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Neural and Behavioral Correlates of Emotion Recognition in Children and Adults

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Event-related potentials (ERPs), accuracy scores, and reaction times were used to examine the recognition of emotional expressions. Adults and 7-year-old children saw upright and inverted chromatic slides of the facial expressions of happiness, fear, surprise, and anger, and were asked to press a button for either "happy" or "angry" faces. A positive-going waveform (P300) was apparent at parietal scalp (Pz) and at left and right temporal scalp. Although the behavioral data were similar for both children and adults (e.g., both had more difficulty recognizing angry expressions than happy ones, and angry expressions were more difficult to recognize upside-down than were happy faces), the ERPs indicated that children responded differently than adults did to happy and angry expressions. Adults showed greater P300 amplitude to happy faces, while children showed greater P300 amplitude to angry faces. In addition, for adults, but not children, there were greater P300 amplitude responses at right vs. left temporal scalp. © 1992 Academic Press, Inc.

The development of the ability to recognize emotional expressions has received considerable attention in recent years, primarily because of its important role in social communication. Because of speculation that the

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ability to recognize emotional expressions may have a "prewired" component to it (Darwin, 1872/1965; Ekman, 1984; Nelson, 1987), neuropsychologists and cognitive neuroscientists have devoted considerable attention to examining the neural substrate of this ability. This work has concentrated primarily on determining which hemisphere is dominant in the processing of emotional expressions. This theme has been explored in two ways. First, work with unilaterally brain-damaged individuals has indicated that lesions in the right hemisphere tend to disrupt the ability to recognize facial expressions more so than do lesions in the left hemisphere (e.g., Dekosky, Heilman, Bowers, & Valenstein, 1980; Etcoff, 1984; Kolb & Taylor, 1981). Second, divided-field studies with healthy individuals have generally shown a left visual field (i.e., right hemisphere) superiority for recognizing emotional expressions in both adults (Bryden & Ley, 1983; Ley & Bryden, 1979; McLaren & Bryson, 1987; Suberi & McKeever, 1977) and children (Saxby & Bryden, 1983). There is, however, some disagreement as to whether all emotional expressions are recognized more accurately or quickly if presented to the LVF, and whether the right hemisphere is dominant for all individuals under all conditions of recognizing emotional expressions. For example, Safer (1984) has found individual differences in hemisphere-superiority, and has suggested that the task may determine which hemisphere is dominant. Mandal & Singh (1990) have found that the expressions of disgust and anger were more easily recognized in the LVF, but for sadness and fear, the visual field did not affect ease of recognition. Reuter-Lorenz & Davidson (1981) found that reaction times were quicker when sad faces were presented to the left visual field, but were quicker when happy faces were presented to the right visual field. With these exceptions, however (some of which may be due to differences in methodology), most studies have found a LVF (RH) superiority for emotional expressions; to date, there is not enough evidence to suggest otherwise (see Davidson, 1984).

Although this work has suggested a possible, albeit large, neuroanatomical location that may be responsible for the recognition of emotional expressions, it has provided relatively little information about the actual neural processing that occurs during the time that an individual is identifying an emotional expression. This is largely due to the use of behavioral measures, which tell us only about outcome and not about real-time processing. An alternative to such measures would be to examine the neural manifestation of emotion recognition as determined by the recording of event-related potentials (ERPs). ERPs are transient voltage oscillations in the brain that occur in response to discrete events, such as the brief presentation of individual facial expressions of emotion. The recording of long-latency (endogenous) ERPs has been used to explore a variety of cognitive operations (e.g., attention, memory, and categorization; see Donchin (1984) for an overview of work with adults, and

Friedman (1991) for a review of work with children). ERPs are thought to reflect the neuronal processing demands of a task, with greater neuronal involvement being manifested by increased ERP amplitudes (Donchin & Isreal, 1980). In addition, the latency of a given ERP component can be used to infer the chronometry of mental events, such as *when* a stimulus is recognized by an individual (e.g., Duncan-Johnson, 1981). Finally, the scalp topography of the ERP can provide information about the neural generators, and their spatial positioning, that underlie a given response (cf. Johnson, in press).

With adults, and with children to a lesser extent, the late component that has received the most attention is the P300 response. The P300 is a positive-going component of the ERP that generally peaks between 300 and 600 msec after stimulus onset (later for children) that is most prominent at parietal (Pz) scalp. This component is usually invoked by directing an individual's attention to one stimulus to the exclusion of other stimuli, and is thought by many to reflect the updating of working memory (Donchin, 1981; Donchin & Coles, 1988; but see Verleger, 1988, for dissension). The amplitude of this response is thought to vary on the dimensions of (1) subjective probability, such that greater responses occur to less frequently occuring stimuli, (2) stimulus meaning in terms of complexity and/or value, and (3) the effectiveness, or accuracy, of the presentation for the individual (Johnson, 1986, in press).

