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Modeling Face Identification Processing in Children and Adults

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Two face identification experiments were carried out to study whether and how children (5-year-olds) and adults integrate single facial features to identify faces. Using the paradigm of the Fuzzy Logical Model of Perception each experiment used the same expanded factorial design, with three levels of eyes variations crossed with three levels of mouth variations as well as their corresponding half-face conditions. In Experiment 1, an integration of facial features was observed in adults only. But, in adjusting the salience of the features varied, the results of Experiment 2 indicate that children and adults evaluated and integrated information from both features to identify a face. A weighted Fuzzy Logical Model of Perception fit the judgments significantly better than a Single Channel Model and questions previous claims of holistic face processing. Although no developmental differences in the stage of the integration of facial information were observable, differences between children and adults appeared in the information used for face identification. © 2001 Academic Press

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Notwithstanding the impressive face identification capabilities during infancy (e.g., Bushnell, 1982; Bushnell, Sai, & Mullin, 1989; Pascalis, de Haan, Nelson, & de Schoenen, 1998), face identification during the 1st decade of life continues to undergo development. Young children are dramatically worse than adults at encoding and subsequently identifying unfamiliar faces. Marked improvement between ages 2 and 10 is observed on simple recognition tasks (for an overview see Flin & Dziurawiec, 1989). Although these differences could be differences in information processing of faces, current research does not offer a definite answer. On the one hand, the literature on face recognition suggests that 6-year-old children as well as adults process faces holistically (e.g., Carey, 1996). On the other

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hand research on nonfacial visual processing modes demonstrated that children 5 years of age and older process visual stimuli analytically as do adults (Ashkenasy & Odom, 1982; Thompson & Massaro, 1989; Wilkening & Lange, 1989).

In an attempt to integrate these research lines, in the present study, we investigate face processing by employing expanded factorial designs varying several sources of information and mathematical model testing. We examine whether children's and adults' face processing can be explained by analytic models of perception like the Fuzzy Logical Model of Perception or the Single Channel Model. If these models are able to explain face identification data, evidence for analytic face processing is given; if they fail to explain the data, analytic face processing would be questionable.

Research on Processing of Faces in Adults

Most recent research on face identity processing focused on issues of holistic and analytic processing (Bruce & Humphreys, 1994; Diamond & Carey, 1986; Farah, Tanaka, & Drain, 1995; Farah, Wilson, Drain, & Tanaka, 1998; Tanaka & Farah, 1993; Tanaka & Sengco, 1997). However, whereas most investigators agree on the definition of analytic processing in terms of analyzing featural dimensions, at least two definitions of holistic processing can be differentiated: holistic encoding and configurational encoding (Carey & Diamond, 1994). According to Tanaka and Farah (1993) as well as Farah et al. (1998), holistic encoding means that a particular face is not represented in terms of its parts but in terms of a templatelike representation of the whole face. Farah, Tanaka, and Drain (1995) characterized holistic representations as relatively non-part-based representations. In contrast, configurational encoding emphasized the specific spatial relationships among the individual facial features (first-order relational information) as well as the second-order relationships which include the spatial locations of the facial parts relative to the prototypical arrangement of the eyes, nose, and mouth (Diamond & Carey, 1986). Diamond and Carey suggested that with experience, participants develop a finely tuned face prototype, with respect to which they can encode the second-order relational information in faces.

Both kinds of holistic processing are in agreement with the findings of Tanaka and Farah (1993) that individual facial features were more easily recognized when they were part of the complete face than when they were presented alone. In Tanaka and Farah's task, participants learned to identify a set of faces and a set of some contrasting class of stimuli (scrambled faces, inverted faces, and houses). The task was to identify the single parts of the faces in isolation as well as in the context of the whole face. The results showed that participants identified upright facial stimuli more easily and correctly in the whole face condition, whereas this advantage disappeared with other classes of visual stimuli as scrambled faces, inverted faces, or houses.

A current version of holistic processing also acknowledges the influence of individual facial parts (Tanaka & Sengco, 1997). The authors demonstrated that adults performed above chance when recognizing face parts presented in isolation, indicating that the individual face parts were encoded independently of the other features and their configuration. Nevertheless, the authors emphasized the interaction between featural and configurational information from a face because their results also showed that alterations in facial configurations interfered with the retrieval of facial features, whereas this interference did not appear with inverted faces or nonface stimuli. Thus, for adults, current research suggests that upright faces are processed more holistically than inverted faces or other nonface stimuli.

Research on Face Processing in Children

Tanaka, Kay, Grinell, Stansfield, and Szechter (1998) argued for holistic processing because they observed an advantage of identifying facial parts in whole faces relative to those presented in isolation during the age range between 6 and 10 years. In line with these results, the studies carried out by Baenninger (1994) emphasized young children's (6 years of age) tendency to rely more on configural information than on featural information. In light of new findings, Carey and Diamond (1994) and Carey (1996) modified their original assumption of an analytic to holistic shift. Using the task of Young, Hellawell, and Hay (1987), Carey and Diamond (1994) asked children between 6–7 and 10 years as well as adults to name the upper half of a face when the lower half of the face belonged to a different person. In different conditions the face halves were aligned (composite faces) or not aligned (noncomposite faces) and the faces were shown upright or inverted. The authors reported that children and adults were slowed by the mismatch of the upper half of the composite in comparison to the noncomposite faces and at all ages this interference was obtained only when the faces were upright. Thus, there was no processing shift from analytic to holistic processing because at all ages children processed the faces holistically. The effect of inversion on the measure of holistic processing was constant over age. Second, older participants were more affected by inversion than were younger participants. With increasing age inverted faces were encoded less efficiently than upright faces. This latter effect was independent of the effect of inversion on the measure of holistic encoding. In sum, the current state of affairs concerning the development of face processing is that children as young as 6 years of age process upright faces but not inverted faces holistically, just as do 10-year-olds and adults.

Research on Processing of Nonfacial Stimuli in Children and Adults

The conclusion that children and adults process faces holistically stands in sharp contrast to findings on visual development using nonfacial stimuli. A longstanding proposal is centered around the idea of a developmental shift from holistic modes of processing in young children (around age 4 to 7) to analytic modes of processing in older children and adults (Kemler Nelson, 1989; Shepp, 1978; Smith & Kemler, 1977; Werner, 1926). Although this view of a developmental shift has been challenged and modified, subsequent studies did not question the assumption of an adult as an analytic processor but simply the proposal that children are typically holistic processors.

