FACE RECOGNITION IN CHILDREN
EVIDENCE FOR THE DEVELOPMENT OF RIGHT HEMISPHERE SPECIALIZATION

by

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Abstract

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Despite the objective similarity of faces, adult humans are remarkably good at distinguishing particular faces and remembering them over long periods of time (Galton, 1883). Moreover, adults are able to form a representation of a new face from a stimulus as degraded as a single still photograph. Existing evidence suggests that this representation reflects orientation specific configurational aspects of a face (Yin, 1970; Carey, Diamond and Woods, in press).

Children under 10 years of age, however, need much more exposure to a face in order to form such a representation. Young children apparently represent new faces in terms of salient isolated features, rather than in terms of orientation-specific configurational properties (Carey, Diamond and Woods, in press; Diamond and Carey, in press). What might account for this protracted development? Perhaps experience with a wide range of faces, including the opportunity to make these faces familiar, is required. Sufficient experience might not be available before age 10. The adult efficiency for encoding faces may also depend on a maturational change of the relevant cortical areas, presumably the right posterior sector (e.g., Milner, 1960, 1968; De Renzi, Scotti, and Spinnler, 1969; Yin, 1969).

Experiments in this thesis proceeded from the following question: Is the development of the adult efficiency for representing faces associated with changes in right hemisphere specialization? The first study tested tachistoscopic recognition of words and previously unfamiliar faces across a range of ages (8-adult). All age groups showed a RVF advantage for word recognition and all but the 8 year olds, the youngest age group tested, showed a LVF advantage for recognition of previously unfamiliar faces. The emergence of a LVF advantage for recognition of new faces at age 10, but not before, supports the hypothesis that changes in right hemisphere specialization are involved in the development of the ability to represent previously unfamiliar faces in terms of configurational properties.

Evidence from developmental studies suggests that children, well before age 10, represent familiar faces in the same manner as normal adults, i.e., in terms of configurational properties rather than isolated features. If configurational representation of faces necessarily involves the right hemisphere, one would expect a LVF advantage for recognition of familiar faces to be developmentally prior to that for unfamiliar faces. Experiments II and III test tachistoscopic recognition of familiar and unfamiliar faces in the left and right visual fields in adults and children (aged 8-11), respectively. All age groups, except the 8 year olds,show a LVF advantage for recognition of both familiar and unfamiliar faces. Whereas the 8 year

olds show no visual field differences when faces are unfamiliar, or even moderately familiar, a LVF advantage is obtained when faces are highly familiar, i.e., subjects' own classmates. This pattern of results support the hypothesis that the right hemisphere is involved in configurational representation of faces, and leaves open the possibility that it is innately specialized for such processing.

The combined results of the three studies suggest that what is developing during the first decade of life is the ability to encode new faces in terms of configurational properties, more and more efficiently, culminating in the ability to do so from a stimulus as degraded as a single still photograph. Moreover, an argument is made that maturation of the right hemisphere contributes to this development.

BIOGRAPHICAL NOTE

The author was born on February 3, 1950 in Hartford, Connecticut. She attended New Britain High School in New Britain, Connecticut and then entered Simmons College, Boston, Massachusetts. At Simmons, she majored in mathematics and psychology, and received her B.S., with distinction, in 1972. From there, she entered the M.I.T. graduate program in psychology where she has worked on problems of human cognitive and perceptual development.

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With the help of Ed Walker and Joe Bauer, who introduced me to Alice, I was able to perform necessary statistical tests with relative ease. As an added bonus, I even learned to use Alice myself.

A few dedicated undergraduates have also helped me in carrying out this research - notably Jeri Riggs of Wellesley and Andy Cahn of M.I.T. Thank you.

During these four years at M.I.T., my husband David has supplied the moral support and encouragement which I needed. Moreover, he has patiently typed drafts of this thesis and made many of the figures. During the past month, my sister Janet has also provided much needed manpower.

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I truly enjoyed my four years at the M.I.T. Psychology Department. I will miss you all.

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TABLE OF CONTENTS

SECTION I

General Introduction

For more than a century, it has been realized that the left and right cerebral hemispheres of adult humans are functionally asymmetrical. As early as the 1860s, Dax (1836) and Broca (1861) observed that injury to the left hemisphere in adult life is frequently followed by aphasia whereas speech disturbance is rarely seen after injury to the right hemisphere. By a curious extrapolation, the idea that the left hemisphere was dominant for language lead to the idea that it was dominant for all cognitive functions. Despite the warnings of Hughlings Jackson, as early as 1874, that the posterior lobes of the right hemisphere are specialized for "visual ideation", the left hemisphere was christened the "dominant hemisphere", and the right hemisphere, by default, the "minor hemisphere"(Milner, 1974).

This theory of hemispheric dominance has been replaced by a theory of complementary specialization of the two cerebral hemispheres, the left for language functions and the right for various nonverbal functions. For example, the right hemisphere is differentially specialized for the discrimination of tonal patterns (e.g., Milner, 1958; Kimura, 1964), for certain tactuo-spatial functions (e.g., Faglioni, Scotti and Spinnler, 1969; Corkin, 1965) and for certain visuo-spatial functions, including face recognition (e.g., Milner, 1958, 1960, 1968, 1974; Warrington and James, 1967; Kimura, 1969; DeRenzi, Scotti and Spinnler, 1969; Yin, 1970). Complementary specialization of the two cerebral hemispheres in human adults receives support from a variety of sources. Studies of patients with unilateral brain lesions (e.g., Teuber, 1955, 1962, 1974; Milner, 1958, 1962, 1968, 1974; Hécaen, 1962; Corkin, 1965), studies of commissurotomy patients (e.g., Levy, Trevarthen and Sperry, 1972; Sperry, 1974) and studies with normal adults (e.g., Kimura, 1967, 1973; McKeever and Huling, 1971; Hermelin and O'Connor, 1971; Klein, Moscovitch and Vigna, 1976) all provide evidence for complementary hemispheric specialization.

Recently, there has been considerable interest in the development of these contrasting specializations. Much of this developmental work, like the early work on hemispheric specialization in adults (e.g., Broca, 1861), has focused on specialization of the left hemisphere for language functions. A number of lines of evidence suggest that the left hemisphere may be specialized for language functions at birth or soon after. There is also scattered evidence suggesting early right hemisphere specialization for perception of nonspeech sounds, a function for which it is specialized during adulthood (e.g., Kimura, 1964).

Recent behavioral studies suggest that infants as young as four weeks of age, like adults, perceive speech sounds categorically (e.g., Eimas, Siqueland, Juscyk and Vigorito, 1971). While young infants are able to discriminate acoustic differences across phonemic boundaries relevant for linguistic classifications, they are unable to discriminate equivalent acoustic differences within phonemic categories, suggesting that aspects of speech perception may be biologically preprogrammed. Dichotic listening studies have demonstrated a right ear advantage for perception of verbal stimuli in subjects as young as three years of age (Nagafuchi, 1970; Ingram, 1975) and a left ear advantage for perception of nonverbal environmental sounds in children as young as five years of age (Knox and Kimura, 1970). Larger amplitude auditory evoked responses have been obtained from the left hemisphere to verbal stimuli and from the right hemisphere to two nonspeech sounds in infants, children and adults (Molfese, Freeman and Palermo, 1975). Finally, a morphological asymmetry in favor of the left temporal planum has been found in neonates as well as adults (Geschwind and Levitsky, 1968; Wittelson and Pallie, 1973; Wada, Clarke and Hamm, 1975). Such an anatomical difference in the temporal speech zone could well provide an advantage for the left hemisphere in language acquisition from birth onwards. McRae, Branch and Milner (1968) report that the occipital horn of the lateral ventricle tends to be longer on the left than on the right in adult brains, suggesting that the actual mass of brain tissue may be greater in the posterior part of the right hemisphere than in the left. This asymmetry has not been studied developmentally.

Does commitment of the left and right hemispheres to their respective adult functions proceed in parallel (Teuber, 1974)? Existing evidence suggests that both hemispheres are genetically predisposed to their respective functions. However, subsequent commitment of the two hemispheres to their adult functions may follow different developmental time courses.

While no study has placed a lower age limit on left hemisphere commitment to language functions, several studies suggest that age 10 marks a milestone in the commitment of the right hemispehre to certain visuo-spatial functions which it subserves during adulthood (Kohn and Dennis, 1974; Rudel,Denckla and Spalten, 1974).

One visuo-spatial ability clearly subserved by the right hemisphere in normal adults is face recognition (e.g., De Renzi, Scotti and Spinnler, 1969; Yin, 1969). Two recent developmental studies (Carey, Diamond and Woods, in press; Diamond and Carey, in press) suggest that children begin to represent unfamiliar faces as do adults at around age 10. One of these studies (Carey, Diamond and Woods, in press) demonstrated that children aged 10 and over show the same differential sensitivity to orientation of faces as normal adults, i.e., spatial inversion interferes with the recognition of previously unfamiliar faces significantly more than the recognition of other mono-oriented objects such as houses (Yin, 1969). In contrast, 8 year olds show the same insensitivity to orientation of faces as patients with right posterior cerebral injuries (Yin, 1970). A second study demonstrated that 6 and 8 year olds, unlike older children and normal adults, rely on isolated paraphernalia cues (e.g., earrings, hats, etc.) in judging which two of three photographs of unfamiliar faces depict the same person.

Face recognition is an important social skill. Moreover, from early infancy, faces as a class are of particular interest (e.g., Haaf and Bell, 1967; Lewis, 1969; Goren, Sarty and Wu, 1975). Why, then, is the adult level of efficiency for recognizing faces not present until age 10? The similarity of the performances of 6-8 year olds and patients with right posterior lesions on Yin's task suggests that changes in right hemisphere specialization may be involved in the development of the adult ability to encode a previously unfamiliar face from a stimulus as degraded as a single still photograph.

If such an association exists, one might expect to find a change in the visual field advantage for tachistoscopic recognition of unfamiliar faces at age 10. Tachistoscopic studies with normal adults have generally reported a LVF advantage for the recognition of previously unfamiliar faces (e.g., Rizzolatti, Umilta and Berlucchi, 1971; Geffen, Bradshaw and Wallace, 1971; Hilliard, 1973; Klein, Moscovitch and Vigna, 1976). Experiment I investigates the time course for emergence of this LVF advantage during development. In addition, the time course for emergence of a RVF advantage for word recognition is investigated. Results of tachistocopic (Marcel and Katz and Smith, 1974) and dichotic listening studies (Nagafuchi, 1970; Ingram, 1975) suggest that a RVF advantage for word recognition will be present by age 8. In contrast, a LVF advantage for recognition of unfamiliar faces may not be present before age 10, if, in fact, development of the adult efficiency for representing faces awaits commitment of the right hemisphere to the relevant visuo-spatial specialization.

Existing evidence suggests that familiar faces, unlike previously unfamiliar faces, are represented in the adult manner by age 5-6. Diamond and Carey (in press) have demonstrated that 5-6 year old children are not mislead by confounding paraphernalia cues when models to be identified are their own classmates. If the right hemisphere is always differentially involved when faces are represented efficiently, one might expect a LVF advantage for the recognition of familiar faces to be present before age 10, developmentally prior to the LVF advantage for the recognition of unfamiliar faces. Experiments II and III address this hypothesis. Experiment II attempts to establish a LVF advantage for the recognition of familiar faces in adult subjects, and Experiment III directly compares the development of a LVF advantage for the recognition of familiar and unfamiliar faces.

SECTION II

Face Perception in Children
Evidence for the Development of Right Hemisphere Specialization

Abstract

Tachistoscopic recognition of words and previously unfamiliar faces presented in the left and right visual fields was tested across a range of ages (8-adult). All age groups recognized more words in the right visual field and all but the youngest age group tested recognized more faces in the LVF. The 8 year olds showed no visual field difference for the recognition of previously unfamiliar faces. These findings suggest that commitment of the right hemisphere to its adult functions may not be complete before age 10.

Introduction

Complementary specialization of the cerebral hemispheres in human adults receives support from a variety of sources. Studies of patients with unilateral brain lesions (e.g., Teuber, 1955, 1962, 1974; Milner, 1958, 1962, 1968, 1974; Hécaen, 1962; Corkin, 1965), studies of commissurotomy patients (e.g., Levy, Trevarthen and Sperry, 1972; Sperry, 1974) and studies with normal adults (e.g., Kimura, 1967, 1973; McKeever and Huling, 1971; Hermelin and O'Connor, 1971; Klein, Moscovitch and Vigna, 1976) all provide evidence for complementary hemispheric specialization. Existing evidence indicates that the left hemisphere is differentially specialized for language functions and the right hemisphere is differentially specialized for various nonverbal functions such as the discrimination of tonal patterns (e.g., Milner, 1958; Kimura, 1964), certain tactuo-spatial functions (e.g., Corkin, 1965; Faglioni, Scotti and Spinnler, 1969) and certain visuo-spatial functions, including face recognition (e.g., Milner, 1958, 1960; Warrington and James, 1967; Kimura, 1969; De Renzi, Scotti and Spinnler, 1969; Yin, 1970).

Recently there has been considerable interest in the development of these contrasting specializations. Much of this developmental work, like the early work on hemispheric specialization in adults (e.g., Dax, 1836; Broca, 1861), has focused on left hemisphere commitment to language functions. For example, a right ear advantage for perception of verbal stimuli has been demonstrated in subjects as young as three years of age (e.g., Nagafuchi, 1970; Ingram, 1975). Thus far, no lower age limit has been placed on the right ear advantage for verbal stimuli, leaving open the possibility that the left hemisphere is specialized for processing speech sounds from birth.

