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P3b reflects maltreated children's reactions to facial displays of emotion

SETH D. POLLAK,[a] RAFAEL KLORMAN,[b] JOAN E. THATCHER,[b] AND DANTE CICCHETTI[c]

[a]University of Wisconsin, Madison, USA
[b]University of Rochester, Rochester, USA
[c]Mt. Hope Family Center and University of Rochester, Rochester, USA

Abstract

Processing of emotion information by maltreated and control children was assessed with event-related brain potentials (ERPs). Maltreated children, for whom negative facial displays may be especially salient, and demographically comparable peers were tested to increase knowledge of differential processing of emotion information. ERPs were measured while children responded to pictures depicting facial displays of anger, fear, and happiness. Maltreated children showed larger P3b amplitude when angry faces appeared as targets than did control children; the two groups did not differ when targets were either happy or fearful facial expressions or for nontargets of any emotional content. These results indicate that aberrant emotional experiences associated with maltreatment may alter the allocation of attention and sensitivity that children develop to process specific emotion information.

Descriptors: Event-related potentials, Child maltreatment, Emotion, Psychopathology, Development

The unfolding of basic emotional processes during postnatal development appears to be guided by biological factors. Evidence for a maturational process includes cross-cultural commonalities in the recognition of facial expressions of affect, similar facial expressions of emotion in children born both blind and deaf (who could not have learned emotional displays via modeling or observation), and the relatively invariant sequencing and timing of the emergence of emotion displays (Eibl-Eibesfeldt, 1973; Ekman, Sorenson, & Friesen, 1969; Sroufe, 1979). At the same time, experience clearly plays an important role in the affective strategies and patterns that children develop in that the extent and circumstances under which emotions are displayed differ across cultures (Lutz, 1988). Still uncertain are questions regarding the extent to which emotion systems remain flexible to environmental input and the mechanisms by which social experience influences the development of emotion systems. These questions may be explored by examining the effects of markedly species atypical emotional input on cognitive/affective functioning.

In 1995, over 1.5 million children were victims of substantiated child maltreatment in the United States. More than half of these children were seven years of age or younger, with 26% below age four (U.S. Department of Health and Human Services, 1996, 1997). The sequelae of child maltreatment place children at extremely high risk for the development of psychopathology (Cicchetti & Toth, 1995; Malinosky-Rummell & Hansen, 1993). One well-documented problem area for maltreated children is their emotional functioning. For example, maltreated infants and children show patterns of emotional expression and recognition that differ from those of nonmaltreated children (Camras et al., 1990; Gaensbauer & Hiatt, 1984), and experience greater difficulty in the regulation of emotional states than do their peers (Camras, Sachs-Alter, & Ribordy, 1996; Cummings, Hennessy, Rabideau, & Cicchetti, 1994; Main & George, 1985). These behavioral patterns are noteworthy because problems in emotional functioning are associated with nearly all forms of child and adult psychopathology, though the nature of these problems vary among different disorders. Thus, understanding the role of social experience on the organization of affective processes may shed light on the development of psychopathology.

Recent studies have suggested a relationship between socio-emotional experiences and brain organization, but such data on young children is sparse. A recent and relevant study by Dawson, Panagiotides, Klinger, and Spieker (1997) showed that infants who are cared for by depressed mothers exhibit increased relative right

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Address reprint requests to: Seth Pollak, Department of Psychology, 1202 West Johnson Street, University of Wisconsin at Madison, Madison, WI 53706-1696, USA. E-mail: spollak@facstaff.wisc.edu.

frontal EEG power when expressing negative emotion in comparison with control infants. Although event-related potential (ERP) research has focused heavily upon nonaffective cognitive processes, ERPs have also proven valuable in identifying constituent operations involved in subjects' processing of affective information (Chung et al., 1996; Johnston, Burleson, & Miller, 1987). ERP procedures have revealed that former soldiers suffering from post-traumatic stress disorder showed larger amplitudes of the P3b component in response to combat-related as compared to emotionally neutral pictures (Attias, Bleich, Furman, & Zinger, 1996). Other anatomically based studies involving brain imaging procedures, such as Bremner et al. (1995), report that persons with combat-related post-traumatic stress disorder had smaller right hippocampal volume relative to demographically matched comparison subjects.

