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Cognitive Brain Event-Related Potentials and Emotion Processing in Maltreated Children

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Cognitive event-related potentials (ERPs) were recorded from 23 maltreated and 21 nonmaltreated children. Children were presented with slides of Ekman photographs of a single model posing an angry (25%), a happy (25%), or a neutral (50%) facial expression. In 1 of 2 counterbalanced target conditions, children were asked to press a button in response to the angry face; in the other target condition, they responded to the happy face. Both samples, as expected, exhibited the largest amplitude of the P300 component of the ERP to target stimuli and the smallest amplitude to nontargets. For nonmaltreated children, the average amplitude of P300 across slides was comparable for the 2 target conditions. In contrast, maltreated children displayed larger P300 amplitude to stimuli when they were directed to attend to angry, as opposed to happy, targets. These results suggest different cognitive processing for positive versus negative affective expressions by children with histories of atypical emotional experiences.

INTRODUCTION

Theories of emotional development postulate that aberrations in caregiving, such as child maltreatment, may alter the processing and organization of emotions (Cicchetti & Tucker, 1994; Izard & Harris, 1995). This perspective includes emotion systems among those domains that develop based upon information that the nervous system receives from the environment. Such experience-dependent development assumes that information from the environment, however typical or aberrant, contributes to the organization of an organism (Greenough & Black, 1992).

Most research on the emotional development of maltreated children has focused upon their overt behavior, with relatively little emphasis upon physiologic and cognitive processes. However, behavioral responses such as maltreated children's social interactions, or subjective evaluations such as self-reports, may reveal only a partial picture of maltreated children's difficulties. Extending these investigations to include the cognitive processing of emotional information may help to clarify the developmental mechanisms that place maltreated children at risk for maladaptive development.

Emotional Development and Child Maltreatment

In general, behavioral observations of maltreated children reveal biases toward negative emotions. Because maltreated children develop within environments marked by threat and stress, negative affective cues have been posited to be highly salient for them. This hypothesis is supported by behavioral evidence that physically abused infants manifest negative emotional expressions earlier and more frequently than do nonabused children (Gaensbauer & Hiatt, 1984; Sroufe, 1979). The influences of early experience upon children's interpersonal behavior may also be indicated by varying patterns of attachment. Maltreated infants are more likely than nonmaltreated infants to develop insecure attachments with their primary caregivers, and are often classified as having a "disorganized/disoriented" (type D) attachment pattern (Carlson, Cicchetti, Barnett, & Braunwald, 1989; Lyons-Ruth, Repacholi, McLeod, & Silva, 1991). The prevalence of the Type D attachment pattern is thought to be caused by maltreated children's early experience with negative affect, including frightening parental behavior (Main & Hesse, 1990).

Maltreated children's emotional difficulties are not limited to their interactions with others. In visual self-recognition tasks, maltreated children are more likely to express neutral or negative affect rather than positive affect (Schneider-Rosen & Cicchetti, 1991). Yet, these children use fewer emotion-specific language words, and, in particular, fewer verbal references to physiological states and negative affect (Beeghly & Cicchetti, 1994). These difficulties are later manifested in peer relations, with abused children often having difficulty in responding to distress and reacting with hostile gestures to other children (Klimes-Dougan & Kistner, 1990; Main & George, 1985). Poor organization of affect is also reflected in the finding of Camras et al. (1990) that 3- to 7-year-old maltreated

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children were less accurate at recognizing emotions than their nonmaltreated peers.

Both cognitive and emotional processes have been implicated in individuals' appraisal and response to environmental cues (Bower, 1981; Campos, Campos, & Barrett, 1989). In particular, maltreated children experience difficulty avoiding distracting information, particularly aggressive stimuli, in both experimental (Rieder & Cicchetti, 1989) and observational settings (Dodge, Bates, & Pettit, 1990). More specifically, physically abused children's biases in the interpretation and representation of affective information appear to manifest themselves in response to both live and simulated anger (Cummings, Hennessy, Rabideau, & Cicchetti, 1994; Hennessy, Rabideau, Cicchetti, & Cummings, 1994). Therefore, maltreated children appear to respond differentially to negative emotional cues, and are likely primed to detect negative affect (Weiss, Dodge, Bates, & Pettit, 1992). Consistent with the ideas of Campos et al. (1989), these children's emotional behavior includes both action tendencies and coping processes that may be adaptive within environments marked by threat. A complete understanding of maltreated children's modulation of emotion would benefit from a perspective that accounts for children's behavior, subjective experience, and physiologic reactions as developing within markedly atypical caregiving contexts.

Event-Related Potentials and Emotion

Attachment theorists have argued that attachment systems permit flexible responses to environmental circumstances, influence the regulation of emotion, and function through mental representations that children hold of themselves and their relationships with others (Cassidy, 1994). The activation of these representations may be reflected through physiologic activity as well as behavior. The extant psychophysiological literature on emotion has focused primarily upon autonomic measures that indicate whether somatovisceral processes are involved in the perceptual processing of emotion (see Cacioppo, Klein, Berntson, & Hatfield, 1993, for discussion). Yet, another type of physiological reaction may also be used to study cognitive processes in emotion.

The event-related potential (ERP) is an index of central nervous system (CNS) functioning thought to reflect the underlying neurological processing of discrete stimuli (for review, see Hillyard & Picton, 1987). Event-related potentials are scalp-derived changes in brain electrical activity over time, obtained by averaging time-locked segments of the electroencephalogram (EEG) that are synchronized to the presentation of a stimulus. Research employing ERP methods has focused heavily upon cognitive processes, and ERP components have proven particularly useful in studying attention, memory, and categorization (Donchin, Karis, Bashore, Coles, & Gratton, 1986). Yet the influences of affective stimuli have generally received less attention (for exceptions, see Miller, Simons, & Lang, 1984, and Gunnar & Nelson, 1994).

One particular ERP component, P300,[1] is a positive wave that occurs approximately 300–600 ms after the presentation of a task-relevant stimulus, and is maximal at the central-parietal scalp. The amplitude of the P300 varies as a function of task relevance and stimulus probability (Johnson, 1993), and has been used in conjunction with behavioral measures to classify specific cognitive operations such as the evaluation of stimulus significance. The P300 may also reflect processes involved in the updating of representations in working memory (Donchin et al., 1986). In general, such psychological processes serve to maintain accurate representations of one's environment by highlighting events that are significant. Therefore, the P300 component may be useful in illuminating the cognitive processes that accompany the encoding of salient emotional stimuli and highlight differences in such processes between maltreated and nonmaltreated children.