Does commitment of the left and right hemispheres to their respective adult functions proceed in parallel (Teuber, 1974)? One visuo-spatial task clearly subserved by the right hemisphere in normal adults is face recognition (e.g., De Renzi, Scotti, and Spinnler, 1968; Benton and Van Allen, 1968; Yin, 1970). Two recent developmental studies (Carey, Diamond and Woods, in press; Diamond and Carey, in press) suggest that children begin to represent unfamiliar faces as do adults at around age 10, while younger children appear to rely on some other form of representation. One of these studies (Carey, Diamond, and Woods, in press) capitalized on an experiment by Yin (1969), which demonstrated that for normal adults spatial inversion hampers the recognition of unfamiliar faces significantly more than the recognition of other mono-oriented objects (e.g., houses, airplanes, stick figures of men). Patients with right posterior lesions, however, were not differentially sensitive to the orientation of faces, in contrast both to normal adults and other lesion groups (Yin, 1970). Carey and Diamond (in press) found that children under age 10 show this same insensitivity to orientation of faces, while children 10 and over show the normal adult pattern. While the patients with right posterior lesions and the children under 10 years of age recognized inverted faces as well as normal adults, they were significantly impaired relative to normal adults on the recognition of upright faces (Yin, 1970; Carey, Diamond and Woods, in press). Development of the adult ability to recognize faces is apparently orientation specific. A second study demonstrated that children under age 10 use isolated paraphernalia cues (e.g., earrings, hats, etc.) in judging which two of three photographs depict the same person, while children aged 10 and over, like normal adults, are able to ignore these misleading isolated cues.

Development of the adult efficiency for recognizing faces has been characterized as a shift from piecemeal to configurational encoding of faces (Carey, Diamond and Woods, in press). The confounding cues experiment provides direct evidence for a shift away from reliance on misleading isolated features at around age 10. Results of this experiment also suggest that configurational properties, rather than better isolated features, are encoded from age 10 onwards (for details, see Diamond and Carey, in press). The onset of differential sensitivity to orientation of faces at age 10 can also be explained by the emergence of configurational encoding, if one assumes that encoding isolated features is less affected by inversion than encoding configurational information (for details, see Carey, Diamond and Woods, in press).

What might account for this protracted development of the adult ability to encode a previously unfamiliar face from a single still photograph? The involvement of changes in right hemisphere specialization is supported by the finding that patients with right posterior brain lesions appear to process unfamiliar faces as do 6-8 year olds. Although different mechanisms may underlie their similar performances, processing new faces in terms of configurational properties may be dependent on an intact and developmentally mature right posterior hemisphere. If there is an association between development of the adult level of efficiency for representing faces and changes in right hemisphere specialization, a LVF advantage for the recognition of unfamiliar faces may not emerge until age 10.

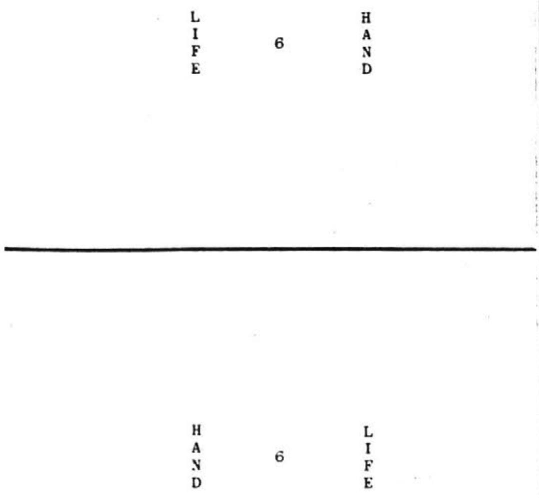
The present study investigates the time course for development of a LVF advantage for the recognition of previously unfamiliar faces and the time course for development of a RVF advantage for the recognition of words. Tachistoscopic recognition of words and faces in the left and right visual fields is compared, across a range of ages (8-adult). Results of tachistoscopic (Marcel, Katz and Smith, 1974) and dichotic listening studies (Nagafuchi, 1970; Ingram, 1975) suggest that a RVF advantage for word recognition will be present by age 8. In contrast, a LVF advantage for recognition of previously unfamiliar faces may not emerge until age 10, if, in fact, configurational representation of previously unfamiliar faces awaits commitment of the right hemisphere to the relevant visuo-spatial specialization.

Method

Subjects. Forty subjects (20 males and 20 females) in each of five age groups (8, 10, 12, 14, and adult) were tested. Children were drawn from public schools in the Boston area and from the M.I.T. Day Camp. Adult subjects were M.I.T. undergraduates. All subjects were right handed with right handed parents and had vision correctable to 20/20.

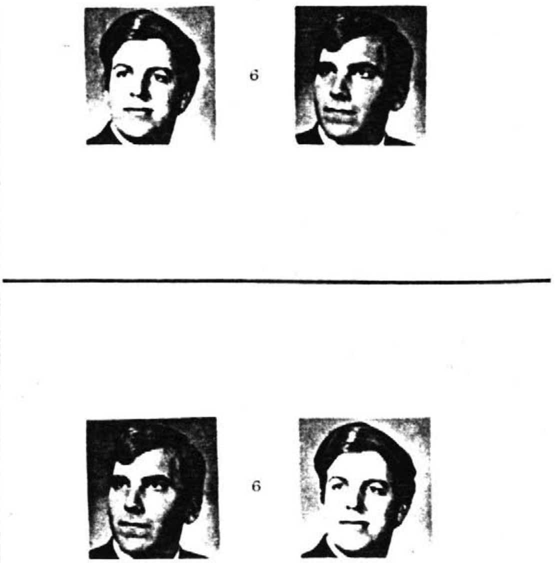
Apparatus and Stimuli. Following the design of McKeever and Huling (1971), stimuli were bilaterally presented. A Gerbrands 2-channel tachistoscope (Model T-2B1) was used to present stimuli. Word stimuli consisted of eight practice pairs and twenty test pairs (high frequency four letter nouns, Kucera and Francis, 1967). Face stimuli consisted of eight practice pairs and twenty test pairs (half male and half female, taken from college yearbooks) (Examples: Figure 1). Words were oriented vertically rather than horizontally to avoid the interaction of differential informativeness of beginning vs. end of word with distance from the fixation point. For the adults, the near point of each word was located $1^{o}36'$ to the left or right of fixation and each word subtended $1^{o}32'$ of vertical visual angle. In an attempt to make the word task of comparable difficulty for all age groups, a bolder type face was used for the 8-14 year olds than for the adults. For the children, the near point of each word was located $1^{o}14'$ to the left or right of fixation and each word subtended $1^{o}23'$ of vertical visual angle. For all groups, the near point of each face was located 55.5' to the left or right of fixation and each face subtended $3^{o}51'$ of horizontal visual angle. An Arabic numeral ranging from 2 to 9 was chosen at random and typed at the fixation point of each stimulus.

Procedure and Design. Subjects began each trial by viewing a preexposure field consisting of six lines radiating from an open space in the center. This space was just large enough to be filled by the fixation point numeral on each stimulus card as it was flashed. Two trials with cards having only fixation point numerals were given to accustom S to the procedure. Eight practice trials preceded both the face recognition and word recognition portions of the experiment. Prior to each trial E said "focus" to alert S to fixate on the center space. The stimulus card was then flashed followed immediately by the return of the preexposure field. The digit provided positive control over fixation, and only trials on which the digit was reported correctly were counted, as



WORD STIMULI

FACE ARRAY



FACE STIMULI

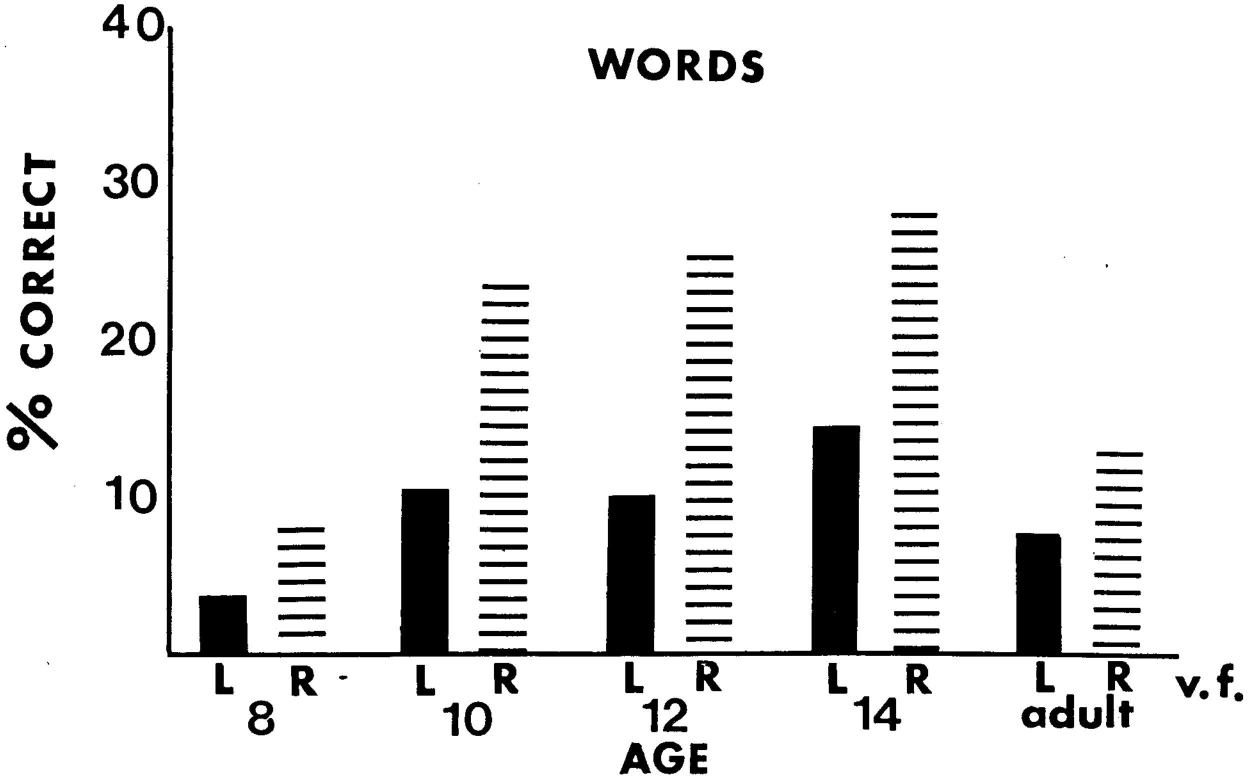
an error could indicate eye movement or improper fixation. As a further precaution, both words and faces were presented at durations below eye movement latency, faces at 120 msecs and words at 80, 100, or 120 msecs. It was necessary to use a variable exposure duration in the word recognition task to control for inter-subject variability in ability to recognize words. Exposure duration for the word pairs was chosen on the basis of performance on eight practice trials. Once chosen, this duration was used for the twenty test trials.

On the word task, after reporting the digit, if possible, S verbally reported the words or any part of the words which appeared on the card along with the digit. On the face task, after reporting the digit, S made a forced choice of two faces from an array of six, two of which were identical to those which were flashed. Distractor faces were not chosen to "look like" target faces, but were chosen to be similar in head orientation, expression, and hairstyle in order to discourage processing by single isolated features. A unique array was associated with each face pair (Example: Figure 1). Five random orders of presentation, balanced across condition, were used for each age group.

Materials were blocked such that half the subjects in each age group (10 males, 10 females) were shown words before faces and half were shown faces before words. Each word and face pair appeared only once during an experimental session; side of presentation was counterbalanced across Ss. All stimuli were viewed binocularly.

Results

Figure 2 (a and b) shows the percentage of words and faces recognized


WORDS
% CORRECT
40
30
20
10
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8
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10
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12
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adult
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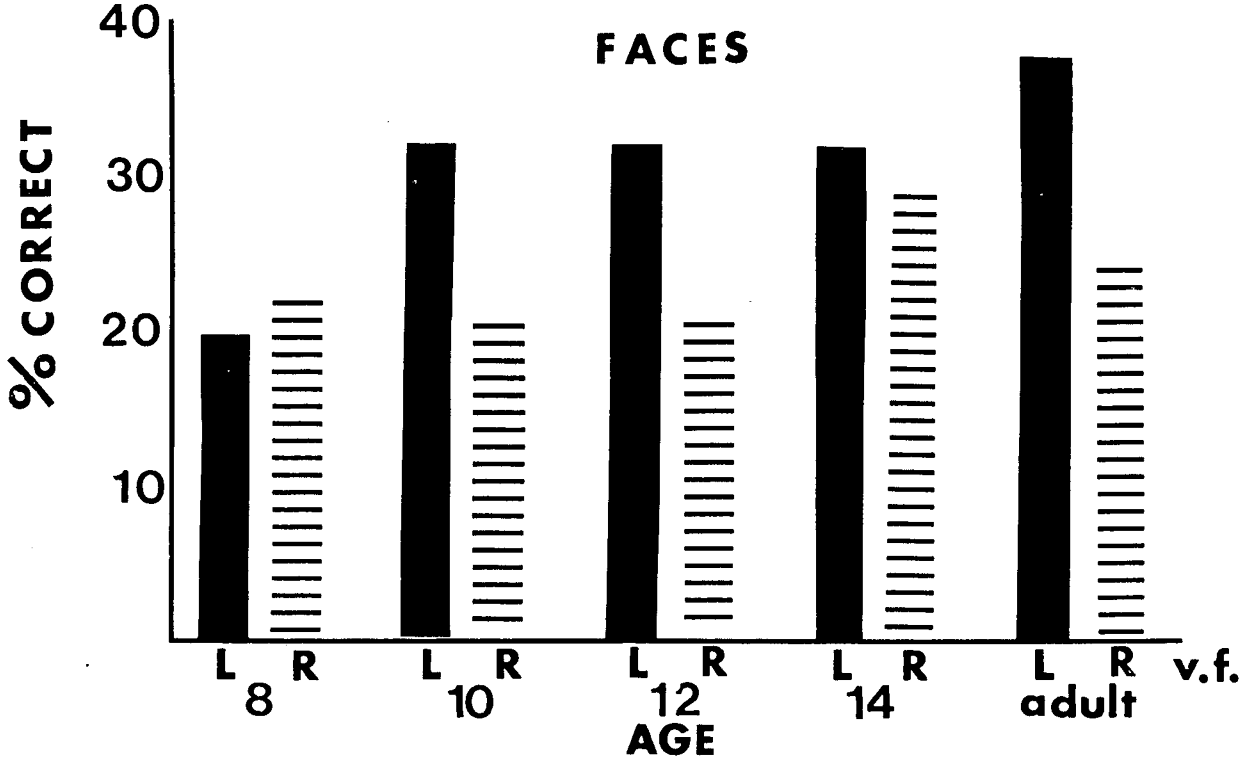
AGE


FACES
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40
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adult
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AGE

in the LVF and RVF for each of the age groups tested. The percentage of faces recognized on each side was corrected for guessing.[1] As can be seen from Figure 2a, all age groups recognized more words in the RVF than in the LVF. In contrast, Figure 2b shows that all age groups, except the 8 year olds, the youngest age group tested, recognized more faces in the LVF than in the RVF.