One issue concerns the diagnosis of holistic processing in the commonly used restricted classification task (Ashkenasy & Odom, 1982). The authors proved that the putative holistic classifications could be the result of not finding an exact match on the dimension young children focused on. Indeed, Ashkenasy and Odom (1982) found that young children focused on single visual dimensions, usually the dimension containing the most stimulus variability or distinctiveness (see also Odom & Guzman, 1972). In a differential sensitivity account of cognitive development, Cook and Odom (1992) explicated that what changes across development is not the processing mode—from holistic to analytic—but the information's relative position in hierarchies of perceptual sensitivity. Performance is more accurate in problems that require use of dimensions that are higher in perceptual salience than in problems that require use of dimensions lower in salience. Salience can change with prior experience with the dimension that is perceived and the way the dimension is physically represented in the environment.

An important concern is that the diagnosis of holistic processing in children has analyzed average results and ignored individual differences. When individual results are analyzed in the context of the restricted classification task paradigm or a concept-learning task, children and also adults have a strong bias to use just a single dimension to make their judgments (e.g., Schwarzer, 1997; Thompson, 1994; Ward, Vela, & Hass, 1990; Wilkening & Lange, 1989).

Another line of research explored the nature of perception in preschool children and adults during the earliest moments of visual processing (Thompson & Massaro, 1989). In contrast to the mentioned restricted classification or concept learning tasks, the goal was to investigate perceptual processing while minimizing processes of postperceptual decision making. The experimental test was carried out within the paradigm of a pattern recognition situation and mathematical model testing within the context of the Fuzzy Logical Model of Perception (explained in detail below). The general logic of these experiments is to manipulate the features of a multidimensional stimulus independently of one another and to measure the rule of their joint influence on the performance of interest. In the study by Thompson and Massaro (1989) the children's and adults' judgments were best described by the predictions of the Fuzzy Logical Model of Perception. The model predicts that children and adults encode (evaluate) single features independently and combine them during a second multiplicative operation. Independent encoding of features is consistent with analytic processing rather than holistic processing. The role of individual features in the conceptualization of holistic processing—if they have any role—is only secondary and processing of the whole stimulus cannot be reduced to processing of separate features (see Kemler Nelson, 1989).

In sum, previous studies on visual nonfacial processing concerning the putative holistic processing in children showed that children, like adults, indeed have access to single visual features and therefore their processing modes can be named as analytical.

There is evidence that children process nonfacial visual stimuli analytically and also that the processing of faces is built up from single facial attributes (Schwarzer, 2000; Schwarzer & Korell, in press). These authors used a category learning task in which children and adults had to categorize faces which varied in four attributes (eyes, nose, mouth, and outline). The construction of the categories allowed participants to categorize faces either by focusing on a single facial attribute or by taking the features of the whole face into account. The results showed that children of ages 4–5 and 10 years categorized faces by focusing on single facial features, whereas the majority of the adults based their categorizations on the whole face, using three or four facial attributes. Moreover, Schwarzer and Korell's (in press) study is the first to show that even 4- to 5-year-old children are able to recognize faces above a chance level. By using an age-specific experimental setting Schwarzer and Korell (in press) demonstrated significant face recognition capabilities even in processing very similar faces. Moreover, Schwarzer's results (2000) were consistent with those from Pedelty, Levine, and Shevell's (1985) study on face processing using a multidimensional scaling approach. Young children (between 7 and 10 years of age) focused on singular dimensions, whereas older children and adults attended to two or more dimensions when making face similarity judgments. Thus, developmental differences seem to appear only with respect to the amount of facial information (one feature or more features) used in processing and not with respect to the mode of processing (analytic or holistic). However, these studies do not address the question of how multiple facial features are integrated when several features are used.

These studies as well as the studies on nonfacial visual processing cast doubt on the conclusion that children and adults process faces holistically. One appropriate method to test the hypothesis of analytic and holistic processing—not used in the context of face processing until now—is to test whether analytic models like the Fuzzy Logical Model of Perception or the Single Channel Model could explain face identification in children and adults. If these models fit data on face identification, evidence for analytic processing is given; if they fail to explain the data holistic face processing seems more appropriate.

Fuzzy Logical Model of Perception

The Fuzzy Logical Model of Perception assumes three stages between stimulus event and a response: evaluation, integration, and decision. With regard to the current experiments, the Fuzzy Logical Model of Perception predicts that participants evaluate the identity of a face according to information arriving from multiple sources, i.e., separate facial features. Stimulus variation is made along several dimensions [in this case, eyes variations (including variations of eyebrows and forehead) and mouth variations]. An important criterion for manipulating two features is that they can be varied independently of one another. Varying one cue in the upper face and one cue in the lower face fulfilled this condition. In the current experiments, three levels of the upper face and three levels of the lower face were combined factorially. In addition, according to the expanded factorial design, six half-face conditions were presented. The half-face conditions displayed only the three levels of the upper and the three levels of the lower halves of the stimulus faces. The variations of the eyes (including their covariates) and mouth features were varied as can be seen in Fig. 1.[1]

The eyes, eyebrows and the height of the forehead were varied in the upper face. As is shown in Fig. 1 (comparing the faces within each column), the eyes varied from straight gaze, narrow eyebrows, and a long forehead (Level 3 at the bottom of each column) to a gaze toward the left corner, wider eyebrows, and a shorter forehead (Level 1 at the top of each column). Variations of the mouth in terms of its width comprised the second factor. The mouth varied from a small mouth (Level 1 at the left side of each row) to a wide mouth (Level 3 at the right side of each row).

In order to use the 15 faces (9 whole faces plus 6 face-halves) in the context of a face identification task we defined two prototypical faces. These faces contained the extreme levels on both features, eyes (and their covariates) and mouth. One prototype had eyes with a straight gaze, a long forehead, narrow eyebrows, and a wide mouth (prototype with Level 3 for the eyes and Level 3 for the mouth; see the face at the right corner at the bottom). The contrasting prototype had eyes which look to the left corner, a short forehead, wider eyebrows, and a small mouth (prototype with Level 1 for the eyes and Level 1 for the mouth, see the face at the left corner at the top). We named these prototypes Bob (1,1) and John (3,3). The participants had been familiarized with these prototypes and the prototypes were present during the entire experiment.

