s.d. = 5.5) was not significantly different from the mean for ninth-graders ($\bar{X}$ = 19.7, s.d. = 3.4; t = -1.51, d.f. = 30, N.S.).

The presence of familial sinistrality (FS+) was assessed roughly by asking the subjects (for fourth-graders, the subjects' parents) whether a biological parent or sibling was left-handed (i.e., wrote with the left hand). Seven fourth-graders, eight ninth-graders, and one college student were classified as FS+.

Apparatus

Visual condition. The tachistoscope apparatus used in this part of the experiment was the same as that described for "difficulty" scaling, except for four changes. First, the time setting for the stimulus field was variable. Second, the tachistoscope was triggered by a momentary push-button switch operated by the subject. Third, the offset of the stimulus field triggered the onset of the blank third field (for 1.5 secs.), the offset of which then initiated the advancement of the rototray. This additional step was needed to give the subjects time to respond before the noisy rototray movement. Finally, response time was not measured.

Tactual condition. The subject and experimenter sat opposite each other at a small table. Between them was a large cardboard box, with the side facing the subject cut out. There were two holes in the bottom of the box through which the subject placed his hands. A cardboard shelf was placed over the holes on the subject's side to ensure that the subject could see neither his hands nor the letters.

A block of wood containing two metal card-holders about .5 cm. apart was used to present the stimuli. The card-holders (as well as the holes in the box) were placed close together to reduce the possibility that attention directed to the left or right of body midline would influence hand differences.

Materials

Visual condition. For the visual condition, 144 stimulus slides were used--16 for each of eight test typefaces and one practice typeface selected in Part I. For every typeface, each of the eight letters occurred once in the LVF and once in the RVF. Photographs were taken under the same general conditions as those used for "difficulty" scaling. The small squares of poster board with letters in the center were placed one at a time either to the left or right of the center point of the background board. Positioned at the center point was a number from one to nine (excluding seven),[10] also on a 7.6 cm. square of poster board. For the eight test typefaces, each number was associated with a particular letter twice, once with the letter in each visual field. The numbers were randomly assigned to letters for the practice typeface. All slides were checked to see that the number was in the center of the slide; if not centered to within 1.5mm., the slide was remounted.

As viewed through the tachistoscope, each stimulus slide contained a black number (in simple print) in the center outlined by a thin square, with a single letter to the left or right also outlined by a thin square. The center of each lateralized letter was 2.23 degrees from the center of the number. The maximum and minimum visual angles projected by the lateralized letters were nearly equal to those of the letters used for "difficulty" scaling (averaging about .01 degrees less).[11] The fixation slide was the same as that used for "difficulty" scaling.

Tactual condition. For the tactual condition, 32 letters were used--eight for each of three test typefaces and one practice typeface selected in Part I. The letters were raised surfaces of zinc plates made from photocopies of the letters by a process used commercially to make rubber stamps. All black parts of the letters were raised 1 mm. from the plate, and the edges were beveled. The range of letter sizes was about the same as the range for the original transfer lettering. The plates (about 3.7 cm. square) for individual letters were glued onto the center of ordinary plastic playing cards, which could be slipped into the card-holders.

Procedure

Visual condition. Subjects (tested individually) were seated facing the tachistoscope, with the experimenter sitting to their right, opposite the control panel. A large board was placed between the subject and experimenter to block out direct light from the table lamp used by the experimenter. Subjects were told that the general purpose of the experiment was to see how well people could recognize letters of different styles presented for brief times. The instructions were as follows:

> When you press the button, you first will see a slide with a dot in the middle and a bracket in each of the four corners. You should look directly at the dot and position your head to make sure you can see the four brackets out of the corners of your eyes.
>
> After about a second the slide will change. Then you will see a number (from 1 to 9) in the middle (about where the dot was) and a letter to either the right or left side of the number. It is important that you keep looking straight ahead so you will be looking right at the number when it appears.
>
> Your response should be the number and then the letter. For example . . .

Subjects were encouraged to guess at both the number and letter if they were in doubt, but were told to say just the number if they were unable even to guess the identity of the letter. The experimenter emphasized the importance of looking straight at the fixation dot and getting the number correct.

The experimenter gave four additional clarifications of the stimuli and task. The first three were given for the first modality condition, whether it was visual or tactual, and the fourth was given for the second modality condition. The experimenter told the subjects that: (1) because of the nature of a threshold experiment, mistakes were expected (This clarification was needed to reduce frustration and anxiety about doing badly on the tesk.); (2) all letters would be capitals and about the same size; (3) a capital cursive Q could resemble the number two, and a cpaital cursive G could be shaped like the lower case letter, but larger in size. (Pilot testing indicated that these letters sometimes caused confusion. As an added precaution, fourth-graders were shown a photocopy of all eight letters in the practice style and asked to name them. After being reminded about the Q and G, every fourth-grader named all letters correctly.); (4) at least some of the lettering styles had been presented in the first modality condition.

There were 288 trials in all--32 trials in each of eight test typefaces and one practice typeface. The 16 stimulus slides for each typeface were presented in a row, and then the rototray was reset and the 16 slides presented again in the same order. The practice typeface was presented first to provide practice and to establish a presentation time that served as a starting point for the test typefaces.[12] Subjects always were told when the typeface would change. There was a rest period (5 to 7 min.) after the fourth test typeface, and subjects were told to ask for a brief rest (about 1 min.) after a typeface was completed if they were tired. These extra rest periods were noted on the data sheets.

Since the difficulty of the task varied greatly and, according to pilot testing, nonuniformly across typefaces and also across grades, it was not possible to simply determine an appropriate exposure duration for all test typefaces. Therefore, it was decided to obtain an approximate threshold presentation duration for each field and to use that as the dependent measure.

Thresholds were obtained by the random double staircase-method (Cornsweet, 1962). This method was chosen because it is highly efficient (relatively few trials need be presented) and it conceals the contingencies involved in varying the presentation time. The staircase procedure consisted of decreasing the presentation duration by a predetermined step following a correct response and increasing the duration following an incorrect response. Separate staircases were formed for each field, with trials being randomly alternated between the two. The staircases for both fields were started at the point determined during practice. The steps (in msecs.) were 180, 150, 130, 110, 90, 70, 50, 30, 20, 15, 10.[13] For presentation time to be decreased, both the letter and number had to be identified correctly. If the number was incorrect, but the letter correct, the trial was eliminated and the presentation duration remained the same for the following trial in that field.

It was necessary to determine the orders of three factors--modality conditions, typefaces, and letters. First, the order of modality conditions was varied so that half the subjects of each grade received the visual condition first (VT) and half received the tactual first (TV). Testing always was done in one session lasting about one hour and 45 minutes, with about a five-minute break between modality conditions.

Second, eight typeface orders were determined. Each order was used twice in each grade, once for each modality-order group. The orders were random, with the constraints that each typeface would occur once in every position and, to control for the possibility that the immediately preceding typeface established a set, no typeface would follow another more than twice.

Finally, the order of the 16 stimulus slides in each typeface was determined separately for every typeface. The orders were random, with the following constraints: (1) no more than three trials in a row to one field, (2) no letter or number twice in a row, and (3) the number of trials on which the field switched equal to the number of trials on which it remained the same. These primary letter orders (A) were assigned to the typefaces in four of the typeface orders. The arrangement of letters assigned to the RVF was designated Set 1, and the arrangement assigned to the LVF was designated Set 2. For the other four typeface orders, Set 1 was assigned to the LVF and Set 2 to the RVF (B).

Tactual condition. The subjects were seated opposite the experimenter facing a large box. They were shown one of the tactual practice letters to give them an idea of the letter size and of the fact that the zinc plate was not part of the letter. The instructions were as follows:

> Place your hands through the two holes in the box and rest them on these card-holders. Hold them in the same position in-between letter presentations. I will slide a card under either your right or left hand (in random order). When I say "go" and push your fingers down, start to feel the letter with your index and middle fingers. You will have varying amounts of time to feel each letter (1 to 15 secs.). When the time is up, I will remove the card and say "answer," and you should make the best guess you can.

There were 104 trials in all--eight trials in the practice typeface and 32 trials in each of the three test typefaces. The practice letters were presented first for 12 seconds each. Four letters were presented to each hand, with the letters assigned to hand switched for half of the subjects of each grade. Fewer trials were used in the tactual condition than in the visual condition because of time limitations and because it was less important to determine a starting point for the test typefaces. Following practice, the three test typefaces were presented, with brief rest periods (1 to 2 min.) in-between.

A staircase procedure was used to determine a rough threshold presentation duration for each hand. The procedure differed from that described for the visual condition only in that presentation times were longer and fewer steps were used. The steps (in secs.) were 16, 12, 8, 4, 2, 1. For all subjects, the starting point for each hand was 12 seconds for every typeface.

As in the visual condition, eight typeface orders were determined. They were the six possible orders of the three typefaces, with two of them (randomly selected) repeated. Each order was used twice in each grade, once for each modality-order group, and always was paired with the same visual typeface order. The letter order for each typeface was the same as the letter order used for that typeface in the visual condition.

Computation of Laterality Coefficients and their Stability/Effectiveness

For each field in each typeface, a threshold measure was computed in two steps. First, to lessen the effects of the starting point, the first three runs were eliminated from the measure. A run was defined as a series of increasing or decreasing times including the reversal point between it and the preceding run, but not the reversal point following it. Second, the median of the remaining points was computed without interpolation and was used as the threshold measure. All points were included in the measure whether they represented correct or incorrect letter identifications, except those representing correct identifications for which the fixation number was incorrect.[14] Interpolation was not considered justified because of the rank order nature of the data. Thus, if a median occurred directly on a time step, that step was taken as the median, regardless of the number of points that occurred on that step. If a median occurred between two steps, it was defined as the average of those steps.

Laterality coefficients (LCs) to be used as the dependent variable in the main analyses were computed by subtracting the right field threshold measure from the left field measure and then dividing that difference by the average of the two thresholds (combined threshold or CT). Thus, the greater the score in the positive direction, the greater the right sensory field advantage, and the greater the score in the negative direction, the greater the left sensory field advantage. Use of a ratio score was meant to reduce the effects of the subjective inequality of the two ends of the time scale. A main effect of the inequality was that a given time difference between thresholds was more easily perceptible and more meaningful for lower thresholds than for higher thresholds. Minimizing this effect was especially important because threshold level was predicted to be at least moderately related to the direction and degree of field differences.

Several questions may be raised about the stability/effectiveness of the threshold measures: (1) whether the measures were reliable, especially given the relatively small number of trials; (2) whether the measures were successful in establishing a roughly 50% accuracy level; and (3) whether missed fixation numbers significantly affected the visual measures. Finally, an underlying factor in all these concerns was their variation across grade, typeface, and modality condition.

To investigate the first question, a rough stability estimate for each field was computed by taking the median of each run after the third, then averaging the first and last pair of runs and correlating those averages.[15] The correlations are shown in Table 1. In the visual condition, most of the correlations exceeded .7, indicating high stability. The main exceptions were the correlations for Typefaces 1 and 3 (T1 and T3) for fourth-graders. For T1, the overall correlation was only moderately positive ($r = .38$), while for T3, the correlation averaged across fields was slightly negative ($r = -.04$). In the tactual condition, the average correlation was lower than in the visual condition (.63 compared to .78), and there were several instances of moderate to low positive correlations. The general level of stability was still acceptable, though. With the exception of the two cases noted in the visual condition, the correlations did not vary systematically across typeface or field.

To check the second question, the percent correct identifications out of the total number of points included in each threshold estimate served as a measure of accuracy level. These percents are listed for all grades, modality conditions, and (for the tactual condition only)[16] modality orders in Table 2. In the visual condition, accuracy level was markedly lower for T3 than for the other typefaces (averaging about .24 compared to .42 for the next lowest), and slightly lower for T2 relative to the others (.42 compared to .47). Except for these two typefaces, all the percents ranged from .4 to .6 and were highly consistent across grades and visual fields. A 3 x 2 x 8 ANOVA was used to test the effects of grade, visual field, and typeface on accuracy level, and a 3 x 2 x 7 ANOVA tested those effects

TABLE 1.--Stability* of threshold measure by sensory field, modality condition, typeface, and grade. (In parentheses is the number of subjects per group included in each stability estimate.)

Modality Condition	Grade	Typeface 1		2		3		4		5		6		7		8		All	
		LF	RF	LF	RF	LF	RF	LF	RF	LF	RF	LF	RF	LF	RF	LF	RF	LF	RF
Visual	4th (N=16)	.47 (13)	.30 (12)	.93 (12)	.92 (10)	.26 (11)	-.34 (10)	.71 (13)	.82 (14)	.86 (14)	.89 (14)	.61 (15)	.71 (14)	.72 (14)	.79 (15)	.84 (10)	.88 (13)	.68	.62
	9th (N=16)	.90 (12)	.90 (14)	.82 (14)	.83 (11)	.98 (8)	.96 (9)	.92 (15)	.84 (14)	.84 (14)	.79 (15)	.95 (16)	.84 (14)	.57 (16)	.81 (15)	.72 (12)	.71 (14)	.84	.84
	Coll (N=16)	.76 (13)	.89 (13)	.87 (12)	.95 (10)	.92 (10)	.76 (13)	.91 (15)	.71 (15)	.94 (14)	.92 (15)	.88 (16)	.88 (15)	.86 (15)	.73 (16)	.92 (13)	.86 (13)	.88	.84
	All (N=48)	.71	.70	.87	.90	.72	.46	.85	.79	.88	.87	.81	.81	.72	.78	.83	.82	.80	.77
Tactual	4th (N=16)	.75 (15)	.84 (15)	.60 (16)	.02 (15)									.50 (14)	.75 (15)			.62	.54
	9th (N=16)	.11 (13)	.82 (13)	.78 (14)	.49 (14)									.85 (15)	.63 (15)			.58	.65
	Coll (N=16)	.84 (15)	.83 (14)	.43 (15)	.82 (15)									.40 (16)	.82 (16)			.56	.82
	All (N=48)	.57	.83	.60	.44									.58	.73			.59	.67

*Stability = correlation of average of medians of first pair of runs after cut-off and average of last pair of runs. (Only those subjects with at least four runs for a given field in a given typeface were included in that stability estimate.)

TABLE 2.--Percent of correct identification after cut-off by sensory field, typeface, and grade for each modality condition, and (for the tactual condition only) modality order

Modality Condition	Grade	Typeface 1		2		3		4		5		6		7		8		All	
		LVF	RVF	LVF	RVF	LVF	RVF	LVF	RVF	LVF	RVF	LVF	RVF	LVF	RVF	LVF	RVF	LF	RF
Visual	4th (N=16)	.52	.52	.42	.41	.20	.21	.50	.56	.49	.57	.46	.45	.56	.48	.44	.48	.45	.46
	9th (N=16)	.46	.43	.47	.42	.21	.28	.50	.48	.52	.49	.53	.50	.54	.50	.53	.56	.47	.46
	Coll (N=16)	.47	.44	.40	.36	.25	.28	.53	.52	.54	.59	.51	.46	.50	.52	.51	.52	.46	.46
	All (N=48)	.48	.46	.43	.40	.22	.26	.51	.52	.52	.55	.50	.47	.54	.50	.50	.52	.46	.46
																(Without T3 =		.50	.49

Modality Condition	Grade	1 VT (N=8) LH	RH	1 TV (N=8) LH	RH	2 VT (N=8) LH	RH	2 TV (N=8) LH	RH	7 VT (N=8) LH	RH	7 TV (N=8) LH	RH	All (N=16)	
Tactual	4th	.69	.66	.59	.59	.48	.49	.40	.34	.48	.42	.44	.43	.51	.49
	9th	.62	.60	.63	.65	.46	.49	.54	.48	.59	.46	.60	.59	.57	.54
	Coll	.62	.60	.63	.59	.53	.62	.50	.52	.52	.55	.54	.50	.56	.56
	All (N=24)	.64	.62	.62	.61	.49	.53	.48	.45	.53	.48	.53	.51	.55 (N=48)	.53

excluding T3. Both analyses revealed a significant main effect of typeface (F = 43.37, d.f. = 7,315, $\underline{p} < .001$; F = 7.67, d.f. - 6,270, $\underline{p} < .001$) and no other effects. Thus although the requirements for a roughly 50% accuracy level generally were met, the level varied across typefaces, and especially differend from 50% for T2 and T3.

In the tactual condition, accuracy generally was higher than in the visual condition. This effect was especially large for T1, for which all grades averaged over 60% correct. For T2 and T7, the effect was smaller and was found only for the ninth-graders and college students, whose accuracy was higher than that of the fourth-graders. A 2 x 2 x 3 x 3 ANOVA testing the effects of hand, modality order, grade, and typeface on accuracy level revealed a significant effect of typeface (F = 34.47, d.f. = 2,84, $\underline{p} < .001$) and a typeface by grade interaction (F = 3.91, d.f. = 4,84, $\underline{p} < .006$). The typeface effect reflected the high accuracy for T1, caused in part by a ceiling effect. T1 was so simple to identify that many subjects were able to repeatedly identify letters at the shortest time step (1 sec.), thus preventing the staircase from operating. The typeface by grade interaction reflected the higher accuracy of the ninth-graders and college students compared to the fourth-graders for T2 and T7. There was no systematic variation of accuracy with hand or modality order.

To answer the third question, the number of missed fixation numbers with and without a correct letter identification was tabulated by grade, typeface, and visual field. The results are shown in Table 3. Three effects were evident. First, the overall number of missed fixations was low. Even for T1, which had the greatest number

TABLE 3.--Total number of missed fixation points (summed across subjects) with correct and incorrect letter identification for each typeface and visual field for the grades separately and averaged across grades

Grade	Letter ID	Typeface 1		2		3		4		5		6		7		8		All (C+I)	
		LVF	RVF	LVF	RVF	LVF	RVF	LVF	RVF	LVF	RVF	LVF	RVF	LVF	RVF	LVF	RVF	LVF	RVF
4th	correct	1	7	1	2	1	0	5	7	2	3	2	3	7	4	2	0	5.8	5.2
(N=16)	incorrect	6	4	1	3	2	1	5	2	7	2	1	1	3	2	1	1		
9th	correct	12	6	1	1	0	2	6	6	3	5	2	1	5	7	2	3	5.5	7.1
(N=16)	incorrect	4	8	1	0	0	0	2	5	2	4	1	3	2	4	1	2		
Coll	correct	11	11	4	7	0	2	3	4	1	5	0	0	1	6	0	1		
(N=16)	incorrect	13	5	4	1	2	2	7	1	8	6	2	2	10	5	3	3	8.6	7.6
(mean across	correct	8.0	8.0	2.0	3.3	0.3	1.3	4.7	5.7	2.0	4.3	1.3	1.3	4.3	5.7	1.3	1.3		
grades)	incorrect	7.7	5.7	2.0	1.3	1.3	1.0	4.7	2.7	5.7	4.0	1.3	2.0	5.0	3.7	1.7	2.0		
All (N=48)	C + I	14.7	(4)*	4.3	(3)	2.0	(1)	8.9	(4)	8.0	(3)	3.0	(2)	9.4	(4)	3.2	(2)	6.6	6.6

*In parentheses, the most fixation points per visual field missed by an individual subject.

of missed fixations, the missed points represented only about 6% of the 256 total trials per field for each grade. Second, the number of missed fixations varied across typeface. The most errors occurred for T1, the simplest typeface usually presented for very short times. The least errors occurred for T3 and T6, two typefaces that generally required long presentation times. This pattern indicates that a large number of fixation errors probably resulted from difficulty in perceiving the number at short presentation times, rather than solely from inattention or carelessness. Finally, the number of missed fixations tended to increase with age, especially for T1. This trend cannot be explained by a decrease across grades in reluctance to guess, since the number of "no guess" responses was actually smallest for fourth-graders for T1 (38 compared to 61 for ninth-graders, 43 for college students). Better explanations might be higher motivation or longer presentation times for the fourth-graders. This grade difference, then, minimizes any concern that a grade effect on laterality coefficients is caused by the relatively greater difficulty of the task for fourth-graders or their inability to maintain fixation. A 3 x 2 x 8 ANOVA testing the effects of grade, visual field, and typeface on missed fixations revealed only a significant main effect of typeface ($F = 13.83$, d.f. = 7,315, $p < .001$).