Significance of predicted visual field advantages were tested by using the min F' procedure suggested by Clark (1973) where min $F' = F_1F_2/F_1 + F_2$, F_1 being the *F*-ratio resulting from the comparison of the subject means in the relevant conditions, and F_2 being the *F*-ratio resulting from the comparison of item means. A factorial analysis of variance across all age groups reveals a significant Age (8-Adult) x Materials (faces, words) x Position (left, right) interaction for all but the youngest age group tested. (Adults: min $F'(1,78) = 11.46$, $p < .005$; 14 year olds: min $F'(1,69) = 6.93$, $p < .025$; 12 year olds: min $F'(1,73) = 18.61$, $p < .001$; 10 year olds: min $F'(1,75) = 14.86$, $p < .001$; 8 year olds: min $F'(1,67) = 0.392$, $p > .10$.) Neither the main effects nor interactions of sex or order of presentation of words and faces were significant.

Subsequent t-tests for correlated means reveal that the differences between words recognized in the RVF and words recognized in the LVF is significantly greater than zero for all age groups tested. (Adults: $t = 2.514$, $df = 39$, $p < .005$; 14 year olds: $t = 3.256$, $df = 39$, $p < .001$; 12 year olds: $t = 4.303$, $df = 39$, $p < .001$; 10 year olds: $t = 3.488$, $df=39$ $p< .001$; 8 year olds: $t = 1.829$, $df = 39$, $p < .05$, all one-tailed tests.) In contrast, a LVF advantage for recognition of unfamiliar faces is not present at age 8, and fails to reach a statistically significant level for the 14 year olds. (Adults: $t = 3.777$, $df = 39$, $p < .001$; 14 year olds: $t = .851$, $df = 39$, $p > .10$; 12 year olds: $t = 3.658$, $df = 39$, $p < .001$; 10 year olds: $t = 3.358$, $df = 39$, $p < .001$; 8 year olds: $t = -.552$, $df = 39$, $p > .10$, all one-tailed tests).

Emergence of the LVF advantage for recognition of unfamiliar faces at age 10 is entirely due to the marked improvement between ages 8 and 10 in the recognition of faces in the LVF ($t = 3.805$, $df = 78$, $p < .001$, two-tailed test). From age 10 on, the number of faces recognized in the LVF remains constant. Recognition of faces in the RVF is constant from age 8 through adult, with the exception that the 14 year olds recognized significantly more faces in the RVF than the three younger age groups ($p < .05$). This increased recognition of faces in the RVF at age 14 accounts for the failure of the LVF advantage to reach statistical significance at this age.

Discussion

The major predictions of this study were confirmed. Children as young as 8 years of age, the youngest age group tested, showed a RVF advantage for word recognition. In contrast, a LVF advantage for the recognition of unfamiliar faces was not present until age 10.

Obtained visual field differences can be affected by performance level, i.e., actual differences can be masked by "floor" and "ceiling" effects. The absence of a LVF advantage for face recognition at age 8, however, cannot be a "floor effect" since the 8 year olds recognized as many faces in the RVF as the older age groups.

The emergence of a LVF advantage for the recognition of previously unfamiliar faces between ages 8 and 10 is entirely due to improvement in the recognition of faces presented in the LVF. Coincident with this improvement is the development of differential sensitivity to orientation of faces, compared to other mono-oriented stimuli, e.g., houses (Carey, Diamond and Woods, in press). The onset of this differential sensitivity is entirely due to improvement in the recognition of upright faces between ages 8 and 10 since recognition of inverted faces remains constant across this age difference. The convergence of improved recognition of faces presented in the LVF and improved recognition of upright faces suggests that developmental changes in right hemisphere specialization are associated with developmental changes in the ability to recognize [illegible] faces.

Age 10 also marks the onset of the ability to ignore misleading paraphernalia cues in judging the identity of two faces from their photographs. The convergent development of differential sensitivity to orientation of faces and resistance to confounding paraphernalia cues at age 10 may reflect a shift from piecemeal to configurational encoding of faces (Carey, Diamond and Woods, in press). The emergence of a LVF advantage for the recognition of previously unfamiliar faces at this same age is consistent with the hypothesis that developmental changes in right hemisphere specialization are associated with development of the ability to represent faces configurationally.

What might account for the protracted development of the ability to recognize faces? A maturational change of relevant cortical areas within the right hemisphere might be necessary before faces can be represented at the adult level of efficiency. Such a change may not occur until age 10. A change in lateralization on a particular task, however, is not necessarily indicative of a maturational change. Bever and Chiarello (1974) report that musically experienced adults recognize simple melodies better in the right ear than the left, while the reverse is true of naive listeners. It is extremely unlikely that this change in lateralization awaits a maturational change of relevant cortical structures.

Changes in face recognition ability at around age 10 may depend on a maturational change but this is not necessarily the case. Alternatively, development of the adult efficiency for representing faces may depend on the accumulation of sufficient experience in making faces familiar. Before age 10, a great deal of exposure to a particular face might be necessary before that face can be represented configurationally in long-term memory. During development, the schema for representing new faces configurationally from a stimulus as degraded as a single still photograph might derive from the set of familiar faces which have been represented in this manner. During adulthood, experience with particular faces certainly contributes to one's ability to recognize new faces, since adults are better at recognizing members of their own racial group than a group with which they are unfamiliar (Shepherd, Deregowski and Ellis, 1974).

Whether a physical-maturational change or a cognitive-developmental change is the bottleneck in the emergence of the adult efficiency for representing new faces remains an open question. Several lines of evidence, however, suggest that there may be a maturational component to the change in face recognition abilities at age 10. For example, age 10 apparently marks a milestone in the commitment of the right hemisphere to several visuo-spatial functions it subserves during adulthood. Development of right hemisphere specialization for such diverse abilities as complex maze solving and map reading (Kohn and Dennis, 1974), Braille reading (Rudel, Denckla and Spalten, 1974) and recognition of previously unfamiliar faces at around age 10, supports the involvement of maturational changes of the right hemisphere. Concurrent development of such diverse abilities would be difficult to explain solely on the basis of experience.

The falloff in the LVF advantage for the recognition of previously unfamiliar faces at age 14 also supports there being a maturational component to the development of the adult efficiency for recognizing faces. Evidence from several other sources suggests that there is further reorganization of face representation between ages 12 and 16 (Goldstein, 1973; Carey, Diamond and Woods, in press). For example, Carey, et al. (in press) found 14 year olds to be less accurate than 10 year olds in recognizing upright faces, and the difference between upright and inverted faces was not statistically significant at this age. These findings lend further support to the hypothesis that maturation of the right cerebral hemisphere plays a role in the development of efficient representation of faces as it would be difficult to explain a falloff in the LVF advantage and in the recognition of upright faces as a result of experience. These reversals are followed by recovery of the LVF advantage and differential orientation sensitivity by young adulthood. Perhaps maturational factors related to the onset of puberty are responsible for these temporary developmental changes.

Finally, a maturational change in right hemisphere specialization would provide a possible explanation for the clinical finding of relatively rapid and complete recovery of language functions if a left hemisphere lesion occurs early in life (Lenneberg, 1967; Woods and Teuber, in preparation; Milner, 1974). The right hemisphere, still uncommitted to certain visuo-spatial functions, including the recognition of unfamiliar faces, might be able to subserve these language functions. Results of sodium Amytal tests (Milner, 1974), routinely used to determine side of speech representation in all left-handed and ambidexterous patients being considered for brain surgery, support this hypothesis. Milner (1974) reports that speech is subserved by the right hemisphere in 18% of left-handed or ambidexterous patients <u>without</u> early left hemisphere damage as compared to 54% of left-handed and ambidexterous patients <u>with</u> early left hemisphere damage.

According to recent studies of Woods and Teuber (in preparation), comparable sparing of visuo-spatial functions after early right hemisphere lesions does not occur (Teuber, 1974). If the left hemisphere is committed to its adult functions at birth, or soon after, it would not be available to subsume right hemisphere functions. Developmental studies of left hemisphere specialization are compatible with this hypothesis as none have placed a lower age limit on the commitment of this hemisphere to language functions. In fact, no developmental change in left hemisphere specialization analogous to the change in right hemisphere specialization at age 10 is known. The priority of language functions in recovery from early brain damage may result from the temporal priority of left hemisphere specialization. Results of the present experiment are consistent with this possibility.

Footnotes

[1] A simple guessing correction for faces was performed. On the face recognition task, subjects were required to pick two faces out of six on each trial. The probability of guessing a particular face correctly on the first choice was 1/6; on the second choice, 1/5. Since it is not clear that the order of pointing reflects the order of recognition, both first and second choices were corrected by the average of 1/6 + 1/5. For each subject, the number of faces recognized in the left and right visual fields was computed by the following formula:

$$\text{CORRECTED TOTAL} = \text{UNCORRECTED TOTAL} - \frac{1/6 + 1/5}{2} \times 20$$

The maximum correct out of 20, under this formula, becomes 16.33, so the percentage correct shown in the figures is the corrected total ÷ 16.33.

SECTION III

Perceptual Asymmetries in the Recognition of Words, Familiar Faces and Unfamiliar Faces

Abstract

Tachistoscopic recognition of words, familiar faces and unfamiliar faces in the left and right visual fields was tested in adult subjects. A RVF advantage was obtained for word recognition, and a LVF advantage for recognition of both familiar and unfamiliar faces. The obtained LVF advantage for recognition of familiar faces is consistent with recent studies which indicate right hemisphere involvement in the recognition of complex visuo-spatial stimuli, whether or not these stimuli have verbal labels.

Introduction

The involvement of the right cerebral hemisphere in the recognition of unfamiliar faces is supported by studies of patients with unilateral cortical lesions (e.g., Milner, 1960, 1968; Warrington and James, 1967; Benton and Van Allen, 1968; De Renzi, Faglioni and Spinnler, 1968; Yin, 1970), by studies of commissurotomy patients (e.g., Levy, Trevarthen and Sperry, 1972; Sperry, 1974) and by tachistoscopic studies with normal adults (e.g., Geffen, Bradshaw and Wallace, 1971; Rizzolatti, Umilta and Berlucchi, 1971; Hilliard, 1974; Klein, Moscovitch and Vigna, 1976).

In contrast to the LVF advantage obtained with unfamiliar faces, a RVF advantage has recently been reported when stimuli are well-known public figures (Berlucchi, 1974; Marzi, Brizzolara, Rizzolatti, Umilta and Berlucchi, 1974). Subjects in this experiment were required to identify each stimulus face by name. Kimura (1963) suggests that as material becomes more verbal, its perception depends more on the left hemisphere, since final identification involves speech. It is possible that the involvement of the left hemisphere in naming verbalizable stimuli contributes to the RVF advantage obtained in Berlucchi's experiment, quite independent of the fact that the stimuli were familiar faces. However, recent experimental evidence suggests that the perceptual complexity of material, rather than its verbalizability, is a critical determinant of right hemisphere involvement. For example, in a tachistoscopic task requiring recognition of the time on a clock face, a LVF advantage was obtained, even though the response was verbal (Brizzolara, Umilta, Marzi, Berlucchi and Rizzolatti, in press). Similarly, a left hand advantage has been found for Braille reading, suggesting that the difficulty of the tactual configuration far outweighs the language requirement (Hermelin and O'Connor, 1971; Rudel, Denckla and Spalten, 1974). A study of patients with unilateral cortical lesions (De Renzi and Spinnler, 1966) reveals right brain damaged patients to more impaired than left brained damaged patients on the Street Completion Test and the Ghent Figures Test, both of which involve perception of degraded realistic figures that can easily be identified by name. Warrington and James (1967) obtained similar results not only with Gollin pictures and an incomplete shapes test, but also with an incomplete letters test. Moreover, in comparison to other lesion groups, patients with left temporal lesions were maximally impaired in naming well-known public figures from their photographs. In contrast, patients with right temporal lesions were maximally impaired in recognizing the faces. Correct recognition without naming was demonstrated by a subject stating specific details of the photographed person's profession, country of origin, etc.