In addition to the P300 response, a second component generally observed only in children is the N400 response. The N400 is a negative-going wave that peaks approximately 400 msec after stimulus onset, and that has a more central scalp topography maximum. A number of different explanations of the function of the N400 have been offered, such that it reflects additional processing of a salient stimulus (Courchesne, 1978), that it is a response to "meaningful" stimuli (Symmes & Eisengart, 1971), or a response to complex stimuli (Friedman, Sutton, Putnam, Brown, & Erlenmeyer-Kimling, 1988; for discussion, see Friedman, 1991).

Most studies that have used ERPs to study responses to emotion have used stimuli designed to invoke emotions in the individual, usually through the viewing of unpleasant or pleasant scenes (e.g., Johnston, Miller, & Burleson, 1986; Yee & Miller, 1987), rather than stimuli of actual facial expressions for looking at the recognition of emotional expressions. Exceptions to this are studies that have recorded ERPs in response to either line drawings of positive, negative, and neutral facial expressions (Vanderploeg, Brown, & Marsh, 1987) or photographs of happy and angry facial expressions (Lang, Nelson, & Collins, 1990; Nelson & Nugent, 1990). Vanderploeg et al. found that P300 amplitudes were greater to drawings of neutral expressions than drawings of positive or negative expressions, when each type of expression was presented an equal number of times, at left hemisphere sites and along the midline. In contrast, a later positive component, the slow wave, had greater amplitude to the positive and negative stimuli than to the neutral stimuli at midline sites, and greater amplitudes were found for positive expressions than neutral expressions at right hemisphere sites. Lang et al. (1990), using an "oddball" paradigm, in which the target stimulus occurred less often (20% of the time) than the other nontarget stimulus, found that P300 area was greater when the target was the happy face, but peak amplitude was greater when the target was the angry face.[1] In both studies, effects that distinguished emotions were most prominent at parietal scalp (Pz).

In a study similar to that by Lang et al. (1990), Nelson & Nugent (1990) recorded ERPs from 4- to 6-year-old children in response to one happy face and one angry face. The target was either "happy" or "angry" and occurred either 20% of the time (Experiment 1) or 80% of the time (Experiment 2), depending on the condition. When the targets occurred only 20% of the time, the N400 distinguished between the two expressions; specifically, area and peak amplitude were greater to angry faces, regardless of whether anger served as the target or nontarget. A later positive component (P300/P700) distinguished only between target and nontarget events (greater to target than nontarget). When the target expressions were presented 80% of the time, no N400 differences were found; moreover, the P300 was observed to be larger to the infrequent (but nontarget) event. All responses were most prominent at parietal (Pz) and central scalp (Cz).

Although the differential effects to happy and angry expressions found by Lang et al. (1990) and Nelson and Nugent (1990) are intriguing, the source of the differences is not clear. Since in both studies only one exemplar of each face was presented, discrimination was fairly simple and the faces could have been discriminated on the basis of one or more idiosyncratic features, rather than by attending to the affective nature of the stimuli. Thus, in the present study, several exemplars of each expression were included, and task demands were increased by including several emotional expressions. In addition, for two conditions, the emotional expressions were presented upside-down.

[1] The peak amplitude of the P300 is typically measured by identifying the time point within some specified interval (e.g., 300–600 msec) that contains the maximum voltage. It is possible to speculate that this peak reflects the revision of the subject's neuronal template, and thus the point at which memory has been updated. In contrast, the *area* of the P300 is typically measured by integrating (in microvolts) the area above baseline for the entire specified interval. As summarized by Nelson and Nugent (1990) and discussed in detail by Fabiani, Gratton, Karis, and Donchin (1987), area scores are particularly useful when ERP deflections are slow and sustained (vs. peaked). Larger area scores likely reflect the presence of slow wave activity coinciding with and overlapping the P300, which in turn presumably reflect the need for additional or further processing (for discussion, see Ruchkin, Johnson, Mahaffey, & Sutton, 1988).

The present study combined aspects of the Lang et al. (1990) study, the Nelson and Nugent (1990) study, and a behavioral study conducted in our laboratory (Kestenbaum & Nelson, 1991), which looked at children's and adults' recognition of emotional expressions that were presented either upright or inverted. In the latter study, 5- and 7-year-old children and adults were shown slides of several models posing happiness, surprise, fear, or anger, either oriented upright or inverted, and accuracy scores and reaction times were measured. In general, reaction times were slower for inverted expressions than upright expressions, but differences in accuracy were found for only certain expressions (surprise and anger), and only for the children. Kestenbaum and Nelson (1991) suggested that when expressions have a dominant feature (e.g., the mouth for happiness, and the eyes for fear), recognition is less likely to be disrupted when the face is inverted since the individual feature, rather than the total configuration of features, can be used for identification.

The aims of the present study were to see if there were differences, both behaviorally and electrophysiologically, for children and adults in their recognition of the expressions of happiness and anger, when presented both upright and inverted, and to compare findings from behavioral measures to recordings of ERPs. With behavioral measures, previous research has suggested that happiness is recognized more easily than anger, particularly when inverted. In addition, previous investigations with ERPs have found that children have greater amplitude responses to an angry face than to a happy face, whereas for the adults, results have been equivocal. An additional aim was to examine whether right hemisphere sites vs. left hemisphere sites produced greater activity, for both children and adults.