Previous work from our laboratory has examined the extent to which maltreated and sociodemographically matched nonmaltreated children recognize emotions. In one study (Pollak, Cicchetti, Hornung, & Reed, 2000, Experiment 1), preschool-aged children were presented with brief emotional stories and were asked to match the feeling of the protagonist in the story with a photograph of a model posing a facial expression. Physically abused children had a response bias toward incorrect interpretations of anger, whereas the other groups of children did not. In another study (Pollak et al., 2000, Experiment 2), physically abused, physically neglected, and control children were shown two photographs of different models posing emotional expressions and were asked to rate how similarly they perceived the expressions. Although maltreated children generally detected fewer differences between facial expressions than did control children overall, physically abused children perceived anger as distinct from other negative emotions such as disgust, fear, and sadness. These findings are consistent with the idea that traumatic experiences selectively increase children's sensitivity to specific emotional cues, and may provide insight into the development of behavioral problems in these children.

We reasoned that maltreated children's difficulties in recognizing and responding to emotional cues might reflect differences in attentional resource and memory operations (Pollak, Cicchetti, & Klorman, 1998). Our hypothesis is that maltreated children's traumatic experiences affect their attentional resource allocation and that this focus, in turn, creates their risk for emotion-related problems. Our first study (Pollak, Cicchetti, Klorman, & Brumaghim, 1997) employed a three-stimulus "oddball paradigm" involving one frequent and two rare stimuli. In alternate conditions, one rare stimulus (an angry or happy face) was designated as a target whereas the neutral face always appeared as the frequent nontarget. Although both young adult and child control groups displayed equivalent P3b amplitude when either happy or angry faces served as targets, maltreated children displayed relatively larger P3b amplitude to the angry as compared to the happy targets. We interpreted these results as consistent with theories that P3b amplitude is proportional to the amount of attentional resources engaged in a given task (R. Johnson, 1993; Kramer & Spinks, 1991; Polich & Kok, 1995). In this view, P3b reflects workload variations that are cognitive–perceptual in nature and indicates the relative amount of attention allocated to each task (Polich & Kok, 1995). Similar interpretations of P3b have suggested that aspects of information processing related to resource allocation and attention differentiate adults with psychological disorders such as mood disorders from controls (Yee & Miller, 1994). This perspective suggests that in our study (Pollak et al., 1997), children with histories of maltreatment engaged in differential attention and monitoring of emotional information in the environment.

The focus of the present study is the degree of specificity in maltreated children's differential P3b amplitude to angry versus other negative emotional displays. In particular, it remains unclear whether the maltreated children's differential ERP responses reflected processing of positive versus negative valence stimuli, or were specific to displays of happiness or anger. Current models of neural–behavioral development suggest that aspects of postnatal experience exert significant effects upon developmental organization. However, to elucidate the mechanisms underlying neural–behavioral plasticity requires detailed examinations of the timing, nature of, and relationships between the characteristics of sensory/perceptual input and resultant modifications of cognitive function. Therefore, greater understanding of the relative specificity of children's responses to various kinds of emotional information is a critical step in formulating tractable theories about the role of social experience in the development of psychopathology.

To examine the role of emotional experience on emotion processing, the present study contrasted ERPs to three different types of affective facial stimuli—anger, fear, and happiness. Once again, we used a three-stimulus oddball paradigm to test whether maltreated children would process the negative emotions of anger and fear similarly, as compared to the positive emotion of happy. Maltreated children may witness anger more frequently, and with more drastic consequences, than do nonmaltreated children; yet, other negative emotions, such as fear, are also frequently associated with episodes of maltreatment. However, because discrete emotional signals likely convey different information, we examined whether maltreated children's P3b waves for angry stimuli, particularly those requiring greater attention, would be relatively larger than those of nonmaltreated children. Angry cues serve as salient predictors of potential changes in the environment for maltreated children, but it was unclear whether our previous findings were specific to angry displays. As in our previous study, controls were expected to display comparable psychophysiological reactions to all three emotion targets.[1]