Event-related potentials have been used to explore emotion processing in infants, children, and adults. Although the P300 has not been observed in infants, other ERP components have been used successfully with infants as young as 6 months of age (for review, see Nelson, 1994). In a study with 7-month-old infants, Nelson and de Haan (1996) found that ERPs to pictures of happy, as compared to fearful, facial expressions had larger amplitudes upon an early and a later positive component. In the same study, fearful expressions resulted in greater amplitudes than happy expressions of an early negative component. Yet, no differences in these ERP components

1. Two types of P300 have been reported in the psychophysiological literature. The P3a tends to be maximal over the frontal-central scalp region and is elicited during passive attention, whereas the P3b is maximal over the central-parietal region and is associated with a participant's active cognitive processing. Another critical feature of the P3b is that it is sensitive to the probability with which certain classes of stimuli are presented, with larger amplitudes invoked by rarer stimuli. Because in different experimental conditions the latency of P3b can be as short as 300 ms but may exceed 900 ms poststimulus, by convention P3b is labeled by its mean latency in a particular paradigm (e.g., P470 or P590). Generally, longer latencies reflect more complicated categorizations or stimuli; however, latency differences also emerge based upon participants' chronological age. Most of the literature reported herein, and the wave described in our results, pertains to the P3b component. However, we refer to it with the more general term, P300. (For discussion, see Squires, Squires, & Hillyard, 1975).

emerged when infants saw angry versus fear faces. Similarly, ERP amplitude in year-old infants has been observed to correlate with the infant's expression of positive and negative emotions, but not with the particular emotional stimuli (Gunnar & Nelson, 1995).

The literature on child and adult ERP responses to emotional stimuli is more equivocal. In large part, differences in methodology and analytic methods make comparisons across these studies difficult. Nelson and his colleagues (Nelson & Nugent, 1990; Kestenbaum & Nelson, 1992) have explored normative children's ERP responses to pictures of happy or angry faces. Two basic waves are noted in these studies: a negative component (N400) and a later positive component (P300/P700). In one experiment (Nelson & Nugent, 1990), 4- to 6-year-old children were asked to respond verbally to photographs of happy or angry faces, which were presented very briefly (100 ms). In each of two conditions, one of the faces served as a target and appeared either frequently (80%) or infrequently (20%). The N400 component distinguished between the facial expressions, with greater ERP area and peak values in response to angry as compared to happy faces. In contrast, the amplitude of the P300/P700 wave distinguished only target from nontarget faces, as it failed to differentiate between happy and angry faces. A second study involving both 7-year-old children and adults presented participants with photographs of angry, happy, fearful, and surprised faces (Kestenbaum & Nelson, 1992). In each of two conditions, children were asked to respond to the happy or the angry face. In this study, the N400 was not reliably observed. Findings with regard to the P300/P700 varied depending upon the method of scoring: Area scores for the children indicated greater values for the angry target, whereas peak values did not differentiate between happy and angry faces (Kestenbaum & Nelson, 1992).

The results for the adults in this same study were nearly the opposite of those for the children, with both area and peak measurements indicating greater values for happy as compared to angry faces. In a similarly designed study, Lang, Nelson, and Collins (1990) asked adults to respond to either a happy (20%) versus a neutral (80%) face or an angry (20%) versus a neutral (80%) face. Their results were only partially similar to those of Kestenbaum and Nelson (1992). Adult P300 area measurements showed a greater response to the happy target; however, for peak amplitude measurements, P300 values were greater to the angry rather than happy target.

Other studies with adults have compared processing of positive, negative, and neutral emotional verbal stimuli to processing of nonemotional material. Johnston, Miller, and Burleson (1986) reported increased P300 amplitude for emotionally toned pictures (dermatological slides, babies, nude photographs) when compared to neutral pictures (clothed people). Similarly, Vanderploeg, Brown, and Marsh (1987) found larger amplitudes to positive and negative facial expressions for a factorially derived positive ERP component they labeled Slow Wave. However, this same study indicated that P300 was greater to line drawings of neutral pictures as compared to positive or negative line drawings.

Differences in stimuli and scoring methodology appear to influence the effect of affective information upon the scalp topography of ERP components. Such differences are manifested in the presence or absence of particular wave patterns as well as the relative amplitude and timing of these components. For example, the studies reviewed above used stimuli consisting of pictures of affective scenes, line drawings, and photographs of faces. Additionally, the complexity of tasks varied based upon the stimulus duration, size of the stimuli, number of stimulus items, and overall length of the experiment. Data scoring procedures and age of participants also varied across studies.

One general conclusion that can be drawn from ERP studies with adults is that larger P300 responses are elicited by emotionally intense, as opposed to neutral, pictures of scenes (Johnston, Burleson, & Miller, 1987; Johnston et al., 1986; Yee & Miller, 1987). Such findings are replicated with clinical populations of adults, such as those with emotion-related precursors of psychiatric disorders (Miller et al., 1984; Yee & Miller, 1988). Therefore, it appears that affective information can influence scalp topography of ERP components if the affective loading of the stimulus is high and individuals attend to stimulus meaning (Johnston & Wang, 1991; Williamson, Timothy, & Hare, 1991).

Whereas the studies reviewed earlier may be used to argue that positive and negative valence stimuli increase P300 amplitude, these increments might be secondary to more (or less) intensive processing of emotional stimuli in general, rather than specific to discrete emotions. A second general conclusion that can be drawn from these reports is that stimulus significance and probability of occurrence are implicated in P300 responses of both adults and children.

The Present Study

The present study was aimed at investigating the integration of cognitive, physiological, and psychological factors in the emotional experiences of maltreated children. In addition to extending our knowledge of the processes with which maltreated children have difficulties, such an approach may also cast light upon the role of aberrant experience in the development of individual differences in the processing of emotion (see Hesse & Cicchetti, 1982). Although affective information is conveyed to children in many forms, a developmentally early means by which children gain affective information from the environment is face recognition (Johnson & Morton, 1991; Nelson, 1987). Accordingly, well-validated happy and angry facial expressions were selected as stimuli, with a neutral facial expression as an affective control. The ERP literature indicated that this methodology could be sensitive to children's processing of affective information, although it was difficult to make specific predictions regarding the direction of these effects. Because the behavioral literature suggests the presence of negative response biases in maltreated children, we predicted that these children would display heightened reactivity to anger relative to happiness. Such reactivity would be reflected in increased P300 amplitude as well as concomitant speeded reaction time and increased accuracy to angry stimuli.

A second aim of the present study was to clarify some aspects of the literature on normative populations. Because previous work (except for Kestenbaum & Nelson, 1992) did not compare emotional stimuli of equivalent probabilities (i.e., one expression was typically presented more often than another), the present design included these comparisons. To aid in our identification of P300 in this task, a sample of young adults was studied in the same paradigm. This effort was aimed at clarifying the ERP responses obtained from the children and helped place the children's results in context with the normative developmental P300 literature.