In summary, with a few exceptions, the threshold measures were highly stable, resulted in an approximate 50% accuracy level, and were not biased by a large number of missed fixation points. One main exception was T3 in the visual condition. For this typeface, accuracy level was only about 25% for all grades, but was especially low for fourth-graders, who also had a slightly negative T3 stability correlation. Other possible exceptions to consider when analyzing the visual results are T2, for which a generally lower accuracy level was obtained across grades, and T1, for which fourth-graders showed a relatively low stability correlation. For the tactual condition, the stability correlations were lower in general, and the higher accuracy levels for T1 indicated a possible ceiling effect. In no case was a sensory field effect found, which suggests that the laterality coefficients were not biased directly by any of the three potentially confounding factors named above.

RESULTS: PART I--SCALE VALUES AND SELECTION OF TYPEFACES

Ratings, Dispersion Measures, and Reliability

In general, ratings given to the initial group of 22 typefaces indicated that undergraduates were able to distinguish among typefaces on the five characteristics measured and that these distinctions were consistent across subjects. These conclusions were suggested by the uniform and widespread distribution of ratings and by moderate to high alpha values. Based on the ratings for difficulty, script-likeness, and confusability, eight typefaces were selected for the visual condition in Part II. Two criteria for their selection were met. First, a wide range of ratings on those characteristics was represented. Second, correlations between the characteristics were low. Three of the eight typefaces also were selected for the tactual condition--one at each end of the rating scale and one with moderate ratings.

Initial Group of Typefaces

Mean rating and dispersion measures for the initial group of 22 typefaces are shown in Table 4. Ratings of "difficulty" for each typeface were based on the mean of the median naming latencies for individual subjects. The general level of latencies[17] was not so important as the relation between naming latencies for the different typefaces, which was highly consistent across subjects (Alpha = .97).

TABLE 4.--All 22 typefaces. Alphas, means, and dispersion measures of ratings on five characteristics

	Characteristics				
	Rating=mean RT in msecs. Dispersion=s.d.	Rating = median category placement on a ten-point scale; Dispersion = semi-interquartile range (Q)			
	(1) Difficulty	(2) Scriptlikeness	(3) Confusability	(4) Unfamiliarity	(5) Superfluity
Mean Rating	685.2 (621 - 831)*	4.79 (1.08 - 9.78)	4.52 (1.04 - 9.99)	5.35 (1.04 - 9.82)	5.61 (1.14 - 9.95)
Mean Dispersion Measure	75.4 (46.8 - 119.2)	1.04 (0.3 - 1.9)	.94 (0.25 - 1.7)	.95 (0.23 - 1.7)	1.04 (0.32 - 2.1)
Alpha	.97	.78	.86	.46	.69

*The highest and lowest rating and dispersion measures are in parentheses.

Ratings for the other four characteristics all were based on median placements on a 10-point scale and were similar in three regards: (1) mean ratings within one point of the scale midpoint (5.5), (2) extension of ratings over the entire scale, and (3) Q-values of about 1.0. For all characteristics except familiarity, the Alpha values were at least moderately high, indicating that the relative ratings of the typefaces were consistent across subjects. The lower Alpha value for familiarity is consistent with the idea that experience with different lettering styles would be likely to vary greatly across indivdiuals.

The correlations between the five characteristics for all 22 typefaces are shown above the diagonal in Table 5. The values are positive, generally moderate to high, and, except in one case, significant at least at the .05 level. These results are consistent with the correlations between the first three characteristics (ranging from .73 to .96) found for the ratings given to Bryden and Allard's sample of 10 typefaces. The implication is that these characteristics are correlated in the majority of typefaces and probably tend to occur together naturally. Therefore, typefaces selected with the goal of obtaining a sample in which these characteristics are not highly correlated might be very atypical. This would limit the generalizability of findings based on that sample, and is a problem to be considered when interpreting the results.

Selected Typefaces

Visual condition. The three main goals (in order of importance) for selecting the eight typefaces to be used in the visual condition were that their ratings should be: (1) minimally correlated on the first three characteristics (those found by Bryden and Allard to be related to visual field differences), (2) spread over a wide range of values on the three scales, and (3) low in variability. With the first goal in mind, the three scales were divided at the median, and typefaces were categorized according to the eight possible combinations of high and low values on the three scales. No typeface was found for one combination (low 1 and 2, high 3), so the typeface with the closest possible fit was used. Then one typeface was selected from each combination. The correlations between the characteristics for these eight typefaces are shown below the diagonal in Table 5. For the first three characteristics, the correlations were low and not significant.

Table 6 shows the ratings and dispersion measures for the eight selected typefaces on each of the three characteristics.[18] Again, the higher the rating, the greater the degree of the characteristic for which the scale was named and for which right hemisphere processing should be important. Consistent with the second goal, the typefaces do cover a wide range of values on all three characteristics, with the emphasis, if any, on the higher end of the scales. The third goal of choosing typefaces with low rating variability was not met. The mean dispersion values for the eight selected typefaces are higher than for the whole group of 22 typefaces.

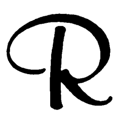
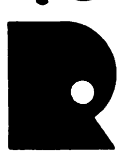
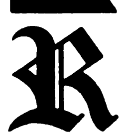
TABLE 5.--Correlations of five characteristics for all 22 typefaces (above diagonal) and eight selected typefaces (below diagonal). All correlations are Pearson r

	(1) Diff.	(2) Script. (N=22)	(3) Confus.	(4) Unfam.	(5) Superflu.
(1) (N=8)		.47*	.64**	.59**	.66**
(2)	-.06		.61**	.38	.47*
(3)	.23	.28		.89**	.74*
(4)	.40	.09	.93**		.82**
(5)	.61	.32	.79*	.86**	

*p < .05

**p < .01

TABLE 6.--Selected eight typefaces. Individual and mean rating and dispersion measures and alpha for three characteristics. The last column shows the overall z-score for each typeface based on the average of the z-scores for each characteristic

Typeface	Characteristics			
	(1) DIFFICULTY Rating=mean RT in msecs.	(2) SCRIPT. Rating = median placement on 10-points	(3) CONFUS.	OVERALL Z
1* 	623 s.d. = 56.9	1.08 Q = .3	1.04 Q = .3	-1.22
2* 	639 59.4	7.65 1.2	3.92 1.2	- .02
3 	772 111.2	2.50 1.1	2.26 .8	.02
4 	663 60.8	5.17 .9	6.62 1.4	.15
5 	689 101.2	3.67 1.4	8.50 1.2	.35
6 	697 64.5	9.07 .8	4.40 1.1	.57
7* 	721 80.5	3.83 1.6	8.81 1.2	.61
8 	706 107.2	7.12 1.9	9.30 .7	.96
Mean rating	688.8	5.01	5.61	
Mean dispersion score	80.2	1.15	.99	
Alpha	.93	.64	.67	

*Chosen for the tactual condition also.

Since Bryden and Allard found that visual field differences were significantly correlated with all three characteristics, a combination of the three ratings was used as the best a priori predictor of sensory field differences in the current study. These composite complexity scores are shown in the last column of Table 6. The complexity score for each typeface was obtained by computing a z-score for each of the three characteristics based on the mean and standard deviation for all 22 typefaces, and then averaging the three scores. The prediction is that the higher the composite complexity score, the greater the degree of right hemisphere involvement in the processing of that typeface. The fact that only two of the composite scores were negative is another indication of the emphasis on the higher end of the scales.

In addition to the main group of eight typefaces ("test" typefaces), a typeface of average difficulty was chosen to be used as a practice typeface in both the visual and tactual conditions. It was a simple script (Brush script) and had a mean naming latency of 681 msecs.

Tactual condition. The three typefaces selected for the tactual condition met the following requirements: (1) for each typeface, all letters were recognized with at least about 25% accuracy using unlimited exploration time in pilot testing with college students, and (2) the extremes and a middle point of the composite scale were represented.

T3, T6, and T8 were not considered because they did not meet the first requirement. T1 and T7 then were chosen to represent the extremes of the composite scale, and T2 was chosen as a middle point. Even though T2 was not midway between T1 and T7 on the basis of rank order, it was selected because (1) the composite _z_-score was closest to midway between the scores for T1 and T7, and (2) it was rated high on scriptlikeness, the characteristic Bryden and Allard found to be most strongly related to visual field differences.

RESULTS--PART II--FACTORS AFFECTING LATERALITY COEFFICIENTS IN THE VISUAL AND TACTUAL MODALITIES

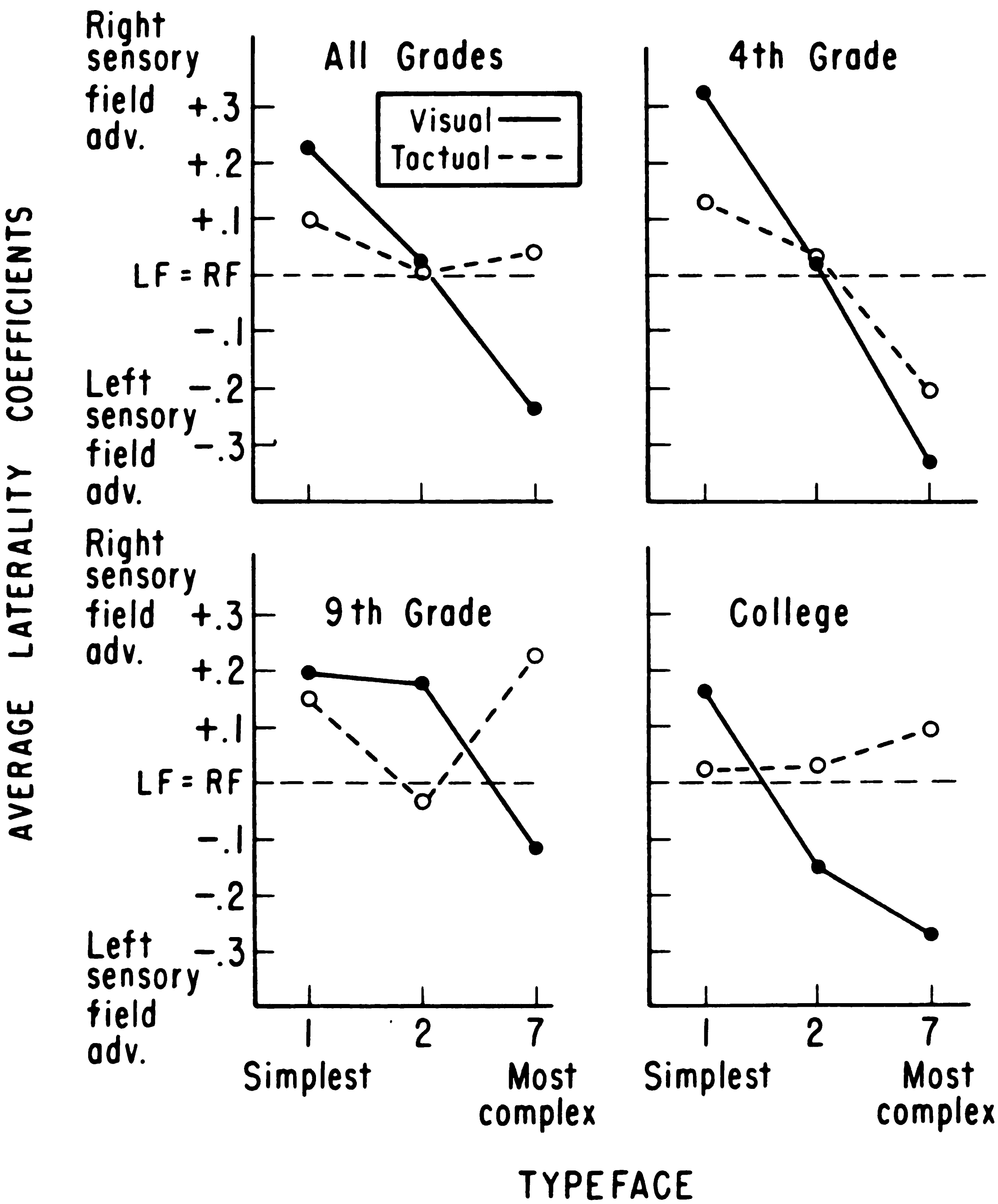
Main Analysis: Effects of General Typeface Factor, Grade, and Modality Order

This section describes three repeated measures ANOVAs used to test the effects of typeface complexity, modality, grade, and modality-order on laterality coefficients. The results of the first ANOVA, which included all variables, reflected two findings about the central hypotheses of this dissertation. First, the predicted increase in right hemisphere participation with increasing typeface complexity was found for the visual condition, but not for the tactual condition. Second, contrary to prediction, right hemisphere participation was not systematically greater in the tactual condition than in the visual condition. The results of the other two ANOVAs, one for each modality condition separately, reflected two additional findings. One was a grade difference in the visual condition and the other a modality-order difference in the tactual condition.

Three Repeated-Measures ANOVAs

Analysis including modality factor. To examine the main hypotheses of increasing right hemisphere participation with increasing typeface complexity and tactual as opposed to visual presentation, laterality coefficients (LCs) were plotted as a function of typeface and presentation modality in Fig. 2. Only the scores for the three

Fig. 2. Average laterality coefficients for the three typefaces in the visual and tactual conditions for each grade separately and all grades combined.


All Grades
Visual
Tactual
4th Grade
9th Grade
College
Right sensory field adv.
Left sensory field adv.
+.3
+.2
+.1
LF = RF
-.1
-.2
-.3
AVERAGE LATERALITY COEFFICIENTS
1
2
7
Simplest
Most complex
TYPEFACE

typefaces presented in both modality conditions were shown, and they were plotted separately for each grade and for all grades combined. (To supplement the graphs in this section, average LCs, standard deviations, and significance levels for all grade by modality by typeface conditions are given in Table 7.)

Fig. 2 indicates that in the visual condition, the predicted increase in right hemisphere participation with increasing typeface complexity was found for each grade. With grades combined, _t_-tests indicated a significant RVF advantage for the simplest typeface, no visual field difference for the medium complex typeface, and a significant LVF advantage for the most complex typeface.

In the tactual condition, only the scores for the fourth-graders showed an increase in right hemisphere participation with increasing typeface complexity. Right hemisphere participation for the ninth-graders and college students was lowest for the most compelx typeface. For no typeface, with grades considered either separately or combined, was there a significant hand difference. In general, the hypothesis of a greater right hemisphere participation in the tactual as opposed to the visual condition was not supported. Only the scores for the simplest typeface were consistently in the predicted direction--a weaker right field advantage was found for the tactual as opposed to the visual condition for each grade.

To test the effects of these factors (typeface, modality, grade, and modality order), the LCs were analyzed in a 3 x 2 x 3 x 2 ANOVA with repeated measures on the first two factors. A summary of the

TABLE 7.--Average laterality coefficients, standard deviations (in parentheses), and significance of field differences according to grade, typeface, modality condition, and (tactual only) modality order

Modality Condition	Grade	Typeface 1	2	3	4	5	6	7	8	All
Visual	4th (N=16)	.33* (.53)	.03 (.50)	-.00 (.11)	.10 (.52)	.12 (.45)	-.15* (.23)	-.33* (.59)	.04 (.40)	.02
	9th (N=16)	.20* (.36)	.18 (.54)	-.03 (.33)	.23* (.44)	.32* (.41)	-.26* (.35)	-.11 (.64)	.29* (.53)	.10
	Coll (N=16)	.16 (.34)	-.15 (.42)	.01 (.45)	-.11 (.48)	-.18 (.51)	-.31* (.48)	-.27* (.53)	-.27 (.67)	-.14
	All (N=48)	.23***	.02	-.01	.08	.09	-.24***	-.24***	.02	
Tactual	4th (N=16)	.13 (.58)	.03 (.32)					-.21 (.52)		-.02
	9th (N=16)	.15 (.54)	-.03 (.56)					.23 (.75)		.12
	Coll (N=16)	.02 (.53)	.03 (.67)					.10 (.60)		.05
	All (N=48)	.10	.01					.04		
	All_{VT} (N=24)	.02 (.49)	-.04 (.60)					-.16 (.64)		-.06
	All_{TV} (N=24)	.19 (.59)	.06 (.45)					.23 (.60)		.16

*p < .05, using t-test for dependent measures to compare left and right field scores corrected for CT $\left(\frac{Threshold_L}{CT}, \frac{Threshold_R}{CT}\right)$

**p < .01

***p < .001

analysis is shown in Table 8. Only the typeface main effect ($F = 6.94$, d.f. = 2,84, $p < .01$)[19] and the typeface by modality interaction ($F = 3.54$, d.f. = 2,84, $p < .05$) were significant, reflecting the increase in right hemisphere participation with increasing typeface complexity in the visual but not in the tactual condition.

The LCs then were analyzed further in separate ANOVAs for each modality for the purpose of clarifying the following: (1) the different pattern of scores across typeface for the two modalities, (2) the nearly significant interaction of modality with modality order ($F = 3.14$, d.f. = 1,42, $p < .10$), and (3) the effect of the additional typefaces presented only in the visual condition and not included in the analysis.

Visual condition. Fig. 3 shows the average LCs for all eight typefaces presented in the visual condition for each grade separately. As predicted, right hemisphere participation generally increased with increasing typeface complexity for each grade. However, the increase in right hemisphere participation was very irregular across the medium complex typefaces (T2 through T5) and for T8.

For T2, T3, T4, and T8, a grade difference also was apparent. Contrary to the prediction of a decrease in the need for right hemisphere analysis with increasing age, college students showed the greatest degree of right hemisphere participation, reflected in a LVF advantage for those typefaces. The ninth-graders showed a large RVF advantage for those typefaces, and the fourth-graders, a somewhat weaker RVF advantage.