Within the context of the Fuzzy Logical Model of Perception, it is assumed that participants evaluate the information from each source (i.e., the varied features) according to the degree of match to the given prototypes. At the feature evaluation stage, each physical input is transformed to a psychological value and is represented in the model equations in lowercase (e.g., if E_i represents the eyes information, E_i would be transformed to e_i, the degree to which the eyes variations support the alternative “Bob”). An important assumption is that the evaluation of a particular feature occurs independently of the presence or absence of other features and their information value. With just two alternatives, Bob (B) and John (J), we can make the assumption that the degree to which the eyes variations (including their covariates) support alternative J is $1 - e_i$ (Massaro & Friedman, 1990). Feature evaluation occurs analogously for the mouth variations, M_j.

The evaluation stage is followed by the integration stage. Feature integration consists of a multiplicative combination of the feature values supporting a given alternative. If e_i and m_j are the values supporting the alternative B, then the total support, $M(B)$, for the alternative B would be given by the product of e_i and m_j:

$$M(B) = e_i m_j.$$

The third stage within the Fuzzy Logical Model of Perception is decision, which uses a relative goodness rule (Massaro & Friedman, 1990) to give the

[1]We thank Dr. N. Troje for constructing and providing the faces.

FIG. 1. Stimulus faces used in Experiment 1. The four faces displaying the maximum feature variations (at the corners of the figure) as well as faces displaying "neutral" variations (in the middle of the figure). The prototype "Bob" is the face at the left corner at the top and the prototype "John" is the face at the right corner at the bottom. The half-face conditions displayed only the upper or lower half of the stimulus face. The reader can cover half of the face to experience these conditions.

relative degree of support for each of the test alternatives. In the two-alternative choice task, the probability of a Bob choice, $P(B)$, is equal to

$$P(B|E_iM_j) = M(B)/[M(B) + M(J)],$$

where $P(B|E_i,M_j)$ is the predicted choice given stimulus E_i, M_j. The Fuzzy Logical Model of Perception requires three free parameters for the eyes variations and three for the mouth variations. The parameters represent the degree to which these features match those in the Bob and John prototypes.

Single Channel Model

The question of analytic or holistic processing could also be answered if alternative mathematical models, especially nonintegrative models like the Single Channel Model, fit the observed data. This is the case because the Single Channel Model emphasizes the independent evaluation of single features, which is the antithesis of holistic models, as is the Fuzzy Logical Model of Perception. Whereas the Fuzzy Logical Model of Perception assumes an integration of the feature values, it is assumed in the Single Channel Model that only one of the inputs of the upper or lower part of the face is functional on any trial. The information on the upper part of the face is selected with some bias probability p and the lower part with bias $1 + p$. Using Bob as an example, for a given whole-face condition the upper face information, E_i, will be identified as one specific face, with probability e_i, and the lower face information with probability m_j. Thus, the predicted probability of the identification of Bob given the i^{th} level of the upper face information, E_i, and the j^{th} level of the lower face information, M_j, is as follows:

$$P(B|E_iM_j) = (p)(e_i) + (1 - p)m_j.$$

This equation predicts the probability of identifying Bob for each of the nine conditions in the factorial conditions. The predictions for the half-face conditions are given simply by e_i and m_j. Since the 15 equations have three different values of e_i and three different values of m_j and we also do not know the value of p in the whole-face conditions seven free parameters are necessary: the p value, the three e_i values, and the three m_j values.

The Single Channel Model is a nonintegration model that assumes that only one of multiple inputs is used. In contrast, the Fuzzy Logical Model of Perception is an integration model that proposes a multiplicative combination of several features. Thus, examining the fit of the Fuzzy Logical Model of Perception in comparison to the fit of the Single Channel Model answers not only the general question of analytic or holistic processing but also the specific question of whether and how the facial features are integrated.

Models of Holistic and Configurational Encoding

Unfortunately, we know of no holistic model that can be quantitatively tested against the results. Holistic models in terms of holistic encoding would assume that each unique feature combination would create a unique face that could not be predicted from its component features. This formulation captures the idea of Garner's (1974) description of integral (holistic) perception in that features do not have any psychological reality in integral perception. According to Garner, features of an integral stimulus only exist in the experimenter's mind and not in the mind of the perceiver. It is not possible to test a specific quantitative formulation of this holistic model because it requires as many free parameters as observed data points. Every face is unique and its identification cannot be predicted on the basis of its components. This model remains untestable until there is some implementation of its principles with fewer free parameters. However, regardless of whether a particular holistic encoding model can be tested, an adequate fit of either the Single Channel Model or the Fuzzy Logical Model of Perception provides evidence against holistic models because this would be evidence that face identification is based on independently evaluated features.

The second characterization of holistic processing, configurational encoding, refers to the possibility that the spatial relations among the parts of the face are more influential than the parts themselves. The parts are represented but it is the relation among the parts that are critical. In the framework of the Fuzzy Logical Model of Perception, however, a relation between two parts of the face could function as an additional source of information. Configurational encoding models would be most directly tested by manipulating the relations among parts of the face. A good fit of the Fuzzy Logical Model of Perception would eliminate the possibility that the spatial relation between the upper and lower half of the face was a functional feature for face identification in our task. If spatial relations were functional, the identification of the whole and half faces could not have been predicted with the same parameter values, which are necessarily based on the component features. Tanaka and Sengco's (1997) less strong version of holistic processing based on the interaction of featural and configurational information also predicts that the Fuzzy Logical Model of Perception should fail.

In summary, the expanded factorial design provides a strong test of the various forms of holistic processing. The research paradigm is rich enough to investigate what information is actually being used by the perceiver, even if a spatial relation among features is involved.

In our experiments we test children's (5-year-olds) and adults' performance in a face identification task against the predictions of the Fuzzy Logical Model of Perception and the Single Channel Model. Although most of the face processing studies focused on children as young as 6 years of age (e.g., Baenninger, 1994; Carey, 1996), our study concentrated on the age group of 5-year-old children because their face recognition capabilities are similar to the capabilities of 6-year-old children (see Schwarzer & Korell, in press) and these results would be directly comparable to the studies from the nonfacial visual domain focusing on children as young as 5 years of age (e.g., Ashkenasy & Odom, 1982; Thompson & Massaro, 1989; Wilkening & Lange, 1989).

Taking into account that children's perceptual sensitivity to the dimensions at hand might be a significant factor for performance and development (see Cook & Odom, 1992), we varied the distinctiveness of the attributes of the faces in two separate experiments (1 and 2).