EXPERIMENT 1

Method

Sample

The sample consisted of 23 maltreated and 21 nonmaltreated children, ranging in age from 7.1 to 11.4 years. The maltreated children were deemed by the Monroe County (NY) Department of Social Services (DSS) to have undergone child maltreatment and were attending an after-school treatment program. Using Child Protective Service (CPS) records, researchers blind to the hypotheses of the study confirmed these classifications following the guidelines established by Manly, Cicchetti, and Barnett (1994). Children were retained if they had DSS documented reports of (1) physical abuse, with or without physical neglect (n = 18), or (2) physical neglect without physical abuse (n = 5). Children who had experienced sexual abuse, with or without other forms of maltreatment, were not included in this study. Although no children in the sample had reports indicating only emotional maltreatment, this type of abuse co-occurred in 33% (n = 6) of the physically abused and 40% (n = 2) of the physically neglected children.

Comparison children were recruited from the community. Following a parent interview to screen for nonmaltreating status, permission was obtained from parents to review CPS and other DSS records. Families were retained in the comparison sample if their records did not indicate protective or preventive services (provided to families in which children are at risk of foster care because of concerns related to maltreatment) or unfounded reports of maltreatment.

At the time of testing, children in both samples were reported to be in good health and free of medications. Parents of all children received detailed information concerning the study protocol and were asked to give informed consent. After being shown the study apparatus and agreeing to participate, all of the children completed the task and were rewarded for their participation with an age-appropriate toy.

As shown in Table 1, maltreated and nonmaltreated children did not differ on age, race, gender, or Peabody Picture Vocabulary Test—Revised (Dunn & Dunn, 1981) standard scores. The two samples were also equivalent on the Hollingshead Four Factor Index (Hollingshead, 1975) and on the percentage of families receiving public assistance. These findings indicate that both groups were drawn from comparable low socioeconomic populations.

Procedure

Children were tested individually in a sound-attenuated booth during the late afternoon. After attachment of electrodes, children viewed black-and-white slides of the same adult female posing a single happy, angry, or neutral expression (slide numbers 48, 53, and 56; Ekman, 1976). These stimuli were presented in four blocks of 160 trials each (total trials = 640), consisting of random arrangements of the three slides with nominal probabilities of 25% each for the angry and happy expressions and 50% for the neutral slide. Slides were presented for 600 ms at intervals of 1,500 ms. Each child received two conditions in which either the happy or angry face was designated as a target. Each target condition consisted of a 50 trial practice and two successive blocks of 160 trials.

Table 1 Demographic and Psychometric Variables for Each Sample

Variable	Maltreated	Comparison	Statistical Test
Chronological age (years):			
M	9.2	9.2	$F(1, 42) < 1$, *ns*
SD	1.6	1.1	
PPVT-R:[a]			
M	82.0	89.2	$F(1, 33) < 1$, *ns*
SD	15.5	12.2	
Family SES:[b]			
M	20.5	22.4	$F(1, 40) < 1$, *ns*
SD	6.3	6.4	
Race (%):			
Caucasian	35.3	20.0	$\chi^2(1, N = 44) = 1.1$, *ns*
Non-Caucasian	64.7	80.0	
Sex (%):			
Boys	78.3	81.0	$\chi^2(1, N = 44) < 1$, *ns*
Girls	21.7	19.0	
AFDC (%)[c]	51.22	48.78	$\chi^2(1, N = 44) = 1.3$, *ns*

Note: Chi-square is reported with Yates's correction.
[a] Peabody Picture Vocabulary Test—Revised, standard score.
[b] Hollingshead Four Factor Index.
[c] Aid to Families with Dependent Children.

The child was asked to indicate targets by pressing a button held in her or his preferred hand. Target assignment was randomly counterbalanced across target conditions, such that half of each sample received the happy as opposed to the angry condition first. Slides were rear-projected by means of Kodak 4200 projectors outfitted with soundproofed Uniblitz VS25 shutters (aperture/closure times = 3 ms) to image sizes of 42 × 64 cm on a screen positioned 120 cm in front of the child (visual angles = 19° × 28°).

Electroencephalogram recording. EEG was detected from silver chlorided In-Vivo Metric electrodes placed at three midline scalp sites: frontal (Fz), central (Cz), and parietal (Pz). Electrodes were attached by means of adhesive collars to a lycra Electro-Cap and referenced to the linked earlobes. For eye movement detection, the vertical electrooculogram (EOG) was derived from two similar electrodes attached to the right supra- and infraorbital ridges. Finally, a mid-forehead electrode was used as ground. All electrode sites were abraded to lower skin impedance below 5 kOhms. EEG and EOG were recorded by means of Grass Model 12 amplifiers with a nominal response frequency of 0.1 to 100 kHz and gains of 1,000 and 200 times, respectively. A Gateway 386 PC equipped with a LabMaster analog-to-digital board (12 bit resolution) controlled stimulus presentation and digitized all physiological signals at a rate of 200 Hz from 150 ms before to 1,200 ms after the onset of each slide. No analog data were recorded for the ensuing 150 ms, after which interval began the prestimulus baseline for the succeeding trial. This cycle was repeated every 1,500 ms (onset-to-onset intertrial interval). Reaction time was detected with a resolution of 2 ms from 200 ms through 1,200 ms poststimulus.

Performance scoring. The following measures of performance were computed: (1) mean and within-subject standard deviation of reaction time for correct responses, (2) percentage of misses (failures to make a response to a target), and (3) percentage of false alarms (incorrect button presses) to the rare (nontarget) slide and to the neutral (frequent, nontarget) slide. Premature reactions (<200 ms) were very infrequent (<2%), yielded no significant findings, and are not discussed further.

Event-related potential scoring. The following trials were excluded from the computation of ERPs: the first trial of every block, those involving an incorrect button press, and those containing amplifier blocking for any electrode. In addition, every other presentation of the neutral (frequent, nontarget) slide was excluded so that the resulting ERPs were based upon approximately the same number of trials as those for the happy and angry slides. Next, to eliminate ocular artifact on EEG, EEG data were adjusted for their regression on EOG, separately for eyeblinks and other eye movements (Gratton, Coles, & Donchin, 1983). As a result, the adjusted EEG data have zero correlation with the corresponding EOG data. Separate ad-