Method

Participants

Twenty-eight maltreated and 14 control children (aged 6.3 to 12.2 years) participated in this experiment. Maltreatment histories of children were classified using the system described in Barnett, Manly, & Cicchetti (1993). Ratings were based upon Child Protective Service (CPS; Department of Social Services, Monroe County, NY), clinical, and medical records. The ratings were performed by doctoral-level psychologists with expertise in child maltreatment who were unaware of the hypotheses for this study and who did not participate in any other aspect of this research. The present sample of children experienced direct maltreatment from caregivers that clearly violated normative standards. *Physical abuse* was indicated when there was evidence of a caregiver inflicting physical injury upon a child by other than accidental means. Ex-

[1] A potential ambiguity of the present experimental design concerns how maltreated children's increased P3b responsiveness to anger would be manifested. That is, would maltreated children be expected to show larger P3b amplitude to angry stimuli only when anger served as a target or to all angry stimuli including nontargets? Based upon our previous study and because the experimental task is relatively easy, even for young children, we did not expect P3b amplitude increases in response to nontarget angry faces. Consistent with our previous findings, we expected that P3b differences would emerge based upon emotion condition, reflecting the emotion target to which children were asked to attend.

Table 1. *Demographic Data for Each Group*

Measure	Group	
	Control	Maltreated
Age (years)	8.5 (1.6)	9.1 (1.7)
Gender (% male)	71	64.3
Race (% Caucasian)	42.9	28.6
Family Income[a]	5,006 (1,964)	4,026 (1,754)

Note. Standard deviations are shown in parentheses.
[a]Income per capita (in dollars) includes welfare and reflects total earnings.

amples of physical abuse included burns, bone fractures, or serious injuries to vulnerable body parts. *Physical neglect* was coded when it was documented that a caregiver failed to meet the child's minimum physical needs. Physical neglect reflected instances of lack of supervision in potentially life-threatening situations.[2] Children with any sexual or exclusively emotional maltreatment were not included in this sample to maximize the homogeneity of the sample. Finally, it is unusual for children to experience only one form of maltreatment; therefore, subtypes were made hierarchically. Whereas our sample of neglected children did not have records indicating physical abuse, the children in the physical abuse group also had records indicating episodes of neglect. Control children were recruited from the community and were free of any child protective service records as determined by the New York State Registry of Child Abuse. At the time of testing, all children were reported to be in good health and not using medications. Parents of all subjects received detailed information concerning the study protocol and gave informed consent; after being shown the study apparatus, all children agreed to participate. As shown in Table 1, the maltreated and control children had similar sociodemographic distributions including age, $F(1,42) < 1$, n.s.; gender, χ^2 $(1, N = 42) < 1$, n.s; race, χ^2 $(1, N = 42) < 1$, n.s; and income per capita, $F(1,30) = 2.19$, n.s.

Procedure

There were three experimental conditions, each of which consisted of two consecutive blocks of 160 randomized presentations of a happy, an angry, and a fearful emotional expression by a single female model (Ekman, 1976, Slide numbers 48, 53, and 50). Probabilities of presentations were distributed such that across conditions, each facial expression occurred, respectively, as a target ($p = .25$), rare nontarget ($p = .25$), or frequent nontarget ($p = .50$). Each emotion target was presented to the subject in two consecutive blocks, so that the remaining two facial expressions could serve as both rare and frequent nontargets. The order and assignment of emotions to stimulus categories was balanced by a modified Latin Square design. In each of the three conditions, children were asked to press a button when a designated emotion expression appeared. Slides were presented for 400 ms at intervals of 1,500 ms, and 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 (vertical × horizontal visual angles = 19 × 28°).

Performance measures. Two measures drawn from signal detection theory were used to characterize the children's behavioral performance. Subjects' sensitivity to detection of targets and their criterion for this task were estimated, respectively, by d' and β (Hochhaus, 1972). Percentage of hits, false alarms (separately for rare and frequent nontargets), and premature responses (reactions < 200 ms) are also reported.