EXPERIMENT 1

Method

Participants. Two age groups participated in the experiment. One group was composed of 10 5-year-old children. Six of them were girls, and four were boys. Their ages ranged from 5 years, 0 months to 5 years, 6 months (mean age = 5,2) and the children came from middle to upper middle-class families. Twenty-three students (mean age: 20 years; age range: 18–24) from the undergraduate psychology subject pool at the University of California, Santa Cruz, made up the adult group. All adults had normal, or corrected-to-normal, visual acuity. The children were free of any known visual impairments.

Stimuli and apparatus. The nine stimulus faces of the experiment depicted in Fig. 1 were constructed at the Max-Planck-Institut for Biological Cybernetics in Tübingen, Germany, using the method of the correspondence-based representation of faces developed by Vetter and Troje (1997), which allowed for the construction of continua along facial features. The four faces at the corners of Fig. 1 display the maximum variations of the features eyes (and their covariates) and mouth. The faces in the middle row and column display neutral variations of the features. The prototype "Bob" is the face at the left corner at the top and the prototype "John" is the face at the right corner at the bottom. In addition to the nine whole faces we constructed six face halves displaying only the three levels of the upper and the three levels of the lower halves of the stimulus faces.

The experimental control programs used to run the experiment and collect participant data (adults' only) were implemented on a Silicon Graphics 4D/Crimson Reality workstation running under the IRIX 5.3 operating system, the stimulus faces were displayed to the participants on 12-in. (30.48 cm) NEC Model C12-202A color monitors, and participants' responses were collected on TV 950 video display terminals (VDTs) and their associated keyboards. Data analyses were performed on the same Silicon Graphics workstation using FORTRAN 77 data analysis routines. To present this experiment at a preschool, the stimulus faces were recorded on VHS tape so that the faces could be presented via a video recorder. The data of the children's group were collected manually.

Procedure. All participants were tested in a quiet location, with the experimenter present. They were seated in front of the computer monitors. Children were tested in a research van parked outside of a day care center, and adults were tested in a laboratory. Children and adults were required to respond to each stimulus face either with Bob or John. Adults gave their response by pressing a correspondingly labeled button on either the left or right edge of the VDT keyboard. To minimize the effect of memory performance, pictures of the prototypes Bob and John were fastened next to the response buttons. Children responded either verbally (Bob or John) or by pointing to pictures of Bob and John that were fastened beneath the monitor.

After a short title sequence, the control program began displaying the individual faces on the monitor. The faces were displayed for 1500 ms each. They were sized to fill the vertical dimension of the 12-in. (30.48-cm) monitor screens (15 cm high) and were viewed at a distance of about 45 cm. No visual fixation point was provided.

Each experimental session included a familiarization phase where the prototypical faces of Bob and John were presented 15 times each, 10 practice trials, and 120 stimulus trials; the stimulus trials were selected from the stimulus set according to a random selection without a replacement protocol, which resulted in each stimulus face being displayed 8 times per session (not including 15 familiarization trials and 10 practice trials). Children and adults were involved in two experimental sessions and so saw each stimulus face 16 times. In the adult group the two experimental sessions were separated by a 5-min rest period during the same day. For the children the two sessions were divided over two following days. Each session per day was also divided into four subsessions where the children had to identify 30 stimulus trials.

Results and Discussion

Mean probabilities of identifying "Bob." Because in this experiment the participants were limited to two choices, their mean responses to a particular stimulus face could be expressed as a probability of identifying the faces as Bob [(*P*)*B*]. Consequently, the probability of identifying the faces as John was 1-(*P*)Bob. The points in Figs. 2a and 2b show the average probabilities of identifying the faces as Bob's face as a function of the levels of the mouth and eyes variations in adults and children respectively.

The left panels of Figs. 2a and 2b (points) show the identification of just the lower half of the faces and the right panels for just the upper half. For the adult group (see Fig. 2a), a comparable influence of eyes and mouth in the half-face conditions was observable (see points of the left and right panels of Fig. 2a). Also, in the whole-face conditions (see points of the middle panel of Fig. 2a) both variables were significantly influential. There was also a significant interaction of the variables in that the influence of one variable was larger than the extent to which the other variable was neutral or ambiguous (all *F*s were significant at the .01 level).

In contrast, for the children (see Fig. 2b), the steeper course of the mouth variable (see left panel) illustrates that the mouth was much more influential than the eyes variable (see right panel), although both half-face conditions were effective in changing the identification from Bob to John (*F*s were significant at the .01 level). However, in the whole-face conditions (middle panel) the effect of the mouth was significant only, $F(2, 18) = 197.19$, $p < .01$, whereas the influence of the eyes did not reach the level of significance, $F(2, 18) = 2.32$, $p > .05$. This means that the children's identification of the whole face was nearly exclusively influenced by the mouth. If the eyes were also influential, the points of the three eyes levels would have been more separated from each other in the middle panel of Fig. 2b.

Thus, a different use of facial information by adults and children was observed. In the whole-face conditions, the adults took both sources of facial information into account, whereas the children were solely influenced by the mouth of the faces.

Model tests. The Fuzzy Logical Model of Perception makes specific predictions about how participants should perform when viewing stimulus faces involving features that are independent of one another. Identification probabilities should be more extreme when features are congruent and nonambiguous, whereas they