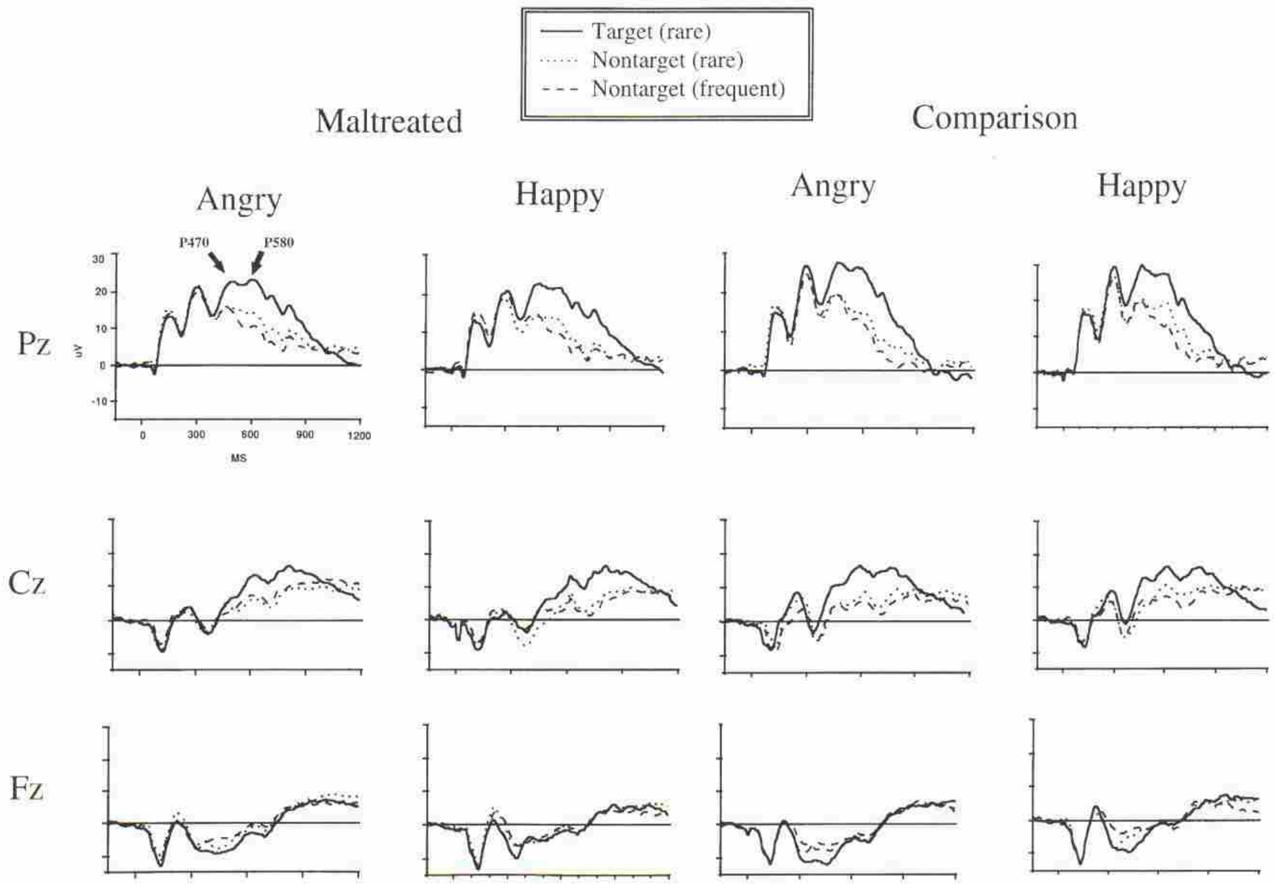

Figure 1 Grand average ERPs for maltreated and comparison children. Stimuli were presented at 0 ms. Relative positivity at the scalp is displayed upward.

justments were required for eyeblinks and other ocular activity because these two types of ocular activity have different propagation functions over the scalp. Finally, ERPs were derived by averaging the adjusted EEG data separately for each electrode, stimulus, and target condition. The average number of trials retained for ERPs was 77.1 for rare target trials, 76.1 for rare nontarget trials, and 70.5 for frequent nontarget trials.

Figure 1 displays grand average ERPs for both target conditions and groups. We focus upon two late positive components for which we had a priori hypotheses, and which peaked on average at 470 and 590 ms, respectively. Individual ERP components were scored as follows. First, for each participant, an average of her or his 6 ERPs (three conditions × two stimuli) was computed. Next, for each component, a computer algorithm identified the largest positive value of the participant's grand average at the Pz electrode site within a time window based upon the entire sample's grand average: 450–500 and 585–635 ms, respectively. The algorithm then defined intervals of +/−40 ms around each of these features in the participant's grand average and, for each of her or his six ERPs at Pz, identified the most positive point within these windows. The amplitude of the ERP at this latency was computed separately for each electrode, and deviated from the mean amplitude in the prestimulus 150 ms interval. In summary, this completely automatic algorithm identified amplitudes for components at each electrode based upon latencies at the Pz electrode, at which these two components were maximal. Similar procedures were used to score three additional ERP components (N100, P200, and N200) based upon the electrodes at which each was maximal. However, these procedures will not be detailed because (1) no specific hypotheses had been advanced for these components, and (2) the exploratory analyses of these data did not yield findings related to the experimental manipulations.

As described by Nelson and Nugent (1990), the presence of multiple peaks in individual responses may cause difficulties in identifying particular components. Therefore, we also scored area measures consisting of the average voltage of the same two intervals used for scoring peak measures (450–500 ms and 585–635 ms, respectively) minus the average voltage in a 150 ms prestimulus baseline. Because the same pattern of results emerged based upon peak and area ERP scoring, the analyses emphasize results for peak amplitude values.

Results

Performance and ERP data were submitted to analyses of variance with maltreatment status (maltreated, comparison) and order (angry or happy first) as between-subject factors and two repeated measures: condition (angry or happy slide as target) and stimulus (angry, happy, or neutral facial expressions). In this article, condition designates the stimulus (happy or angry target) to which the child's attention was directed. For analyses of ERP data, electrode site (Fz, Cz, Pz) was treated as an additional repeated measure. Children's chronological age was used as a covariate to reduce error variance and to describe developmental trends. The test of the regression coefficient of each dependent variable on age was used to assess developmental effects. We report unstandardized pooled regression coefficients (*B*) based upon Myers and Wells's (1995, p. 523) recommendation. Probability values for repeated measures are based upon the Geisser-Greenhouse correction. The magnitude of effect size is reported as partial omega-square (ω_p^2; Keppel, 1991).

Performance

Reaction time for hits. Analysis of variance of mean reaction time for targets indicated that maltreated children ($M = 647$ ms) were slower overall than comparison children ($M = 599$ ms), $F(1, 39) = 5.49$, $p < .03$, $\omega_p^2 = .05$. No reaction time differences between samples based upon target condition emerged, target condition x maltreatment status $F(1, 40) = 2.09$, *ns*, $\omega_p^2 = .01$. As expected, averaging over maltreatment groups, reaction time was faster for older children, $F(1, 39) = 37.59$, $p < .001$, $B = -49.39$.

The combined sample had larger within-subject standard deviation of reaction time in responding to the happy ($M = 168$ ms) as compared to the angry face ($M = 149$ ms), $F(1, 40) = 8.72$, $p < .005$, $\omega_p^2 = .08$. Group differences in average variability of reaction time between maltreated ($M = 149$ ms) and nonmaltreated ($M = 169$ ms) children were minimal, $F(1, 39) = 2.67$, *ns*, $\omega_p^2 = .02$. As anticipated, younger children had more variable reaction time, $F(1, 39) = 9.52$, $p < .004$, $B = -14.52$.