TABLE 8.--Summary of analysis of variance on laterality coefficients with modality factor included

Source	D.F.	MS	F	ω^2+
Between Subjects				
Mean (sensory field)	1	.222	.70	
Grade	2	.400	1.26	
Order	1	.551	1.73	
Grade x Order	2	.072	.22	
Sub. w. groups	42	.318		
Within Subjects				
Modality	1	.146	.36	
Grade x Modality	2	.158	.38	
Order x Modality	1	1.290	3.14	.01
Grade x Order x Modality	2	.112	.27	
M x sub. w. groups	42	.411		
Typeface	2	1.675	6.94**	.03
Grade x Typeface	4	.371	1.54	.01
Order x Typeface	2	.207	.86	
Grade x Order x Typeface	4	.103	.42	
T x sub. w. groups	84	.241		
Modality x Typeface	2	1.036	3.54*	.02
Grade x Modality x Typeface	4	.167	.57	
Order x Modality x Typeface	2	.078	.27	
Grade x Order x Mod. x type	4	.074	.25	
MT x sub. w. groups	84	.293		

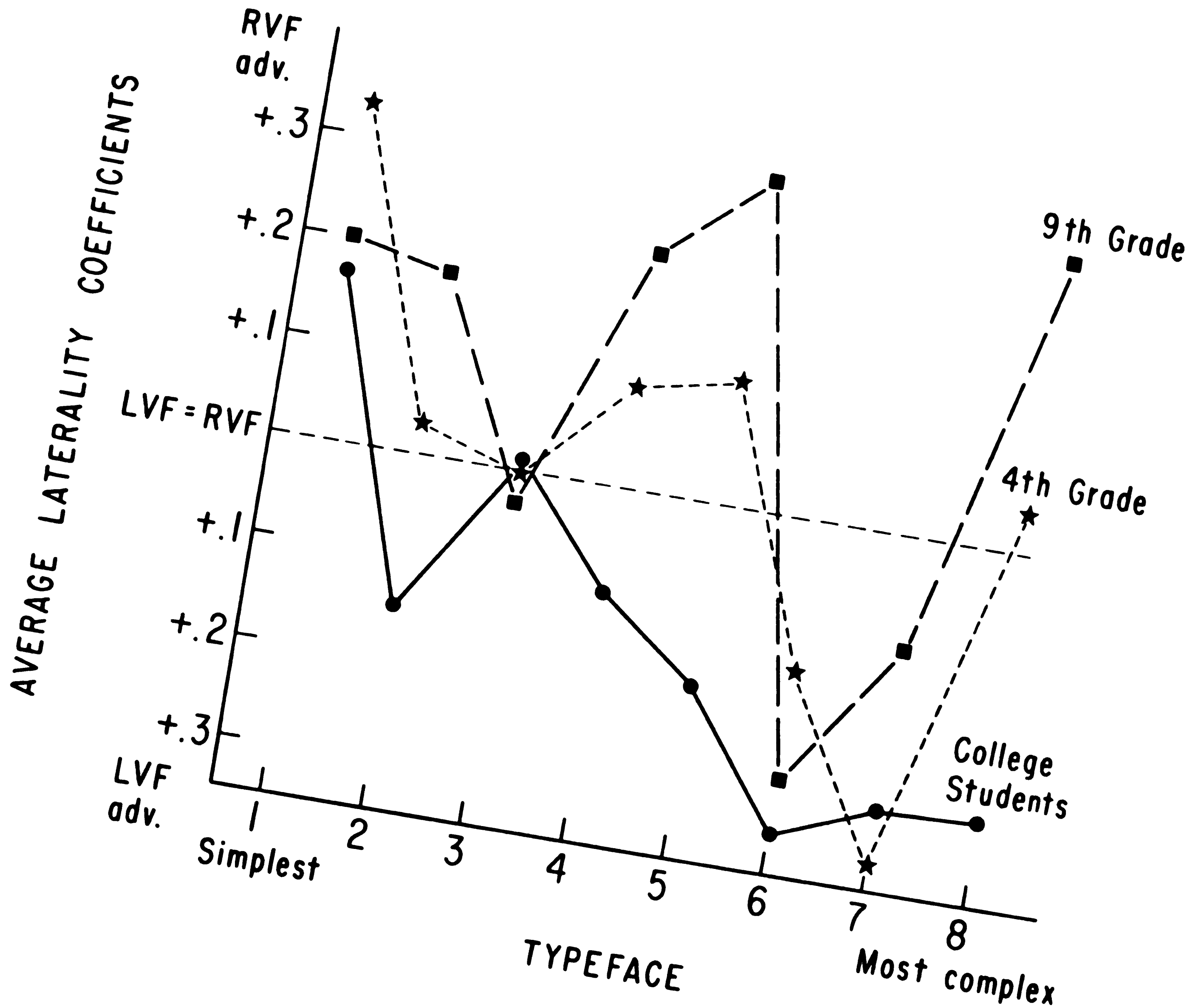
F_{max} = 2.28, d.f. = 5,47, N.S.

Test of no association in the correlation matrix:

X^2 = 9.48, d.f. = 15, N.S.

*p < .05
**p < .01
$+W_A^2 = \frac{\text{Variance accounted for by Factor A}}{\text{Variance for all factors + error term}}$

Fig. 3. Average laterality coefficients for the eight typefaces presented in the visual condition for each grade.


RVF adv.
+.3
+.2
+.1
LVF = RVF
+.1
+.2
+.3
LVF adv.
AVERAGE LATERALITY COEFFICIENTS
1 Simplest
2
3
4
5
6
7
8 Most complex
TYPEFACE
9th Grade
4th Grade
College Students

A 3 x 2 x 8 ANOVA (grade by modality order by typeface) with repeated measures on the typeface factor was performed on the visual LCs. The summary is shown in Table 9.[20] Both the main effects of typeface and grade were significant ($F = 5.97$, d.f. = 7,294, $p < .01$; $F = 4.99$; d.f. = 2,42, $p < .05$, respectively). Newman-Keuls multiple comparison procedures (shown in Appendix B) were used to examine the pattern of differences across typeface and grade. T6 and T7, those for which right hemisphere participation was greatest, significantly differed from all other typefaces, but not from each other. None of the other differences between typefaces was significant. The college students showed significantly greater right hemisphere participation overall than did the fourth- or ninth-graders, who did not differ from each other.

Tactual condition. Fig. 4 shows the average tactual LCs as a function of typeface for each grade by modality order. (The average LCs for each modality order with grades combined are provided in Table 7.) While no general trend across grade or typeface was found, there was a clear difference between modality orders that would account for the nearly significant order by modality interaction in the ANOVA with modality included. For every grade by typeface combination except T1 for college students, relatively more right hemisphere participation was shown when the visual condition came before the tactual condition (VT) rather than after (TV). This finding is contrary to the hypothesis that, if anything, prior visual exposure to the stimuli would make right hemisphere processing less critical.

TABLE 9.--Summary of analysis of variance on visual laterality coefficients

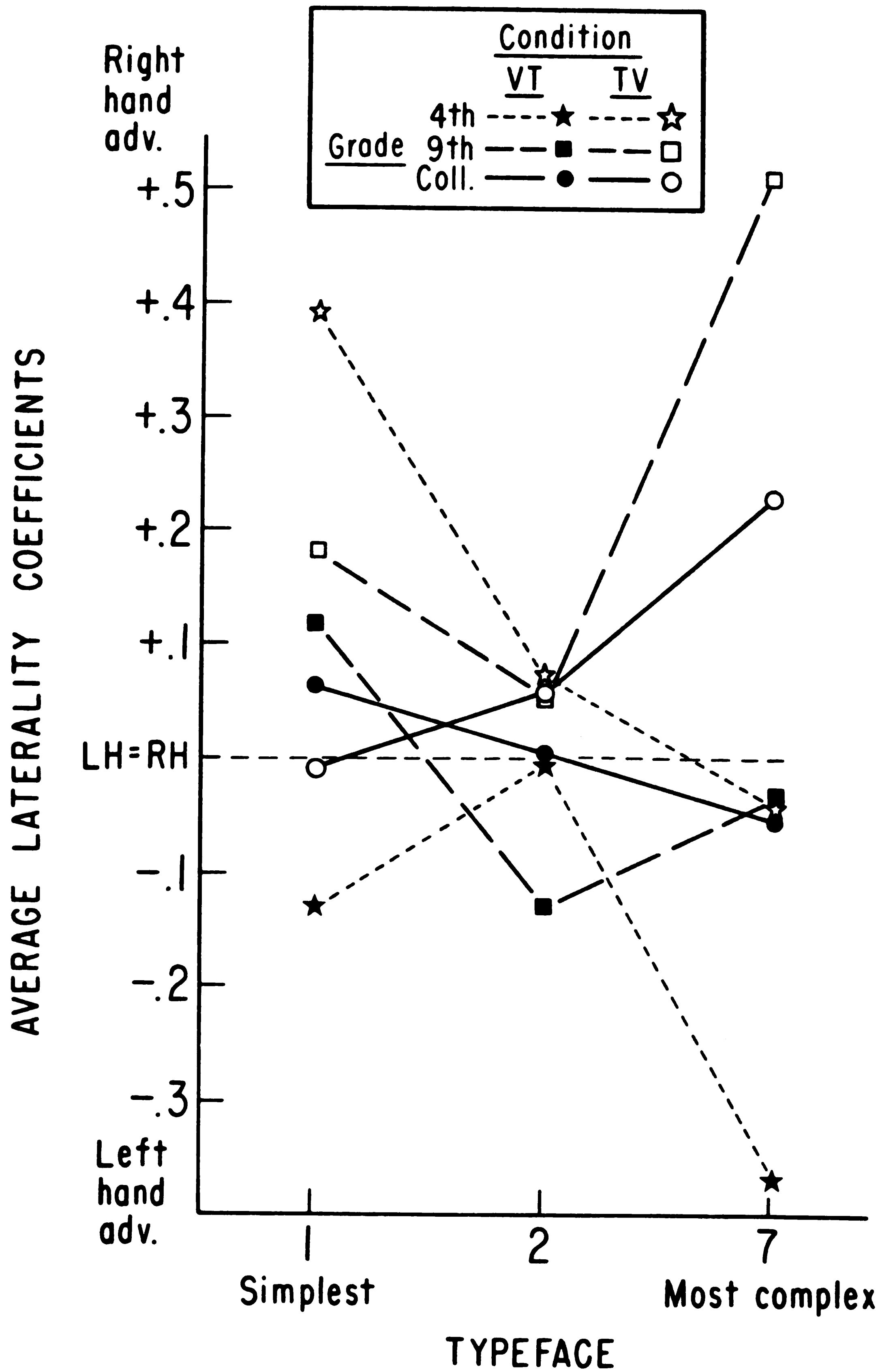
Source	D.F.	MS	F	ω^2
Between Subjects				
Mean (Visual field)	1	.013	.03	
Grade	2	1.902	4.99*	.03
Order	1	.020	.05	
Grade x Order	2	.010	.03	
Sub. w. groups	42	.381		
Within Subjects				
Typeface	7	1.234	5.97**	.07
Grade x Typeface	14	.239	1.16	
Order x Typeface	7	.153	.74	
Grade x Order x Typeface	14	.039	.19	
T x sub. w. groups	294	.207		

F_{max} = 4.15, d.f. = 7,47, $p < .05$

Test of no association in the correlation matrix:

$X^2 = 34.04$, d.f. = 28, N.S.

Fig. 4. Average tactual laterality coefficients for each typeface according to grade and modality order.



Condition
VT
TV
4th
Grade
9th
Coll.
Right hand adv.
+.5
+.4
+.3
+.2
+.1
LH=RH
-.1
-.2
-.3
Left hand adv.
AVERAGE LATERALITY COEFFICIENTS
1
2
7
Simplest
Most complex
TYPEFACE

The effect of modality order on the pattern of LCs across typeface was not consistent across grades. With grades combined, the predicted increase in right hemisphere participation with increasing typeface complexity was found for the VT condition, but not for the TV condition or both combined. Even in the VT condition, though, right hemisphere participation was not systematically greater in the tactual compared to the visual modality.

A 3 x 2 x 3 (grade by modality order by typeface) repeated measures ANOVA on the tactual LCs revealed only a significant main effect of modality order ($F = 4.44$, d.f. = 1,42, $p < .05$). The ANOVA summary is provided in Table 10.

Specific Typeface Characteristics: Average Threshold, Scriptlikeness, Confusability, and Difficulty

This section pertains to the relation between visual LCs and specific typeface characteristics. The relation was examined by three measures: (1) first-order or simple correlations between LCs and the characteristics, (2) regression analysis including the following as predictors of LCs: the characteristics, dummy-coded variables for subjects, grade, and the interaction of grade with the characteristics, and (3) separate regression analyses for each grade including only the characteristics as predictors of average LCs. The characteristics considered were those on which the typefaces were rated in Part I, scriptlikeness, confusability, and naming latency (NL), and a fourth characteristic, the average of the individual combined thresholds for each typeface (average threshold or AT). The major finding with all

TABLE 10.--Summary of analysis of variance on tactual laterality coefficients

Source	D.F.	MS	F	ω^2
Between Subjects				
Mean (Hand)	1	.364	.92	
Grade	2	.199	.50	
Order	1	1.763	4.44*	.03
Grade x Order	2	.179	.45	
Sub. w. groups	42	.397		
Within Subjects				
Typeface	2	.104	.35	
Grade x Typeface	4	.345	1.18	
Order x Typeface	2	.269	.92	
Grade x Order x Typeface	4	.173	.59	
T x subj. w. groups	84	.293		

F_{max} = 1.03, d.f. - 2,47, N.S.

Test of no association in the correlation matrix:

X^2 = 1.25, d.f. - 3, N.S.

three measures of the relation was a grade difference. For fourth- and ninth-graders, NL was the best predictor, while scriptlikeness was a poor predictor, and no combination of characteristics significantly predicted LCs. In contrast, for college students, scriptlikeness and confusability were significant predictors.

Average Threshold

Visual condition. Average threshold (AT) was used as a predictor for LCs in addition to the three characteristics used to select the typefaces in Part I. Even though AT reflected typeface difficulty, which to some extent already was measured by the naming latencies (NL) from Part I, it was included because it shared the same measurement factors with the LCs. If the results showed a high correlation of LCs with AT, but not with NL, an explanation of the change in right hemisphere processing across typeface in terms of peripheral measurement factors could not be eliminated. In other words, raising the general threshold level for the more complex typefaces could have changed the task in some way or failed to completely equalize task difficulty across typeface.

In contrast, NL estimates were obtained with a method independent of LC measurement. The NL estimates involved different subjects and centralized rather than lateralized letter presentation. A high correlation between LCs and NL would suggest an explanation of the change in right hemisphere processing across typeface in terms of difficulty in the higher-order analysis of images of letters all clearly perceived.

Table 11 shows ATs (in msecs.) for the eight typefaces in the visual condition for grades separated and combined. In general, ATs varied widely across typeface, covering nearly the entire scale. There was also a general increase in AT with increasing grade. Except for T1, which most subjects found very easy, and T3 for fourth-graders,[21] the standard deviations were large (averaging about 37 msecs.). These large standard deviations are one indication that the use of individually determined presentation durations was justified.

A 3 x 8 ANOVA to test the effects of grade and typeface on visual ATs revealed significant main effects of both grade and typeface. According to Newman-Keuls tests, all differences between typefaces were significant except those between T5 and T7 and between T6 and T8. Also, fourth-graders were significantly different from ninth-graders and college students, who did not differ from each other. The ANOVA summary and Newman-Keuls results are provided in Appendix C.[22]

Tactual condition. Since there were only three typefaces used in the tactual condition and since tactual LCs did not vary significantly across typeface, ATs and the three characteristics from Part I were not examined as predictors of tactual LCs. The ATS were tabulated, though, to look at the general pattern of scores according to typeface, grade, and modality order. These ATs (in secs.) are shown in Table 11. Three observations about the pattern of scores can be made. First, it was of interest to see whether there was a modality order difference in AT that would correspond to the significant order

TABLE 11.--Average combined thresholds* (ATs) and standard deviations (in parentheses) according to grade, typeface, modality condition, and (tactual only) modality order

Modality Condition	Grade	Typeface								
		1	2	3	4	5	6	7	8	All
Visual (msecs)	4th (N=16)	35.6 (16)	111.2 (45)	173.1 (9)	58.1 (36)	77.0 (40)	124.5 (34)	79.6 (37)	128.1 (39)	98.4
	9th (N=16)	24.8 (12)	80.8 (39)	153.0 (37)	45.3 (38)	50.8 (32)	85.0 (46)	57.0 (28)	97.3 (32)	74.2
	Coll (N=16)	21.5 (8)	63.1 (52)	148.3 (26)	39.6 (23)	57.3 (41)	102.8 (41)	52.8 (28)	88.2 (53)	71.7
	All (N-48)	27.3	85.0	158.1	47.7	61.7	104.1	63.1	104.5	
Tactual (secs)	4th (N=16)	2.3 (1.9)	12.6 (3.9)					12.2 (3.6)		9.1
	9th (N=16)	2.3 (1.5)	10.0 (5.1)					7.6 (3.9)		6.6
	Coll (N=16)	2.8 (2.0)	9.5 (3.7)					7.1 (4.1)		6.4
	All (N=48)	2.5	10.7					9.0		
	All_{VT} (N=24)	2.2	10.1					9.4		7.2
	ALL_{TV} (N=24)	2.7	11.3					8.6		7.5

*Where combined threshold (CT) = $\frac{Threshold_L + Threshold_R}{2}$

effect found for LCs. A higher AT for the VT condition might indicate that the greater right hemisphere participation for that condition was related to the greater difficulty of the task for those subjects. A lower AT for the VT condition might indicate that a more wholistic type of processing was needed in that condition because of shorter presentation times. From Table 11 it is apparent that there was no difference between modality orders. Thus, an explanation of the LC difference in terms of presentation time is eliminated.

Second, the pattern of ATs across typeface and grade was observed. The ATs were very low, approaching ceiling, for all grades on T1. There was a large increase in AT between T1 and T7 and a relatively smaller increase between T7 and T2. Scores generally decreased with increasing grade, with the main difference occurring between fourth and ninth grades. A 3 x 3 ANOVA testing the effects of grade and typeface revealed significant main effects of both factors and a significant interaction. The interaction reflected the finding, confirmed by simple main effects tests, of a grade effect for T2 and T7, but not for T1. The ANOVA summary and relevant comparison tests are shown in Appendix D.[23]

Third, the pattern of tactual ATs across grade and typeface was compared to the corresponding pattern for visual ATs and to the LCs. Averaged across grade, the relative difficulty of T1, T2, and T7, as reflected in AT scores, was similar in the two modalities. In the tactual condition, greater difficulty was related to a greater degree of right hemisphere processing. This relation was weak, however, because of the lack of a significant change in LCs across typeface, and, if the grades were considered separately, the relation was no longer apparent.

For both modalities, ATs were significantly higher for fourth-graders than for ninth-graders and college students, indicating that the fourth-graders were slower at perceiving the letters and that the ninth-graders and college students did not differ in ability. This pattern of ATs was not similar to the pattern of LCs for either modality. The greatest discrepancy was in the visual modality, where even though the college students showed significantly greater right hemisphere participation than the fourth- and ninth-grades, they did not differ from the ninth-graders in performance level.

Correlations of Visual LCs, ATs, and Part I Characteristics

Table 12 shows the correlations among the four characteristics to be used as predictors of LCs for each grade, and Table 13 shows the correlations of those predictors with LCs.[24] The correlations both with and without T3 were considered in both tables for two reasons. The first reason was that the validity and reliability of the LCs for T3 were uncertain. For every grade, the average percent correct for T3 was much lower than for any other typeface. In addition, only for fourth-graders, the stability correlations for T3 were low, the standard deviation for the T3 LC was much lower than for the other typefaces, and the T3 AT approached the upper limit of 180 msecs. Since percent corrent was the only very questionable measure for

TABLE 12.--Correlations between Part I ratings on difficulty, scriptlikeness, and confusability and average combined threshold (AT) for each grade--(a) with all typefaces included, and (b) with T3 eliminated

	(a) All Typefaces (N=8)			(b) T3 Excluded (N=7)		
	Diff.	Script.	Confus.	Diff.	Script.	Confus.
Diff.		-.06	.22		.31	.83*
Script.			.28			.15
AT-4th	.74*	.36	-.07	.50	.90*	.34
AT-9th	.77*	.20	-.15	.48	.90*	.36
AT-Coll	.82*	.23	-.14	.60	.87*	.33

*p < .05

TABLE 13.--Correlations of laterality coefficients with Part I ratings on difficulty, scriptlikeness, and confusability and with average combined threshold (AT) for each grade--(a) with all typefaces included, and (b) with T3 eliminated

Grade	(a) All Typefaces (N=8)				(b) T3 Excluded (N=7)			
	Diff.	Script.	Confus.	AT	Diff.	Scipt.	Confus.	AT
4th	-.57	-.40	-.42	-.40	-.77*	-.45	-.49	-.51
9th	-.44	-.23	.24	-.34	-.38	-.36	.15	-.22
Coll	-.29	-.76*	-.75*	-.20	-.86*	-.72	-.70	-.83*

*p < .05

ninth-graders and college students, the correlations and prediction equations including T3 were emphasized for those grades. For fourth-graders, though, since the majority of measures indicated lack of reliability and validity for T3, the correlations excluding T3 were emphasized.

The second reason for considering the correlations both with and without T3 was that because of its values on the predictor variables--very high on AT and NL and very low on scriptlikeness and confusability--T3 generally had a large effect on the pattern of correlations. Therefore, it was necessary to examine which correlations were altered significantly by the inclusion of T3, how they were altered, and whether the conclusions based on those correlations should be modified.

In Table 12, the correlations with all typefaces included fit the expected pattern, given the assumption that both NL and AT measured aspects of a general difficulty factor. For all grades, the correlation between AT and NL was high, while the correlations between AT and the other characteristics were low to moderate. Therefore, with AT included as a predictor, mainly the effects of AT and NL were expected to be hard to separate.