It would appear from these findings that the right hemisphere is involved in tasks requiring subtle discriminations and integrations of perceptually complex materials. Moreover, it appears that attaching a verbal label to a perceptually complex stimulus does not switch the hemispheric advantage. According to this line of reasoning, unfamiliar, as well as familiar faces, should be recognized more quickly and accurately when presented in the LVF.

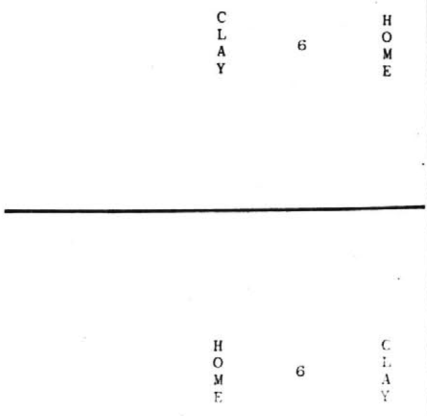
Why, then, did Berlucchi obtain a RVF advantage for the recognition of well-known public figures? The obtained RVF advantage may result from the familiarity of the faces, per se. That is, the right hemisphere may be specialized for the recognition of unfamiliar faces, the left for the recognition of well-known faces. In order to test this hypothesis, the present experiment directly compares tachistoscopic recognition of familiar (Ss' colleagues) and unfamiliar faces.

Method

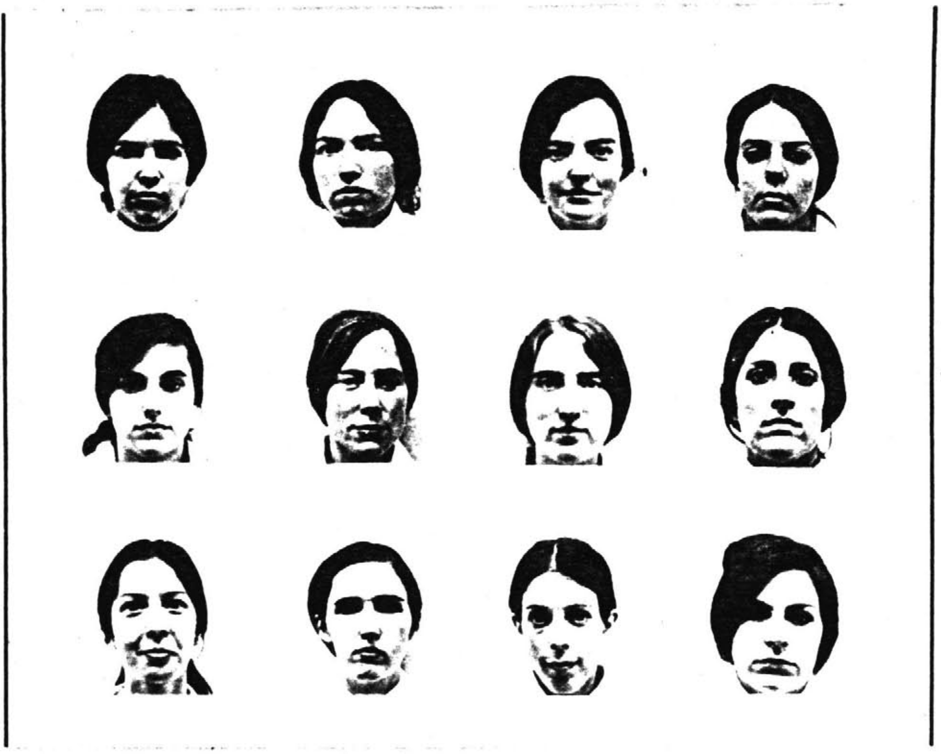
Subjects. Two groups of thirty-two adult subjects (16 males and 16 females in each group) were tested. One group consisted of subjects for whom the face stimuli were highly familiar (Group F); the other group consisted of subjects for whom the face stimuli were unfamiliar (Group UF). All subjects were right handed with right handed parents and had vision correctable to 20/20.

Apparatus and Stimuli. Following the design of McKeever and Huling (1971), stimuli were bilaterally presented. A Gerbrands 2-channel tachistoscope (Model T-2B1) was used to present stimuli. Word stimuli consisted of 8 practice and 18 test pairs(high frequency four letter nouns taken from Kucera and Francis, 1967). Similarly, face stimuli consisted of 8 practice and 18 test pairs (half male and half female), familiar to one group of subjects (Group F), and unfamiliar to the other (Group UF) (Examples: Figure 3).

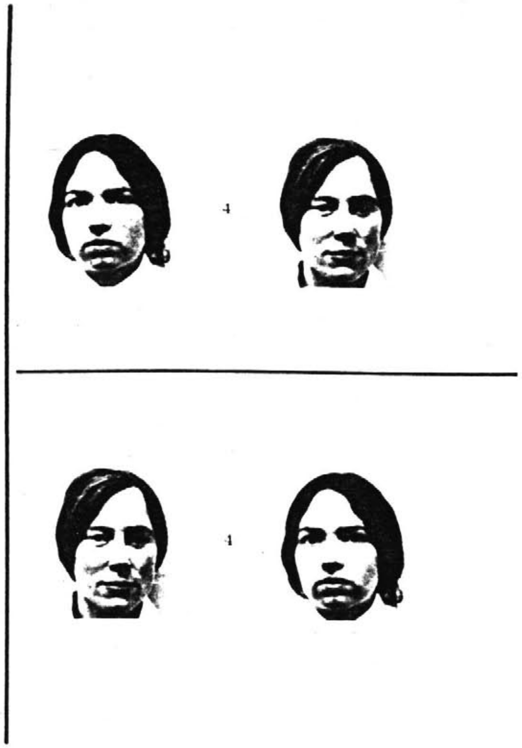
The near point of each word was located $1^o36'$ to the left or right of fixation, and each word subtended $1^o32'$ of vertical visual angle. The near point of each face was located 55.5' to the left or right of fixation, and each face subtended $3^o33'$ of horizontal visual angle. An Arabic numeral ranging from 2 to 9 was chosen at random and



WORD STIMULI



FACE ARRAY



FACE STIMULI

typed at the fixation point of each stimulus.

Procedure and Design. Subjects began each trial by viewing a pre-exposure field consisting of six lines radiating from an open space in the center. This space was just large enough to be filled by the fixation point numeral on each stimulus card as it was flashed. Two trials with cards having only fixation point numerals were given to accustom S to the procedure. Eight practice trials preceded both the face recognition and word recognition portions of the experiment. Prior to each trial E said "focus" to alert S to fixate on the center space. The stimulus card was then flashed, followed immediately by the return of the pre-exposure field. The digit provided positive control over fixation. As a further precaution, both words and faces were presented at durations below eye movement latency, faces at 60 or 120 msecs, and words at 80, 100 or 120 msecs. Two different exposure durations were used on the face recognition task in an attempt to equate the performance levels of Group F and Group UF (60 msecs for Group F; 120 msecs for Group UF). It was necessary to introduce a variable exposure duration to the word recognition task to control for inter-subject variability in ability to recognize words. Exposure duration for the word pairs was chosen on the basis of performance on 8 practice trials. Once chosen, this duration was used for the 18 test trials.

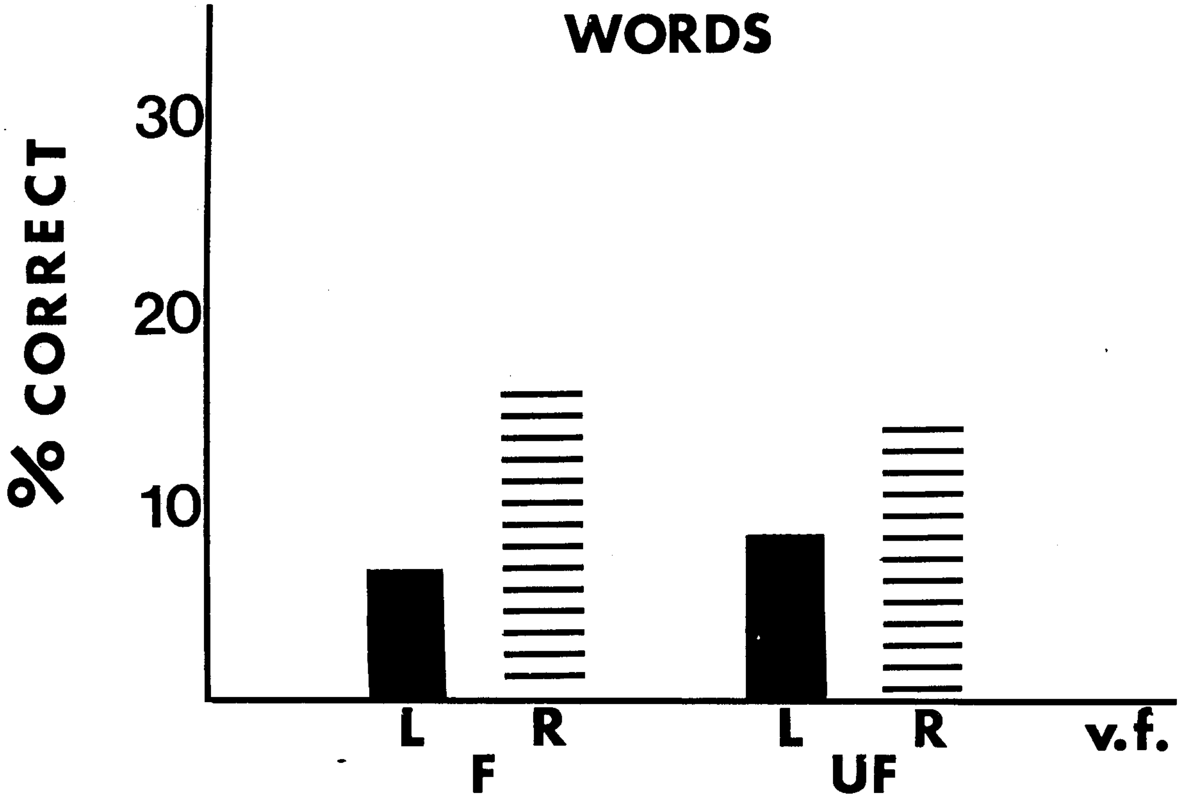
On the word task, after reporting the digit, if possible, S reported the words or any part of the words which appeared on the card along with the digit. On the face recognition task, after reporting the digit, S made a forced choice judgement of two faces from an array of 12, two of which were identical to those which had been flashed. Two arrays of 12 faces were used throughout the experiment, one consisting of photographs of 12 males and the other of 12 females. For each array, 8 faces were presented twice each, 2 were presented once each and 2 were never presented, in order to discourage subjects from using a "process of elimination" strategy to match targets shown late in the series. _S_s were informed that this would be the case in the instructions. Repeated items were presented in the opposite visual field and were paired with a different face than on the first presentation.

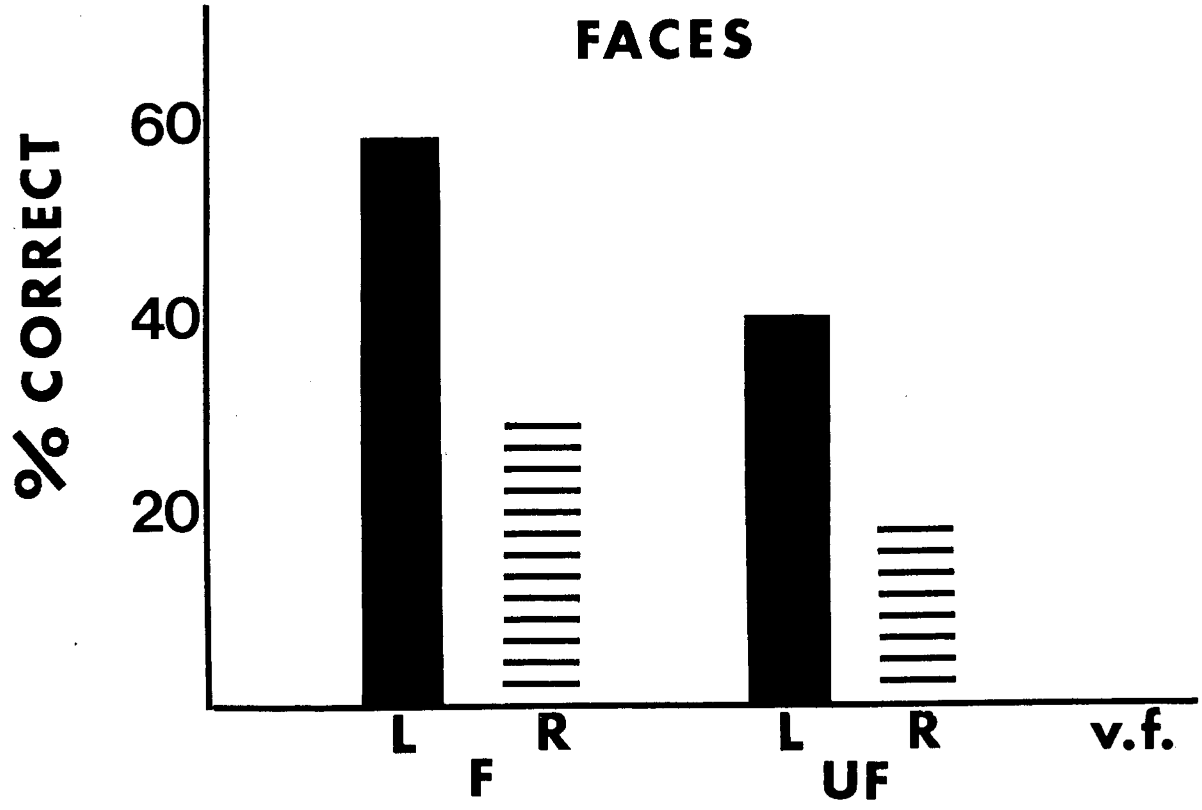
Materials were blocked such that half the subjects in each group were presented words before faces and half were presented faces before words. Eight random orders, balanced across conditions, were used throughout the experiment. Each word and face pair was shown only once during an experimental session. Side of presentation was counterbalanced across _S_s. All stimuli were viewed binocularly.