Percentage of misses. No statistically significant differences between samples emerged for accuracy. The mean percentage of targets missed was 7.5% for maltreated children and 5.2% for comparison children, $F(1, 39) < 1$, *ns*, $\omega_p^2 < .01$. Younger children were less accurate in this respect than were older children, $F(1, 39) = 7.95$, $p < .01$, $B = -3.00$.

Percentage of false alarms. Children made more false alarms to rare nontarget slides ($M = 7.6\%$) than to frequent nontarget slides ($M = 5.2\%$), $F(1, 40) = 30.55$, $p < .001$, $\omega_p^2 = .14$. No group differences emerged between the frequencies of false alarms by maltreated and nonmaltreated children for either the rare nontarget or frequent stimuli, $F(1, 39) < 1$, *ns*, $\omega_p^2 < .01$. Children's chronological age did not affect the rate of false alarms, $F(1, 39) < 1$, *ns*.

Event-Related Potentials

Mean amplitudes for both the P470 and P590 peaks are presented in Table 2, separately for target conditions and electrode sites. As detailed below, although both peaks showed larger amplitude for the target than for other stimuli, only P590 distinguished between rare nontarget and frequent stimuli. Therefore, the P590 wave was identified as the P300 component. Children's age did not emerge as a significant covariate for either ERP measure. The first set of results presented describes the characteristics of the two components that were used to classify P590 as P300. Next, the analyses related to the specific hypotheses about group differences are presented.

General characteristics of P470. As shown in Table 2, P470 was largest at posterior sites, electrode $F(2, 80) = 281.72$, $p < .001$, $\omega_p^2 = .52$. Specifically, P470 was significantly larger at Pz than at Fz, $F(1, 40) = 374.79$, $p < .001$, $\omega_p^2 = .32$, or Cz, $F(1, 40) = 8.69$, $p < .02$, $\omega_p^2 = .02$. Similarly, amplitudes at Cz were larger than those at Fz, $F(1, 40) = 333.96$, $p < .001$, $\omega_p^2 = .30$.

P470 was sensitive to low probability and target conditions, stimulus $F(2, 80) = 26.67$, $p < .001$, $\omega_p^2 = .06$. Specifically, P470 was larger for target than rare nontarget slides, $F(1, 40) = 45.40$, $p < .001$, $\omega_p^2 = .20$. P470 amplitudes were larger over parietal than over frontal sites, and this electrode difference was greatest for responses to target (as opposed to nontarget or frequent) stimuli regardless of emotion presented, stimulus × electrode $F(4, 160) = 38.31$, $p < .001$, $\omega_p^2 = .18$; stimulus × Pz versus Fz $F(1, 40) = 71.82$, $p < .001$, $\omega_p^2 = .49$. However, as noted earlier, P470 amplitude did not distinguish between the nontarget rare slides and the frequent neutral slides, $F(1, 40) < 1$, *ns*.

P470 latency decreased with children's age, $F(1,$

Table 2 Mean Component Amplitude (Standard Deviation) in μVs by Electrode Site and Condition

	Angry Target Condition			Happy Target Condition		
	Angry (Target)	Happy (Rare)	Neutral (Frequent)	Happy (Target)	Angry (Rare)	Neutral (Frequent)
P470:						
Fz:						
Maltreated	−7.70 (8.3)	−4.94 (10.6)	−4.09 (6.6)	−9.04 (6.0)	−10.73 (7.8)	−5.78 (6.0)
Comparison	−1.68 (8.3)	−3.60 (9.7)	−2.00 (9.2)	−.27 (9.7)	−7.79 (7.5)	−2.81 (8.2)
Cz:						
Maltreated	7.26 (10.4)	2.87 (10.6)	4.06 (10.4)	6.43 (9.6)	.21 (9.1)	3.69 (6.7)
Comparison	11.97 (11.0)	7.00 (10.8)	7.21 (11.8)	13.92 (13.7)	3.60 (11.0)	7.45 (11.0)
Pz:						
Maltreated	24.78 (10.3)	16.93 (11.1)	16.40 (9.3)	23.54 (8.4)	15.89 (9.0)	17.09 (6.7)
Comparison	29.82 (14.4)	21.28 (12.4)	21.56 (13.5)	31.36 (13.2)	21.04 (9.4)	21.70 (11.3)
P590:						
Fz:						
Maltreated	−2.23 (7.7)	−.08 (11.0)	−.51 (6.5)	−5.35 (7.9)	−5.21 (7.0)	−3.16 (6.7)
Comparison	−.17 (8.4)	−.98 (9.2)	−.89 (7.0)	−.81 (9.3)	−.66 (8.5)	−.33 (8.4)
Cz:						
Maltreated	13.30 (8.2)	8.72 (9.4)	6.89 (8.3)	10.20 (8.4)	5.38 (8.2)	5.17 (5.9)
Comparison	16.49 (11.1)	8.62 (10.4)	7.31 (10.3)	15.02 (9.3)	10.48 (12.3)	7.84 (11.1)
Pz:						
Maltreated	24.60 (8.7)	16.47 (10.5)	11.95 (8.5)	22.23 (8.5)	14.49 (8.1)	11.99 (6.7)
Comparison	28.04 (14.9)	16.57 (13.3)	14.42 (13.3)	29.14 (11.4)	20.40 (11.0)	15.89 (10.8)

39) = 6.34, $p < .02$, $B = -7.98$. However, no latency differences emerged based upon maltreatment status or target condition.

General characteristics of P590. Several aspects of the present P590 are consistent with its designation as P300. As indicated in Table 2, P590 was largest at posterior sites, electrode $F(2, 80) = 181.04$, $p < .001$, $\omega_p^2 = .19$. Consistent with P300 scalp topography, P590 amplitude was significantly larger at Pz than at Fz, $F(1, 40) = 233.25$, $p < .001$, $\omega_p^2 = .23$, marginally larger at Pz than at Cz $F(1, 40) = 2.71$, $p < .10$, $\omega_p^2 = .01$, and larger at Cz than at Fz, $F(1, 40) = 216.55$, $p < .001$, $\omega_p^2 = .22$.

Also consistent with P300 characteristics was the sensitivity of P590 to low probability and target conditions, stimulus $F(2, 80) = 30.13$, $p < .001$, $\omega_p^2 = .04$. A stimulus × electrode interaction, $F(4, 160) = 78.45$, $p < .001$, $\omega_p^2 = .07$, reflects, in large part, the fact that the discrepancy in P590 amplitude for targets versus nontargets was greatest parietally and smallest frontally, Pz versus Fz $F(1, 40) = 145.66$, $p < .001$, $\omega_p^2 = .16$. Specifically, at Pz, P590 was larger for target than for rare nontarget slides, $F(1, 40) = 57.02$, $p < .001$, $\omega_p^2 = .16$, and was larger for the nontarget rare slides than to the frequent neutral slides, $F(1, 40) = 10.97$, $p < .005$, $\omega_p^2 = .03$.