In the present study, an "oddball" paradigm similar to that used by Lang et al. (1990) and Nelson and Nugent (1990) was used. However, in this study, several exemplars of each emotional expression were used, so that individuals could not use idiosyncratic features of one model to identify expressions. Seven-year-olds and adults were presented with four series of 100 slides each, consisting of 25 happy faces, 25 angry faces, 25 fearful faces, and 25 surprised faces, posed by different models. For each series, participants were asked to press a button when they saw either "happy faces" or "angry faces", once each when the faces were presented upright, and once each when they were presented upside-down. Accuracy scores, reaction times, and ERPs from midline and lateral leads were recorded.

METHOD

Subjects

Twenty-four 7-year-olds and 21 adults were tested, with 15 from each group remaining in the final sample. Of the 7-year-olds, two were not included because of eye or scalp artifacts, two because of equipment-related difficulties, and three because of inattention. Five adults were not included because of eye or scalp artifacts, and an additional adult was excluded because of equipment-related difficulties. The remaining sample of 7-year-olds included eight males and seven females, ranging in age from 83 months to 92 months (M = 87, SD = 2.8). The final group of adults ranged in age from 19 to 37 years and included six males and nine females. None of the subjects reported any history of neurological problems.

Stimuli and Design

The stimuli were black-and-white slides of three female models posing happiness, anger, surprise, and fear, chosen from Ekman's Pictures of Facial Affect (1976). The stimuli were viewed from a distance of 132 cm. All slides were of equal luminance and were rear-projected onto a screen. The slide projectors were housed in a sound-attenuated chamber.

Four sets of 100 slides each were created that consisted of 25 slides of each of the four emotions. For the 25 slides for each emotion, two of the model's photographs were repeated eight times, and one model's photograph was repeated nine times. Each set was run in a different fixed quasi-random order, with the stipulation that no emotion or model could appear more than two times consecutively. Two of the sets of slides were presented upright, and two were presented upside-down. Each subject saw all four sets of slides. Half of the subjects were presented with the two sets of upright slides first, and half were presented with the inverted slides first. For one of the sets of upright slides and one of the sets of inverted slides, "happy" was the target emotion, and for the other two sets, "angry" was the target. "Happy" served as the target emotion for half of the subjects who saw the upright slides first, and half who saw the inverted slides first; for the others, "angry" served as the target emotion first.

Electroencephalogram (EEG) Procedure

The EEG was recorded using Grass AgAg-Cl electrodes. EEG recordings were made from midline parietal, central, and frontal (Fz) scalp and from left (T5) and right (T6) temporal regions in accordance with the International 10/20 system (Jasper, 1958), referenced to linked ears, with a ground electrode placed on the forehead. The electrooculogram (EOG) was recorded using miniature silver electrodes positioned above and below one eye in a transverse configuration. For the children, the scalp electrodes were fixed to the scalp using Grass paste, adhesive foam padding, and headbands. For the adults, the scalp electrodes were fastened with collodian. For adults, EEG gain was 10,000 for the midline leads and 100,000 for lateral leads; for the children, these figures were 20,000 and 100,000, respectively. Lower and upper cut off frequencies were .1 to 30 Hz, and a 60-Hz notch filter was in place. All scalp impedances were less than 10 kohm, and EOG impedances were less than 20 kohm.

EEG and EOG data were sampled every 10 msec for 1300 msec, beginning 100 msec preevent. The stimulus duration was 200 msec, and trial duration was 1200 msec. The interval between trials varied randomly between 500 and 1500 msec.

Procedure

The electrodes were fastened to the subjects in one room, and then the subjects were brought into a separate testing room, where they sat facing the screen and were given a button to push with their dominant (in all cases, right) hand. Children received a short training session before the testing began, in which they were shown 24 slides of cats', dogs', monkeys', and mice faces. They were asked initially which type of animal they liked best; this stimulus was used as the target. They were told that they would see slides of animals that would pass by very quickly, and they were instructed to push the button whenever they saw the target animal. They needed to respond correctly on at least five out of the six possible times in order to proceed to the test. If they did not perform adequately the first time, the instructions were repeated using a different target animal, and the procedure was repeated. All children were successful by the second time.

For the testing session, subjects were told that they would be shown pictures of people showing different emotions, and that they were to look straight ahead at a dot in the center of the screen. They were then instructed to "push the button whenever you see a happy face (or a "mad" face)." In addition, they were told whether the faces would be right-side up or upside-down. This procedure was repeated three more times, varying the orientation and the target emotion. If at any time a subject looked away from the slides, an observer pressed a button that caused the slide to be repeated. In this way, it was assured that subjects saw all of the slides.

Artifact Rejection, Data Reduction and Analysis

Data from the midline leads (Pz, Cz, and Fz) were analyzed separately from the data from T5 and T6 because of differences in the gains used and the hypotheses under investigation.