At the conclusion of the experimental session, subjects rated the face stimuli for "familiarity" on a scale from 1-10, a 1 being given to a face never seen before the experimental session, a 10 being given to a face one would recognize anywhere, even after a five year interval. Subjects were also asked to name the persons in the photographs, if possible.

Results

The percentage of words and faces recognized in the left and right visual fields are shown in Figure 4 (a and b), for Group F and Group UF. The percentage of faces recognized in each visual field was corrected


WORDS
% CORRECT
30
20
10
L
R
L
R
v.f.
F
UF


FACES
% CORRECT
60
40
20
L
R
L
R
v.f.
F
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for guessing.[1] t-tests for correlated means reveal that the difference between words recognized in the right and left visual fields is significantly greater than zero for both groups, in favor of the RVF (Group F: $t = 2.837$, $df=31$, $p < .01$, 1-tailed test; Group UF: $t = 2.142$, $df = 31$, $p < .025$, 1-tailed test). The difference between faces recognized in the right and left visual fields is significantly greater than zero for both groups, in favor of the LVF (Group F: $t = 7.071$, $df = 31$, $p < .001$; Group UF: $t = 4.950$, $df = 31$, $p < .001$).

Significance of predicted Materials (faces, words) x Position (left, right) interactions were tested by using the min F' procedure suggested by Clark (1973) where min $F' = F_1F_2/F_1 + F_2$, F_1 being the F-ratio resulting from the comparison of the subject means in the relevant conditions and F_2 being the F-ratio resulting from the comparison of item means.[2]

A factorial analysis of variance for each group separately revealed a significant Materials (faces, words) x Position (left, right) interaction for Group F and Group UF (Group F: min $F'(1,48) = 43.63$, $p < .001$; Group UF: min $F'(1,48) = 16.76$, $p < .001$). The Group (F, UF) x Materials (faces, words) x Position (left, right) interaction was not significant min $F'(1,66) = 1.919$, $p > .10$).

Group F and Group UF differed only in the total number of faces recognized, Group F recognizing significantly more faces ($t = 4.813$, $df = 62$, $p < .001$), even though exposure duration was 60 msecs for Group F and 120 msecs for Group UF. The two groups did not differ in the total number of words recognized ($t = .030$, $df = 62$, $p > .10$).

The average familiarity rating given the faces by Group F was 7.7/10 and by Group UF was 1.8/10. Group F was able to name an average of 79% of the faces; Group UF, an average of 1.4%.

Discussion

The principal result of this experiment is the demonstration of a clear LVF (right hemisphere) advantage for the recognition of both familiar and unfamiliar faces. This LVF advantage presumably reflects the differential involvement of the right hemisphere in the recognition of both familiar and unfamiliar faces.

The finding of a LVF advantage for the recognition of familiar faces contrasts the RVF advantage for the recognition of famous faces obtained in previous studies (Berlucchi, 1974; Marzi, et al., 1974). How might this discrepancy in obtained visual field advantages be explained? Consider the possibility that both hemispheres can encode faces, but do so in fundamentally different manners. The encoding of familiar faces might differentially involve the right hemisphere; the encoding of famous faces, the left hemisphere.

Results of an experiment involving recognition of faces by split-brain patients suggest that both hemispheres, in fact, have face recognition capabilities (Levy, Trevarthen and Sperry, 1972). Chimeric faces were tachistoscopically presented to these patients. Three different modes of response were tested, each on a different day. In the first, subjects responded by selecting the flashed face from an array of choice faces by pointing with the right hand; in the second, by pointing with the left hand; and in the third, the choice stimuli were removed and subjects were required to name the flashed face. The patients showed a LVF recognition advantage when a nonverbal pointing response was required both with the left or right hand, and a RVF advantage when a verbal naming response was required. This result indicates that faces can be recognized by the right and left hemispheres. However, results suggest that the two hemispheres recognize faces in qualitatively different manners. First of all, recognition of faces presented in the RVF when a naming response was required was significantly less accurate than recognition of faces in the LVF when a pointing response was required. Moreover, Levy, et al. observed that all four commissurotomy patients tested had difficulty learning the names associated with the three face stimuli involved. They finally succeeded after 10 or 15 minutes by associating salient features of the face with the name and saying "'Dick has glasses, Paul has a moustache, and Bob has nothing.'" Normal controls, in contrast, could learn the names after stating them only once. Levy, et al. suggest that the right hemisphere processes faces as Gestalten, and the left hemisphere processes them in terms of salient, verbalizable features. Evidence from studies of patients with unilateral cortical lesions (e.g., Yin, 1970), as well as developmental studies (Diamond and Carey, in press; Carey, Diamond and Woods, in press), suggests that the latter mode of processing is relatively inefficient.

Despite the relative inefficiency of the left hemisphere at recognizing faces, normal adults may rely on this mode of processing under certain circumstances. While familiar faces may be encoded as Gestalten, famous faces may be encoded in terms of salient verbalizable features (e.g., Big nose (Jimmy Durante); Big ears (Lyndon Johnson); Cleft chin (Kirk Douglas)). Consequently, the right hemisphere may be differentially involved in the recognition of familiar faces, the left in the recognition of famous faces.

Alternatively, differential involvement of the left hemisphere in naming famous vs. familiar faces may explain the opposite visual field advantages obtained. Differing response requirements of the present experiment (pointing) and Berlucchi's experiment (naming) cannot explain the discrepant visual field advantages, since we have obtained a LVF advantage with familiar faces even when the required response is verbal naming (pilot study) and Marzi, et al. (1974) report a RVF advantage with famous faces even when the required response is a manual key press. However, name accessing of faces one sees several times each day is usually not difficult, nor do we necessarily access the names of people we recognize. In contrast, it may be impossible to "recognize" a famous face without engaging the left hemisphere in the difficult task of accessing the name, even when a naming response is not required. Kinsbourne's (1970) attentional model of hemispheric asymmetries predicts that attention will be biased toward the visual field contralateral to the more active or primed hemisphere. Naming, either overt or covert, may prime the left hemisphere during the recognition of famous, but not familiar faces, and thus explain the divergent visual field advantages obtained.

A less interesting explanation also exists. The discrepant visual field advantages may be explained by procedural differences between the two experiments. For example, faces in Berlucchi's (1974) experiment were presented unilaterally for 400 msecs while faces in the present experiment were presented bilaterally for 60 msecs.

Whether the opposite visual field advantages obtained with famous and familiar faces are due to encoding differences, differential naming demands or procedural differences remains to be determined. The present experiment simply establishes a LVF advantage when the task involves recognition of one's own colleagues, without requiring naming. The obtained LVF advantage for recognition of familiar faces agrees with results which indicate differential right hemisphere involvement in the recognition of complex visuo-spatial stimuli, whether or not these stimuli have verbal labels (e.g., Warrington and James, 1967; Rudel, Denkla and Spalten, 1974; Brizzolara, et al., in press).

However, the discrepancy in experimental results points out the necessity of regarding hemispheric advantages as relative rather than absolute. Just as the right hemisphere can recognize at least familiar, concrete nouns (e.g., Gazzaniga, 1972; Hines, 1976; Day, 1976), the left hemisphere apparently has its own procedures for recognizing faces.

Footnotes

[1] A simple guessing correction for faces was performed. On the face recognition task, subjects were required to pick two faces out of twelve on each trial. The probability of guessing a particular face correctly on the first choice was 1/12; on the second choice, 1/11. Since it is not clear that the order of pointing reflects the order of recognition, both first and second choices were corrected by the average of 1/12 and 1/11. For each subject, the number of faces recognized in the left and right visual fields was computed by using the following formula:

$$\text{CORRECTED TOTAL} = \text{UNCORRECTED TOTAL} - \frac{1/12 + 1/11}{2} \quad \text{x} \quad 18$$

The maximum correct out of 18, under this formula, becomes 16.43, so the percentage correct shown in the figures is the corrected total ÷ 16.43.

[2] Because sixteen faces were presented twice each, an item was considered to be a pair of faces. Each pair of faces was unique since repeated faces were presented in the opposite visual field and were paired with a different face than on the first presentation. Although no words were repeated, a word item was also considered to be a pair of words.

SECTION IV

Development of Right Hemisphere Specialization for the Recognition of Familiar and Unfamiliar Faces

Abstract

Tachistoscopic recognition of words and faces in the left and right visual fields was compared across a range of ages (8-11). All groups showed a RVF advantage for word recognition and all but the 8 year olds, the youngest age group tested, a LVF advantage for recognition of unfamiliar faces. Whereas 8 year olds showed no visual field differences when faces were unfamiliar or even moderately familiar, a LVF advantage was obtained when face stimuli were highly familiar, i.e., subjects' own classmates. We suggest that what is developing during the first decade of life is the ability to encode new faces more and more efficiently, culminating in the ability to compute a configurational representation from a stimulus as degraded as a single still photograph.

Introduction

Results of several recent studies suggest that a milestone in the development of right hemisphere specialization is reached at around age 10. For example, Kohn and Dennis (1974) have demonstrated that patients who had sustained right infantile hemidecortication perform adequately on a number of visuo-spatial tasks. In contrast, persons who sustain right hemisphere injury during adulthood are markedly deficient on these tasks. Sparing of spatial abilities after right infantile hemidecortication is limited to those tasks on which normal children succeed before age 10. This pattern of results suggests that the two hemispheres become differentiated with respect to certain spatial abilities around age 10. A second example concerns the Braille alphabet. Adult readers of Braille perform better with their left than right hands, presumably because such tactual configurations are better mediated by the right cerebral hemisphere (Hermelin and O'Connor, 1971). Rudel, Denkla, and Spalten (1974) have demonstrated that this left hand advantage does not emerge until age 11 for boys and age 12 for girls in an experiment in which sighted children were taught letters of Braille. A final example concerns the development of right hemisphere specialization for the recognition of unfamiliar faces. Clinical studies of patients with unilateral brain lesions (Milner, 1960, 1968; De Renzi, 1966; Warrington and James, 1967; Benton and Van Allen, 1968), studies of commissurotomy patients (e.g., Levy, Trevarthen, and Sperry, 1972; Sperry, 1974) and tachistoscopic studies with normal adults (Rizzolatti, Umilta, and Berlucchi, 1971; Geffen, Bradshaw, and Wallace, 1971; Hilliard, 1973; Klein, Moscovitch, and Vigna, 1976) all indicate differential involvement of the right hemisphere in the recognition of unfamiliar faces by normal adults. In a recent tachistoscopic study, Leehey (Experiment I) has demonstrated that a LVF advantage for recognition of unfamiliar faces emerges between ages 8 and 10, while a RVF advantage for recognition of words is present by age 8, the youngest age group tested. The emergence of a LVF advantage for the recognition of unfamiliar faces coincides with a developmental change in the ability to recognize faces. Two recent studies suggest that children begin to represent previously unfamiliar faces as do adults at around age 10 (Carey, Diamond, and Woods, in press; Diamond and Carey, in press). One of these studies (Carey, Diamond and Woods, in press) demonstrated that children 10 and over show the same differential sensitivity to orientation of faces as normal adults, i.e., spatial inversion interferes with the recognition of unfamiliar faces significantly more than the recognition of other mono-oriented objects such as houses (Yin, 1969). In contrast, 8 year olds show the same insensitivity to orientation of faces as do patients with right posterior brain lesions (Yin, 1970). A second study (Diamond and Carey, in press) demonstrated that 6 and 8 year old children use isolated paraphernalia cues (e.g., earrings, hats, etc.) in judging which two of three photographs depict the same person when the models to be identified are unfamiliar.

The changes at age 10 toward greater sensitivity to orientation of faces and greater resistance to confounding paraphernalia may be explained by the development of the ability to encode faces in terms of configurational properties. The confounding cues experiment provides direct evidence for a shift away from reliance on isolated features at age 10. There is also evidence in this experiment that what replaces encoding in terms of isolated features at this age is encoding in terms of configurational properties (for details, see Diamond and Carey, in press). Likewise, the onset of differential sensitivity to orientation of faces can be explained by the emergence of configurational representation of faces, if one assumes that encoding of isolated feature is less affected by inversion than encoding of configurational information.

Presumably, representation of faces in terms of isolated features, however distinctive, is inadequate to differentiate the large number of faces we recognize. Configurational representation of facial features is not merely equivalent to encoding gross spatial relationships amongst the features. Surely this is done for faces as well as other visuo-spatial stimuli such as houses. For example, just as we perceive the eyes to be above and to the left and right of the nose on a face, we perceive the windows to be above and to the left and right of the door on a house. These relationships are isomorphic for all faces. Since both isolated features and gross positional relationships are inadequate to differentiate the faces we encounter, configurational encoding of facial features may involve such complicated relationships as the distance of the tip of the nose from the upper lip in comparison to the distance of the upper lip from the chin. This form of encoding reflects the unique ratios amongst the distances between various points on a particular face.