Consistent with previous developmental findings, P590 latency decreased with children's age, $F(1, 39) = 21.86$, $p < .001$, $B = -13.58$. No latency differences emerged based upon maltreatment status or target condition.

Group differences. No group differences emerged based upon peak measurements for P470, maltreatment status × condition, $F(1, 40) < 1$, *ns*. However, area P470 amplitude values indicated a maltreatment status × target condition interaction, $F(1, 40) = 5.49$, $p < .03$, $\omega_p^2 = .01$. Simple effects analyses revealed that maltreated children had larger P470 area values for all of the faces in the angry ($M = 4.7$ μV) as compared to the happy ($M = 2.5$ μV) target condition, $F(1, 21) = 6.86$, $p < .02$, $\omega_p^2 = .02$. Nonmaltreated children, in contrast, had equivalent responses in both angry and happy ($M = 7.5$ and 7.8 μVs, respectively) target conditions, $F(1, 19) < 1$, *ns*.

Figure 2 shows P590 amplitude differences at Pz by group and each target condition. Differences between maltreated and comparison children across target conditions resulted in an interaction of maltreatment status × target condition, $F(1, 40) = 6.68$, $p < .02$, $\omega_p^2 = .01$. Simple effects analyses indicated that, averaging over slide categories and electrodes, maltreated children exhibited larger P590 amplitudes during the angry ($M = 7.1$ μV) compared with the happy ($M = 4.7$ μV) target condition, $F(1, 21) = 8.03$, $p < .03$, $\omega_p^2 = .02$. In contrast, comparison children's P590 amplitudes were equivalent for both angry ($M = 8.2$ μV) and happy ($M = 9.2$ μV) target conditions, $F(1, 19) = 1.52$, *ns*. Post hoc analyses suggested that

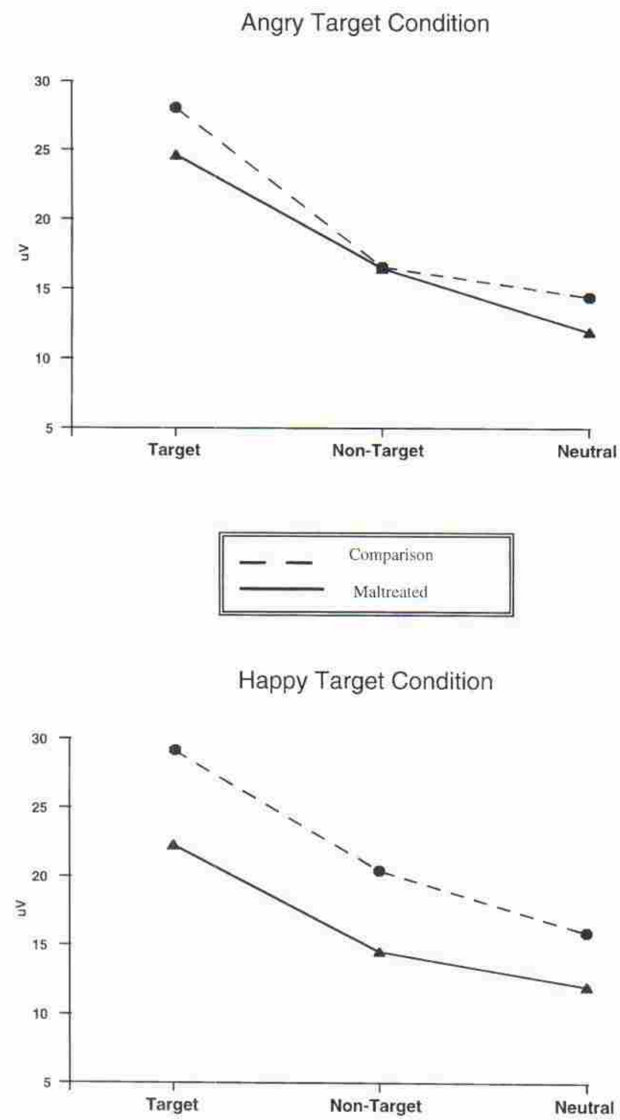

Figure 2 **P590 amplitude recorded at the midline parietal electrode site.**

maltreated and nonmaltreated children's P300 responses were equivalent in the angry target condition, $F(1, 39) < 1$, *ns*, but differed significantly in the happy target condition, $F(1, 39) = 4.43$, $p < .05$. These results were similar to those for area measurements, which will not be detailed.

EXPERIMENT 2

Method

Sample and Procedure

The sample comprised 14 (seven males) college students, with a mean age of 23.3 years ($SD = 4.6$). Participants received credit toward a course research requirement for participation. All had normal or corrected vision, were in good health, and denied use of drugs or medication with the exception of birth control pills. Informed consent was received from all participants. All procedures were identical to those described in Experiment 1.

Event-related potential scoring. Figure 3 displays the adults' grand average ERPs. As was the case for the sample of children, there were two prominent positive-going peaks. Peak and area measurements were computed with procedures identical to those described for children in Experiment 1, except that to accommodate the earlier latency of the two positive components among young adults, these waves were identified in the windows of 355–405 ms and 455–505 ms, respectively. Comparison of Figures 1 and 3 reveals the expected decrease in P300 amplitude from childhood to adulthood. These developmental trends were not evaluated formally because of the drastic mismatch in socioeconomic background between the present samples of children and adults.

Results

Performance

There was a trend for participants to respond faster in the angry ($M = 443$ ms) as compared to the happy ($M = 456$ ms) target condition, $F(1, 12) = 3.56$, $p < .10$, $\omega_p^2 = .01$. The standard deviation of reaction time was nearly identical in the angry ($M = 77$ ms) and happy ($M = 76$ ms) target conditions, $F(1, 12) < 1$, *ns*. As the task was very easy for adults, error rates were too low for meaningful statistical analyses.

P364

There was an overall difference in electrode site, $F(2, 24) = 63.83$, $p < .001$, $\omega_p^2 = .15$, with larger amplitudes at Pz than Fz, $F(1, 12) = 98.17$, $p < .001$, $\omega_p^2 = .17$, and larger amplitudes between the central and frontal sites, $F(1, 12) = 146.32$, $p < .001$, $\omega_p^2 = .11$. As expected, P364 was larger for the low probability target than for the rare nontarget stimulus, target versus nontarget $F(1, 12) = 15.83$, $p < .01$, $\omega_p^2 = .03$. However, P364 amplitude did not distinguish between rare nontarget and frequent stimuli, $F(1, 12) < 1$, *ns*. There were no significant differences between target conditions in P364 amplitude, $F(1, 12) < 1$, *ns*. No latency differences emerged for P364 based upon target condition or stimuli.