EEG and EOG artifacts detected by computer algorithm resulted in deleting that trial from subsequent analyses. After editing, data were averaged across target trials for each individual for each run at each lead. The maximum number of trials (i.e., if none of the trials had been edited out) was 25, and the minimum number of trials was set at 10. If a subject did not have 10 or more artifact-free trials at every lead, s/he was not included in the analyses. Thus, for the midline lead analyses, 15 adults and 15 children were included, while for the lateral lead analyses, 15 adults, but only 9 children were included.

After the target trials were averaged, averages of an equivalent number of nontarget trials were calculated based on a random selection of the total number of artifact-free trials. Grand averages were then constructed by averaging all of the subjects' data, separately for each lead. For both children and adults, a positive-going waveform (P300) was apparent, most prominently at Pz along the midline, as well as at T5 and T6. Unlike in Nelson and Nugent (1990), the N400 was not as well pronounced for the children, and was not apparent for the adults. Further, when this component was analyzed for the children, it resulted in an uninterpretable four-way interaction between Emotion, Orientation, Target, and Lead. Accordingly, discussion will be restricted to the P300.

The grand averages and the individual averages were inspected in order to determine the time interval, or "window," in which these effects occurred. For the midline leads, this interval extended from 520 to 1200 msec for children, and from 470 to 900 msec for adults. For T5 and T6, the interval extended from 540 to 1200 msec for the children and 380 to 930 msec for the adults. These components were analyzed for peak amplitudes, area scores relative to baseline, and latency to the peak amplitude within the window.

In addition, the behavioral data were inspected to determine on which trials correct responses ("hits" and "correct rejections") had occurred. Averages were then computed using only correct response trials. In other words, only target trials that were "hits" were averaged, and then equivalent numbers of "correct rejections" were averaged, for all leads. For the midline leads, only 13 adults and 9 children met the requirement of having at least 10 artifact-free trials at each lead. For T5 and T6, 15 adults and 9 children were included. Positive-going waveforms (P300), similar to those found for the full data set, were again apparent within the same time intervals. Peak amplitudes, area scores, and latency to peak amplitude were computed for these components.

RESULTS

Behavioral Measures

Button pushes yielded two types of scores: "hits," when the push was to a target emotion, and "false alarms," when the push was to a nontarget emotion.

Frequency scores. As can be seen in Fig. 1, age differences were negligible. When "happy" was the target, hits approached the ceiling, false alarms approached the floor, and orientation had little effect. In contrast, when angry was the target, hits approached the ceiling for upright, but

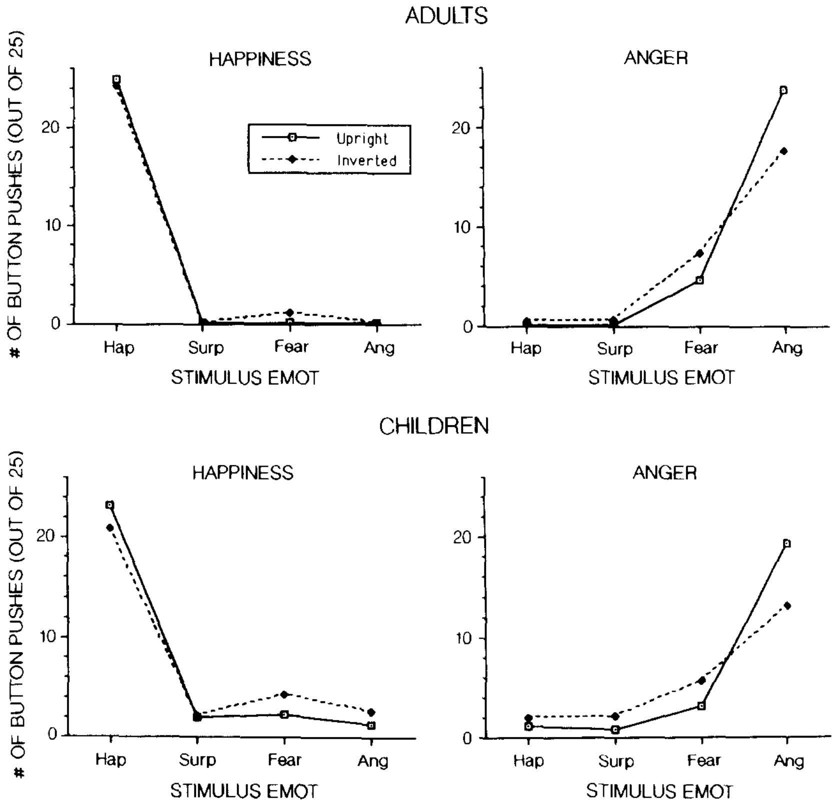

FIG. 1. The frequency of button pushes (out of 25) for children and adults when happiness and anger were the targets, and the stimuli were presented either upright or inverted.

not inverted stimuli, and false alarms approached the floor except for the fear stimulus. Analyses of variance were not performed on these data due to the floor and ceiling effects.