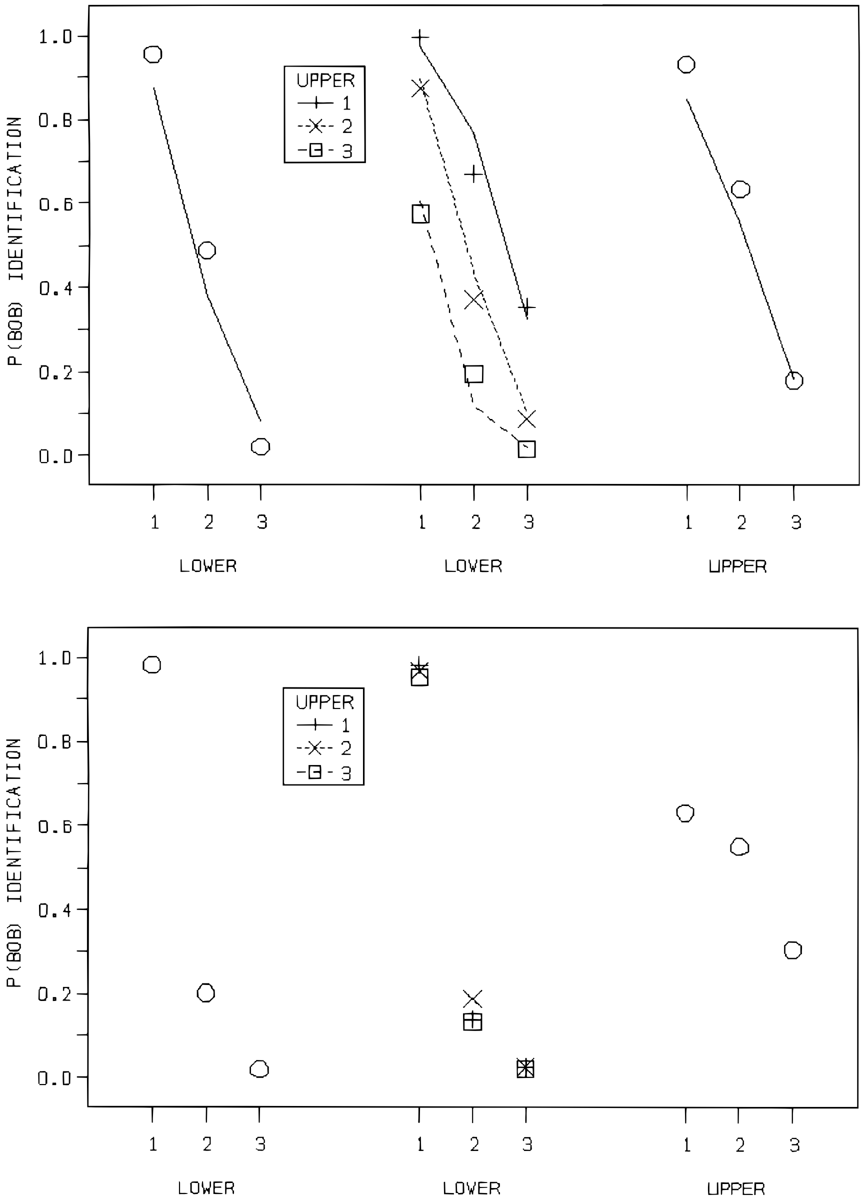

FIG. 2. (a) Predicted (lines) and observed [points; P(Bob)] identification judgments in the adults in Experiment 1. Predictions are for the Fuzzy Logical Model of Perception. (b) Observed [points; P(Bob)] identification judgments in the children in Experiment 1 as a function of the eyes and mouth variations.

should be less extreme when features disagree or are neutral or ambiguous. Furthermore, as the ambiguity of one feature increases, judgments should be influenced more by the other, less ambiguous feature.

For the model tests to answer the question of an analytic or holistic processing as well as integrative or nonintegrative processing, both sources of information have to influence performance. If there is an influence of just one source of information the Fuzzy Logical Model of Perception and Single Channel Model make the same predictions. Because, as described above, both sources of information varied on the face had been influential in the adult group only, the model tests were exclusively run in this age group (lines in Fig. 2a correspond to the predictions of the Fuzzy Logical Model of Perception).

Model fitting was accomplished using the STEPIT subroutine (Chandler, 1969), which finds the parameter values that maximizes a model's predictions. In our tests, the subroutine minimized the root-mean-square deviation (RMSD) between an individual participant's observed data points and a set of data points predicted by the Fuzzy Logical Model of Perception with six free parameters (seven in the case of the Single Channel Model). The subroutine iterates the model equations, changing parameter values until values are found that minimize the RMSD between the observed data and the predicted data. The value of the final RMSD is an indication of the model's goodness of fit. The models are tested against the results of individual participants in order to avoid the pitfalls in analyzing average results and simultaneously allowing an exploration of individual differences (Massaro, 1998).

Given the 3 X 3 expanded factorial design, six free parameters are necessary to fit the Fuzzy Logical Model of Perception to the 15 data points: three parameters for each level of eyes and mouth. The parameters represent the degree to which these features match those in the Bob prototype. As mentioned earlier, both the fit of the Fuzzy Logical Model of Perception and the fit of the Single Channel Model stand for an analytic processing in terms of an independent evaluation of the facial features. If the Fuzzy Logical Model of Perception gives a better fit of the data than the Single Channel Model, it can be argued that the facial features were integrated by a multiplicative algorithm. Therefore, the Fuzzy Logical Model of Perception and the Single Channel Model were fit to each of the adults and to the mean participant computed by averaging the results across participants. As can be seen in Fig. 2a (see lines), the predictions of the Fuzzy Logical Model of Perception did reasonably well in capturing the trends in the data. The Fuzzy Logical Model of Perception's RMSDs for the adults ranged from .02 to .17, with an average RMSD of .08. The fit of the mean participant gave an RMSD of .06. The fit of the Single Channel Model produced larger RMSDs, with a range between .02 to .22 and an average RMSD of .11. The fit of the Single Channel Model to the mean participant data was .07.

A comparison of the RMSD fits of the two models is informative. The RMSD fits for each subject for the two models were submitted to an analysis of variance, and the Fuzzy Logical Model of Perception provided a significantly better overall fit than did the Single Channel Model, $F(1, 22) = 4.86$, $p < .05$. Thus, the good fit of the Fuzzy Logical Model of Perception, which assumes independence at the feature evaluation stage, provides evidence against holistic models. If each combination of features is unique—as assumed by the holistic encoding approach—then a model assuming independence between features should fail. The fact that the Fuzzy Logical Model of Perception does not fail is therefore evidence against holistic processing. Furthermore, the results of the present experiment showed developmental differences in terms of the facial information used by children and adults. Whereas the children nearly exclusively focused on the mouth of a whole face, the adults took both the mouth and eyes into account. The children might have been influenced exclusively by the mouth of the faces because they associated John's mouth with a smiling mouth and managed the whole-face task by looking for just the smiling face.

These results on the differences between children and adults in terms of the facial information used fit nicely into Cunningham and Odom's (1986) study on differential salience of facial features in children's perception of affective expression. Their results showed that 5- to 11-year-old children were more likely to evaluate and remember information from the mouth region first and the eye region second.