The correlations among predictors with T3 excluded were higher in general. This was to be expected for the three characteristics from Part I because the correlations between those characteristics were minimized for the group of eight typefaces as a whole. In addition, for every grade, correlations between AT and the other characteristics were moderate to high. With T3 eliminated from the prediction equations, these higher correlations between predictors would make a significant prediction of LCs less likely and would make it harder to separate their effects. The especially high correlations between scriptlikeness and AT would hinder the detection of a theoretically important effect of scriptlikeness over and above a task difficulty effect.

Table 13 shows the correlations of the four predictors with LCs for each grade. With the exception of the confusability correlation for ninth-graders, all the correlations were negative, as predicted. Thus, high ratings for a given typeface on the characteristics named by the scales tended to be associated with low LCs or relatively more right hemisphere participation in recognizing letters of that typeface. For fourth-graders, with all typefaces included, the correlations were all moderate, with the correlation for NL being the highest. With T3 excluded, which was the condition to be emphasized, the correlations increased in strength. The increase was especially great for the NL correlation, which became significant. In general, since the pattern of correlations was not changed by excluding T3, the lack of T3 should not be an important factor in the conclusions.

For ninth-graders, the correlations with all typefaces included were again all moderate, although slightly lower than for fourth-graders. The NL correlation was again the highest. With T3 excluded, most of the correlations were slightly lower, but the pattern did not change. Therefore, it seems that the inclusion of T3 in the prediction equation for ninth-graders should not affect the conclusions drawn in any major way.

For college students, with all typefaces included, the correlations distinctly differed across characteristics. The correlations for scriptlikeness and confusability were higher than the correlations for NL and AT. This pattern of correlations indicated that right hemisphere participation was related to scriptlikeness beyond any effect of task or typeface difficulty. When T3 was excluded, however, the correlations for NL and AT became significant and slightly higher than the other correlations. According to this pattern, difficulty overshadowed scriptlikeness. Since the exclusion of T3 caused a marked change in the pattern of correlations, conclusions regarding the relative importance of the characteristics must be tentative.

Prediction of Visual LCs from Typeface Characteristics Using Multiple Regression

Regression including variance from grade and subject variables. To examine whether a significant part of the variance in LCs was explained by typeface scriptlikeness, confusability, and difficulty (NL), those variables were entered into a regression along with dummy coded variables for subject, grade, and the interaction of grade with the three characteristics. All the variables are listed in Table 14, followed by their standardized regression coefficients, and the amount of additional variance accounted for when they were entered into the regression in the order listed. The number of contrasts tested for grades was equal to the degrees of freedom for the grade

TABLE 14.--Regression coefficients and statistics for analysis including subject and grade variables and for separate analyses by grade with four predictors of laterality coefficients

ALL GRADES (all typefaces included)	SOURCE OF VARIANCE	STANDARDIZED REGRESSION COEFFICIENTS	% ADDITIONAL VARIANCE ACCOUNTED FOR IN STEP-WISE ANALYSIS	
Overall Test:	Grade Variable 1 (GV1 = Coll v 4, 9)	-.39	4.04	d.f. = 2,381 $p < .0004$
Square mult. R=.288 F=2.36, d.f.=56,327 $p < .0001$	Grade Variable 2 (GV2 = Coll, 9 v 4)	.63		
	45 Subject Variables		17.03	d.f. = 45,336 $p < .01$
	Difficulty (NL)	-.23	2.49	d.f. = 1,335 $p < .001$
	Scriptlikeness	-.16	2.74	d.f. = 1,334 $p < .0005$
	Confusability	.19	0.01	d.f. = 1,333 $p < .80$
	GV1 x Diff.	1.19		
	GV1 x Script.	-.03		
	GV1 x Confus.	-.37	2.43	d.f. = 6,327 $p < .08$
	GV2 x Diff.	.17		
	GV2 x Script.	.02		
	GV2 x Confus.	-.28		
4th Grade (T3 excluded)	Scriptlikeness	-.48	20.45	d.f. = 1,5 $p < .31$
OVERALL TEST:	Difficulty (NL)	-1.14	43.84	d.f. = 1,4 $p < .09$
Square mult.R=.715 F=1.25, d.f.=4,2	Confusability	.42	5.47	d.f. = 1,3 $p < .51$
$p < .49$	AT	.35	1.69	d.f. = 1,2 $p < .76$
9th Grade	Scriptlikeness	-1.01	5.29	d.f. = 1,6 $p < .58$
Overall Test:	Difficulty (NL)	-1.99	20.92	d.f. = 1,5 $p < .29$
Square mult. R=.868 F=4.94, d.f.=4,3	Confusability	1.20	19.89	d.f. = 1,4 $p < .29$
$p < .11$	AT	1.58	40.71	d.f. = 1,3 $p < .06$
College	Scriptlikeness	-.92	57.30	d.f. = 1,6 $p < .03$
Overall Test:	Difficulty (NL)	-.89	11.45	d.f. = 1,5 $p < .23$
Square mult. R=.955 F=15.80, d.f.=4,3	Confusability	-.19	23.48	d.f. = 1,4 $p < .025$
$p < .02$	AT	.71	3.23	d.f. = 1,3 $p < .24$

factor (2). The specific contrasts are given in the table. For subjects, the number of contrasts tested was 45, equal to the degrees of freedom for subjects in each grade (15) times three.

The relative magnitude of each variable's contribution was represented, in part, by the standardized regression coefficients. Considering absolute values, the grade coefficients were the largest, with one exception. The exception was the first interaction term for grade and difficulty, an effect suggested by the simple correlations of NL with LCs (relatively high for fourth-graders and low for college students). The interaction terms for grade and confusability also were fairly high. Again, this was consistent with the simple correlations (high and negative for college students, positive for ninth-graders).

The overall test of the prediction equation was highly significant ($F = 2.36$, $p < .0001$), indicating that at least one element in the vector of beta weights differed from zero. However, the total variance accounted for was only about 29%, most of which (17%) was attributable to the subject variables taken together. The grade variables combined accounted for only about 4% of the variance, even when entered into the equation first. And the remaining 8% was divided about equally among scriptlikeness, difficulty (both of which were significant), and the six interaction variables taken together (which nearly reached significance even though entered into the equation last).

In summary, the proportion of variance in LCs accounted for by typeface characteristics was significant, although small in an absolute sense and dwarfed by subject variance and variance unaccounted for. Given that the interaction terms for grade and typeface characteristics approached significance, regressions not including subject variables were computed for each grade separately to clarify the effects of the typeface characteristics.

Separate regressions by grade. The same information shown in Table 14 for the first regression is also shown for the regressions for individual grades. For every grade, the predictors used were the three characteristics from Part I and AT. Scriptlikeness was entered into the equation first because of its possible theoretical importance. Since four predictors were used to explain only eight scores (seven, for fourth-graders), the results in general should be regarded as tentative.

For fourth-graders, in agreement with the simple correlations, difficulty (NL) accounted for the highest proportion of variance by far. That proportion was over 40% regardless of the order in which the variables were entered into the equation. Scriptlikeness accounted for the second highest proportion of variance when entered into the equation first, but this proportion dropped to less than 3% when scriptlikeness was entered following AT.

For ninth-graders, difficulty again was a moderately strong predictor of LCs. However, in contrast to the results for fourth-graders, AT and, to a lesser extent, confusability were also fairly strong predictors. The variance accounted for by AT and confusability was especially large (over 60%) when they were entered into the equation following scriptlikeness and NL, thereby controlling for the shared variance with those characteristics. It should be noted that, contrary to expectation, the coefficients for AT and confusability were both positive, suggesting that higher AT and greater confusability were related to less right hemisphere participation. For confusability, this suggestion was supported by the direction of the simple correlation with LCs. For AT, however, a suppressor effect probably was operating. Finally, scriptlikeness accounted for a very small proportion of the variance, even when entered into the equation first.

In marked contrast to the equations for fourth- and ninth-graders, scriptlikeness accounted for the largest portion of the variance for college students. This proportion generally was large, regardless of order of entry into the equation. Confusability also was a strong predictor, but its effect was eliminated if entered after AT. Again, the relative importance of scriptlikeness and confusability compared to AT and NL could change dramatically if T3 was excluded.

The overall tests of the regression equations did not reach significance for the fourth- or ninth-graders, but did so for college students, with about 95% of the variance accounted for. Thus, explaining the fourth- and ninth-graders' LCs not only involved weighing the four predictors very differently than for adults, but might also involve the use of other predictors not already considered or a different scaling of the given predictors.

Stimulus and Procedural Factors: Typeface Position, Letter Order, and Specific Letters

To clarify possible problems with the method used for determining threshold in this dissertation and to investigate further the types of factors affecting LCs, the specific effects of three stimulus and procedural factors were examined. Since the factors were counterbalanced with field and typeface, interpretation of the main analyses was not an issue. Results showed that all three factors systematically affected LCs at least in the visual condition. In the case of the first factor, typeface position, a relation was found between visual LCs and whether a typeface was presented in the first or second half of the visual condition. The LCs computed from second-half presentations compared to those from first-half presentations reflected a stronger asymmetry in the direction of the overall LC for a given typeface. The second factor, letter order, affected LCs for two typefaces in the visual condition. An advantage was found for the orders in which the first three letters were relatively very easy to identify. Finally, both the strength and direction of the LCs varied widely with the third factor, specific letter. Variation was greater for visual presentation than for tactual presentation, and it tended to be in the opposite direction for the two modalities.

Typeface Position

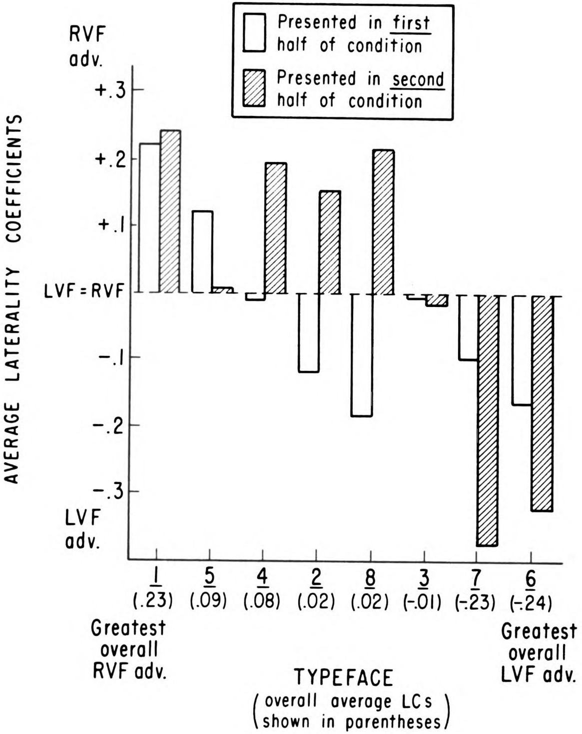
Visual condition. Since each typeface was presented twice in each of the eight order positions for each grade, typeface position was not confounded with the effects of typeface and grade.

Nonetheless, the relation between LCs and whether a typeface occurred earlier or later within the condition was examined to look for possible effects of practice, task familiarity, or an increasing attentional set across trials.

To observe the general position effect for each typeface, the cases were divided according to whether the typeface was presented before or after the halfway rest period. Average LCs then were computed for both groups. In Fig. 5 these scores are shown for all typefaces, which were arranged along the horizontal axis in order of increasing right hemisphere participation with grade and typeface position groups combined. The two typefaces for which there was a significant overall LVF advantage (T6 and T7) tended to show a greater LVF advantage when presented in the second half of the condition than when presented in the first half. In contrast, with the exception of T2, typefaces for which there was at least a slight overall RVF advantage showed a greater RVF advantage when presented in the second half of the condition than when presented in the first half. Thus, in general, in the second half of the condition there was a greater differentiation of LCs for the typefaces which tended toward opposite field advantages overall. As opposed to explanations in terms of increasing ease of the task or establishment of a general attentional set, this effect would be better explained by an increase over time of flexibility in allocating the most efficient type of processing for a given typeface.

The effects of typeface position, grade, and the interaction of these two variables were tested in a 2 x 3 ANOVA for each typeface.

Fig. 5. Average LCs for each typeface when presented in the first half of the visual condition (N=24) compared to the average LCs when presented in the second half (N=24), with typefaces ordered according to degree of right hemisphere participation.


Presented in first half of condition
Presented in second half of condition
RVF adv.
+.3
+.2
+.1
LVF = RVF
-.1
-.2
-.3
LVF adv.
AVERAGE LATERALITY COEFFICIENTS
1 (.23)
5 (.09)
4 (.08)
2 (.02)
8 (.02)
3 (-.01)
7 (-.23)
6 (-.24)
Greatest overall RVF adv.
Greatest overall LVF adv.
TYPEFACE
(overall average LCs shown in parentheses)

A summary of the F-values is provided in Appendix E. Typeface position was significant only for T8, and there were no significant interaction effects.

Tactual condition. It was particularly important to consider the effects of typeface position on tactual LCs because position was not perfectly counterbalanced with typeface. Given only six possible permutations of three typefaces, two of the eight typeface orders used for each grade necessarily were repeated. To test the effects of grade, typeface position, and their interaction using an equal-n ANOVA, the four subjects in each grade for whom an order was repeated were eliminated. The F-ratios from the separate ANOVAs for each typeface were tabulated in Appendix E. No significant effects were found, and there were no apparent trends in the LCs across typeface position.

Letter Order

Visual condition. Given the high interdependency of succeeding trials within a field using the staircase procedure, lower thresholds could have been facilitated by particular letter orders, such as those containing a cluster of relatively easy letters. Thus, it was of interest to examine letter order as a factor affecting the process of threshold determination, even though the two letter orders for each typeface were counterbalanced with field for each grade. Letter order was not counterbalanced with trial order, though, since for each typeface, each letter in a given order was always presented on the same trial. Therefore, trial order was considered when interpreting any letter order effects.

A 3 x 2 ANOVA was performed for each typeface to test the effects of grade, letter order, and their interaction on LCs. The F-ratios are summarized in Appendix E. The only significant order effect was for T5, and there were no significant interactions. Since the order effect for T8 approached significance, and since it was helpful to have at least two typefaces to find a shared difference between orders, the pattern of correct responses across trials was analyzed for both T5 and T8.

Table 15 shows the average LCs for each letter order by grade group. For T5, Order A led to a greater RVF advantage compared to Order B. This implies a relative advantage for Letter set 1, since that occurred in the RVF for Order A. In contrast, for T8, a greater LVF advantage was shown for Order A compared to Order B, implying a greater advantage for Set 2. Letter sets 1 and 2 also are shown in Table 15 for T5 and T8 along with information about percent correct responses.[25] The most striking factor in favor of Set 1 for T5 and Set 2 for T8 was the large percent of correct responses for the first few letters in those sets. In those sets, percent correct for the first three letters was at least 20% greater than percent correct for all letters, while in the other sets, percent correct for the first three letters was always less than overall percent correct.

At least two possible reasons for the association between a relatively high percent correct for the first three letters in a set and a relatively low threshold can be eliminated. First, the trial orders for the beginning of Set 1 for T5 and Set 2 for T8 were very

TABLE 15.--Average laterality coefficients for each letter order group at each grade for T5 and T8, and relative percent correct for the first three letters in each set

Grade	Letter Order		Letter Set					
T5	A RVF-Set 1 / LVF-Set 2	B LVF-Set 1 / RVF-Set 2	1 BRGPOFQC (2,3,4,7,9,10,12,13)*			2 OPQCBRGF (1,5,6,8,11,14,15,16)		
			% Correct-1st 3 letters	% Correct-all letters	% 1st 3 / % total	% Correct-1st 3 letters	% Correct all letters	% 1st 3 / % total
4th	.12	.12	.71	.54	1.31	.61	.62	.98
9th	.48	.17	.78	.61	1.28	.62	.63	.98
Coll	.13	-.49	.77	.62	1.24	.60	.62	.97
T8	A RVF-Set-1 / LVF-Set 2	B LVF-Set 1 / RVF-Set 2	1 BGQFCORP (3,4,6,7,9,10,11,14)			2 PQOGBRFC (1,2,5,8,12,13,15,16)		
			% Correct-1st 3 letters	% Correct-all letters	% 1st 3 / % total	% Correct-1st 3 letters	% Correct-all letters	% 1st 3 / % total
4th	-.12	.19	.26	.37	.70	.69	.51	1.35
9th	.12	.46	.35	.50	.70	.67	.55	1.22
Coll	-.37	-.16	.39	.56	.70	.66	.53	1.24

*Trial numbers for each of the letters in the order they are listed.

different--one contained a run of three consecutive trials and one contained the first two trials--suggesting that trial order was not responsible for the association. Second, a large number of correct responses at the beginning of a typeface for a given field could mean a greater number of trials before the third reversal, thereby lowering the level of the staircase before the cut-off. A comparison of the number of trials before cut-off revealed that the favored set for T5 did have about one more trial, on the average, before cut-off than the other set. There was no difference between sets for T8. Therefore, if number of trials before cut-off did have an effect, it was only slight.

One explanation that cannot be eliminated is that a few easy letters in one field at the beginning of a typeface led the subject to have more confidence in judgments for that field or to shift attention toward that field, thereby producing a lower threshold.

Tactual condition. A 3 x 2 ANOVA also was performed for each typeface in the tactual condition to examine the effects of grade, letter order, and the interaction of those factors on LCs. The F-ratios, summarized in Appendix E, all failed to reach significance.

Specific Letters

Visual condition. In addition to the comparison of letter orders, the pattern of percent correct responses for individual letters was analyzed as a factor contributing to threshold determination. The questions examined were whether individual letters contributed differently to field effects, and whether, as hypothesized, relative accuracy and field differences for individual letters differed across typeface. Since for a given subject the presentation times of individual letters differed within and across fields, accuracy and field differences were computed only by summing across all subjects, with the goal of approximately equalizing presentation times across letters and fields. This goal generally was met. In addition, since one of the prime purposes of the letter analysis was to make cross-modal comparisons, only the three typefaces presented in both modality conditions were analyzed.

Table 16 shows the individual letters listed in order of decreasing accuracy for each typeface. In general, F, P, R, and C were the letters most accurately identified, and B, O, and Q were the least accurately identified. Despite these similarities, there were some unique patterns for each typeface. For instance, F was the easiest letter for T1 and T7, but next to the hardest letter for T2, and R progressed in relative difficulty with increasing typeface complexity. As indicated in Table 17, the correlations between visual typefaces in relative accuracy for individual letters were, on the average, positive and moderately strong. In overall average percent correct responses, T1 was highest and T2, lowest, consistent with the ATs for those typefaces. The number of letters for which a 10% increase across grades in percent correct responses was shown was greater for the most complex typeface, suggesting that all grades were highly familiar with T1 letters presented visually.

TABLE 16.--For T1, T2, and T7 in each modality condition, individual letters listed in order from highest to lowest average percent correct identifications (shown in parentheses)

	Visual Condition			Tactual Condition		
	T1	T2	T7	T1	T2	T7
Highest accuracy	F (.77)	P (.81)*	F (.91)	O (.93)	O (.92)	O (.93)
	R (.77)	C (.78)*	P (.89)	C (.74)	C (.88)	B (.55)*
	P (.75)	R (.61)*	C (.84)*	F (.72)	Q (.52)	Q (.54)
	C (.69)	G (.57)	G (.60)	P (.64)*	G (.36)	C (.52)*
	G (.66)	Q (.46)	R (.52)*	B (.62)	P (.36)*	P (.49)*
	O (.66)	B (.35)*	B (.43)	Q (.60)	B (.28)*	R (.46)*
	B (.61)	F (.33)	O (.40)	G (.59)*	R (.25)*	F (.29)
Lowest accuracy	Q (.42)*	O (.12)	Q (.21)*	R (.51)*	F (.06)	G (.19)
Overall average % correct responses	.67	.50	.60	.67	.45	.50

*Letters that showed an increase in accuracy of at least 10% from 4th grade to college.