Reaction times (RT's). Only the RT's for hits were examined because there were not enough data points for false alarms. For children and adults, a 2 (Age) × 2 (Target Emotion: happiness and anger) × 2 (Orientation: upright and inverted) repeated measures analysis of variance was run on the RT's for hits. The main effects of Age, $F(1, 28) = 17.52$, $p < .001$, Target Emotion, $F(1, 28) = 14.80$, $p < .001$, and Orientation, $F(1, 28) = 7.99$, $p < .01$, were all significant. Adults in general responded more quickly than did the children (721 vs. 892 msec) and responses were quicker to happy faces than angry faces (769 vs. 845 msec), and to upright faces than inverted faces (782 vs. 831 msec). In addition, the interaction of Target Emotion × Orientation was also significant, $F(1, 28) = 4.87$, $p < .05$. Follow-up Tukey tests indicated that upright angry faces were responded to more quickly than were inverted angry faces, $p < .05$. There was no effect of inversion for happy faces.

ERP Components

Preliminary analyses—Midline leads. Separate ε-corrected (Greenhouse-Geiser) repeated measures analyses of variance were run for Lead (Pz, Cz, Fz), Emotion (happiness, anger), Orientation (upright, inverted) and Target (target, nontarget) for both children's and adults' area scores, peak amplitude scores, and latencies to peak. Similar analyses were also run for "hits" and "correct rejections." Because all of the analyses indicated that significant effects of target vs. nontarget (or hits vs. correct rejections) occurred only at Pz, subsequent analyses included data only from this lead. Thus, separate 2 (Emotion) × 2 (Orientation) × 2 (Target) repeated measures analyses of variance were run for both children and adults for all trials (i.e., target vs. nontarget) and for trials edited for correct responses (hits vs. correct rejections) for area, peak amplitude, and latency scores (but see Figs. 2 and 3 for illustrations of the effects at all leads).

Area scores—Pz. For adults, when all trials were considered, the main effect of Target was significant, $F(1, 14)$ 33.81, $p < .001$, as was the interaction of Orientation × Target, $F(1, 14) = 6.85$, $p < .05$. Follow-up Tukey tests indicated that for both upright and inverted orientations, area scores were larger for target than for non-target averages (4628 vs. 2337, for upright; 4135 vs. 2845, for inverted), p's $< .05$. However, the difference between the target and nontarget scores was greater in the upright orientation than in the inverted orientation, $t(14) = 2.61$, $p < .05$.

When only adults' correct responses were analyzed, the main effect of Target again was significant, $F(1, 12) = 29.72$, $p < .001$, but in this case, the interaction of Emotion × Target was also significant, $F(1, 12) = 4.75$, $p < .05$. Tukey tests revealed that area scores were greater for hits than correct rejections when both happiness and anger were the targets (4972 vs. 2341, for happiness; 4312 vs. 2902, for anger), p's $< .05$, but the difference was greater when happiness was the target, $t(12) = 2.18$, $p < .05$ (see Fig. 2).

For the children, when all trials were included, the main effect of Target was significant, $F(1, 14) = 47.67$, $p < .001$, as was the interaction of Emotion × Orientation, $F(1, 14) = 5.39$, $p < .05$. Area scores were greater to target trials than to nontarget trials (5851 vs. 2077). Tukey tests indicated that they were also greater when the stimuli were upright than when inverted when anger was the target (5094 vs. 2451), $p < .05$, but there were no differences in orientation when happiness was the target (4295 vs. 4016).

When only correct responses were included for children, the main effect of Target was still significant, $F(1, 8) = 42.01$, $p < .001$, but the interaction