Experiment 1 did not allow to test different mathematical models of children's face identification capabilities because of the age related differences in using facial information. Therefore, in Experiment 2 we changed the salience pattern of the face stimuli to allow for model tests in children.

EXPERIMENT 2

To accomplish the goal to compare children's and adults' information processing of faces by means of mathematical model testing, in Experiment 2, we modified some of the experimental conditions of Experiment 1 to get the children to consider both facial features, eyes and mouth. We adjusted the salience of eyes and mouth information given in the faces to increase the likelihood that the eyes will be evaluated in the children as well. Salience is considered a characteristic of the relative distinctiveness of the properties in stimulus arrays (Cunningham & Odom, 1978). In Experiment 2, we decreased the salience of the mouth—the most influential feature in the children's responses observed in Experiment 1. According to Ashkenasy and Odom (1982), we decreased the distinctiveness-based salience of the mouth by decreasing the value differences of the mouth to yield lower levels of sensitivity to these mouth differences. In addition, we decreased the overall size of the stimulus faces to make sure that the whole face could be projected on the fovea.

Method

Participants. There were 11 children from middle- to upper middle-class families participants, 6 girls and 5 boys, ranging in age from 5 years, 4 months to 5 years, 11 months (mean age: 5 years, 8 months). All children were attending a kindergarten group at the time of testing. The 13 adults were students at the University of California, Santa Cruz, 6 females and 7 males (mean age: 20 years; age range: 18–22). Participants had normal visual acuity, with or without correction.

Stimuli. The stimuli were the same as in Experiment 1 with the following exceptions. (1) To decrease the distinctiveness-based salience of the variable mouth we increased the similarity of mouth Level 1 and 3 to Level 2 as can be seen in Fig. 3. The variations of the eyes remained the same as in Experiment 1. The stimulus faces of Experiment 2 consisted of nine new faces plus the corresponding six face halves. We expected that in decreasing the distinctiveness-based salience of the mouth we would increase the relative salience of the eyes and therefore increase children's sensitivity to the eyes variable. (2) To facilitate the identification of Bob and John in the familiarization phase we constructed new facial prototypes for Bob and John in which the features—mouth and eyes—were exaggerated (see the faces of the separated right column of Fig. 3). The prototypes were also shown on the pictures which were used by the participants to give their responses during the test phase, but they were not used as test stimuli. The test faces were the nine faces depicted in Fig. 3 plus the corresponding six

FIG. 3. Stimulus faces of Experiment 2. The four faces displaying the maximum feature variations (at the corners of the figure) as well as faces displaying "neutral" variations. The prototype "Bob" is the face at the top of the separated right column and the prototype "John" is the face at the bottom of this right column. The half-face conditions displayed only the upper or lower half of the stimulus face.

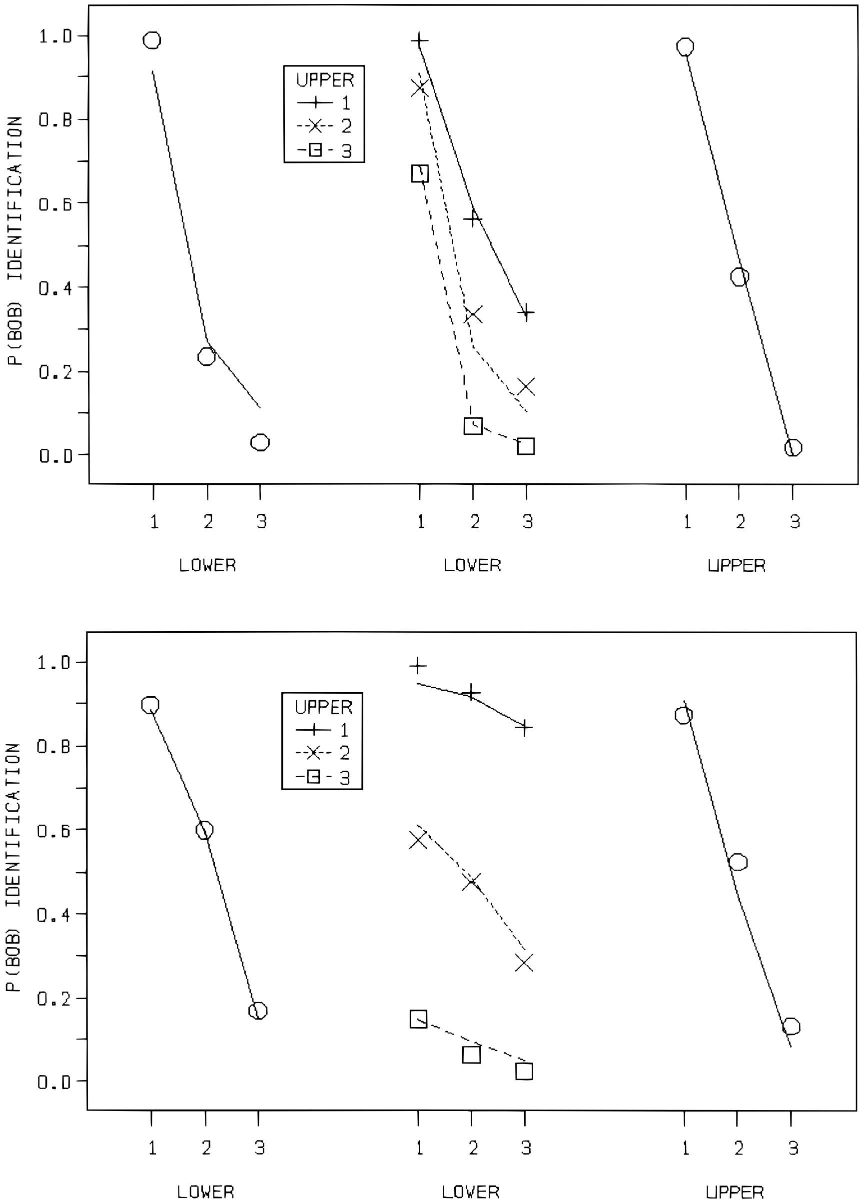

FIG. 4. Predicted (lines) and observed [points; P(Bob)] identification judgments in the children (a) and adults (b) in Experiment 2. Predictions are for a weighted Fuzzy Logical Model of Perception.

face- halves. (3) We decreased the overall size of the faces (9 cm high) to encourage the participants' consideration of both features varied. We expected that smaller faces increase the probability that people look at the whole face.