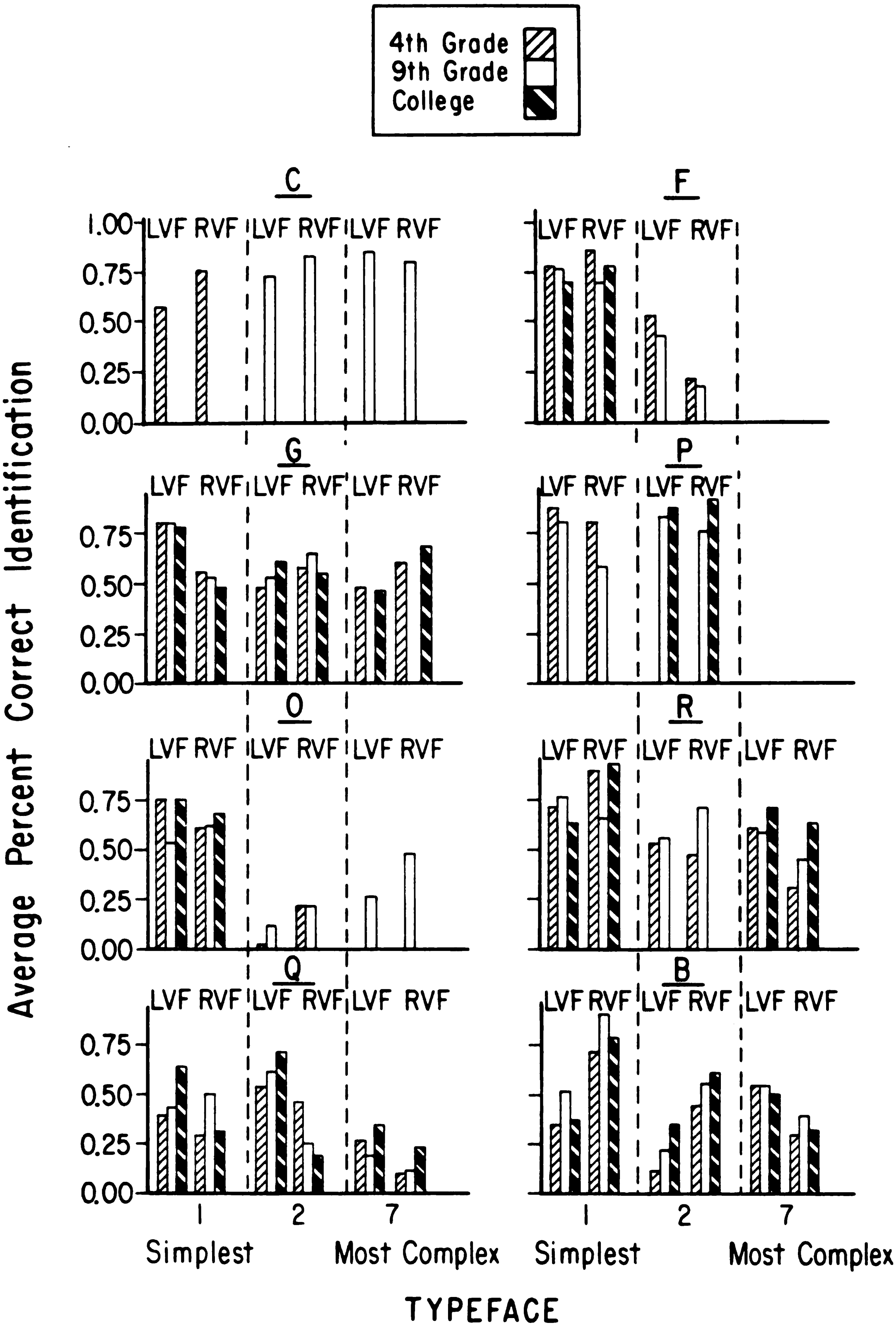
TABLE 17.--Correlations between typefaces in average percent correct responses for individual letters. Correlations are shown for each modality condition separately (above and below diagonals) and across modality condition within typeface (between diagonals)

			Visual			
			T1	T2	T7	
				.24	.77	(T1)
	T1		.06		.50	(T2)
	T2	.65		-.05		
Tactual	T7	.66	.70		-.43	
		(T1)	(T2)			

The average percent correct responses per field for individual letters are shown in Fig. 6. The results were separated by grade and typeface, and only those grade by typeface combinations with a field difference of at least 5% were included. The major finding is that the amount of asymmetry differed greatly across letters. The letters B, Q, G, and R showed larger asymmetries than the others. In addition, the direction of asymmetry varied across letters and across typefaces within letters. The variation was usually, but not always, consistent with field threshold differences. For instance, the variation was consistent with threshold differences for B, but almost exactly opposite for G.

The amount and direction of asymmetry apparently was not related to the initial grouping of letters in terms of circular v. straight line features. The one exception to this generalization is that for college students, the circular letters in T1 (O, C, Q) tended to show a LVF advantage, while the letters with a straight line showed a RVF advantage, possibly reflecting a hemisphere processing difference. Asymmetry also was not related to the frequency of letter use, since, for example, B and P are about equal in frequency (Mayzner & Tresselt, 1965), but very different in amount of asymmetry shown. One factor at least partly related to the amount of asymmetry shown was the average percent correct responses for the letters (from Table 16). Low accuracy, in the case of B and Q and F (T2 only), tended to be associated with a large degree of asymmetry. However, this was not the case for G and R. In general, then, the letters showed very different

Fig. 6. Visual condition. Average percent correct responses per visual field for individual letters shown separately for each grade for T1, T2, and T7. (Only the cases where the field difference exceeded 5% were included.)


4th Grade
9th Grade
College
C
F
G
P
O
R
Q
B
LVF RVF
1.00
0.75
0.50
0.25
0.00
Average Percent Correct Identification
1
2
7
Simplest
Most Complex
TYPEFACE

asymmetry patterns, which can only be speculated on given the current paradigm.

Tactual condition and cross-modal comparison. Table 16 also provides a list of individual letters in order of accuracy for each of the three typefaces in the tactual condition. In general, letters with the highest accuracy were O, C, and Q, and one letter with an overall low accuracy was R. As shown in Table 17, there were moderately high positive correlations between the typefaces in individual letter accuracy. In terms of percent correct responses across all letters, T1 showed the highest and T2 showed the lowest, again in agreement with AT ordering. The number of letters showing an increasing accuracy with increasing grade was consistent across typeface, suggesting a general ability factor related to age, but not related to differential familiarity with the tactual typefaces.

Individual letter comparisons in the visual and tactual conditions revealed marked modality differences, as predicted. The correlations within the diagonal lines in Table 17 indicated that there was absolutely no association between the patterns of individual letter accuracy in the visual and tactual modalities for T1 and T2. The correlation between modalities was moderately negative for T7. This finding that cross-modal correlations were much lower than within-modal correlations indicates that the sensory systems differed in the particular letter qualities they were most adept at processing. The initial division of letters into those with a circular pattern vs. those with a left vertical line may be associated in part with the characteristics differently favored by the two modalities. In general, the circular letters tended to be recognized better in the tactual condition,[26] while the letters with a left vertical were recognized better in the visual condition.

An analysis of the percent correct responses per field for individual letters in the tactual condition revealed that the number of grade by typeface combinations for which a field difference occurred was much lower than in the visual condition. Since the few differences found tended to be inconsistent across grades, no conclusions could be drawn about the pattern of asymmetry for individual letters. A figure showing the hand asymmetries comparable to the one for the visual modality is provided in Appendix F. One comparison of interest was between the direction of asymmetry for individual letters in the two modalities. Of the 24 grade by typeface combinations for which there was an asymmetry for a particular letter in both modalities, 15 (65%) showed asymmetries in opposite directions for the two modalities. Again, a marked difference in processing between the two modalities was suggested.

Individual Difference Factors: Individual LC Distribution and Relation to AT, LC in Other Modality, and Familial Sinistrality

In this final section, LCs were examined on an individual subject level. First, average scores were compared with two measures of individual variation: (1) the distribution of individual LCs for each typeface, and (2) the change in LCs across typeface for each individual. These measures generally were consistent with the trends for average

LCs in both modality conditions, though marked individual differences existed. Second, the possible effects of an individual's threshold level, LC in the other modality, and FS status on his LC for a given typeface were examined. In general, there was no systematic relation between these variables and LCs. The most unexpected result was the tendency toward negative cross-modal correlations for LCs in a given typeface.

LC Distribution

Visual condition. Individual LCs were examined to determine whether average LCs adequately reflected the pattern of scores for the majority of individual subjects. Table 18 lists the frequencies of positive and negative visual LCs for each typeface for each grade separately and for all grades combined. The relative number of subjects with positive and negative scores followed the average LCs very closely. At least half the subjects in each grade showed the expected RVF advantage for T1, with only six subjects in all grades combined showing a reversal. In contrast, the majority of subjects in each grade showed a LVF advantage for T6 and T7.

For the four typefaces requiring an overall medium amount of right hemisphere processing (T2, T4, T5, and T8), the subject distribution reflected the grade difference found for average LCs. A large majority of ninth-graders showed a RVF advantage, only a few more fourth-graders showed a RVF advantage than showed a LVF advantage, and the majority of college students showed a LVF advantage.

The large number of fourth- and ninth-graders with LCs of zero for T3 is still another indication of the possible floor effect for

TABLE 18.--Number of subjects per grade with a left or right field advantage* for each typeface and modality condition, and (tactual only) modality order. The last column shows the number of subjects whose laterality coefficients were consistent with the pattern across typeface set by the average LCs**

Modality Condition	Grade	TYPEFACE (in order of increasing right hemisphere participation) 1		5		4		2		8		3		7		6		Number of subjects with $LC_{T1,5,4,2} > LC_{T8,3,7,6}$
		LVF adv	RVF adv	LVF adv	RVF adv	LVF adv	RVF adv	LVF adv	RVF adv	LVF adv	RVF adv	LVF adv	RVF adv	LVF adv	RVF adv	LVF adv	RVF adv	
Visual	4th (N=16)	3	10	4	9	6	6	6	7	7	8	3	3	10	4	10	3	13
	9th (N=16)	1	8	1	9	3	9	4	6	2	10	3	3	9	5	11	3	14
	Coll (N=16)	2	8	7	5	8	5	10	3	9	4	3	9	9	3	12	3	10
	All (N=48)	6	26	12	23	17	20	20	16	18	22	9	15	28	12	33	9	

Modality Condition	Grade	1 VT (N=8)		1 TV (N=8)		2 VT (N=8)		2 TV (N=8)		7 VT (N=8)		7 TV (N=8)		Number of subjects with $LC_{T1} > LC_{T2,7}$
		LH adv	RH adv	LF adv	RH adv	LH adv	RH adv	LH adv	RH adv	LH adv	RH adv	LH adv	RH adv	
Tactual	4th (N=16)	3	1	1	4	3	2	2	2	5	1	1	1	9
	9th (N=16)	1	2	1	2	4	2	3	2	6	2	1	5	8
	Coll (N=16)	1	1	2	1	3	4	3	4	3	2	1	5	7
	All (N=24)	5	4	4	7	10	8	8	8	14	5	3	11	

*Subjects with a laterality coefficient of zero for a given typeface were omitted from the frequency count for that typeface.

**For the visual condition, this pattern was defined as a higher average LC for the first four typefaces (as listed here) compared to the last four typefaces. For the tactual condition, the pattern was defined as a higher LC for T1 compared to the average of T2 and T7.

that typeface. However, the finding that 12 out of 16 college students had non-zero laterality scores for T3, nine of which were positive, supports the inclusion of that typeface in the analyses of characteristics affecting college students' scores.

Besides examining the distribution of scores for each typeface separately, another question asked was whether LCs for individuals tended to vary across typeface in the same manner as the average LCs. To determine agreement with the average LC pattern, the scores for each subject were set up as follows: (1) the typefaces were arranged in order of increasing right hemisphere participation, as shown by all grades combined, and (2) LCs for the first and last four typefaces were averaged separately, and the averages then compared. The criterion for a general agreement with the overall pattern was a greater average score for the first four typefaces than for the last four. The last column of Table 18 shows the number of subjects per grade who met this criterion. Nearly all the fourth- and ninth-graders followed the pattern, and the majority of college students did. The main reasons for failure to meet the criterion were: (1) a large number of zero LCs, and (2) fairly large negative LCs for one or more of T2, T4, and T5, coupled with positive LCs for T8 and/or T3. Most subjects switched field advantages at least once, although one college student and one fourth-grader had all non-negative scores, and one ninth-grader had all non-positive scores. Thus, while the pattern of average LCs across typeface generally was valid for most individuals, in very few cases was there an exact match, and some of the individual patterns were very different. As suggested by the regression analysis, the amounts of subject variance and variance unaccounted for were high.

Tactual condition. As in the visual condition, the distribution of individual LCs in the tactual condition generally followed the pattern set by the average LCs. With modality order groups combined, for every typeface the number of subjects with a left hand advantage was about equal to the number with a right hand advantage, consistent with the average LCs close to zero found for all three typefaces. The number of subjects with zero LCs generally was greater than in the visual condition, especially for T1. For this typeface, over half of all subjects in the three grades combined had tactual LCs of zero.

With modality order groups considered separately, a group difference in the distribution of subjects across hand advantage categories was apparent. A higher frequency of left hand advantage was found for the VT groups, while a higher frequency of right hand advantage was found for the TV groups. This modality order difference was especially strong for T7 and for the fourth-graders for T1, reflecting the greater modality order difference in average LCs for those cases.

To examine the agreement between the patterns of individual and average LCs across typeface, each indivdiual's T1 LC was compared to the average of his T2 and T7 scores. The criterion for agreement was a greater LC for T1. Only about half the subjects in each grade met the criterion, supporting the conclusion of no definite trend across typeface for average LCs.

Relationship of Individual LCs and Combined Thresholds, Corresponding LCs in Other Modality, and FS

Visual condition. If the correlation between average LCs and ATs (average combined threshold or CT) can be interpreted to indicate more than just a general typeface difficulty effect on right hemisphere participation, the correlations for individual LCs and CTs within typeface should parallel the average correlations. These correlations for individual scores were computed for each grade by typeface combination (see Appendix G). None of the absolute values of the correlations exceeded .49 (all non-significant), and the pattern of correlations across grade and typeface was not systematic in any apparent way. Rather than reflecting the negative correlations between average LCs and ATs, the correlations based on individual scores were positive for 17 of the 24 grade by typeface combinations. Given these results, the correlations between the average LCs and ATs must be interpreted with caution.

An additional variable whose relation to individual LCs also should be considered is the presence or absence of familial sinistrality (FS+ v. FS-). Since there was only one FS+ college student, no conclusion can be drawn about the effect of FS for that grade. It can be noted, though, that the LCs for the FS+ subject followed closely the pattern set by the average LCs. For the fourth- and ninth-graders, about half of the subjects were FS+. Average LCs for the FS+ and FS- groups of both grades were computed for each typeface and compared using *t*-tests (summarized in Appendix H). Of the eight FS+ v. FS-comparisons for fourth-graders, three differences exceeded .10, and all three were in the direction of a greater positive score for the FS+ group. Only one difference was significant, though (T7; $\overline{FS}+ = .08$, $\overline{FS}- = -.64$). Of the eight FS+ v. FS- comparisons for ninth-graders, four exceeded .10, half in each direction. Only one difference reached significance (T2; $\overline{FS}+ = -.12$, $\overline{FS}- = .48$).

Further, for both grades, the absolute values of the average LCs for the FS+ and FS- groups were about equal, and the pattern across typeface of the average LCs for each group followed the pattern set by the overall average LCs. In summary, the difference between FS+ and FS- groups was not great and not apparently systematic, except that the fourth-grade FS+ subjects tended to show more positive LCs. One further note is that all three fourth-graders who did not meet the criterion for agreement with the average LC pattern across typeface (see Table 18) were FS+, and one of the two ninth-graders who did not meet the crition was FS+. Thus, possibly other variables related to FS+ influenced the pattern of scores.

Tactual condition and cross-modal comparison. Correlations between individual LCs and CTs were computed for each grade by typeface combination in the tactual modality. As in the visual condition, about two-thirds of the correlations were positive and the absolute values of all but one did not exceed .49. The one exception was a correlation of .66 ($p < .05$) for the fourth-graders on T1, reflecting the fact that the subjects who tended toward a ceiling effect on T1 (those with low CTs) showed no field difference, while the majority of the other subjects had positive LCs. In general, though, tactual LCs were not influenced greatly by overall performance level, as measured by CT.

The effect of FS on tactual LCs also was examined. Average LCs for the FS+ and FS- groups were not significantly different for any typeface for either the fourth- or ninth-graders. Of the six possible comparisons between FS+ and FS- groups (one for each grade by typeface combination), three differences exceeded .10, and all three were in the direction of greater negative LCs for the FS+ group. Therefore, although FS did not have a large effect on tactual LCs, the weak trend that did exist was in the opposite direction to the trend found for the visual condition.

Finally, a positive relationship between individual LCs in the two modalities was predicted. To test this prediction, cross-modal correlations between LCs for the same typeface were computed for each grade by typeface combination and are presented in Table 19. None of the correlations was significant, but six of the nine correlations were negative, a trend contrary to the prediction and suggestive of a dissociation between the modalities.

TABLE 19.--Cross-modal correlations of laterality coefficients for each of the three typefaces presented in both modality conditions

Grade	Typeface		
	T1	T2	T7
4th	.27	-.31	-.03
9th	-.29	.06	-.27
Coll	.08	-.22	-.23

DISCUSSION

Presentation Modality

There were two principal hypotheses concerning modality differences in degree of right hemisphere participation in letter identification. First, for both modality conditions, right hemisphere participation was expected to increase systematically with increasing typeface complexity. Second, right hemisphere participation was expected to be greater in the tactual than in the visual condition at every point of complexity. The first hypothesis, although accurate for the visual condition, was not supported for the tactual condition. In fact, summed across modality orders, the average tactual LCs for the ninth-graders and college students indicated the smallest degree of right hemisphere participation for the most complex typeface. The second hypothesis also was not supported. As opposed to showing a greater right hemisphere participation, the average tactual LCs for most grade by typeface combinations just showed less asymmetry in either direction than the visual LCs. When the tactual LCs were summed across grades, a very weak left hemisphere (right hand) advantage was found for all typefaces.

These results raised two questions. First, why was there a lack of asymmetry in the tactual condition? In particular, why would a left hand advantage be found for identifying braille letters, but not Roman alphabet letters in a complex typeface? And, second, what conclusions, if any, can be drawn about modality differences in the role of right and left hemisphere processing in letter identification?

Reasons for Lack of Asymmetry in the Tactual Condition

General methodological factors. A possible explanation for the failure to find a hand asymmetry in the current study is that the method was not sensitive enough to pick up existing processing asymmetries. One factor that might have contributed to a lower sensitivity is the use of a unilateral presentation procedure in the current study as opposed to dichhaptic stimulation. The dichhaptic procedure was designed to simultaneously activate homologous cortical areas and thereby hinder interhemispheric transmissions. This procedue would tend to maximize asymmetry by limiting processing as much as possible to the hemisphere contralateral to the input. Contrarily, the unilateral procedure can be assumed to allow greater interhemispheric communication and to permit freer processing of any information from hand or wrist movements transmitted through ipsilateral pathways.

Witelson (1974, 1977a), LaBreche et al. (1977), and Oscar-Berman et al. (1978) all employed the dichhaptic procedure. However, the unilateral procedure was used in one study of hand differences for Roman letters which suggested a left hand advantage (Gardner, 1942) and in both braille learning studies (Rudel et al., 1974; Wagner, 1976). A direct comparison of the two procedures was made by Flanery and Balling (1979) using a tactile shape-discrimination task. They had children and adults feel either a single nonsense form with one hand or two forms with both hands simultaneously, and then judge a tactually presented comparison form as either the same as or different from the first form(s). A left hand advantage was found for the older age groups, and it was of similar magnitude in the unilateral and dichhaptic conditions.

In summary, examination of the procedures used in these studies of tactual asymmetry suggests that although use of a dichhaptic procedure may enhance asymmetry in certain cases, use of a unilateral procedure would not prevent a significant asymmetry, particularly an asymmetry in favor of the left hand.