Under this interpretation, the emergence of a LVF advantage for the recognition of previously unfamiliar faces coincides with the shift from piecemeal to configurational representation of faces. The convergence of results at age 10 suggests that changes in right hemisphere specialization are associated with development of the ability to encode faces in configurational terms.

Although commitment of the right hemisphere to its adult functions at around age 10 appears to have some generality (Kohn and Dennis, 1974: Rudel, Denckla and Spalten, 1974; Experiment I), this convergence of developmental changes does not imply that all right hemisphere functions become specialized concurrently. In fact, the right hemisphere is differentially involved in some tasks long before age 10. For example, children as young as 5 years of age have a left ear advantage for perception of nonverbal environmental sounds (Knox and Kimura, 1970). Results of another study indicate a left hand advantage for tactual recognition of nonsense shapes in 6 year old boys (Wittelson, 1974).

Commitment of the right hemisphere to its adult functions is not necessarily a unitary process. Do all face recognition tasks become lateralized at the same age, i.e., age 10? It seems unlikely that a 6 year old would encode his mother's face in terms of isolated features, e.g., hairstyle, eyeglasses, hat. In fact, Diamond and Carey (in preparation) report that children as young as 5-6 years of age are not susceptible to confounding paraphernalia cues when models to be identified are their own classmates. This finding suggests that children may be able to represent familiar faces in configurational terms long before age 10. Assuming that the right hemisphere is differentially involved in configurational representation of faces, one might expect a LVF advantage for the recognition of familiar faces before age 10, i.e., developmentally prior to that for previously unfamiliar faces. In order to test this hypothesis, the present study directly compares the emergence of a LVF advantage for the recognition of familiar faces to that for unfamiliar faces. In addition, the present study attempts to replicate the finding (Experiment I) that a LVF advantage for recognition of unfamiliar faces emerges between ages 8 and 10, using new subjects and new face stimuli. This replication is crucial, since results of Experiment I rest on the absence of a LVF advantage in one age group, the 8 year olds.

Method

Subjects. Subjects were drawn from two suburban school systems in the Boston area. Four groups of subjects (ages 8, 9, 10, and 11), for whom the face stimuli were completely unfamiliar, were tested. Each of these groups comprised twenty children, half boys and half girls. Another group consisted of children for whom the face stimuli were highly familiar (i.e., photographs were of students in another classroom at the same school). Each of these groups comprised sixteen 8 year old children, half boys and half girls. All subjects were right-handed with right-handed parents and had vision correctable to 20/20.

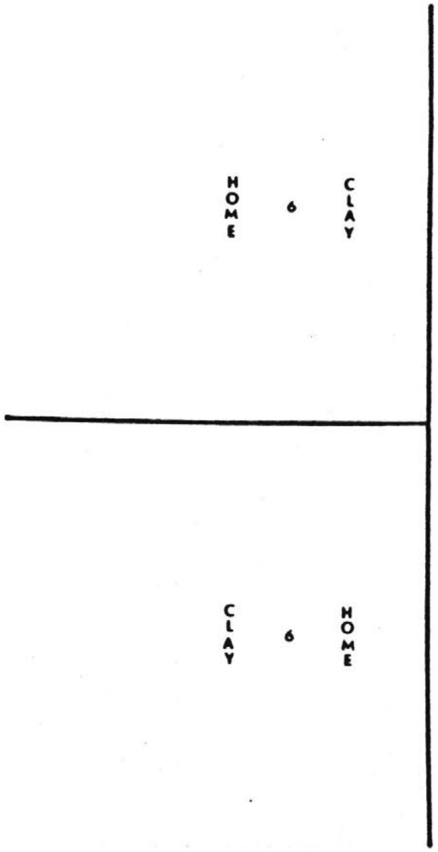
Apparatus and Stimuli. Following the design of McKeever and Huling (1971), stimuli were bilaterally presented. A Gerbrands 2-channel tachistoscope (Model T-2B1) was used to present stimuli. Word stimuli consisted of 8 practice pairs and 18 test pairs (high frequency four letter nouns). Face stimuli consisted of 8 practice pairs and 18 test pairs (half male and half female). The face stimuli were photographs of 8 year old children, highly familiar for one group of eight year old subjects (Group HF), at an intermediate level of familiarity for a second group (Group MF), and completely unfamiliar for a third group (Group UF). The 9, 10, and 11 year olds were also completely unfamiliar with the face stimuli.

The near point of each word was located 1°14' to the left or right of fixation and each word subtended 1°23' of vertical visual angle. The near point of each face was located 55.5' to the left or right of fixation and each face subtended 2°37' of horizontal visual angle at its widest point

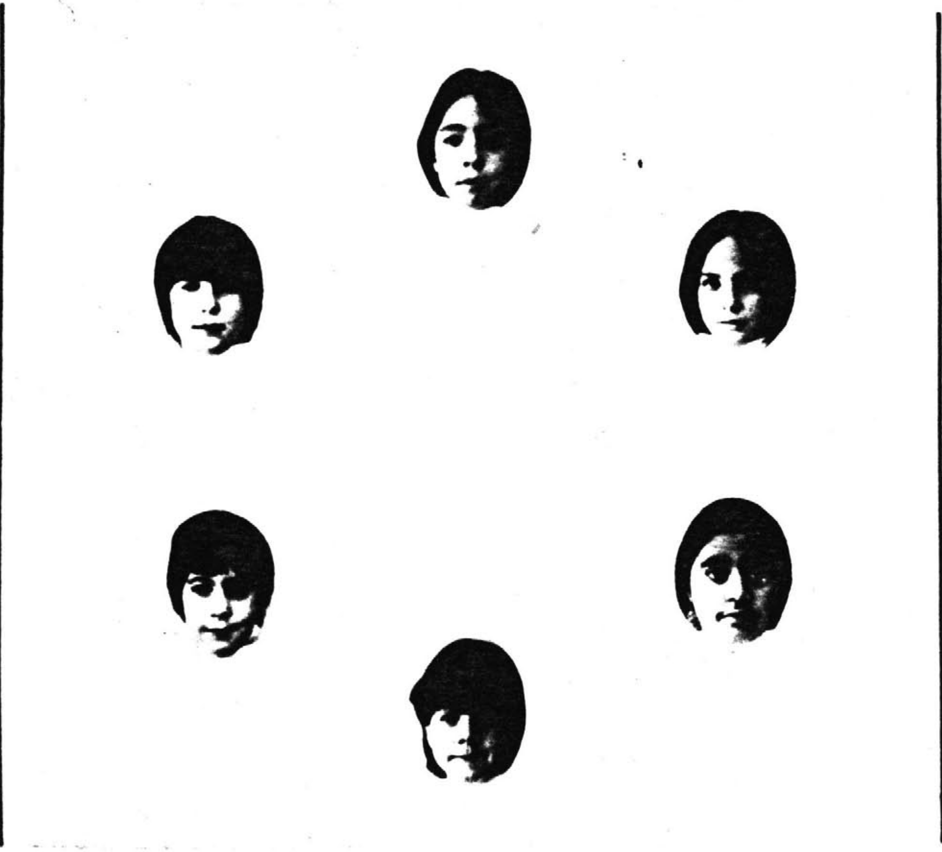
(Figure 5: Examples of stimuli). An arabic numeral ranging from 2 to 9 was chosen at random and typed at the fixation point of each stimulus.

Procedure and Design. Subjects began each trial by viewing a preexposure field consisting of 6 lines radiating from an open space in the center. This space was just large enough to be filled by the fixation point numeral on each stimulus card as it was flashed. Two trials with cards having only fixation point numerals were given to accustom S to the procedure. Eight practice trials preceded both the face recognition and word recognition portions of the experiment. Prior to each trial, E said "focus" to alert S to fixate on the center space. The stimulus card was then flashed followed immediately by the return of the preexposure field. The digit provided positive control over fixation and only trials on which the digit was reported correctly were counted, as an error could indicate eye movement or improper fixation. As a further precaution, both words and faces were presented at durations below eye movement latency, faces at 60 or 120 msecs, and words at 80, 100 or 120 msecs. Two different exposure durations were used on the face recognition task in an attempt to equate the performance levels of subjects familiar with face stimuli (80 msecs for Group HF and Group MF) and those unfamiliar with the face stimuli (Group UF, 120 msecs). It was necessary to introduce a variable exposure duration to the word recognition task to control for inter-subject variability in ability to recognize words. Exposure duration for the word pairs was chosen on the basis of performance on eight practice trials. Once chosen, this duration was used for the 18 test trials.

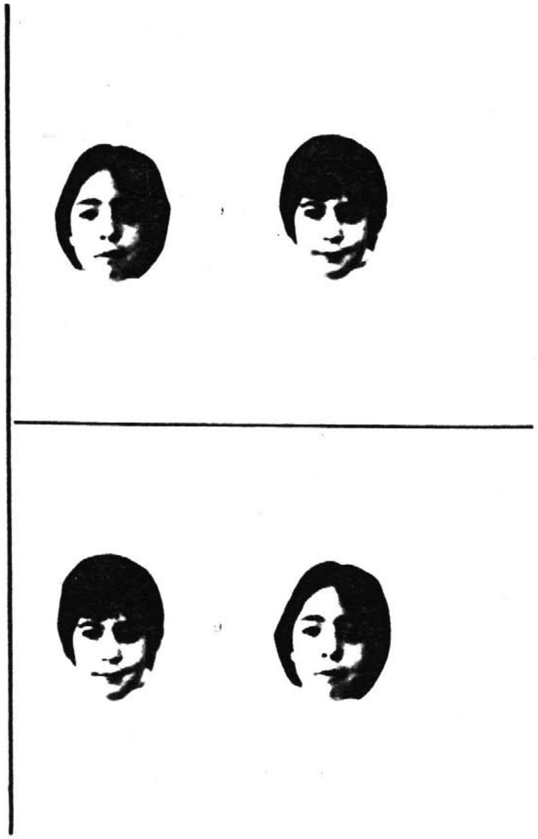
On the word task, after reporting the digit, if possible, S reported the words or any part of the words which appeared on the card along with



WORD STIMULI



FACE ARRAY



FACE STIMULI

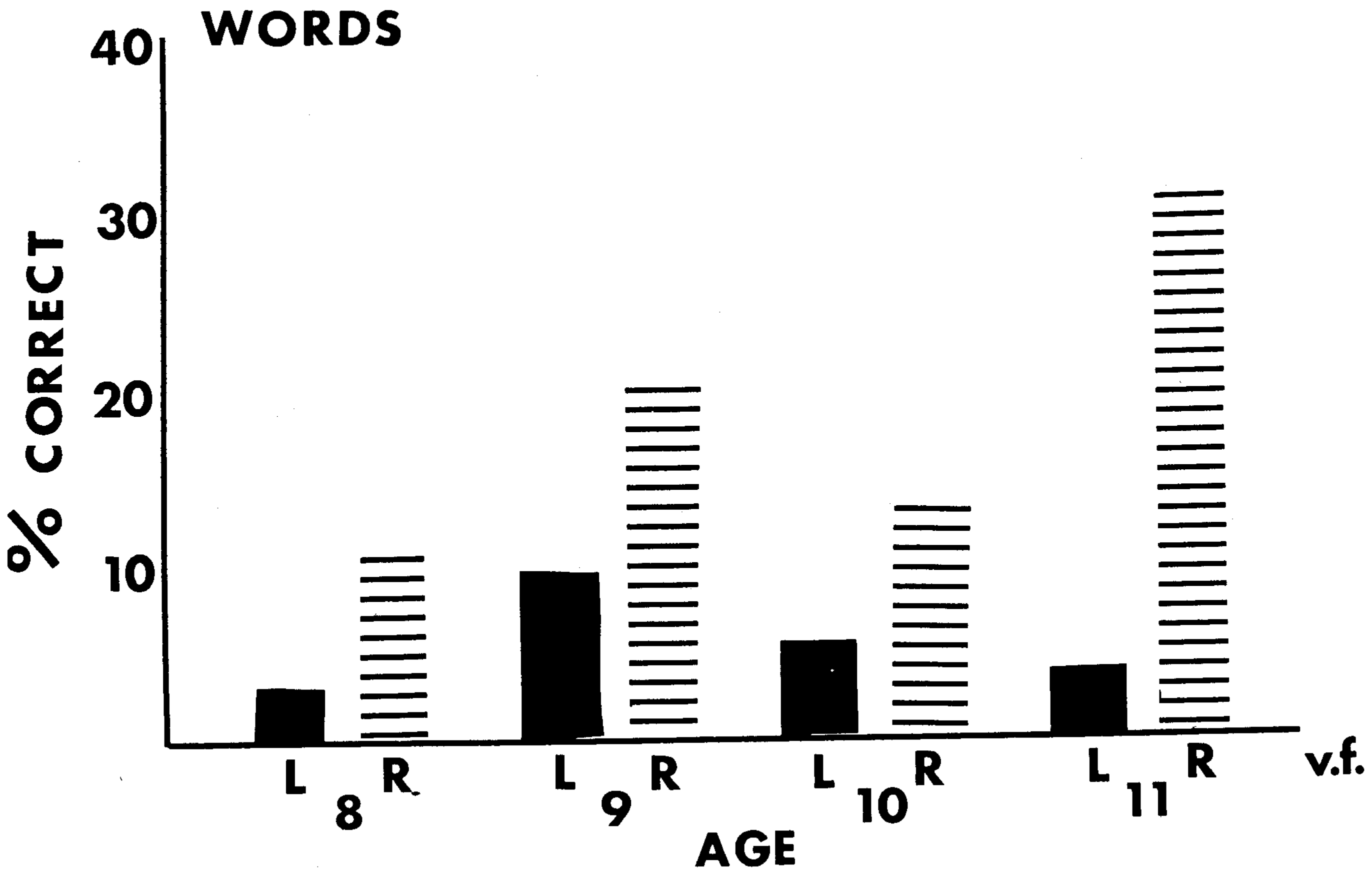
the digit. On the face recognition task, after reporting the digit, S made a forced choice judgement of two faces from an array of six, two of which were identical to those which had been flashed. Four arrays of six faces were used throughout the experiment, two consisting of photographs of six males and the other two of six females (Figure 5: Example). For each array, four faces were presented twice, one was presented once, and one was never presented, in order to discourage subjects from using a "process of elimination" strategy to match targets shown later in the series. Ss were informed that some faces would be presented once, some more than once, and some not at all in the instructions. Repeated items were presented in the opposite visual field and were paired with a different face than on the first presentation. Stimuli were presented in several random orders, balanced across conditions.