Apparatus and procedure. These were the same as those used in Experiment 1. In Experiment 2, we asked the participants to judge whether the stimulus face is more or less similar to Bob or John. Although the two prototypes (Bob and John) were never presented as stimuli, we named this process "identification"—as we did in Experiment 1.

Results and Discussion

Mean probabilities of identifying "Bob." In the children's group the average probabilities of identifying the faces as Bob were analyzed (see points in Fig. 4a). Both half-face conditions, the lower part of the face (see left panel), $F(2, 20) = 155.68$, $p < .01$, and the upper part of the face (see right panel), $F(2, 20) = 81.91$, $p < .01$, were effective in changing the identifications from Bob to John.

In the whole-face conditions (middle panel) the influence of the eyes was attenuated (mean probabilities: .63, .46, and .25) but, in contrast to Experiment 1, it was influential, $F(2, 20) = 14.6$, $p < .01$. The lower part was also influential (mean probabilities: .85, .32, and .18), $F(2, 20) = 47$, $p < 01$. There also was a statistically significant interaction between the variables, $F(4, 40) = 2.92$, $p < .05$. Thus, by decreasing the salience of the mouth variations and the overall size of the stimulus faces, children took into account the eyes information to identify the faces. Note that the variations of the eyes (and their covariates) used in Experiment 2 were identical to those used in Experiment 1.

For the adult group the same pattern of the average probabilities of identifying the faces as Bob appeared (see points in Fig. 4b): The face halves were influential in the half-face (left and right panel) as well as in the whole-face conditions (middle panel). In the latter, the interaction was also significant (all *F*s were significant at the .01 level). In the whole-face conditions, however, the influence of the mouth (mean probabilities: .57, .49, and .38), the more influential feature of the children, was attenuated in comparison to the influence of the eyes (mean probabilities: .92, .45, and .08). In comparing the average probabilities of the whole-face conditions (depicted in the middle panels of Figs. 4a and 4b) for the children the steepness of the curves (the influence of the mouth), whereas for the adults the spreadness of the curves (the influence of the eyes) is pronounced. This result provides evidence for developmental differences in the information used in face identification.

Model tests. Although both children and adults considered eyes and mouth in identifying the whole faces, they weighted eyes and mouth differently. Therefore we tested a biased or weighted Fuzzy Logical Model of Perception in addition to the simple Fuzzy Logical Model of Perception and the Single Channel Model against the results. In the weighted Fuzzy Logical Model of Perception, the contribution of the less important information, i.e., the upper face for the children's group, is attenuated by some proportion in the whole-face condition relative to the half-face condition. This model might be better able to describe the results than the simple Fuzzy Logical Model of Perception. The equation for the weighted Fuzzy Logical Model of Perception is

$$f_i(b) = wf_i(h) + .5(1 - w),$$

where $f_i(b)$ is the feature value on trials of the whole-face conditions and $wf_i(h)$ is the feature value on trials of the half-face condition. The w is a free parameter indicating the relative amount of influence on trials of the whole-face conditions relative to the half-face condition. Given the 3X3 expanded factorial design, in the simple Fuzzy Logical Model of Perception six free parameters are necessary to fit the Fuzzy Logical Model of Perception to the 15 conditions. In the weighted Fuzzy Logical Model of Perception, given the additional weight parameter seven free parameters are necessary.

The results of the children's group confirmed our expectations that the weighted Fuzzy Logical Model of Perception might be better able to describe the results than the simple Fuzzy Logical Model of Perception as well as the Single Channel Model. In comparison to the simple Fuzzy Logical Model of Perception and the Single Channel Model, the weighted Fuzzy Logical Model of Perception yielded the best fit of the data. This can be seen in the generally lower RMSDs of the weighted Fuzzy Logical Model of Perception. The RMSDs of the weighted Fuzzy Logical Model of Perception ranged between .01 to .10, with an average RMSD of .06 and a fit of the mean participant data of .04. The RSMDs of the simple Fuzzy Logical Model of Perception and the Single Channel Model were significantly higher, $F(2, 20) = 5.77$, $p < .01$, (simple Fuzzy Logical Model of Perception's RMSD's ranged from .02 to .13, with an average RMSD of .07 and a fit of the mean participant data of .06, Single Channel Model's RMSDs ranged from .04 to .12, with an average RMSD of .08 and a fit of the mean participant of .04). Thus, the good fit of the weighted Fuzzy Logical Model of Perception (which can be seen by comparing the points and corresponding lines in Fig. 4a) implicates the analytic as well as integrative character of the processing mode in children's face identification performance.

In contrast to the children, the adults were more influenced by the upper part of the face in the whole-face conditions. We therefore contrasted in the adults' group the corresponding weighted Fuzzy Logical Model of Perception with the Single Channel Model and the simple Fuzzy Logical Model of Perception. As for the children, the RMSDs of the weighted Fuzzy Logical Model of Perception were significantly lower than those of the simple Fuzzy Logical Model of Perception and the SCM, $F(2, 24) = 5.19$, $p < .01$, (weighted Fuzzy Logical Model of Perception RMSDs ranged between .03 to .13 with an average RMSD of .07 and a fit of the mean participant of .03, whereas the simple Fuzzy Logical Model of Perception ranged from .03 to .15 with an average RMSD of .1 and a fit of the mean participant of .07 and the Single Channel Model RMSDs ranged from .04 to .13 with an average RMSD of .09 and a fit of the mean participant of .06). The good fit of the weighted Fuzzy Logical Model of Perception in the adults is demonstrated in Fig. 4b in that the predictions of the weighted Fuzzy

Logical Model of Perception (see lines) did reasonably well in capturing the trends in the data (see points).

In sum, the best fit of the weighted Fuzzy Logical Model of Perception implicates that children's face identification processing—like adults'—is based on the independent evaluation of single facial features and can be named as analytic. Taking the age-specific use of information into account, children's processing modes can also be described by a multiplicative integration of the facial features. Although differences in the influence of the information sources were observed in Experiments 1 and 2, there seem to be no differences in the face identification processing between children and adults.

GENERAL DISCUSSION

The presented experiments proved successful in addressing the issues of how two facial features are evaluated and integrated to achieve the identification of a face. In adults as well as in children (see Experiment 2) both eyes and mouth variations were effective in changing the judgment from the identification of one face (Bob) to another face (John). These results were well described by the Fuzzy Logical Model of Perception the weighted Fuzzy Logical Model of Perception respectively relative to the poorer description of the Single Channel Model. Thus, this is evidence for analytic face processing in children and adults.