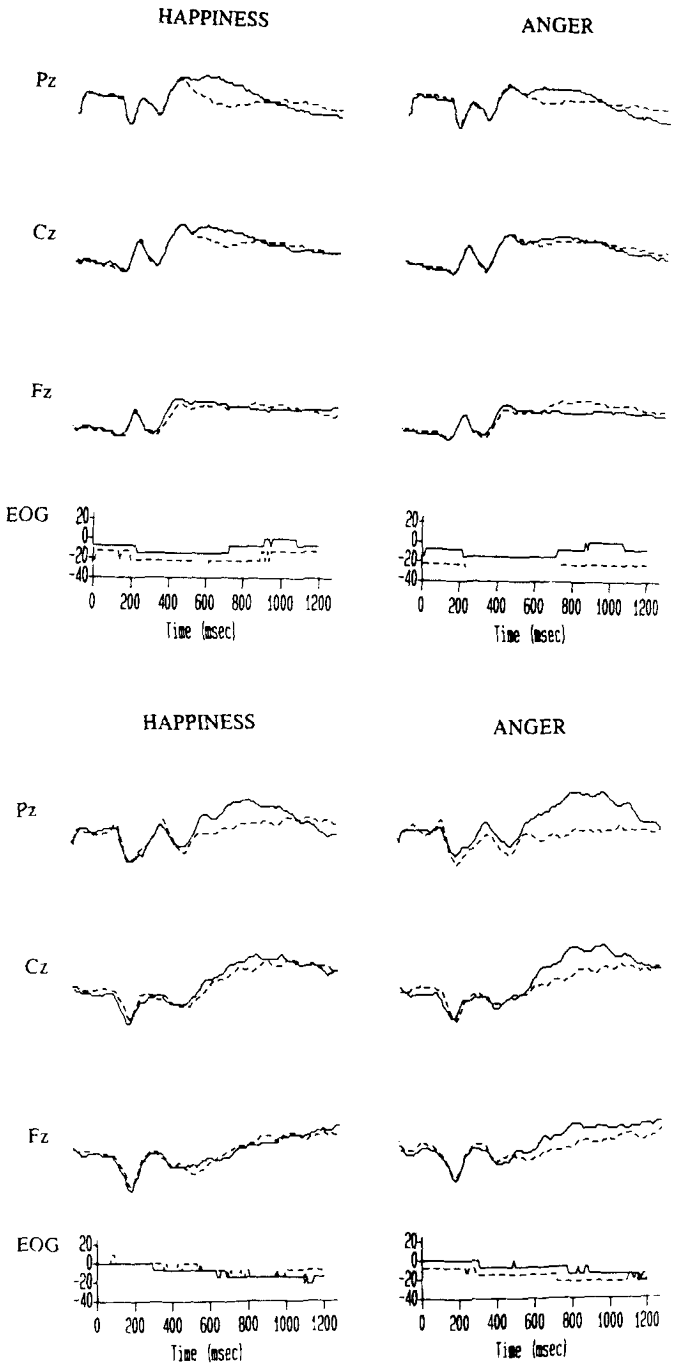

FIG. 2. Grand average data for adults (top) and children (bottom) under the Happiness and Anger conditions. Averages are collapsed over Orientation (upright and inverted). The solid lines represent "hits" and the dashed lines represent "correct rejections." P300 is greatest at Pz. Responses are greater for happiness in adults, for anger in children.

of Emotion × Target was significant as well, $F(1, 8) = 6.75$, $p < .05$. Tukey tests indicated that area scores were greater for target trials for anger rather than happiness (8957 vs. 4149), $p < .05$, and there was no difference between the emotions for nontarget trials (2342 vs. 2784; see Fig. 2).

Peak amplitudes—Pz. For adults, with all trials included, the main effects of Emotion and of Target were significant, $F(1, 14) = 11.25$, $p < .01$ and $F(1, 14) = 32.47$, $p < .01$, respectively. Peaks were greater to target trials than to nontarget trials (14.4 vs. 10.4 μV), and peaks were greater when happiness was the target emotion than when anger was the target emotion (13.4 vs. 11.5 μV). When only correct responses were included, the main effect of Target was again significant, $F(1, 12)$, $p < .001$. In addition, the interaction of Emotion and Target was also significant, $F(1, 12) = 12.76$. Tukey tests indicated that peaks were greater for happiness than anger for target trials (17.2 vs. 13.8 μV), $p < .05$, but there were no differences between the emotions for nontarget trials (10.0 vs. 10.8 μV; see Fig. 2).

For the children, when all trials were included, only the main effect of Target was significant, $F(1, 14) = 21.97$, $p < .001$. Peaks were greater to target trials than to nontarget trials (18.3 vs. 13.0 μV). Similarly, when only correct responses were examined, peaks were greater for hits than for correct rejections (20.7 vs. 13.3 μV), $F(1, 8) = 35.25$, $p < .001$.

Latencies to peak—Pz. For adults, both when all trials were included and when only correct responses were included, main effects of Emotion were significant, $F(1, 14) = 10.57$, and $F(1, 12) = 9.71$, respectively, p's $< .01$. In both instances, latencies were shorter to happiness than to anger (552 vs. 617 msec, and 542 vs. 605 msec, respectively). With correct responses only, the main effect of Target was also significant, $F(1, 12) = 15.43$, $p < .01$. Latencies were shorter to correct rejections than to hits (539 vs. 609 msec).

For the children, in both analyses, the only significant effect was the interaction of Emotion × Target, $F(1, 14) = 7.16$, and $F(1, 8) = 8.09$, respectively, p's $< .05$. Tukey tests indicated that, in both cases, latencies were slower to target trials, $M = 835$ msec, (and hits, $M = 789$ msec) than to nontarget trials, $M = 945$, (and correct rejections, $M = 956$) for happiness, but there were no differences for anger.