P440

As was the case for the children, the later positive peak best met criteria for P300 in the adult sample.

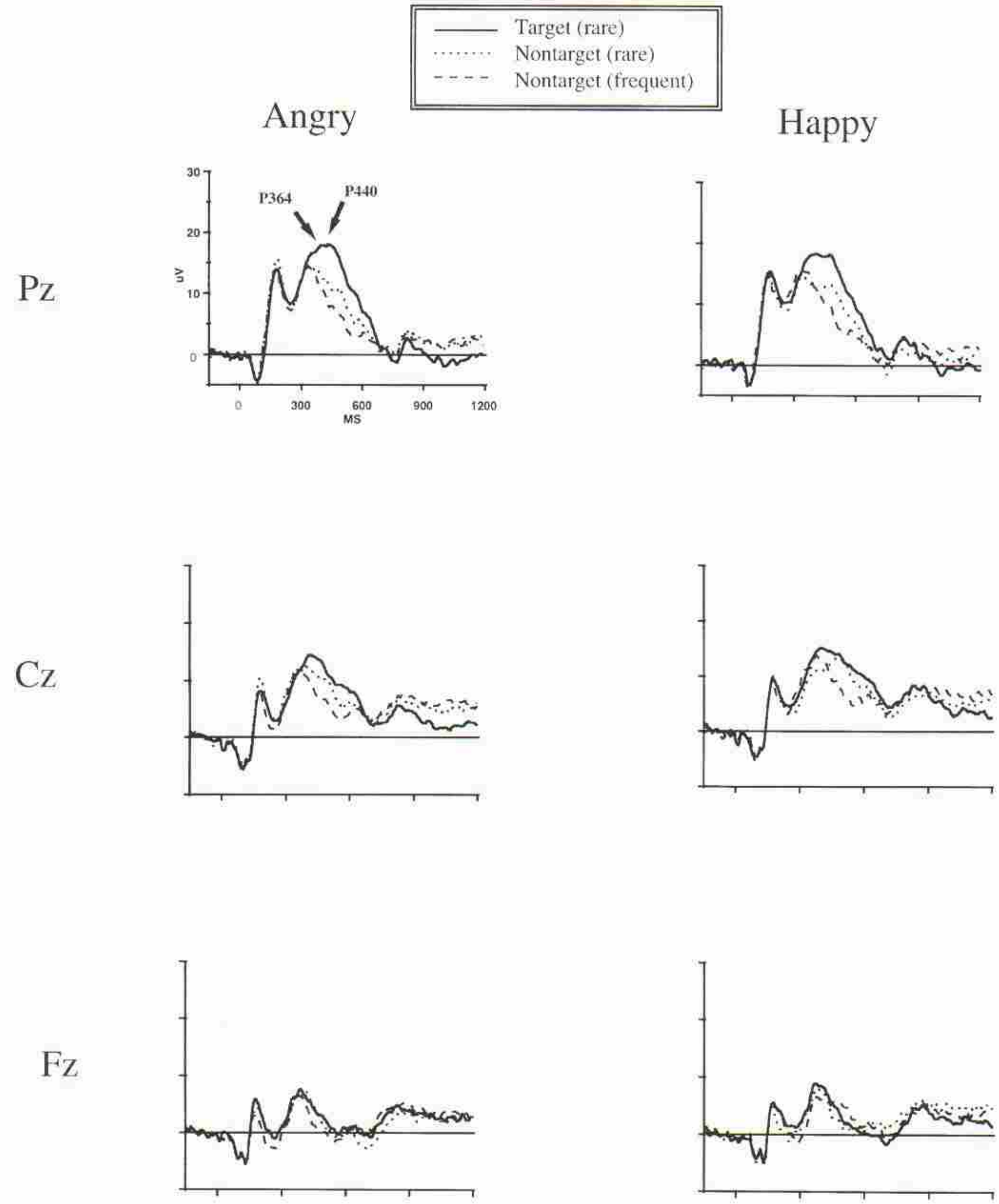

Figure 3 Grand average ERPs for adults. Stimuli were presented at 0 ms. Relative positivity at the scalp is displayed upward

Specifically, P440 exhibited a positive posterior scalp topography, $F(2, 24) = 57.64$, $p < .001$, $\omega_p^2 = .08$. Amplitudes were larger parietally than frontally, $F(1, 12) = 85.58$, $p < .001$, $\omega_p^2 = .10$, and larger centrally than frontally, $F(1, 12) = 189.67$, $p < .001$, $\omega_p^2 = .09$. In addition, unlike P364, P440 differentiated among stimuli, $F(2, 24) = 15.33$, $p < .001$, $\omega_p^2 = .06$. In particular, amplitudes at Pz were larger for targets than for rare nontargets, $F(1, 12) = 42.13$, $p < .001$, $\omega_p^2 = .14$, and larger for rare nontargets than for frequent stimuli, $F(1, 12) = 10.74$, $p < .01$, $\omega_p^2 = .02$. Significant differences in P440 amplitude did not emerge between the angry ($M = 13.3$ μV) and happy ($M = 14.2$ μV) conditions, $F(1, 12) = 1.85$, *ns*. Adults showed faster P440 latency to the frequent (432 ms) slide than to either the rare target (445 ms) or rare nontarget (445 ms) stimuli, $F(2, 24) = 5.21$, $p < .02$.

GENERAL DISCUSSION

P300 Benchmarks

For both children and adults, two ERP components were identified that were responsive to the identification of target faces. The existence of multiple late positive waves in adults' and children's cognitive ERPs has frequently been reported (e.g., Friedman, Boltri, Vaughn, & Erlenmeyer-Kimling, 1985). In a continuous performance test generally similar to the present task, Friedman et al. (1985) identified two parietally focused late positive waves (mean latencies of 450 and 550 ms, respectively) that exhibited larger amplitude to target than to nontarget stimuli.

Both the P470 and P590 in children and the P364 and P440 in adults had scalp topographies consistent with that of P300, including decreasing amplitudes from parietal to frontal sites and sensitivity to stimulus probability and task significance. For both adults and children, the later positive component peaked approximately 100 ms after the earlier component and better met criteria for P300 in that it differentiated among all three classes of stimuli, whereas the earlier wave did not. Specifically, P440 in adults and P590 in children, unlike the respective earlier positive-going waves, conformed to the expected P300 pattern of having the largest amplitude to the stimulus designated as target, with smaller amplitudes to the rare but nontarget stimuli, and smallest values to the frequent nontarget stimuli (Pfefferbaum, Ford, Wenegrat, Roth, & Kopell, 1984).