Electrophysiological recording. EEG was detected from chlorided silver In-Vivo Metric electrodes placed at Fz, Cz, and Pz. Electrodes were attached to a lycra Electro-cap and referenced to the linked earlobes. Vertical eye movement (EOG) was detected from two similar electrodes attached to the right supra- and infraorbital ridges. The subject was grounded with a midforehead electrode. All electrode sites were abraded to lower skin impedance below 5 KΩ. Grass Model 12 amplifiers were set for a nominal response frequency of 0.1 to 100 KHz and gains of 1,000 (EEG) and 200 times (EOG). All physiological signals were digitized by a Labmaster A-D board at a rate of 200 Hz from 150 ms before to 1,200 ms after the onset of each slide. EEG data were adjusted for their regression on EOG, separately for eyeblinks and other eye movements according to the procedures described in Gratton, Coles, and Donchin (1983). ERPs were derived by averaging the adjusted EEG data separately for each electrode, stimulus, trial block, and emotion target for trials evoking correct responses (hits and correct rejections). Only every other nontarget trial was considered for inclusion in ERPs to equalize the number of trials sampled for each stimulus category. The mean number of trials retained for ERPs was 72.7 for target trials, 65.3 for rare nontarget trials, and 68.7 for frequent trials.

The primary ERP component under analysis (Figure 1) was a late positive-going wave with average peak latency of 522 ms ($SD = 66$). The following procedure was employed to score the peak amplitude and latency of this ERP component. First, for each subject, an average of her/his 18 ERPs (3 target conditions × 3 stimuli × 2 repetitions) was computed for each electrode. The repetition factor distinguished between the first and second presentation of a particular combination of emotion × stimulus in this balanced design. Next, a computer algorithm identified the largest positive value of the subject's grand average at the Pz electrode within a time window based upon the entire sample's average: 446–635 ms, respectively. The algorithm defined intervals of ±40 ms around this feature in the subject's Pz grand average and, for each of her/his 18 Pz ERPs, identified the most positive point within this window. For each electrode, the amplitude of the corresponding ERP at this latency was computed separately, and deviated from the mean amplitude in the 150-ms prestimulus interval.

Similar procedures were used to score three additional ERP components (N100, N200, P200), based upon the electrodes at which each was maximal. These results will not be described because, unlike the previously described P522, no specific hypotheses had been advanced for these components and exploratory analyses did not yield findings related to the experimental manipulations.

[2]Statistical analyses indicated that within the maltreated group, there were no differences between those children who had experienced primarily physical abuse ($n = 14$) versus neglect ($n = 14$). One possibility is that both abuse and neglect may heighten children's sensitivity to anger, perhaps for different reasons. Second, these null findings may also reflect that the diagnostic procedures used may have been more sensitive to the presence or absence of maltreatment than to distinctions between type of maltreatment. Current work in our laboratories is focused on achieving greater specificity in this regard.