Another factor that might have reduced the sensitivity of the method is the relatively long presentation time (ranging from 7 to 13 seconds) used for the two more complex typefaces in the current study. For five studies of hand asymmetry for Roman letters (Witelson, 1974, 1977a; Manning; LaBreche et al.; Oscar-Berman et al.) and for both braille learning studies, presentation times were under four seconds (typically, two seconds). These shorter times presumably limited interhemispheric transmissions, although some amount of transfer still could occur within four seconds. While use of a shorter presentation time might have increased the likelihood of finding a significant hand asymmetry, evidence that it was not a requirement was provided by Flanery and Balling (1979). They obtained a significant left hand advantage even though they presented the initial nonsense form(s) for 10 seconds and the comparison form for 5 seconds. This hand asymmetry was attributed to asymmetry in the method used to process (or code) information initially by the recipient hemisphere before that information could be transmitted to the other hemisphere.

Besides limiting interhemispheric transmissions, the short presentation times probably were selected to yield an accuracy level of roughly 50% correct, the level at which the greatest differentiation between hands is likely to be found. Not all of the studies were successful at achieving this level. For instance, accuracy level was about 30% correct in the two studies by Witelson and about 80% correct in the study by Oscar-Berman et al. In contrast, accuracy levels in the current study ranged from 40% to 60% correct for the two more complex typefaces, largely because of the continual adjustment of presentation time. Thus, from the point of view of establishing a 50% accuracy level, presentation times were more favorable towards the appearance of hand asymmetry in the current study than in some of the other studies.

A third factor that might have affected the sensitivity of the method is stimulus size. Although the letters used in the current study (roughly 2 x 1.6 cm) were slightly smaller than the letters used in all the other studies of hand asymmetry for Roman letters, they were much larger than the braille patterns (contained within a .6 x .4 cm grid). This larger size relative to the braille patterns might have increased the need for at least some serial (left hemisphere) processing, as opposed to the largely wholistic approach thought to be favored for braille patterns. However, hand asymmetry trends were found even with letter stimuli larger than those used in the current study, and a significant left hand advantage was found for forms 3.8 x 3.8 cm. (Flanery & Balling, 1979). Therefore, as with the factors of presentation procedure and time, use of a different stimulus size in the current study might have increased the likelihood of finding a hand asymmetry, but stimulus size could not be considered the major reason for lack of asymmetry.

Memory demands. Another possible explanation for the failure to find a hand asymmetry in the current study is that the memory demands were minimal. Only one letter was felt at a time, and it was identified immediately after the exploration period. In contrast, the other studies of hand asymmetry for tactually presented linguistic stimuli involved a greater memory component. For the braille studies, the paired associated learning paradigm required that the braille patterns associated with a particular letter name be recalled over the course of the experiment. For some studies using a dichhaptic procedure with active exploration of the letters, memory load was increased by presenting two pairs of stimuli per trial. The importance of these memory demands for eliciting asymmetries in the tactual modality was demonstrated by Oscar-Berman et al. Using a dichhaptic procedure, they specified the order in which the subject was to identify the stimuli. Asymmetries for letters and line orientations were found only for the hand reported second. Therefore, the difference between the current study and the braille learning studies in terms of memory requirements may partly explain the failure to find a left hand advantage for the more complex typefaces in the current study.

Two points should be made to qualify this conclusion, however. First, several studies have suggested that hemispheric asymmetries may be stronger at later stages of information processing (especially those involving memory) for the visual (e.g., Moscovitch, Scullion, & Christie, 1976; Dee & Fontenot, 1973) and auditory (e.g., Oscar-Berman, Goodglass, & Donnenfield, 1974) modalities as well. While this may be the case, in both modalities there also have been many demonstrations of significant asymmetries at earlier stages of processing for tasks not involving a large memory component (e.g., Bryden & Allard, 1976, for vision). Therefore, it should not be concluded that asymmetries cannot be demonstrated for the earlier stages in processing tactual information.

Second, if it were found that asymmetries in the tactual modality are limited to the stages of processing involving memory, the interpretation of that finding would be different than for a similar finding for the visual or auditory modality. The reason is that the storage of tactual information often involves visual encoding (see Freides, 1974, for review). This is particularly true for: (1) spatial or form information that the visual modality is more adept at handling than the tactual modality, (2) letters that are readily pictured, and (3) tasks with a response mode involving visual recognition (e.g., Witelson, 1974). If asymmetries were found only for tasks with large memory demands, then, the asymmetries might reflect only hemispheric differences in visualization processes, not in processing more purely tactual information.

Stimulus visualizability. A third possible explanation for the difference in asymmetry patterns between the braille letter learning studies and the current study is the amount of visualization likely to be associated with the two kinds of stimuli. Rudel et al. (1977) hypothesized that since most of the evidence for right hemisphere specialization in the tactual modality came from tasks where vision was excluded, the involvement of visualization in a tactual task would reduce or even eliminate a right hemisphere advantage. As Rudel et al. (1977) noted, most naive sighted subjects and blind subjects would not have studied braille visually, and therefore, would not be able to connect the tactile patterns to visually familiar forms. In contrast, cut-outs of familiar Roman alphabet letters that were felt but not seen would be readily visualizable. The visualization theory, then, would predict less right hemisphere advantage for Roman letters, and the findings are consistent with the theory.

Specific evidence to support the visualization theory was reported by Rudel (1979). Seventy-two children learned braille to a specified criterion using vision and then were asked to pick out the braille patterns tactually. According to the theory, since a greater amount of visualization was involved in this task than in the purely tactual braille studies, less right hemisphere advantage or possibly even a reversal of asymmetry was predicted. In agreement with this prediction, no significant hand difference in accuracy was found, but respones with the right hand were faster.

While this evidence is convincing, there still is a general problem with the interpretation of the theory. It is not clear whether it is valid to draw inferences about the effects of visualization from the effects of an actual visual component in the task, as Rudel et al. did in the original formulation of the theory. If visualization can be considered similar to visual participation, then the identification of Roman letters in the current study may be considered in some sense a cross-modal matching task. It is likely that recognition of the tactually-perceived letters was aided by comparing them to stored visual representations. In that case, the findings of Butters et al. (1970) suggesting a left hemisphere involvement in cross-modal matching add further weight to the idea that visualization contributed to the failure to find a right hemisphere advantage for the more complex typefaces.

Two sets of results, however, suggest that the interpretation of the theory of visualization may have to be modified to adequately explain the lack of asymmetry in the current study. First, Witelson's (1974) finding of a left hand advantage for the perception of nonsense shapes was cited by Rudel et al. as evidence that a right hemisphere advantage was found when "vision was excluded." But, while exploration was purely tactual, responses were made by selecting the correct forms from a group of forms presented visually. This response mode would seem to encourage visualization, and to involve cross-modal matching.

Second, the modality order effect in the current study was in the opposite direction to that predicted by the visualization theory. According to that theory, if right hemisphere participation were greater in one modality order, it should be the TV order, because subjects in that group had no prior visual exposure to aid in visualization during the tactual condition. Instead, right hemisphere participation was significantly greater for the VT order. While this modality order difference could be explained by a general learning effect or strategy change, the pattern of results for the specific typefaces suggests otherwise. The two simpler typefaces in the tactual condition were fairly common styles, but T7 was a unique, ultra-modern style (rated 9.1 on a 10-point scale of unfamiliarity), which would not be readily visualizable. The order effect was much larger for T7 than for the other typefaces (both in terms of group means and distribution of individual subjects), suggesting that the main reason for the effect was an increased ability to visualize the typefaces after seeing them in the visual condition. Thus, contrary to the visualization theory, increased visualization led to a greater right hemisphere participation.

One way to modify the visualization theory to explain these conflicting results is to take into account the stimuli and task used and the nature of the visualization involved. In the current study, Roman letters, even if unfamiliar in style and presented tactually first, required at least some visualization because they had to be matched to the stored visual images of essential letter elements in order to be identified. For instance, when T7 was presented tactually first, the visualization may have been relatively weak and based on specific salient features. This type of cross-modal matching may have been relatively left-hemisphere dependent. When T7 was presented tactually after being seen first, more wholistic, typically right hemisphere visualization may have occurred, thus resulting in a relative increase in right hemisphere participation.

In contrast to Roman letters, braille letters in the tactual learning studies did not necessarily have to be matched to stored visual images in order to be identified. When braille letters were taught visually first, however, any number of visualization strategies could have been used. Given the greater spatial resolving power in the visual modality, the braille dots might have been counted and localized much more specifically than in the tactual modality, thus encouraging a more analytical or possibly even verbal encoding. In that case, greater left hemisphere participation than in the purely tactual studies would be expected.

Finally, in contrast to both types of letters, visualization requirements did not affect hand differences for nonsense shape matching. A left hand (right hemisphere) advantage was found whether the palpated shapes were matched to visually presented comparison forms (Witelson, 1974, 1976) or another tactually presented form (Flanery & Balling, 1979). This lack of a visualization effect can be attributed in part to the nonlabelable character of the shapes, and the wholistic quality of the visualizations associated with them.

In summary, the greater involvement of visualization in the identification of Roman letters compared to braille letter learning might account in part for the difference in asymmetry patterns. However, the effects of visualization in these and related studies of hand asymmetry are more complex than previously hypothesized and need to be considered in interaction with the particular tasks and stimuli used and the character of the visualizations they evoke.

Stimulus appropriateness for the tactual modality. The typefaces and specific letters used in the current study and the typeface characteristics that were varied were selected on the basis of ratings and evidence from the visual modality. In contrast, braille was designed originally to facilitate reading by touch and so was based on characteristics that influenced the efficiency of tactual perception. This comparison suggests a fourth possible explanation for the lack of a tactual asymmetry in the current study. It could be that the more complex typefaces did not differ from plain print enough or on characteristics that would affect right hemisphere participation in tactual information processing. The stimuli may have been inappropriate on three levels: (1) the specific typefaces and letters chosen, (2) the characteristics that served as a basis for typeface selection, and (3) the nature of Roman alphabet letters in general.

First, the eight letters used were chosen according to their ratings for visual confusability and their past ability to elicit visual field asymmetries. Given that characteristics differ in saliency for vision and touch (Goodnow, 1969) and that letter difficulty ratings in the two modalities generally are only moderately correlated (Loomis & Apkarian-Stielau, 1976), modality differences in the relation between the letters as well as in their processing might be expected. In fact, the cross-modal correlations of letter difficulties for each of the three typefaces were low, and, for two typefaces, negative. Further, considering only the letters for which there was both a hand and visual field difference in accuracy of at least 5%, the majority showed opposite sensory field differences for the two modalities. These findings indicate that the letters probably do not vary along similar continuums for vision and touch, and that at least some of the letters are processed differently in each modality. Therefore, it is not unlikely that the use of different letters would have altered the pattern of hand asymmetry.

The eight typefaces used also were chosen according to ratings for visually presented stimuli. Following the same reasoning used to predict a modality difference in the relation between letters, it also might be expected that the distance between typefaces on the characteristics measured would differ for vision and touch. For instance, for a typeface to be rated 6 or 7 on a scale of tactual scriptlikeness might require simpler, bolder lines but more slant and curve than an equivalent rating for visual scriptlikeness. Therefore, if the typefaces used in the tactual condition had been chosen according to ratings given to tactually presented typefaces, a left hand advantage might have been found.

While this possibility always exists, there are at least two reasons to suggest that the effect of using tactually rated typefaces would have been limited. The first reason is that the three typefaces used in the tactual condition differed significantly in AT.

Given the inherent relationship between AT, difficulty (naming latency), and general complexity, at least some variation on the characteristics of interest must have been achieved for the tactual condition. The other reason is that since all typefaces were designed for visual presentation, many of them involve discriminations of fine lines and curlicues beyond the capabilities of the tactual modality. Therefore, it might not have been possible to find typefaces for which the variation in tactual ratings on the characteristics considered would have been greater.

The second level on which the stimuli might have been inappropriate pertains to the characteristics that were used to select them. The characteristics were those found by Bryden and Allard (1976) to be significantly correlated with visual field differences. There is no reason why those characteristics also should have been related to hemispheric differences for processing tactual information, especially in the case of "scriptlikeness." Visually, scriptlikeness is one of the major ways that reading material is differentiated. Cursive writing is a subject taught in school, and it is used nearly exclusively by most adults, who typically develop their own unique style. In contrast, cursive writing has no special significance for the tactual sense, apart from a possibly greater connection with the kinesthetic feedback from scanning letter outlines. Changing the characteristics on which the typefaces were varied might well have altered the pattern of hand differences. However, characteristics more meaningful for the tactual sense might be hard to find.

Finally, the third level of possible stimulus inappropriateness pertains to the nature of Roman alphabet letters in general. Possibly the fundamental nature of Roman letters is such that no variation in typeface could induce the right hemisphere to play a major role in the processing of letters perceived by touch. The perceptual abilities needed to differentiate the letters are not those at which the tactual modality is particularly adept. For instance, it might be difficult for the hand to pick up the small lines that differentiate a G from a C or a Q from an O, and to feel spaces contained within fairly small contours (such as with R and B). Increasing the irregularity of the letters (in terms of size, slant, etc) by varying the typeface would seem to increase the relative inappropriateness for the tactual modality. In contrast, braille letters, which did require a large degree of right hemisphere processing, always are contained within a constant framework of six dot positions, with spacing appropriate for the spatial resolving power of the tactual modality.

In summary, all four explanations mentioned--insensitivity of the method, insufficient memory demands, necessity of matching the letters to stored visual images, and inappropriateness of the typefaces for the tactual modality--could have contributed to the lack of asymmetry in the tactual condition. None of the explanations is without limitations, however, and it is unlikely that one of the factors alone would have prevented an asymmetry from occurring. It is possible to test the influence of most of the factors by altering the method accordingly. A dichhaptic presentation technique, shorter presentation time, and longer interval between presentation and response could be used, along with typefaces and letters selected on the basis of tactual criteria. In addition, the effects of matching to a visual image and of the fundamental nature of Roman alphabet letters could be tested by examining hand differences for learning the association of nonsense letter names with shapes consisting of Roman letter features.

Modality Differences in Processing

Although it may be questionable whether inferences about cognitive processing can be drawn from the absence of a significant hand difference for all grade by typeface by modality order combinations, some speculations do seem to be warranted about the striking modality difference in field asymmetries (reflected in the significant modality by typeface interaction). If the experiments suggested in the preceding subsection to test the effects of the four possible explanations for lack of tactile asymmetry all failed to reveal hand differences in any condition, speculations about the results of the current study would be much stronger. However, even if significant hand differences were found in some conditions, the fact that they were not found in the current study with method variables consistent across modalities suggests at least some degree of modality difference in processing. Method variables were roughly equalized across modalities in the current study partly by using many of the same variables in both conditions, such as typefaces varying in complexity, unilateral presentation, staircase procedure, identification response, and low memory demands (to avoid bias due to the supposed lower retention accuracy in the tactual modality). Part of the attempt to equalize the method across modalities also involved changing some variables according to the special qualities of the tactual modality, such as using larger letters and longer exploration times than in the visual condition to match the poorer spatial resolving power and slower information gathering tempo attributed to touch.

The direction of the modality difference for the simplest, block-printed typeface was in general agreement with the prediction. The significant RVF advantage (averaged across grades) was expected, given the significant RVF advantage found for most previous studies of letter identification in adults (e.g., Bryden, 1973) and a similar trend found for studies of asymmetry for verbal material in children (e.g., Marcel & Rajan, 1975). The non-significant hand difference was not out of line with previous studies, most of which also found no hand asymmetry for printlike letters. Witelson's (1974) suggestion that linguistic information presented tactually is first analyzed in a spatial code (right hemisphere processing) and then translated to a linguistic code explains the pattern of results very well. It can be added that the general reason for this modality difference in asymmetry is that the tactual modality is associated with more right hemisphere processing because of its peculiar nature, poorer spatial resolution, and so forth.

The problem with this interpretation of the processing of tactually perceived letters is its implication that when the demands on the spatial coding aspects of the task are increased, right hemisphere participation should increase (or a shift toward a left hand advantage should occur). In the current study, it is likely that the demand for the spatial or form analysis of the letters was increased by increasing typeface complexity, yet, contrary to the implication of the theory, no change in hand difference was found.

At least two elaborations of the theory to account for this finding seem possible. First, the stage of letter processing roughly attributed to the left hemisphere (that of translation into a linguistic code) might have an increased function with increasing letter complexity that coincides with the increase for spatial processing. A constant hand difference thus would be maintained. For instance, perhaps the hand cannot break down or "normalize" the more complex letters to the extent that is possible with the eye. In that case, translating into linguistic coding by matching the letters to stored visual images would be much more difficult than with the simpler letters. One problem with this suggestion is that the left hemisphere might not be able to analyze forms that could not be broken down further by the right.

A second possible elaboration of the theory is that the "spatial coding" of tactually perceived letters actually involves a greater need for both hemispheres acting in combination than does the spatial processing of visually perceived complex letters. It might be the case that the ratio of right to left hemisphere processing in the visual analysis of complex typefaces cannot be compared to the ratio in the tactual analysis of letters of any typeface. The visual system is finely tuned for letter analysis. The right hemisphere can readily pick out regularities across a wide variety of slants and extra details and then break down the letters into their simple forms. In contrast, perhaps in the tactual system, the "spatial coding" of letters involves more of a building up process. This would entail use of the probably left-hemisphere dominated image of the letters, possibly verbal instruction, and a serial integration of points, as well as right hemisphere skills. The processes used, then, would be very different from those used in the visual modality, which might explain the tendency toward negative cross-modal correlations of LCs.

At a minimum therefore, if any inferences can be drawn regarding modality differences in Roman letter processing, the tactual modality does not require greater right hemisphere participation, and, in fact, might require greater cooperation of the hemispheres than the visual modality.

Stimulus Characteristics

The principal hypothesis about stimulus characteristics was that LVF and left hand scores (right hemisphere participation) would increase relative to RVF and right hand scores (left hemisphere participation) as overall typeface complexity was increased. A secondary hypothesis was that the particular typeface characteristics of difficulty, scriptlikeness, and confusability all would be related to field differences, and that scriptlikeness would be the strongest predictor.

The principal hypothesis was not supported when the letters were presented tactually--no significant effect of typeface on hand asymmetry was found. Possible reasons for this lack of a typeface effect were discussed in the preceding section in conjunction with reasons for the failure to find a significant hand asymmetry in general. Since the lack of typeface and hand effects in the tactual condition precluded any more detailed analysis of the effects of particular typeface characteristics, the results for that condition will not be discussed further.

For the visual condition, the principal hypothesis was supported, as indicated by the highly significant typeface effects on visual LCs. The general pattern of visual field asymmetries across typeface for all grades combined closely followed the predictions, which were based in large part on Bryden and Allard's (1976) findings. The pattern found was a significant RVF advantage for the simplest typeface, no visual field differences for the medium complex typefaces, and a significant LVF advantage for two of the most complex typefaces. Also, as predicted, this general increase in right hemisphere participation with increasing typeface complexity was found for each grade separately. However, the increase was more irregular for the fourth- and ninth-graders than for the college students. Further, this irregularity corresponded with a significant grade difference in overall level of right hemisphere participation which was in the direction opposite to that predicted. The fourth- and ninth-graders showed significantly less right hemisphere participation than the college students, particularly for the medium complex typefaces and the typeface with the highest complexity rating.

The secondary hypothesis, based on Bryden and Allard's findings for adults, was tested in the current study by regression analyses and examination of the pattern of correlations between visual LCs and specific typeface characteristics for each grade separately. The hypothesis was supported only for the college students. Their visual LCs were significantly predicted by a combination of the specific typeface characteristics, of which scriptlikeness was the strongest predictor. For the younger grades, tests of the prediction equations did not reach significance, and difficulty was a more important predictor than scriptlikeness.

The discussion of these results will be centered around two main questions. First, what does the typeface effect imply about the relative participation of the two hemispheres in the letter identification process in adults? Particularly since the results for college students were in nearly complete support of Bryden and Allard's findings, what (if any) additional conclusions about letter processing can be drawn from the current study? And, second, what are the implications of the grade differences in general level of right hemisphere participation and in relative importance of the specific typeface characteristics with respect to: (1) the letter identification process, and (2) the development of modes of processing in the two hemispheres and strategies for their use.