Materials were blocked such that half the subjects in each group were presented words before faces, and half were presented faces before words. Side of presentation was counterbalanced across Ss. All stimuli were viewed binocularly.

At the conclusion of the experimental session, 8 year old subjects in Groups MF and HF rated face stimuli for "familiarity" on a scale from 1-10, a 1 being given to a face never seen before the experimental session, a 10 being given to a face one would recognize anywhere, even after a five year interval. Subjects were also asked to name the persons in the photographs, if possible.

Results

Figure 6 (a and b) shows the percentages of words and faces recognized in the LVF and RVF for the four groups of subjects (aged 8, 9, 10, 11) who


WORDS

40
30
20
10
% CORRECT
L
R
8
L
R
9
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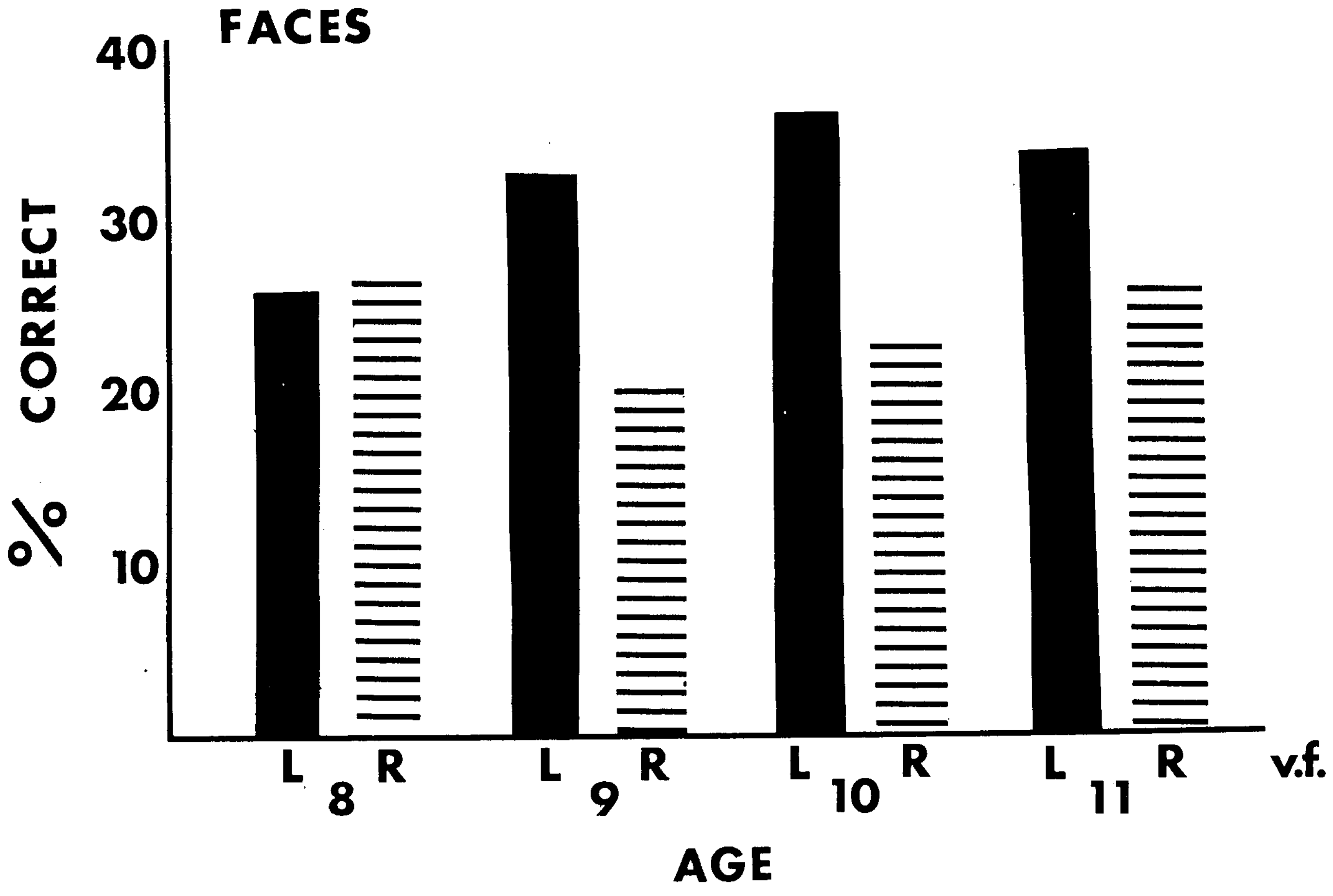
11
v.f.
AGE


FACES

40
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v.f.
AGE

were completely unfamiliar with the face stimuli. The percentage of faces recognized in each visual field was corrected for guessing.[1] As can be seen from Figure 6a, all age groups recognized more words in the RVF than in the LVF. In contrast, Figure 6b shows that all age groups, except the 8 year olds, the youngest age group tested, recognized more faces in the LVF than the RVF. This pattern of results essentially replicates the results of Experiment 1, using new subjects and new face stimuli.

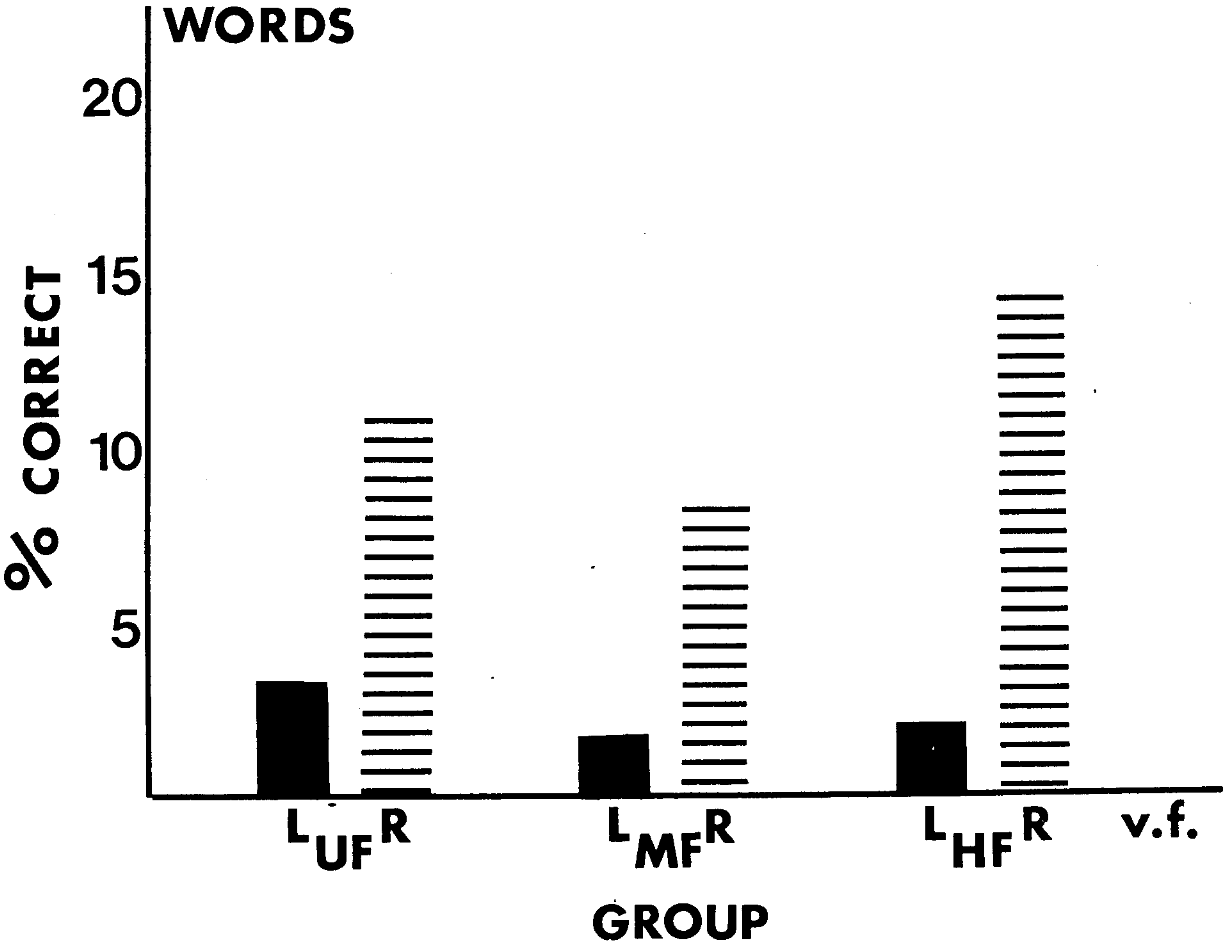
Significance of predicted visual field advantages were tested by using the min F' procedure suggested by Clark (1973), where min $F' = F_1F_2/F_1 + F_2$, F_1 being the *F*-ratio resulting from the comparison of subject means in the relevant conditions, and F_2 being the *F*-ratio resulting from the comparison of item means.

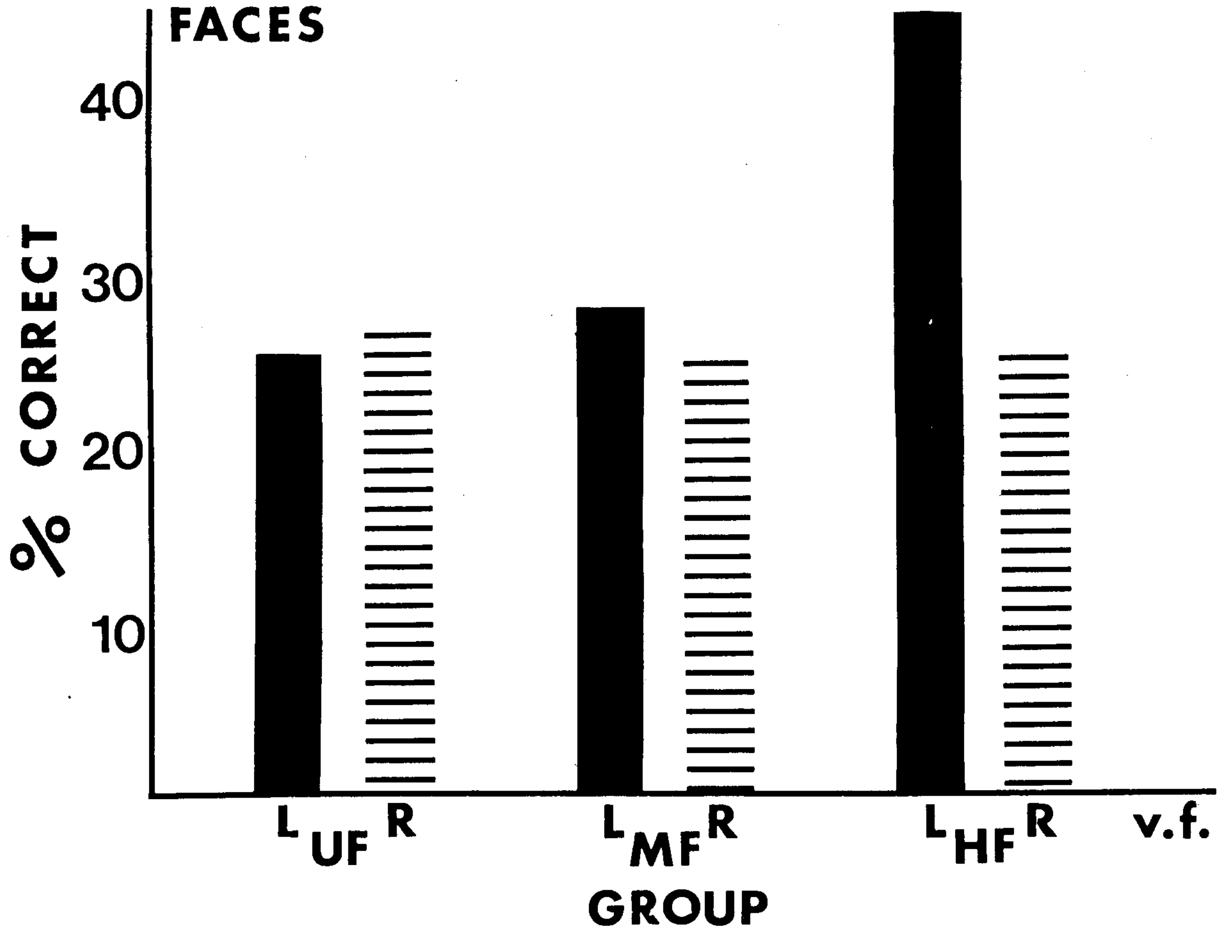
A factorial analysis of variance for each age group separately revealed significant Materials (faces, words) x Position (left, right) interactions for all but the 8 year olds, the youngest age group tested (8 year olds: min $F'(1,36) = 1.162$, $p > .10$; 9 year olds: min $F'(1,36) = 9.396$, $p < .005$; 10 year olds: min $F'(1,35) = 9.689$, $p < .005$; 11 year olds: min $F'(1,33) = 15.49$, $p < .001$). The Age (8, 9, 10, 11) x Materials (faces, words) x Position (left, right) interaction just missed significance by the conservative min F' procedure, but both F_1 and F_2 were significant (min $F'(3,122) = 2.53$, $p < .07$; $F_1(3,76) = 4.2174$, $p < .01$; $F_2(3,51) = 6.3327$, $p < .001$).[2]