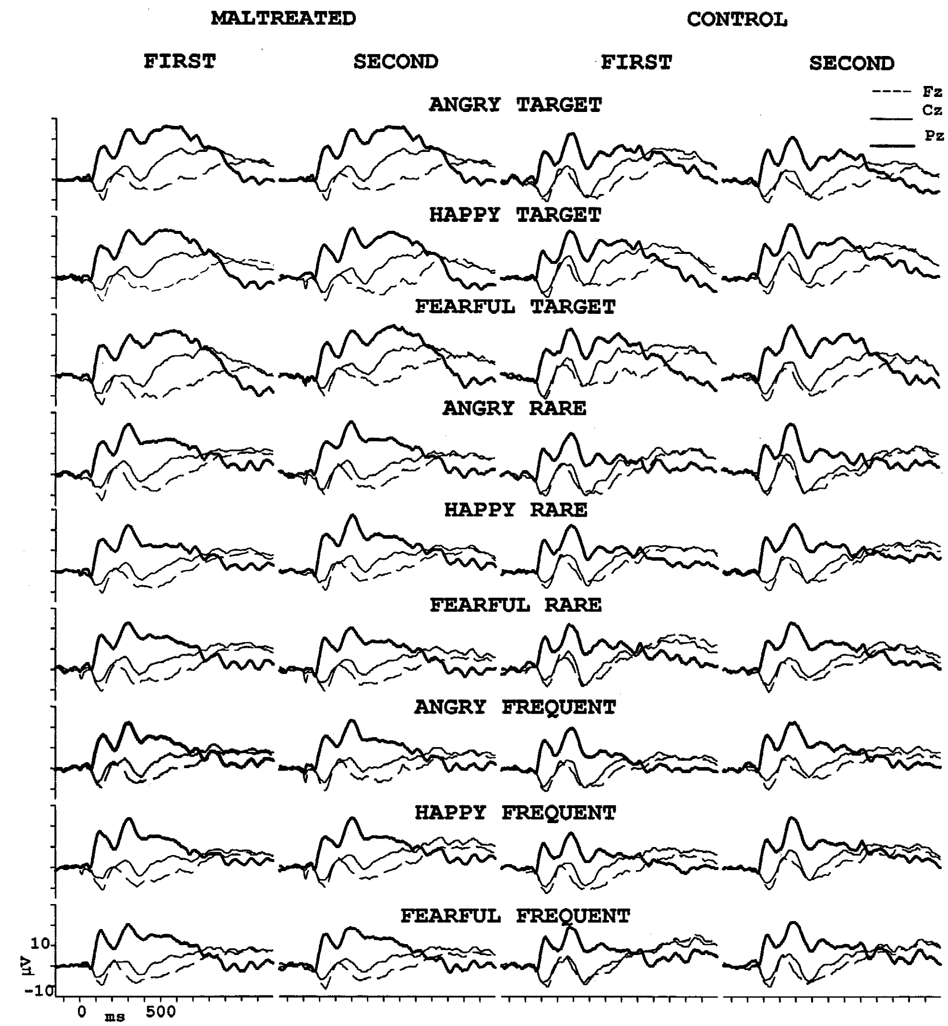

Figure 1. Grand mean event-related potential (ERP) waveforms for maltreated (dashed line) and control (solid line) groups for each presentation of the nine combinations of emotional displays (angry, happy, and fearful) with stimulus categories (target, rare, and frequent nontarget). ERPS for the three midline electrodes are overlaid. Stimuli were presented at 0 ms. The time scale is demarcated in intervals of 100 ms. Relative positivity at the scalp is displayed upward.

Data analysis. Performance measures were entered into a multivariate analysis of variance and those for ERP data into univariate analyses of variance. These analyses considered groups (control, maltreated) as a between-subject factor and the following within-subjects factors: emotion (angry, happy, and fear), repetition, and, for analyses of P522, stimulus type (target, rare nontarget, and frequent nontarget) and electrodes (Fz, Cz, and Pz).

We evaluated planned pairwise comparisons of all stimulus types, all target conditions, and adjacent electrodes. To adjust alpha for multiple comparisons, we used the Holm sequentially rejective Bonferroni procedure (Kirk, 1995). For three comparisons, this procedure requires unadjusted p levels of .0167 for the largest contrast, .025 for the second largest comparison, and .05 for the smallest. We report the unadjusted per comparison probability level. For F tests involving repeated measures, the Greenhouse-Geisser correction was applied. Contrasts involving repeated measures were tested against separate error estimates (Keppel, 1991, pp. 380–382; Myers & Well, 1995, p. 305). We used partial ω^2 (Kirk, 1995) to quantify the proportion of variance of relevant effects accounted by the contrasts detailed above. We estimated the magnitude of multivariate effects with η^2 (Tabachnick & Fidell, 1996).

The preceding analyses were repeated with a covariance adjustment for chronological age. However, the results were unchanged so we report the findings for the analysis without this adjustment.

Results

Performance

Findings for performance measures for each group and condition are displayed in Table 2. A multivariate analysis of variance disclosed discrepant effects of angry versus fearful targets on groups, Angry versus Fear × Groups F_{mult} $(7,34) = 3.20$, $p < .02$, $\eta^2 = .40$. This finding was further evaluated in separate univariate analyses of each dependent variable.

For the measure reflecting sensitivity of detection, d′, there was a significant difference in the differential impact of angry and fearful conditions for control and maltreated children, $F(1,40) = 4.12$, $p < .05$, $\omega_p^2 = .04$. As shown in Figure 2, whereas control and maltreated subjects detected fearful targets with comparably high sensitivity, $F(1,40) < 1$, n.s., for angry targets maltreated subjects tended to obtain higher d′, $F(1,40) = 3.88$, $p < .06$, $\omega_p^2 = .05$.