Implications for Letter Processing in Adults

Possible models for participation of the two hemispheres. Bryden and Allard's results allow for at least two slightly different models of the roles of the two hemispheres in the letter identification process. The first possibility is that a predisposition exists toward processing letters as linguistic elements, thereby primarily activating the left hemisphere. The right hemisphere would be expected to take control over the processing only when the pattern recognition capability of the left hemisphere was exceeded. According to Jonides (1979, p. 425), the overall low accuracy level in Bryden and Allard's task, especially for the typefaces that yielded a LVF advantage, suggests that the visual discrimination involved was difficult enough to warrant the intrusion of a right hemisphere feature extraction mechanism. Since an asymmetry in favor of the RVF was found for the majority of typefaces, it can be assumed that the bias toward the left hemisphere was operating except when the most difficult typefaces were presented.

Several studies of both normal and brain-damaged adults provide support for the premise that the letter recognition task must require perceptual abilities beyond the capability of the left hemisphere in order for the right hemisphere to participate. In fact, most demonstrations of a LVF (right hemisphere) advantage for letter identification or classification have involved tasks for which the perceptual demands have been increased in various ways.

First, two studies found that right brain-damaged patients were imparied relative to controls and to left brain-damaged patients on tasks requiring the recognition of letters presented in perceptually complicated forms. Warrington and James (1967) had their patients identify (or show to have recognized) letters that were 30% or 70% filled in. Patients with right parietal damage were significantly worse than controls and all other brain-damaged groups. Faglioni et al. (1969) used four letter recognition tests in which patients had to match a test letter to the corresponding one(s) among ten multiple choice letters presented in a different graphic form (in italics or lower case). For the first two tests, considered perceptually easy, the test letters were in a regular form. For the third test, the test letters were incomplete, and for the fourth test, they were partly hidden (crossed-out) by nonsense lines. Right brain-damaged patients with visual field defects were significantly impaired relative to all other groups on the last two tests, considered to be perceptually difficult. This difference was eliminated when scores on two spatial-perceptual tests were used as covariates. These results suggest that right hemisphere participation in letter recognition is determined by whether the letters are perceptualy complicated enough for right hemisphere spatial-perceptual processing abilities to become critical.

Second, two studies with college students found a LVF (right hemisphere) advantage for letter processing when visual masks were added to increase the complexity of the visual discrimination involved.

To a task requiring the identification of easily-perceived single lateralized letters, Hellige and Webster (1979) added a visual pattern mask presented at varying intervals before and after the letter. Recognition accuracy was reduced at forward masking intervals less than about 40 msecs. and backward masking intervals less than 80 msecs. For forward masking and short backward masking intervals, at which the letter and mask most likely were treated by the visual processing system as having been simultaneous, a LVF (right hemisphere) advantage for letter identification was found. For longer backward masking intervals, at which ongoing processing was disturbed although the letter and mask most likely were regarded as separate stimuli, no field asymmetry was found. An implication of these results is that the right hemisphere contribution to letter recognition depends on increasing the difficulty of the initial extraction of relevant visual information.

A similar enhancement of right hemisphere contribution with the addition of a mask was found by Polich (1978) using very different experimental conditions. As opposed to letter identification, Polich used a classification task which required the subjects to push one of four response buttons corresponding to the four possible stimulus letters. In the "masking" condition, outlined squares were presented on the left and right borders of the letter, but were not spatially overlapping. A LVF (right hemisphere) superiority in speed and accuracy of classification was found for letters that were masked. No field difference was found in the unmasked condition. Thus, these results again show that perceptual complexity triggers reliance on right hemisphere modes for processing letters.

Third, Jonides (1979) demonstrated that the perceptual complexity involved in the letter processing task, and hence right hemisphere contribution, could be manipulated simply by varying the physical similarity of the letters to be distinguished. He found a RVF (left hemisphere) advantage in reaction time for the EF vs. CG classification, but a LVF (right hemisphere) advantage for the perceptually more difficult CE vs. FG classification. These results seem to indicate that right hemisphere participation depends not only on the difficulty of extracting the relevant information, but on how salient the information is relative to other response alternatives stored in memory.

Finally, in an attempt to bias letter processing toward the right hemisphere, two studies employing Posner's same-different letter matching paradigm with lateralized stimuli increased the difficulty of the lateralized letter pair. Hellige (1976) increased the perceptual difficulty of the task by placing a grid of dark lines on the viewing screen, and Umiltà, Sava, and Salmaso (1980) used scriptlike letters. The expectation in both cases was that when the two letters had the same name but were in different cases, the typically found RVF advantage in RT for same judgments would be reduced, or even changed to a LVF advantage. With the overlapping grid, Hellige (1976) found a significant LVF advantage in accuracy, but not in RT. With the scriptlike letters (Umiltà et al., 1980), the RVF advantage actually increased compared to the identical condition with printlike letters. One suggestion of these findings is that right hemisphere involvement depends more on the difficulty of perceiving the information than on the scriptlike character of the letter.

The second possible model of right hemisphere participation in letter recognition differs from the first in that it assumes the processing of all or most letters consists of a combination of right and left hemisphere modes. It is not clear exactly what parts of the letter recognition process are the special domains of each hemisphere. According to general theories (e.g., Smith & Spoehr, 1974) letter perception can be thought of as containing two main stages--initial extraction of the features of the input letter and interpretation. The interpretation stage can be broken down into at least three separate operations involving: (1) matching features of the input to stored representations of letters, (2) deciding on the final categorization of the input, and (3) translating the letter to an acoustic code. While the right hemisphere is likely to be associated with feature extraction and the left hemisphere with acoustic coding, the process of finding a stored visual representation that best matches the perceived features of the input might be associated with either hemisphere. If, as would be appropriate with non-printlike letters, a "fuzzy logical model of letter identification" (Oden, 1979) was operating, then the <u>degree</u> to which each feature was present in the input also would be coded. In this case, the subtle perceptual distinctions of which the right hemisphere is capable would be especially important in finding a match for the input.

For this second model of right hemisphere participation, the relative contribution of the two hemispheres (reflected in visual field asymmetry) depends on which part of the recognition process is most crucial or limiting. One way of increasing the contribution of the right hemisphere would be to increase the difficulty of extracting the relevant visual features, as was demonstrated in several studies discussed in relation to the first model. However, it also would be possible to increase the right hemisphere contribution in other ways, such as by increasing certain demands placed on the operations of matching the perceived features to stored representations, and categorizing them. For instance, the features of a handwritten letter might be easy to perceive but difficult to classify, because of their inexactness and irregularity. Or, as might be true of Jonides' findings, if there was a high probability that the input letter would fall into one of two physically similar categories, extra care would be needed at the categorization stage. Then either a greater emphasis would be placed on those operations that the right hemisphere already was responsible for, or the right hemisphere would begin dominating those operations.

While Bryden and Allard's results could be interpreted to support either of the two models of right hemisphere participation, the main ways in which those results were extended in the current study seem to favor the second model.

Extensions of Bryden and Allard's findings. First, Bryden and Allard's results were extended with respect to the accuracy level at which the typefaces were presented. The generally low accuracy (about 35% correct) and the strong negative correlation between average typeface accuracy and right hemisphere participation found by Bryden and Allard invite explanations of the LVF advantage for certain typefaces in terms of increased perceptual difficulty. In other words, the letter outline might have been so faint, or the shadow lines so confusing, that the effects could have been similar to those for masked or incomplete letters. The correlation between accuracy and visual field asymmetry was especially evident for Palace Script, the typeface Bryden and Allard's subjects rated as most scriptlike. When this typeface was presented in alternation with other typefaces, it showed by far the strongest LVF advantage, but also the lowest accuracy (about 10%). When presented alone at a much longer duration, accuracy was increased slightly to 33% correct, and the LVF advantage was no longer significant.

In the current study, accuracy for all typefaces except T3 was about 50% correct. The fact that a typeface effect on visual field asymmetry was found even though a constant, moderate level of accuracy was maintained seems to contradict the premise of the first model that the right hemisphere intrudes on preferred left hemisphere processing only when the difficulty of the pattern recognition required exceeds the left's capacity. As Bryden and Allard found, the strongest LVF advantage was found for the most scriptlike typeface, but the association in this case was less readily explained by low accuracy or increased perceptual difficulty. In addition, even though accuracy was higher than in Bryden and Allard's study, the tendency toward LVF advantage was more wide-spread in the current study. For instance, Bryden and Allard found no field asymmetry for Old English, while the current study found a nearly significant LVF advantage for that typeface. Although the difference could be caused partly by the way in which the typefaces were selected (complexity was a factor in the current study), it also indicates that the balance of processing for a given typeface is flexible, as opposed to requiring right hemisphere processing beyond a certain difficulty level.

Second, Bryden and Allard's results were extended with respect to the correlations between specific typeface characteristics. In Bryden and Allard's study, the correlation (Pearson r) of scriptlikeness with laterality indices was at least slightly higher than for the other characteristics, and "multiple correlation procedures indicated that little was added to the predictability of laterality scores by supplementing the script-to-print measure" (p. 196). However, given the high correlations between characteristics, and the fact that all characteristics except familiarity were significantly correlated with laterality indices, no justifiable conclusions could be drawn regarding the superiority of scriptlikeness as a predictor.

In the current study, the typefaces were chosen so that the correlations between characteristics would be as low as possible. Therefore, a firmer conclusion can be drawn about the importance of scriptlikeness from the findings that: (1) scriptlikeness accounted for a large percent of the variance in average LCs regardless of the order in which it was entered into the regression analysis, and (2) scriptlikeness and confusability were significantly correlated with average LCs, while difficulty was not (provided T3 was included). The conclusion that scriptlikeness was a better predictor of increased right hemisphere contribution than difficulty tends to support the second model's characterization of letter recognition as a delicate balance of the processing of both hemispheres, as opposed to an intrusion of right hemisphere processing when difficulty becomes severe. Possibly some type of letter processing "regulator" adjusts the degree of right hemishere analysis involved in certain operations, such as feature matching or defining perceived feature "goodness of fit" to idealized feature. In general, it makes sense that scriptlikeness should serve as an important cue for this "regulator" to shift toward more right hemisphere processing, since scriptlike letters typically are inexact and flourished, and therefore require a more pattern-oriented approach. One possible inconsistency in this association of scriptlikeness with right hemisphere processing is that if handwriting is mainly controlled by the left hemisphere (for nearly all right-handers), it might be expected that the perception of cursive writing also should be left-hemisphere dominated. The explanation for this inconsistency is not clear, although a comparison of visual field asymmetries for one's own handwriting as opposed to general script-like letters might be relevant.

The third extension of Bryden and Allard's results was the analysis of whether an attentional set was formulated over the course of the experiment. The fact that opposite field advantages were found for typefaces presented in an alternating fashion suggests that no overall set was formed in Bryden and Allard's study, and that the balance of processing could shift fairly readily. However, according to Jonides, the right hemisphere could have been intruding on a left hemisphere set when accuracy became very low. In the current study, although the formation of a set for a given typeface was facilitated by grouping the trials for each typeface, analysis of the change in asymmetry over the course of the experiment indicated that neither hemisphere was favored. Rather, the dominant asymmetry for each typeface was strengthened in the second half of the experiment. This pattern of results seems to support the second model in that it could be assumed that some "regulator" was able to readily adjust the balance of right and left hemisphere processing. Further, this regulator became progressively more adept at determining the most efficient processing to emphasize for a given typeface.

Implications for Letter Processing in Children

The lesser degree of right hemisphere participation shown for children compared to college students seems to be more easily interpretable in terms of the second model than the first. In fact, the first model tends to predict the opposite finding based on the following two points: (1) according to the model, the right hemisphere contributes significantly to letter processing only when the perceptual discriminations required exceed the left hemisphere's capacity, and

(2) if anything, the perceptual discriminations involved in processing non-printlike typefaces should be more difficult for children than for adults, thus making the intrusion of right hemisphere processing more likely for children.

According to the second model, the smaller contribution of the right hemisphere for children can be explained in at least two ways, both having to do with the relative efficiency of left and right hemisphere modes. First, it may be that the spatial, pattern recognition abilities for which the right hemisphere typically is specialized are not fully mature for fourth-grade (9 yrs. of age), and undergo a maturational decline at the ninth-grade (14-year-old) level. In that case, emphasis on a less than fully efficient right hemisphere mode, particularly for medium complex typefaces requiring relatively little pattern analysis, would not facilitate the letter recognition process for the younger grades.

Evidence to support the premise of an increasing maturation of right hemisphere perceptual abilities until at least age 10 is provided by studies of face recognition and braille letter learning. Leehey (1976) found that the usual adult pattern of a LVF (right hemisphere) advantage for the perception of unfamiliar, upright faces did not appear until age 10, and subsequently declined at about age 14 for boys. These findings coincide with evidence that overall ability to encode upright faces improves until about age 10, with a dip in performance during a period in adolescence, and then further improvement until college age (e.g., Carey, Diamond, & Woods, 1980).

Similarly, Rudel et al. (1977) found that a left hand (right hemisphere) advantage for discriminating braille patterns did not appear until about age 11 in boys, and then became weaker and non-significant for 13- and 14-year-olds.

While the weight of the evidence supports the idea of a maturation of specific right hemisphere skills peaking at about age 10, an interpretation in terms of changes in preferred strategies with age must also be considered. For instance, the reduced left field advantage found at about age 14 could be interpreted as a tendency to rely on verbal, analytic codes at that age, rather than as a maturational decline in ability. Further, an interaction of those two factors is highly likely.

Therefore, if this first explanation of the grade difference is accepted, the results of the current study could be summarized as follows: (1) When the demand for right hemisphere perceptual discrimination skills was marginal (i.e., the typefaces were only moderately complex), the younger grades either did not have the subtle perceptual skills available to make the use of that mode an effective strategy if another could be used, and/or they preferred another strategy; and (2) When the demand for perceptual discrimination skills was great (for T6 and T7), emphasis on right hemisphere processing probably aided letter recognition for all grades, even though right hemisphere capacity might have been weaker for the younger grades compared to college students. Thus all grades showed about equal LVF advantage for T6 and T7.

A second way in which the smaller contribution of the right hemisphere for children can be explained is with respect to a change across grades in verbal, left hemisphere skills. Possibly the linguistic, phonetic analysis skills of the younger grades (especially fourth-graders) were less efficient than those of the college students. This would cause left hemisphere processing to be a more limiting factor in letter recognition for the younger grades, thereby resulting in a greater tendency toward RVF advantage for those grades. To explain the LVF advantage found for the children for T6 and T7, it could be assumed that left hemisphere processing was the most limiting factor for them until the demand for right hemisphere pattern discrimination skills became relatively great.

While no other developmental study involving identification of unilaterally presented verbal stimuli has found a similar decrease in RVF advantage with age, one study involving letter matching did find tentative results consistent with the current study. In this study (Witelson, 1977a) pairs of vertically arranged uppercase letters were unilaterally presented to boys ranging from 6 to 14 years of age, and the response required was "same" or "different." This task represents a lateralized paradigm of the "physical match" condition of Posner's reaction time studies and is one for which at least a moderate LVF advantage in RT has been found for adults (e.g., Cohen, 1972). Contrary to past findings for adults, a significant RVF advantage in accuracy was found for the youngest subgroup (6- to 7-year-olds), and there was a tendency toward RVF advantage until age 10.

These results, as they pertain to the current study, suggest that letters are highly associated with left hemisphere, linguistic processing for children, either because the relative immaturity of their linguistic skills results in a greater concentration on that type of processing, or because it is a preferred strategy.

Another study (Reitsma, 1978) that could be interpreted to support the explanation for the grade difference in the current study in terms of changing linguistic skills with age also used Posner's same-different letter matching task. First-, second-, and sixth-graders were presented in central vision with pairs of letters that were the same or different in terms of name and/or physical appearance (case or typeface). It was hypothesized that since matches on the basis of name similarity would involve a deeper level of analysis and encoding than matches made purely on the basis of physical feature similarity, RT for name matches would be longer than for physical matches, but the difference would decrease with age. This hypothesis was confirmed for each grade interval, and was interpreted on one level to indicate an increase with age in the "efficiency or automaticity of encoding of visual letter information."

While the encoding that occurs between name and physical matches cannot be attributed solely to left hemisphere processing, the left hemisphere may play a large part in that encoding. Therefore, in terms of the current study, possibly the left hemisphere contribution to the letter recognition process becomes increasingly "automatized" beyond the fourth-grade level, thereby permitting an increasing integration with efficient right hemisphere analysis of perceptual details.[27] Again, an alternative or complementary explanation to the change in linguistic skill with age is a change in favored processing.

In general, the age differences in right hemisphere participation found in the current study are likely to be associated with both explanations described. That is, letter processing in children probably is influenced by the maturing beyond age 9 of both left and right hemisphere skills and by changes in preferred strategy complementary to this cognitive development. However, the age differences found in the current study seem to be inconsistent with the main explanation for age trends expressed by previous developmental studies of laterality for visually-presented linguistic stimuli--that of increasing specialization of the left hemisphere for verbal material. Contrary to the idea that sequential (left hemisphere) processing of verbal material becomes more accentuated with age (Carmon et al., 1976), or that lateralization for the printed word may increase through adolescence (Tomlinson-Keasey et al., 1978), the current study suggests that increasing proficiency with written language is correlated with an increasing tendency to integrate right hemisphere perceptual skills with phonetic coding in the left hemisphere (at least for college students compared to fourth-graders). This suggestion receives added weight because the effects of two factors often confounded with age differences in the past--difficulty level and post-exposural scanning tendencies--were minimized (see Witelson, 1977b, for review). The two opposing developmental trends need to be tested further using tasks in which a constant accuracy level across grades can be maintained and in which the stimuli are either single letters or vertically arranged strings.

Finally, the finding of a grade difference in the importance of scriptlikeness as a predictor of visual field asymmetry fits easily into the second model of right hemisphere participation in letter processing. Before being considered in terms of the model, however, it should be noted that the typefaces were rated on all the specific characteristics only by college students. It could be that the children would rate the typefaces very differently, and that these ratings would be significantly correlated with their laterality coefficients. If so, perhaps there is a "regulator" of the balance of hemispheric processing that tips the balance at the same relative level of scriptlikeness (or other characteristic) at each grade, although criteria for judging the levels vary across grade. If not, possibly the cues that signal the most efficient balance of processing for a given typeface are learned with age and increasing experience with different lettering styles. Thus, fourth- and ninth-graders might not have learned to use scriptlikeness as a cue that greater right hemisphere participation would lead to more efficient letter processing. By college age, though, the hypothesized "regulator" would have become more flexible and responsive so that it could readily alter the degree of participation of the two hemispheres, both of which (according to the second model) contribute to letter processing.

ENDNOTES

[1]Letter symmetry was found to affect accuracy of recognition when letters were presented in groups in both the visual (Fudin, Garcia, & Solomon, 1975) and tactile (Craig, 1976) systems. However, with visual presentation of single letters, no difference in accuracy for symmetrical and asymmetrical letters was found (Bryden, 1968). Thus, it will be inferred in this dissertation that lateral symmetry of letters presented alone either visually or tactually is not a crucial dimension to consider.

[2]Sex differences in asymmetry were found in two of the eight tactual presentation studies. Witelson (1977a) found no hand asymmetry for girls, compared to a marginal right hand advantage for boys. Cioffi and Kandel (1979) found that girls showed a right hand advantage for consonant bigrams, while boys showed a left hand advantage. Thus, in general, since girls showed a smaller right hand advantage in one study and a greater right hand advantage in the other, the overall conclusions of the summary would not be changed by adding the results for girls. The results for boys only will be emphasized in this section to simplify the summary and because the subjects in this dissertation will be male.