Area scores—T5 vs. T6. For adults, both for all trials and for correct responses only, the main effects of Target, $F(1, 14) = 24.74$ and $F(1, 14) = 48.27$, respectively, p's $< .001$, and of Lead, $F(1, 14) = 12.67$ and $F(1, 14) = 15.53$, respectively, p's $< .01$, were significant. Area scores were greater to target trials, $M = 2090$, (and hits, $M = 2182$) than to nontarget trials, $M = 113$, (and correct rejections, $M = 41$), and were greater at T6 (right hemisphere) than at T5 (left hemisphere; 2054 vs. 149, and 2170 vs. 53, respectively). In addition, the main effect of

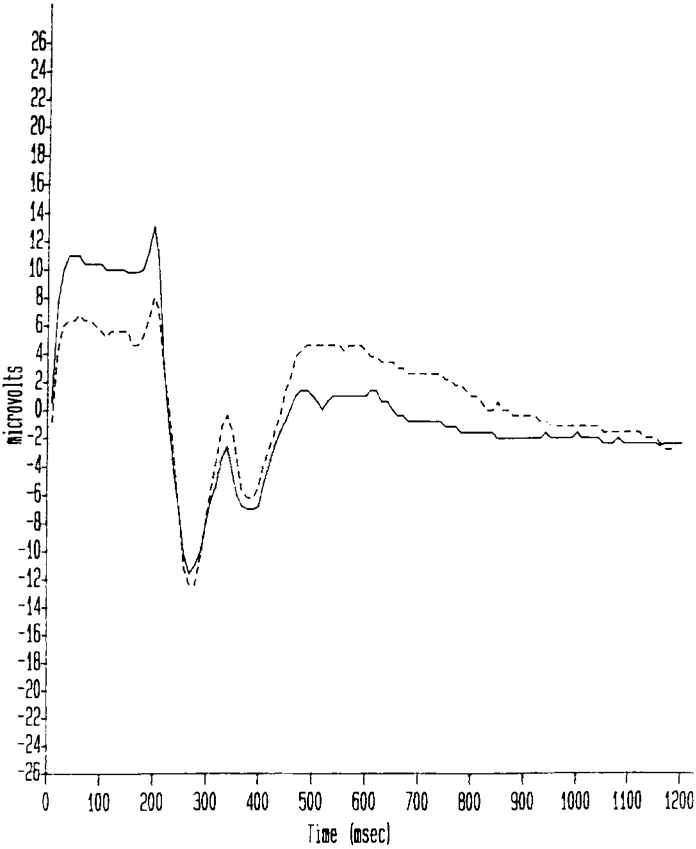

FIG. 3. Grand average data for adults for all "hits" at T5 (left temporal; solid line) and T6 (right temporal; dashed line). Peak amplitude is greater at right than left temporal.

Emotion was significant when all trials were included, $F(1, 14) = 6.55$, $p < .05$; area scores were larger when happiness was the target emotion (1628 vs. 575; see Fig. 3). No significant effects were found for either analysis for the children.

Peak amplitudes—T5 vs. T6. When all responses were included for adults, the main effects of Emotion, $F(1, 14) = 7.24$, $p < .05$, of Target, $F(1, 14) = 55.40$, $p < .001$, and of Lead, $F(1, 14) = 12.32$, $p < .01$, were all significant. Peaks were greater at T6 than at T5 (12.2 vs. 9.1 μV), greater to target than to nontarget trials (13.3 vs. 8.1 μV), and greater when happiness rather than anger was the target emotion (11.7 vs. 9.7 μV). When only correct responses were included, the main effect of Lead was significant, $F(1, 14) = 12.29$, $p < .01$, indicating again that peaks were greater at T6 than at T5 (13.0 vs. 9.8 μV). The main effect of Target was also significant, $F(1, 14) = 70.80$, $p < .001$, but this was qualified by a significant interaction of Emotion × Orientation × Target, $F(1, 14) = 5.06$, $p < .05$. F-tests for simple effects of Target within Emotion and Orientation revealed significant effects for all four comparisons, all F's > 11.00, p's < .01. In all cases, peaks were greater to hits than to correct rejections.

For children, when all responses were included, the only significant effect was a three-way interaction between Orientation, Target, and Lead, $F(1, 8) = 8.56$, $p < .05$. F tests for simple effects for Target within Orientation and Lead revealed that peaks were greater for target trials vs. nontarget trials only when the stimuli were upright, at T5 (17.6 vs. 13.7 μV), $F(1, 8) = 7.98$, $p < .05$, although the effects were in the same direction for the other three conditions as well. When only correct responses were included, the main effects of Emotion, $F(1, 8) = 6.29$, $p < .05$, and Target, $F(1, 8) = 11.19$, $p < .05$, were significant. Peaks were greater to hits than to correct rejections (19.5 vs. 15.5 μV), and when anger rather than happiness was the target (19.4 vs. 15.6 μV).

Latencies—T5 vs. T6. Main effects of Orientation were found for the adults when all trials were included, $F(1, 14) = 19.93$, and when only correct responses were included, $F(1, 14) = 17.10$, p's < .001. Latencies were shorter when the stimuli were presented upright than when they were inverted (611 vs. 677 msec, and 610 vs. 671 msec, respectively). A three-way interaction of Emotion × Target × Lead was also significant for the correct responses, $F(1, 14) = 5.17$, $p < .05$, but F tests for simple effects for Emotion within Target and Lead revealed no significant effects.

The only significant effects for children in both analyses were the interactions of Emotion × Orientation, $F(1, 8) = 8.06$ and 5.37, respectively, p's < .05. However, in both cases, Tukey tests indicated that none of the effects were significant.