Table 2. *Mean + SE for Performance Measures*

Measure	Control Angry	Control Happy	Control Fear	Maltreated Angry	Maltreated Happy	Maltreated Fear
Hits, %	85.81 ± 2.06	87.17 ± 2.08	87.43 ± 2.14	88.77 ± 2.11	86.24 ± 2.47	85.75 ± 2.27
False Alarms, %	9.46 ± 2.01	6.00 ± 1.09	6.38 ± 1.06	5.29 ± 0.75	4.01 ± 0.54	5.76 ± 0.62
d′	2.80 ± 0.16	3.17 ± 0.18	2.79 ± 0.16	3.33 ± 0.13	3.45 ± 0.12	2.85 ± 0.14
β	1.97 ± 0.38	1.55 ± 0.17	2.43 ± 0.37	1.70 ± 0.26	2.11 ± 0.38	2.33 ± .34
Premature, %	0.93 ± 0.24	3.00 ± 0.60	2.06 ± 0.41	0.27 ± 0.08	2.81 ± 0.37	2.43 ± 0.29
Reaction time, ms	715.42 ± 17.92	683.82 ± 18.58	741.17 ± 26.89	675.18 ± 16.29	636.74 ± 14.08	679.00 ± 16.60
Reaction time *SD*, ms	193.68 ± 8.77	186.64 ± 8.18	180.27 ± 9.37	165.81 ± 8.45	155.99 ± 7.37	169.31 ± 8.40

Because d′ reflects the relative difference between correct detections and false alarms, we examined these two scores separately. Although the findings for percentage of hits generally followed the previously described trend of relatively greater accuracy to angry than fearful conditions among maltreated subjects, this effect did not reach significance. However, for false alarms, the two groups differed in that controls were relatively more accurate in the fearful than in the angry condition, Angry versus Fearful × Group $F(1,40) = 6.35$, $p < .016$, $\omega_p^2 = .06$.

The results for β, the measure of strictness of criterion, did not disclose significant differences among conditions or discrepancies among groups in this regard. However, it is noteworthy that both groups obtained β values reflecting strict criteria for decisions. In combination with the high values observed for d′, the results indicate that subjects in both groups were highly accurate and cautious in responding.

Premature responses followed a similar trend of relatively greater accuracy for angry than fearful conditions among maltreated than control subjects, Angry versus Fearful × Group $F(1,40) = 11.05$, $p < .002$, $\omega_p^2 = .10$. As detailed in Table 2, control and maltreated subjects made a comparable number of these errors in the fearful condition, $F(1,40) = 1.72$, n.s., whereas maltreated children made markedly fewer premature responses than controls in the angry condition, $F(1,40) = 9.51$, $p < .005$, $\omega_p^2 = .09$.

The analysis of reaction time disclosed that the two groups combined responded slower to both the angry $[F(1,40) = 11.47$, $p < .002$, $\omega_p^2 = .11]$ and fearful $[F(1,40) = 12.76$, $p < .001$, $\omega_p^2 = .12]$ faces as compared to the happy faces. There were no findings pointing to differences between groups in this regard. For the standard deviation of reaction times, there were no significant effects of conditions. These results suggest that the just noted differences in mean speed were not secondary to variability of reaction time.

Repetition resulted in a moderate decrease in false alarms ($M = 0.06$ and 0.05, respectively), $F(1,40) = 6.60$, $p < .02$, and a slowing of reaction time ($M = 695$ and 732 ms, respectively), $F(1,40) = 14.93$, $p < .0005$.

Psychophysiology

Grand average ERPs under analysis are shown in Figure 1. First, we report benchmark findings pertinent to general ERP issues and then we review results relevant to this experiment in particular.

Stimulus categories influenced the latency of P522 in a different pattern over the two presentations of each slide, Repetition × Stimulus $F(2,80) = 3.72$, $p < .04$. This interaction reflected the absence of differences among stimulus categories in the first presentation, $F(2,80) < 1$, n.s., whereas the second display of each slide evoked reliable differences in this regard, $F(2,80) = 9.60$,