Although in the combined sample, younger children predictably showed slower as well as more variable reaction time and more errors, no P300 amplitude differences were associated with children's age. The latter finding is consistent with the developmental results for P300 reported by Johnson (1989) within this age range. Among the young adult sample, increased latency for the rare versus the frequent stimuli suggests that the emotionally valent slides evoked increased cognitive processing relative to the neutral slide.

Maltreated Children's Information Processing

Overall, maltreated children's information processing of emotional stimuli differed from that of their nonmaltreated peers. These differences were reflected in smaller P300 amplitude and slower reaction times for the maltreated sample. The finding that the maltreated and comparison groups were similarly high in accuracy indicates that their discrepant reaction times cannot be attributed to strategy differences, such as speed/accuracy trade-offs. Possibly, a more difficult task would have elicited accuracy differences between the maltreated and nonmaltreated groups. On the other hand, global dampening of P300 is a general finding that characterizes many psychopathological conditions (Klorman, 1995). The more specific and compelling present finding is that maltreated children's cognitive ERPs varied depending upon whether their attention was directed toward angry or happy faces. In contrast, for nonmaltreated children (and young adults), comparable P300 amplitudes emerged for both the happy and angry face conditions.

Unlike the ERP results, and contrary to our expectation, directing the children's attention to the angry stimuli did not have a differential effect on maltreated children's psychomotor performance. Although maltreated children had slower reaction times overall, no differences in accuracy or speed emerged as a function of target condition. Such differences may not have emerged because full cognitive processing of slide content was not achieved by the time that children executed their responses. The ERP results suggest that processes of emotion/stimulus recognition reflected in P300 were not completed before approximately 600 ms poststimulus. Notably, children initiated motor responses before the resolution of P590, indicating that the processing reflected in this component may not have been fully available when motor reactions were performed.

Affect Processing and Developmental Risk

Two aspects of these data carry important developmental implications. The first is that the electrophysiological differences between the maltreated and nonmaltreated groups emerged based upon whether they were asked to attend to happy or angry faces, independent of the emotional expression presented or probability of occurrence. Whereas nonmaltreated children had equivalent response amplitudes in both happy and angry target conditions, maltreated children had larger P300 amplitude in the angry than in the happy target conditions. This effect for the maltreated children highlights the importance of both context and the deployment of attentional resources in understanding children's emotional behavior. The observation that task condition, rather than facial stimuli alone, elicited the distinct feature of these children's processing indicates that maltreated children's ERPs were not merely stimulus-driven. It may be argued that pictures of angry expressions are more rare than those of happy expressions, such that greater P300 amplitude would be elicited by angry stimuli. Importantly, the results for both groups failed to show differences between happy and angry slides independent of target condition. Yet, it is also possible that instructions to attend to a novel face could produce an overall increase in responsivity to all stimuli.

Second, because P300 is sensitive to the meaning of a stimulus for an individual (Johnson, 1993), the present findings cast light on the differential processing of emotions by maltreated children. The present data suggest that the context defined by anger (or negative affect) exerted a differential effect upon maltreated children's information processing than when their attention was directed to happy cues. A basic question emerging from such data is whether maltreated children were reacting above or below their own baseline in the angry and happy target conditions. There are two ways to address this issue. The first is based upon the separate comparison of the maltreated and nonmaltreated children's responses in the two conditions. This comparison indicated that significant group differences did not occur in the angry condition, but did emerge in the happy condition. Thus, using a literal criterion, a tenable conclusion of the group differences is that, relative to controls, maltreated children displayed normative responses within the anger condition but underresponded in the happy condition. However, a second interpretive strategy is to focus upon within-subject differences (or between-group differences of within-group response patterns). This approach requires a condition in which some baseline condition, such as a neutral face or nonaffective stimulus, is designated as a target. This study did not contain such a condition; thus, these data cannot resolve whether maltreated children's P300 reflects responses above or below their own baseline for anger and happiness, respectively.

In accounting for such findings, we suggest that angry and happy targets activated affective representations differentially for these children, and, further, that the maltreated children's ERP responses in the anger condition reflect more efficient cognitive organization than during the happy condition. Indeed, such patterns of activation would be adaptive for coping with environments marked by stress and threat. However, biases toward negative affect or diminished responsiveness to positive affect would certainly create difficulties for these children when interacting with others in nonmaltreating contexts (Rogosch, Cicchetti, & Aber, 1995).

Emotion systems have been postulated to function as associative networks wherein input that matches significant mental representations activates memory systems (Lang, 1994). P300 amplitude, in this context, may mark the match of facial stimuli with more complex emotional memories. Various information processing theories, including constructs such as schemas and working models, have been posited to describe the mechanisms by which children integrate biologically relevant information with existing knowledge structures (Bretherton, 1990; Estes, 1991). The present psychophysiological results provide concurrent support for such developmental processes. That such representations exist, and are activated or motivated by emotional cues, provides further support for the cognitive mechanisms posited to put maltreated children at risk for insecure attachment relationships (Crittenden & Ainsworth, 1989), as well as various forms of psychopathology such as conduct disorder and depression (Dodge, 1993).

Conclusions

The results of the present study suggest that maltreated children's cognitive processing of emotional information is marked by differential deployment of cognitive resources when attending to cues for negative versus positive affect. Importantly, although overall P300 amplitude differences emerged, a within-subjects design allowed for the comparison of children's responses to expressions of both positive and negative emotions of equal probabilities. The present results are bolstered through our use of a high-risk comparison sample, a control that militates against environmental deprivation as an alternative hypothesis. However, it should be noted that measures of child psychopathology were not administered to participants in either sample. As is the case in most child maltreatment research, our experimental sample contained children who had experienced various subtypes of abuse, and relatively small sample sizes prevented subtype-based analyses. A clear picture of the role of experience in the development of emotion processing will ultimately require specific distinctions among the kinds of experiences that children have. Current studies in our laboratory are attempting to explore these issues.

Combined with other literatures on the effects of maltreatment, this study clearly demonstrates that the emotional and behavioral difficulties observed in maltreated children affect multiple biobehavioral systems. In ascribing psychological meaning to these psychophysiological results, we postulate that attention to negative versus positive affect activates mental representations in these children that are distinct from the patterns of activation observed in nonmaltreated children. Thus, maltreated children's prior experiences are reflected in their physiologic activity. Such processes may allow children to tailor adaptive behavioral responses to meet the challenges presented by their environments, yet provide costly and ultimately maladaptive solutions that contribute to maltreated children's social-cognitive difficulties and increased risk for psychopathology.

Future research should strive to extend the findings reported here with the goal of constructing more specific emotion information processing models. Because child maltreatment is a multidetermined problem that likely affects many neurobehavioral systems, a more complete understanding of the role of experience on the development of brain-behavior relations and organization is necessary. Moreover, such research provides an opportunity to expand current understanding of the role of experiential input in typical development.

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