[3]In an earlier experiment (Manning, Goble, Markman, & LaBreche, 1976, cited by LaBreche et al.), it was shown that line drawings of manually represented English letters were better recognized in the LVF when congenitally deaf subjects responded by fingerspelling. In addition, a non-significant tendency toward better LVF recognition of pictures of American Sign Language (ASL) words was found for deaf subjects using a matching procedure (Manning, Goble, Markman, & LaBreche, 1977). Other studies with deaf subjects showed no visual field asymmetry for ASL words or manual letters (McKeever, Hoemann, Florian, & VanDeventer, 1976; Phippard, 1977; Manning et al., 1976, with a written response). With hearing subjects, a significant LVF advantage for the recognition of ASL words and manual letters was found (McKeever et al., 1976).

[4]From this discussion of the importance of the connection between letters for determining the "handwriting" quality, it might be concluded that words or syllables would be more appropriate stimuli than letters. However, it is proposed that letters be used in this dissertation mainly to facilitate comparison with Bryden and Allard's results and to minimize possible complications resulting from trace scanning tendencies.

[5]Support for this division of the letters was provided by the inter-letter confusion matrix (Condition I) reported by Townsend (1971). This matrix contained the probabilities for all possible pairs of 26 stimulus letters and 26 response letters, using all capital letters in a simple, nonserified typeface. The average confusion probabilities for within group ordered pairs of letters (CGOQ = .083; BFRP = .044) were higher than the average confusion probability for between group pairs (.016).

[6]Of responses eliminated because of equipment problems, the majority occurred when a response failed to trigger the VAR or when a rototray was stuck.

[7]It was decided to use male and right-handed subjects because a greater hemisphere specialization for verbal functions generally has been found for these groups as compared to females (e.g., Harshman & Remington, 1975) and left-handers (e.g., Goodlass & Quadfasel, 1954). Thus, male right-handers might be expected to show more clear-cut visual field and hand asymmetries for letter recognition.

[8]Two fourth-graders and one ninth-grader attended school in a near-by city. Although they tended to need more rest periods and have higher thresholds, the pattern of their laterality scores across typeface was generally not different from the sample as a whole.

[9]As defined by Annett (1970b), the five other primary tasks were throwing, hammering, using a racquet, striking a match, and using a toothbrush. These tasks (along with writing) were the most highly associated with all handedness items, and therefore, were taken as comprising a main handedness factor. Only two ninth-graders and four college students performed any primary tasks with the left hand.

[10]To facilitate systematic pairing of numbers with the eight letters, only eight of the nine possible single digit numbers were used. Seven was chosen as the number to be eliminated because it is two syllables and might take slightly longer to report than the others. If so, and if subjects were reporting the stimuli from a rapidly fading visual trace, more errors might occur for letters paired with seven.

[11]Even though the size of the letters on the slides was equal for the lateralized and central letters, the visual angles they projected were measured differently. Since the computation of the tangent requires a right angle, the visual angle for the lateralized letters was estimated by computing the following: (1) size of the angle projected by the distance between the center point and the outer edge of the letter, (2) size of the angle projected by the distance between the center point and the inner edge of the letter, and (3) the difference between 1 and 2, which was the visual angle of the letter.

[12]This starting point was determined by presenting the practice typeface first at 150 msecs. and then reducing the time by one step if at least two letters were identified correctly in each visual field. The shortest time at which this criterion was met was taken as the starting presentation time for the test typefaces.

[13]These steps were selected because, in pilot testing, they tended to be the ones most efficient for establishing a threshold.

[14]Also excluded from the measure were points presented because of experimenter error. In these cases, points were eliminated until the staircase returned to the level at which the error was made. The number of points excluded for this reason were as follows:

	Condition	
Grade	Visual	Tactual
4th	1	0
9th	0	1
Coll	4	2

[15]There were several reasons for computing the correlations this way. First, the correlations were based on runs and not individual trials because there was a greater interdependency among individual trials than among runs. Second, runs were paired because medians tended to be higher for decreasing runs than for increasing runs. Third, the first and last pairs were chosen to provide the most conservative measure of a change in threshold across trials.

[16]Modality orders were shown separately for the tactual condition because this factor was found to have a significant effect on hand differences, as will be described in the Results section.

[17]While the general level of naming times cannot be compared to other studies because of differences in stimuli and measuring apparatus, the times are within a range of what would be expected given Bryden and Allard's naming times for lateralized letters. Consistent with the expectation that centrally-presented letters should be named faster than lateralized ones, the mean naming latency in the current study was roughly 200 msecs. faster than the mean latency of 875 msecs. found by Bryden and Allard.

[18]The Chartpak names for the typefaces were as follows: T1 - Standard Medium, T2 - Book Jacket Italic, T3 - Fat Shadow, T4 - Hogarth, T5 - Burgundy Right, T6 - Murray Hill Bold, T7 - Shotgun, and T8 - Old English.

[19]In this analysis, typeface was not considered as a random variable. However, if it is assumed that the sample of typefaces represents a whole population of typefaces with infinite variations of complexity, it could be argued that treatment as a random variable was called for. When considered as a random variable in an otherwise identical analysis, the F-ratio for the typeface effect was the same.

[20]Since this ANOVA did not meet one of the assumptions for repeated measures analysis (that of equal subgroup variances), various transformations were used to attempt to satisfy the assumptions. When a square root transformation was applied, and an identical analysis performed, the grade and typeface effects still were significant, while none of the interactions were (see Appendix A). Therefore, the pattern of results found for the initial analysis can be accepted with more assurance.

[21]The small standard deviation for T3 for fourth-graders, as well as the threshold approaching 180 msecs., are indications of the floor effect for that condition, already reflected in stability estimates, accuracy, and standard deviations for LCs.

[22]The results of these tests on the visual AT scores should be interpreted with caution because the assumptions for repeated measures analysis were not met. Analyses on transformed scores (using either square root x or log x transformations) also failed to meet the assumptions.

[23]An initial ANOVA (3 x 2 x 3) was performed including the modality order variable. Since the main effect of order ($F = .11$, d.f. = 1,42, NS) and all interactions with order were non-significant, that variable was eliminated from the analysis to facilitate multiple comparison procedures.

As shown in Appendix D, the assumptions for repeated measures analysis were not met. A 3 x 3 x 3 ANOVA on the scores obtained by applying a log x transformation did meet the assumptions. A significant effect of typeface and a typeface by grade interaction were found, but the grade effect only approached significance ($F = 1.56$, d.f. = 2.42, $p < .2$). Since the grade effect was not of theoretical importance, no further analysis was done. In general, though, all the tests on these tactual AT scores should be interpreted with caution.

[24]Correlations of LCs and the two Part I characteristics not used in typeface selection were as follows for each grade (with all typefaces included):

Grade	Characteristic	
	Familiarity	Superfluity
4th	-.37	-.41
9th	.26	.14
Coll	-.60	-.63

Since at each grade at least two of the correlations between the designated predictors and LCs were higher than these correlations, it was judged that no significant amount of additional variance would be explained by adding these variables to the prediction equations.

[25]For this section on letter order and the next section on specific letters, percent correct figures will include all trials, not just those presented after the cut-off (end of third run).

[26]This relative advantage for the circular letters in the tactual modality can be related to the results of Nilsson, Glencross, and Geffen (1980). They presented dichhaptically to adult male right-handers five random shapes and analyzed performance separately for each shape. Overall percent correct was greatest for the two shapes with curved features.

[27]It is conceivable that the automaticity of letter processing increases even beyond ninth-grade level. For college students, Regan (1981) found that the identification of English letters was capacity-free (i.e., it was automatic in the sense that it did not require the limited space and time of a central processor). In addition, extensive practice was a necessary condition for this capacity-free processing. Possibly ninth-graders have not reached this stage of capacity-free letter processing. Letters might be "super over-learned" stimuli for college students, but only "over-learned" for ninth-graders.

APPENDICES

APPENDIX A

SUMMARY OF ANOVA ON TRANSFORMED VISUAL LCs

TABLE A.1.--Summary of analysis of variance on visual laterality coefficients obtained by applying the transformation $\sqrt{|LC| + .5} \times (\pm 1)$, where the sign of the multiplier is the same as that of the original LC

Source	D.F.	MS	F
Between Subjects			
Mean (Visual field)	1	.000	.00
Grade	2	3.820	3.87*
Order	1	.006	.01
Grade x Order	2	.306	.31
Subjects within groups	42	.986	
Within Subjects			
Typeface	7	4.230	6.80**
Grade x Typeface	14	.718	1.15
Order x Typeface	7	.736	1.18
Grade x Order x Typeface	14	.221	.36
T x subjects with groups	294	.622	

*$p < .05$.

**$p < .01$

$F_{max} = 2.51$, d.f. = 7,47, NS

Test of no association in the correlation matrix:

$X^2 = 21.75$, d.f. = 28, NS

APPENDIX B

SUMMARY OF ANOVA ON VISUAL LCs WITH MODALITY ORDERS COMBINED

TABLE B-1.--Summary of analysis of variance on visual laterality coefficients without the modality order variable, and Newman-Keuls multiple comparison tests for the main effects of Grade and Typeface

Source	D.F.	MS	F
Between Subjects			
Mean (Visual field)	1	.013	.04
Grade (A)	2	1.902	5.33**
Subjects within groups	45	.357	
Within Subjects			
Typeface (B)	7	1.234	6.23**
Grade x Typeface	14	.239	1.21
T x S within groups	315	.198	

Differences between average LCs for levels of Factors A and B:

Typeface

	T1	T5	T4	T2	T8	T3	T7	T6	r
T1		.14	.15	.21	.21	.24	.46*	.47*	8
T5			.01	.07	.07	.10	.32*	.33*	7
T4				.06	.06	.08	.31*	.32*	6
T2					.00	.03	.26*	.26*	5
T8						.03	.25*	.26*	4
T3							.23*	.23*	3
T7								.00	2

*exceeded critical value for $p < .05$, d.f. = r,315 ($S_{\bar{B}} = .064$)

	9th	4th	Coll	r
9th		.09	.24*	3
4th			.16*	2

*exceeded critical value for $p < .05$, d.f. = r,45 ($S_{\bar{A}} = .053$)

APPENDIX C

SUMMARY OF ANOVA ON VISUAL CTs

TABLE C.1.--Summary of analysis of varince on visual combined thresholds, and Newman-Keuls multiple comparison tests for the main effects of Grade and Typeface

Source	D.F.	MS	F
Between Subjects			
Mean	1		5.44**
Grade (A)	2	27843.1	
Subjects within groups	45	5116.8	
Within Subjects			
Typeface (B)	7	80500.4	119.15***
Grade x Typeface	14	909.3	1.35
T x S within groups	315	675.6	

F_{max} = 2.22, d.f. = 7,47, NS

Test of no association in the correlation matrix:

X^2 = 105.8, d.f. = 28, p < .001

Differences between average CTs for level of Factors A and B (arranged in order from highest to lowest av. CT):

Typeface

	T1	T4	T5	T7	T2	T6	T8	T3	r
T1		20*	34*	36*	58*	77*	77*	131*	8
T4			14*	15*	37*	56*	57*	110*	7
T5				1	23*	42*	43*	96*	6
T7					22*	41*	41*	95*	5
T2						19*	20*	73*	4
T6							0	54*	3
T8								54*	2

*exceeded critical value for p < .05, d.f. = r,315 ($S_{\bar{B}}$ = 3.75)

Grade

	4th	9th	Coll	r
4th		24*	27*	3
9th			2.5	2

*exceeded critical value for p < .05. d.f. = r,45, $S_{\bar{A}}$ = 6.32

APPENDIX D

SUMMARY OF ANOVA ON TACTUAL CTs

TABLE D.1.--Summary of analysis of variance on tactual combined thresholds, Newman-Keuls multiple comparison tests, and tests for simple main effects of Grade for each typeface

Source	D.F.	MS	F
Between Subjects			
Mean	1		
Grade (A)	2	103.50	4.53*
Subjects within groups	45	22.85	
Within Subjects			
Typeface (B)	2	909.06	132.53***
Grade x Typeface	4	36.35	5.30**
T x S within groups	90	6.86	

F_{max} = 1.47, d.f. = 2,47, NS

Test of no association in the correlation matrix:

X^2 = 34.08, d.f. - 3, p < .0001

Differences between average CTs for levels of Factors A and B (arranged in order from highest to lowest average CT):

Typeface

	T1	T7	T2	r
T1		6.5†	8.2†	3
T7			1.7†	2

	4th	9th	Coll	r
4th		2.5††	2.7††	3
9th			.2	2

Simple Main Effects of Grade

Typeface 1: F = -0.43, d.f. = 2,97, NS

2: F = 3.65, d.f. = 2,97, *p < .05

7: F = 18.36, d.f. = 2,97, *p < .05

*p < .05,
**p < .01
***p < .001

† exceeded critical value for p < .05, d.f. = r,90, ($S_{\bar{B}}$ = .38)
†† exceeded critical value for p < .05, d.f. - r,45, ($S_{\bar{A}}$ = .69)

APPENDIX E

SUMMARY OF F-RATIOS FOR TYPEFACE POSITION AND LETTER ORDER

TABLE E.1.--Tabulation of F-ratios from separate ANOVAs for each typeface in each modality condition to test the effects of: (1) Typeface position, and (2) Letter order, and their interactions with grade. (Only the F-ratios greater than 1.0 are listed.)

	Modality Condition	Sources of Variance	D.F. For F-Ratio	F							
				T1	T2	T3	T4	T5	T6	T7	T8
(1) Typeface Position	Visual	Grade	2,42		1.79		2.05	4.57*			4.53*
		Position	1,42		3.85		2.98		2.10	2.78	6.97*
		Grade x Pos	2,42								
	Tactual	Grade	2,27							1.32	
		Position	2,27							2.40	
		Grade x Pos	4,27		1.22						
(2) Letter Order	Visual	Grade	2,42		1.81		2.10	5.66*			4.19*
		Order	1,42		2.96			6.28*	2.34	2.17	3.36
		Grade x Ord	2,42				2.18	2.12			
	Tactual	Grade	2,42							1.98	
		Order	1,42							1.38	
		Grade x Ord	2,42		1.44						

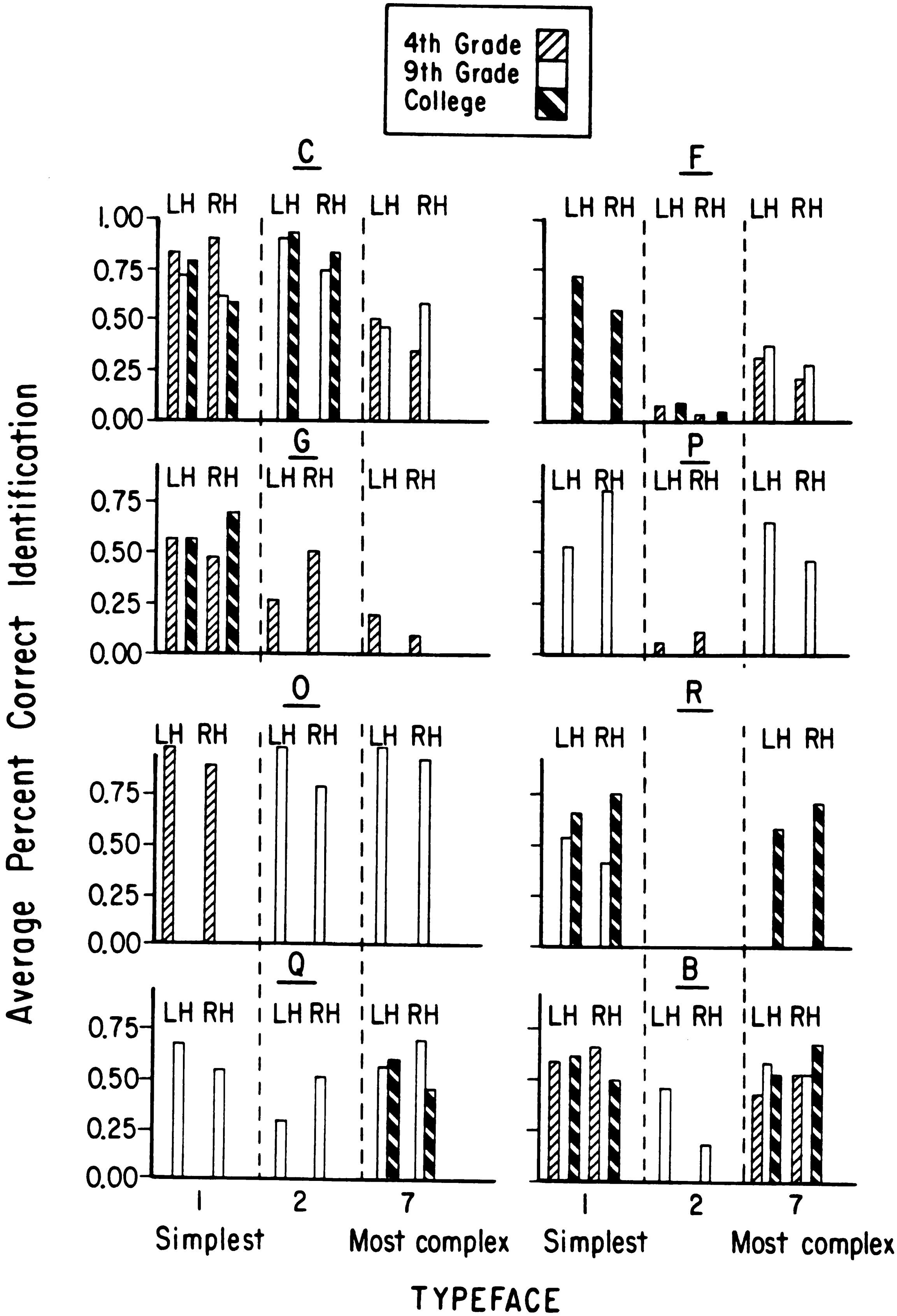
*$p < .05$

APPENDIX F

ACCURACY PER HAND FOR INDIVIDUAL LETTERS

IN THE TACTUAL CONDITION

Fig. F.1. Tactual condition. Average percent correct responses per hand for individual letters shown separately for each grade for T1, T2, and T7. (Only the cases where the hand difference exceeded 5% were included.)


4th Grade
9th Grade
College
C
F
G
P
O
R
Q
B
LH RH
1.00
0.75
0.50
0.25
0.00
Average Percent Correct Identification
1
2
7
Simplest
Most complex
TYPEFACE

APPENDIX G

CORRELATIONS OF INDIVIDUAL LCs AND CTs

TABLE G-1.--Correlations of individual laterality coefficients and CTs by grade, typeface, and modality condition

Modality Condition	Grade	Typeface							
		T1	T2	T3	T4	T5	T6	T7	T8
Visual	4th	.20	.25	.12	-.09	.31	.34	.04	-.24
	9th	.32	-.27	.17	.13	-.04	.45	.24	-.02
	Coll	-.11	-.19	.45	.09	.09	.13	.06	.12
Tactual	4th	.66	-.04					.44	
	9th	.46	-.15					-.48	
	Coll	.19	.28					.20	

APPENDIX H

AVERAGE LCs FOR FS+ AND FS- GROUPS

TABLE H.1.--Average laterality coefficients for FS+ and FS- Fourth-and Ninth-graders for all typefaces in each modality condition

Modality Condition	Grade		Typeface							
			T1	T2	T3	T4	T5	T6	T7	T8
<u>Visual</u>	4th	FS+ (N=7)	.52	.01	-.02	.10	.20	-.21	.08*	.24
		FS- (N=9)	.18	.05	.01	.10	.07	-.11	-.64*	-.12
	9th	FS+ (N=8)	.15	-.12**	-.01	.38	.46	-.21	-.22	.27
		FS- (N=8)	.24	.48**	-.05	.08	.18	-.30	-.00	.31
<u>Tactual</u>	4th	FS+ (N=7)	-.11	.06					-.38	
		FS- (N=9)	.32	.02					-.07	
	9th	FS+ (N=8)	.07	-.15					.18	
		FS- (N=8)	.23	.08					.28	

*t=2.95, d.f. = 14, $\underline{p} < .05$.

**t=2,95, d.f. = 14, $\underline{p} < .05$.

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