DISCUSSION

There were few differences between the children's and the adults' behavioral performance measures. Though adults responded more quickly overall, as would be expected, children and adults both responded more quickly to happy faces than to angry faces. Both children and adults also had more difficulty recognizing inverted anger than upright anger, but there were no inversion effects for happy faces. In addition, more false alarms occurred for angry faces than for happy faces, particularly when the angry faces were inverted. For both inverted and upright faces, most false alarms were for fear faces.

For ERPs, effects of orientation were only apparent when all target trials were included in the analyses. For adults, the difference in area scores between target vs. nontarget trials was greater for upright faces than for inverted faces across both emotions. For the children, area scores were greater to upright anger than inverted anger, but were equivalent for upright and inverted happy faces. However, when only correct responses (based on the behavioral data) were included in the ERP analyses, the orientation effects were no longer significant. This would suggest that inverting the stimuli likely increases the subject's equivocation, making her/him less than certain as to the nature of the expression being displayed. This explanation is consistent with that put forth by Johnson (1986), who has suggested that certain ERP components (such as the P300) may vary as a function of how well individuals recognize a stimulus. However, the results from the analyses performed on "hits" and "correct rejections" would suggest that once the subject has correctly classified the stimulus, orientation makes little if any contribution to the amplitude of the P300.

Several interesting differences in ERPs that were not apparent from the behavioral measures were also found between the children and the adults. At Pz, for the adults, area scores and peak amplitudes were greater, and latencies were shorter, to the target "happy" than to "angry." In contrast, for the children, area scores were considerably greater to the target "angry" (see Fig. 2). In addition, area scores and peak amplitudes at the lateral leads were also greater for happiness for adults, but were greater for anger for the children. Thus, although behavioral measures indicated that both children and adults had more difficulty identifying angry expressions than happy expressions, the ERPs indicated that children responded differently than adults did to happy and angry expressions. Johnson (1986) has suggested that variation in amplitude may result from either differences in stimulus meaning, stimulus effectiveness, or subjective probability. For the children, greater amplitude responses to anger may indicate that emotional expressions of anger are more complex for them than are expressions of happiness, either perceptually or semantically, or both. For adults, it is not clear why they would have greater responses to the happiness targets than to the anger targets since happy faces are generally recognized more readily. One possible explanation for this difference may be because of subjective probabilities. Although the objective probabilities of the presence of happiness and anger were equivalent (25%), *subjective* probabilities may have been different for the adults, who had more false alarms when anger was the target than when happiness was the target (see Fig. 1). Adults averaged 6.7 false alarms for the "angry" conditions, compared to .9 false alarms for the "happy" conditions. In contrast, children averaged 7.5 false alarms for both happy and angry conditions. Adults, then, may have believed that there were more angry faces than there were happy faces. Thus, different subjective probabilities may have contributed to the amplitude differences.

In any case, differences were not as pronounced for the adults as they were for the children. Lang et al. (1990) also found equivocal results for adults: greater area when the target was "happy," but greater peak amplitude when the target was "angry." These differences may be attributable to differences in methodologies (e.g., the present study used multiple models, while Lang et al. presented only one model). Further studies are needed to corroborate these results. Similarly, the results from this study are not consistent with those found by Nelson and Nugent (1990). In their study with children, an N400 component discriminated between the two emotions, but only when the task was very simple. In addition, there were no differences in the P300 components for the two emotions. The differences in the studies may again be due to differences in methodologies (e.g., multiple vs. single models, upright and inverted orientations vs. only upright orientation), and/or may be attributable to age differences. In the Nelson and Nugent study, the children were on average 5 years old, in contrast to the 7-year-olds of the present study.

In the present study, the differences between children and adults do suggest that the stimuli are, in some way, differentially responded to by 7-year-olds and adults. Whether these differences are attributable to different task interpretations by the two age groups, or different responses to the stimuli, either perceptually, cognitively or emotionally, remains to be further explored. For example, it may be that children have more of a subjective emotional response to the expressions of anger, while adults either do not react emotionally to either expression, or react slightly more to happiness.

Other differences were found between children and adults comparing left vs. right temporal activity. The adults were found to have greater amplitude responses at T6 than at T5. This parallels what has been found from divided-field studies (e.g., Bryden & Ley, 1983) and studies of unilaterally brain-damaged individuals (e.g., Etcoff, 1984). For the children, on the other hand, there were no differences in the components at T5 and T6. Thus, for adults, but not children, responses appeared to be more lateralized, such that there was greater activity over the right hemisphere than over the left hemisphere.

In sum, a number of differences have been found between 7-year-olds and adults from ERP recordings that were not apparent from behavioral measures alone. Children had greater amplitude responses to anger than happiness, and adults showed the reverse. In addition, 7-year-olds do not show greater right hemisphere activity to facial expressions, as adults do. It seems reasonable to propose, then, that ERPs represent a useful tool for exploring developmental differences in the process of recognizing emotional expressions that may not be apparent from behavioral measures alone.

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