Subsequent t-tests for correlated means reveal that the difference between words recognized in the RVF and words recognized in the LVF is significantly greater than zero for all age groups tested (_8 year olds_: t = 2.459, df = 19, $p < .025$, 1-tailed test; _9 year olds_: t = 2.605, df = 19, $p < .01$, 1-tailed test; _10 year olds_: t = 3.172, df = 19, $p < .01$, 1-tailed test; _11 year olds_: t = 5.064, df = 19, $p < .001$, 1-tailed test). In contrast, t-tests reveal that a LVF advantage for recognition of unfamiliar faces is not present until after age 8 (_8 year olds_: t = .221, df = 19, $p > .10$, 1-tailed test; _9 year olds_: t = 2.385, df = 19, $p < .025$, 1-tailed test; _10 year olds_: t = 2.874, df = 19, $p < .01$, 1-tailed test; _11 year olds_: t = 2.143, df = 19, $p < .025$, 1-tailed test).

Figure 7 (a and b) shows the percentages of words and faces recognized in the LVF and RVF by the three groups of 8 year olds tested, i.e., those who were unfamiliar with the face stimuli (Group UF), those who were moderately familiar with the face stimuli (Group MF), and those who were highly familiar with the face stimuli (Group HF). Group UF is the same group of 8 year olds shown in Figure 6. As can be seen from Figure 7a, all three groups recognized more words in the RVF than in the LVF. In contrast, Figure 7b shows that only those 8 year olds who were highly familiar with the face stimuli recognized more faces in the LVF.

A factorial analysis of variance for each group separately revealed a significant Materials (faces, words) x Position (left, right) interaction for Group HF, but not for Groups MF or UF (_Group UF_: min $F'(1,36) = 1.162$, $p > .10$; _Group MF_: min $F'(1,30) = 1.621$, $p > .10$; _Group HF_: min $F'(1,32) = 19.575$, $p < .001$). Again the Group (UF, MF, HF) x Materials (faces, words) x Position (left, right) interaction was only marginally significant by the conservative min F' procedure but


WORDS
20
15
10
5
% CORRECT
L UF R
L MF R
L HF R
v.f.
GROUP


FACES
40
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% CORRECT
L UF R
L MF R
L HF R
v.f.
GROUP

both F_1 and F_2 were significant (min $F'(2,76) = 2.66$, $p < .08$; $F_1\ (2,49) = 5.952$, $p < .005$; $F_2(2,34) = 4.808$, $p < .025$).[2]

Subsequent t-tests for correlated means reveal that the differences between words recognized in the RVF and words recognized in the LVF are significantly greater than zero for all three groups of 8 year olds (Group UF: $t = 2.459$, $df = 19$, $p < .025$; Group MF: $t = 2.643$, $df = 15$, $p < .01$; Group HF: $t = 3.487$, $df = 15$, $p < .01$). However, only Group HF shows a significant LVF advantage for faces (Group UF: $t = .221$, $df = 19$, $p > .10$; Group MF: $t = .466$, $df = 15$, $p > .10$; Group HF: $t = 4.037$, $df = 15$, $p < .001$) (all 1-tailed tests).

Groups HF and MF were asked to rate the faces for familiarity at the end of the test session. The average familiarity rating given by Group HF was 9/10, by Group MF, 7.5/10. Group HF was able to name an average of 98% of the faces, Group MF, an average of 60%. Subjects in Group UF had never seen the faces before the test session.

Discussion

The two chief predictions of this study were confirmed. One prediction was simply that results of Experiment 1 would be replicated, i.e., a LVF advantage for the recognition of previously unfamiliar faces would emerge between ages 8 and 10 and a RVF advantage for the recognition of words would be present by age 8, the youngest age group tested. In confirmation, results of the present experiment indicate that a LVF advantage for recognition of unfamiliar faces does not emerge until age 9, while a RVF advantage for word recognition is present by age 8. Closer age sampling in the present study reveals that the LVF advantage for recognition of unfamiliar faces may actually emerge at age 9, rather than age 10. This result is also consistent with findings of Marcel and Rajan (1975) who report a LVF advantage for recognition of unfamiliar faces in a group of 7-9 year olds. Unfortunately, no further breakdown of these subjects by age is reported.

The second prediction of this study was also confirmed. Results indicate that a LVF advantage for recognition of familiar faces is developmentally prior to a LVF advantage for recognition of unfamiliar faces. Whereas 8 year olds show no visual field differences when faces are unfamiliar, or even moderately familiar, a LVF advantage is obtained when face stimuli are subjects' own classmates.

The emergence of a LVF advantage for the recognition of familiar faces by age 8, developmentally prior to that for the recognition of previously unfamiliar faces, is consistent with the hypothesis that representation of faces in terms of configurational properties involves the right hemisphere. The following pattern of results has emerged. Evidence from two recent developmental studies suggests that unfamiliar faces are not represented in terms of configurational properties until age 9-10 (Carey, Diamond and Woods, in press; Diamond and Carey, in press). Familiar faces, in contrast, may be represented configurationally much earlier in development, i.e., by age 5-6 (Diamond and Carey, in press). Results of the present experiment, as well as Experiment I show that a LVF advantage for the recognition of previously unfamiliar faces emerges at age 9-10, coincident with the shift to configurational representation of these faces. A LVF advantage for the recognition of familiar faces, however, is present at least by age 8, the youngest age group tested. In order to determine whether there is a lower age limit for the LVF advantage, children younger than age 8 should be tested on tachistoscopic recognition of highly familiar faces.

This remarkable developmental convergence of a LVF advantage for the recognition of familiar and unfamiliar faces and representation of these faces in configurational terms suggests that changing patterns of hemispheric lateralization are somehow involved in the shift from piecemeal to configurational encoding of unfamiliar faces at age 9-10.

Differential involvement of the right cerebral hemisphere in configurational representation of faces is not surprising in view of evidence suggesting that the right hemisphere is specialized for complex visuo-spatial discriminations and integrations (e.g., Milner, 1958; Kimura, 1969; Warrington and James, 1967; De Renzi, Scotti and Spinnler, 1969). Results of tachistoscopic studies with normal adults, for example, indicate differential right hemisphere involvement in a task requiring location of a dot within a framework (Kimura, 1969; Levy, personal communication). In addition, studies of patients with unilateral brain injuries demonstrate that patients with right posterior lesions are impaired on discriminations of position, slope of line, and size of gap in a contour, compared to other lesion groups but are unimpaired on discriminations of particular features or characteristics of visual stimuli such as size or shade (Taylor and Warrington, 1973). On the basis of these results, Taylor and Warrington (1973) argue that the posterior sector of the right hemisphere is involved in the 'spatial component' of these tasks.

If the right hemisphere is specialized for configurational representation of familiar faces by age 8 or younger, how should later changes in face recognition abilities be characterized? We suggest that what is developing during the first decade of life is the ability to represent each new face in configurational terms with greater and greater efficiency. While adults and children 10 and over can encode the configurational properties of a new face from a stimulus as degraded as a single still photograph, younger children require repeated exposure to a face in order to encode it in these terms. It is as though children 9-10 and over are capable of making each new face familiar from very little experience with it.

Before age 9-10, configurational representation of faces and differential involvement of the right hemisphere in face recognition is limited to a relatively small set of highly familiar faces. The change at age 9-10 is apparently rather powerful and abrupt, since a LVF advantage for moderately familiar faces is not even present at age 8. It would be interesting to test 8 year olds on the confounding paraphernalia task, using moderately familiar faces as models. There is an alternative and less interesting explanation for the absence of a LVF advantage for moderately familiar faces at age 8. Moderately familiar faces, like famous faces, may be impossible to "recognize" without engaging the left hemisphere in the difficult task of accessing the name. Kinsbourne's (1970) attentional model of hemispheric asymmetries predicts that attention will be biased toward the visual field contralateral to the more active or primed hemisphere. An attentional bias toward the RVF, caused by covert naming, may explain the lack of a LVF advantage for moderately familiar faces.

What developmental factor(s) might restrict the LVF advantage and configurational representation of faces to the relatively small set of highly familiar faces before age 9-10? A maturational change involving relevant cortical areas within the right hemisphere might be necessary before faces can be represented at the adult level of efficiency. This physical change may not occur until age 9-10. However, a change in lateralization on a particular task is not necessarily due to a maturational change. For example, Bever and Chiarello (1974) report that musically experienced adults recognize simple melodies better in the right ear than the left, while the reverse is true of naive listeners. It would be absurd to suggest that this change in lateralization awaits a maturational change of relevant cortical structures. Similarly, the emergence of a LVF advantage for the recognition of previously unfamiliar faces and changes in face recognition ability at age 9-10 may not depend on a maturational change.

Alternatively, experience making enough faces familiar may be necessary before a new face can be represented in terms of configurational properties from a stimulus as degraded as a single still photograph. During adulthood, experience with particular faces certainly affects the schema for recognizing new faces, since adults are better at recognizing members of their own racial group than a group with which they are unfamiliar (Shepherd, Deregowski and Ellis, 1974). Analogously, during development, the schema for representing new faces may derive from the set of familiar faces which have been encoded in this manner. Whether a physical-maturational change and/or a cognitive-developmental change is the bottleneck in the emergence of the adult level of efficiency for representing faces remains an open question.

Footnotes

[1] A simple guessing correction for faces was performed. On the face recognition task, subjects were required to pick two faces out of six on each trial. The probability of guessing a particular face correctly on the first choice was 1/6; on the second choice, 1/5. Since it is not clear that the order of pointing reflects the order of recognition, both first and second choices were corrected by the average of 1/6 + 1/5. For each subject, the number of faces recognized in the left and right visual fields was computed by the following formula:

$$\text{CORRECTED TOTAL} = \text{UNCORRECTED TOTAL} - \frac{1/6 + 1/5}{2} \times 18$$

[2] Because sixteen faces were presented twice each, an item was considered to be a pair of faces. Each pair of faces was unique since repeated faces were presented in the opposite visual field and were paired with a different face than on the first presentation. Although no words were repeated, a word item was also considered to be a pair of words. This conservative estimate of the number of items probably contributed to the failure of min F' to reach a statistically significant level.

SECTION V

General Discussion

The preceding sections provide evidence that development of right hemisphere specialization for the recognition of faces is associated with developmental changes in face recognition abilities. The emergence of a LVF advantage for the recognition of previously unfamiliar faces and the emergence of the ability to encode previously unfamiliar faces configurationally, from a single brief exposure, converge at age 10. The finding of a LVF advantage for the recognition of familiar faces by age 8, the youngest age group tested, is consistent with evidence that familiar faces may be represented configurationally as early as age [illegible]. Apparently, what is developing during the first decade of life is the ability to encode faces in configurational terms with greater and greater efficiency (i.e., with less and less exposure), culminating in the ability to do so from a stimulus as degraded as a single still photograph.

The obtained pattern of results suggests that the right hemisphere may always be differentially involved when faces are represented configurationally, i.e., in terms of distinctive spatial relationships amongst features. Such an association is not surprising in view of reports indicating that patients with right posterior cerebral injuries are impaired on various face recognition tasks (e.g., De Renzi and Spinnler, 1966; Warrington and James, 1967; Benton and Van Allen, 1968; Yin, 1970). Moreover, in normal adults, the right hemisphere is known to be differentailly involved in tasks requiring subtle visuo-spatial discriminations and integrations (e.g., Milner, 1958; Warrington and James, 1967; De Renzi, Scotti and Spinnler, 1969).

Several recent studies suggest that age 10 marks a milestone in the commitment of the right hemisphere to its adult functions (Rudel, Denkla and Spalten, 1974; Kohn and Dennis, 1974). Developmental changes on tasks involving recognition of unfamiliar faces at this same age suggest that these changes may be part of a more global commitment of the right hemisphere to its adult functions.

Although faces are objects of particular interest from early infancy (e.g., Haaf and Bell, 1967; Lewis, 1969; Goren, Sarty and Wu, 1975), developmental changes in face perception occur as late as age 10. It has been suggested that possible limiting factor(s) in this protracted development may be cognitive-developmental and/or maturational in nature. An argument has been made that there is at least a maturational component to this development.

In any case, a change in the visual field advantage for recognition of previously unfamiliar faces at age 10 supports the claim that commitment of the right hemisphere to its adult functions may not be complete before this age. Moreover, commitment of the right hemisphere to its adult functions may have a more protracted developmental history than commitment of the left hemisphere to its adult functions.

SECTION VI

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