Given the present results that the Single Channel Model provided a poorer prediction of our empirical data than the Fuzzy Logical Model of Perception, an important question to consider is whether cases could be identified where the Single Channel Model provides a better fit to the data than the Fuzzy Logical Model of Perception. It has been claimed that when a face is turned upside down, the integrative face processing strategy is inhibited, forcing a more analytic processing strategy (e.g., Farah, Tanaka, Wilson, & Drain, 1995; Farah, Wilson, Drain, & Tanaka, 1998; Tanaka & Farah, 1993). If this is true, the Single Channel Model should provide a better account of the faces in an inverted condition than the Fuzzy Logical Model of Perception. However, previous data already showed that changing the information on a face—as you would do in presenting the faces upside down—did not change the fit of the Fuzzy Logical Model of Perception (e.g., Massaro, 1998; Massaro & Cohen, 1996). For example, Massaro and Cohen (1996) examined whether the orientation of the face influences speech perception. Inverting the face reduced the influence of visible speech, but the results with both the upright and inverted faces were adequately described by the Fuzzy Logical Model of Perception. The observed differences between the processing of the upright and inverted faces were due to the amount of visible information but inverting the faces did not change the nature of the information processing. Thus, we might also expect that the amount of information on the faces will be reduced in a face identification situation but with regard to the information processing the Fuzzy Logical Model of Perception will do as well with inverted faces.

As already argued, the good fit of the Fuzzy Logical Model of Perception challenges the conclusion of holistic face processing based on approaches without any formal model testing. Whereas our results illustrated the independent evaluation of facial features which stands for an analytic processing, Tanaka and Farah (1993), Tanaka et al. (1998), Baenninger (1994), and Carey (1996) postulated holistic face processing in children and adults in terms of holistic encoding and configurational encoding. One possible explanation for the results of the present study in comparison to the results of previous results showing holistic processing in children and adults could lie in the different number of target faces used in the different studies. Whereas in our study only two target faces (Bob and John) were used previous face recognition studies have used multiple target faces. Possibly, the use of only two target faces encourage an analytic processing strategy because it is easier to focus on one or two discriminating features when there are only two alternatives in the response set. Holistic processing may be more likely to be employed in the situation of multiple target faces where the discriminating features are less apparent. This conjecture is open to experimental test. In speech emotion perception, the number of test and response alternatives does not diminish the advantage of the description given by the Fuzzy Logical Model of Perception. Another explanation for the difference between the present results and the previous ones showing holistic face processing could be the fact that the target faces in the previous studies were not present when the participant was deciding on the identity of each stimulus face and he or she could only compare the target face to a "blurry" memory representation. However, the stimulus faces were presented in our study for just 1500 ms so that a direct and nearly simultaneous comparison of stimulus and target faces—which could possibly induce analytic processing—could not take place.

Our results confirm and extend current studies concerning children's preference to focus on single facial features when categorizing faces in comparison to adults who took more than one feature into account (Pedelty, Levine, & Shevell, 1985; Schwarzer, 2000; Schwarzer & Korell, in press). However, with the appropriate balance in feature salience, both children and adults not only take more than one feature into account but they integrate these features by using a multiplicative algorithm.

The present results are also consistent with the corresponding studies from the nonfacial visual domain. Different tasks from the present one (Ashkenasy & Odom, 1982; Thompson, 1994; Ward, Vela, & Hass, 1990; Wilkening & Lange, 1989) as well as comparable tasks (e.g., Thompson & Massaro, 1989) revealed the analytic and integrative nature of processing. Given the success of the Fuzzy Logical Model of Perception across a wide range of empirical domains, its success in the present studies might not be too surprising. The Fuzzy Logical Model of Perception has provided an adequate description of the evaluation and integration of sources of information in reading letters and words, in sentence processing, in the visual perception of depth, in memory retrieval, and in cognitive decision making (Massaro, 1998). It is also noteworthy that most of its success has emerged in the description of speech perception (e.g., Massaro, 1987a; Massaro & Burke, 1991). There has been a long tradition of belief that speech perception is somehow specialized and not amenable to a description grounded in prototypical pattern recognition processes. This belief parallels the assumption of many that the perception of faces is also specialized (see for an overview Bruce & Humphreys, 1994). However, studies using the Fuzzy Logical Model of Perception approach in the speech domain have weakened the speech-is-special viewpoint (Massaro, 1987a, 1987b, 1998). We would predict the same for face identification.

What do the current results tell us about the development of face identification processing? Developmental changes could theoretically exist at any of the three stages of processing: evaluation, integration, and decision. Given the fit of the Fuzzy Logical Model of Perception to the children's and adults' data, however, the results of the presented experiments provide evidence for developmental differences only at evaluation. That means that differences in the evaluation process appear to be due to differences in the information made available by the perceptual and memory system. Our results showed those differences between 5-year-old children and adults in that in Experiment 1 and 2 children used the information on the mouth of the faces more than adults did. Adults, by contrast were more influenced by the eyes of the faces as can be seen in Experiment 2. However, it would be oversimplified to conclude from our studies that in face processing children usually prefer information on the mouth of the face and adults usually prefer information on the eyes of a face. These differences seem to depend not simply on the age but on differential salience of the features (see Ashkenasy & Odom, 1982; Cook & Odom, 1992). The influence of the salience of the features was observable in the way children changed their use of information between Experiments 1 and 2. While, in terms of Cook and Odom (1992), the predisposed salience of the mouth information (the effects that perceptual experience with the mouth of a face has on the sensitivity of the perceptual system) was higher than that of the eyes information and their covariates (eyebrows and forehead) in Experiment 2, the salience of the mouth was reduced along with the overall size of the faces, which increased the relative salience of the eyes and their covariates and made them more informative.

Moreover, Experiment 2 showed that no developmental changes exist at the stage of the integration of information from eyes and mouth. Rather, information integration appears to occur in the same manner for children and adults: For both age groups, the two sources of information are integrated by a multiplicative algorithm.

Thus, in line with Cook and Odom's (1992) differential-sensitivity account of cognitive processing (see also Odom & Guzman, 1972), room for the development of facial processing is mainly given in terms of facial information used rather than in terms of information processing. As children become more experienced with the world around them, they learn what information on a face is useful. How they use this information to respond to their environment, however, does not change.

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