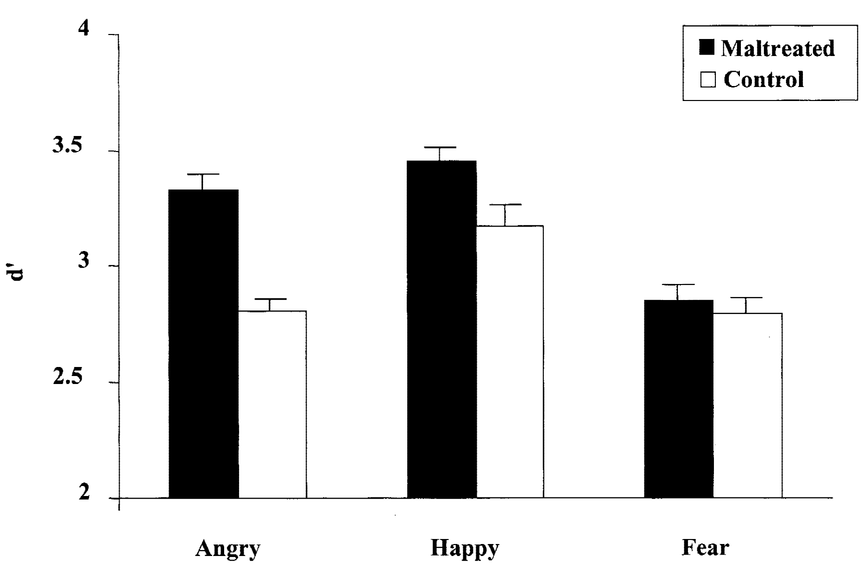

Figure 2. d′ mean ± standard error for each maltreatment group and emotion target.

$p < .0003$. Apparently, P522 became slowed with repetition as a function of the complexity of processing required by each stimulus. Specifically, in the second presentation, P522 latency for frequents ($M = 518$ ms, $SD = 69$) was shorter than those for targets ($M = 525$ ms, $SD = 64$), $F(1,40) = 16.39$, $p < .0003$, or for rares ($M = 522$ ms, $SD = 67$), $F(1,40) = 5.91$, $p < .02$, and shorter for rares than for targets, $F(1,40) = 4.50$, $p < .05$.

Figure 1 reveals that P522 displayed a topography consistent with that of P3b, Electrodes $F(2,80) = 100.62$, $p < .0001$. Specifically, P522 was largest at more posterior sites, Pz versus Fz, $F(1,40) = 128.00$, $p < .0001$; Pz versus Cz, $F(1,40) = 82.58$, $p < .0001$; Cz versus Fz, $F(1,40) = 53.46$, $p < .0001$. On the other hand, P522 was only partially sensitive to stimulus category. Targets evoked greater P522 amplitude than frequent nontargets, $F(1,40) = 8.60$, $p < .006$, and rares, $F(1,40) = 7.15$, $p < .02$. The amplitude of P522 for rare and frequent nontargets was nearly identical, $F(1,40) < 1$, n.s.

Maltreated and nonmaltreated groups were comparable in their responses to fearful in comparison to other displays across stimulus categories, Groups × Fear versus Angry × Stimulus $F(2,80) = 1.44$, n.s.; Groups × Fear versus Happy × Stimulus, $F(2,80) < 1$, n.s. The main difference between groups with respect to stimulus content was found in an interaction of the planned comparison of Angry versus Happy × Groups × Stimulus Category, $F(2,80) = 4.48$, $p < .015$, $\omega_p^2 = .01$. Simple effects analyses disclosed a significant interaction of Groups × Angry versus Happy for targets, $F(1,40) = 9.09$, $p < .005$, $\omega_p^2 = .03$, but not for either rares, $F(1,40) = 1.69$, n.s., or frequents, $F(1,40) < 1$, n.s. As shown in Figures 1 and 3, the amplitude of P522 for maltreated and control children was very similar in response to happy targets, $F(1,40) < 1$, n.s, whereas for angry targets groups differed as a function of electrodes, Groups × Electrodes $F(2,80) = 4.16$, $p < .02$, $\omega_p^2 = .02$. As shown in Figures 1 and 3, the two groups had nearly identical amplitudes at Fz, $F(1,40) < 1$, whereas maltreated children had larger P522 waves than controls at Cz, $F(1,40) = 4.57$, $p < .04$, $\omega_p^2 = .04$, and at Pz, $F(1,40) = 7.84$, $p < .01$, $\omega_p^2 = .08$. Conceivably, the steeper gradient of P522 along the midline for maltreated children could be secondary to this group's relatively larger amplitude of this wave. Therefore, we standardized each subject's P522 amplitude scores, separately for each electrode, based on her/his mean and standard deviation across the 18 conditions (McCarthy & Wood, 1985). An analysis of standardized P522 amplitudes for the angry target again indicated larger amplitudes for maltreated than control children; once again, the differences were significant at Cz and Pz.

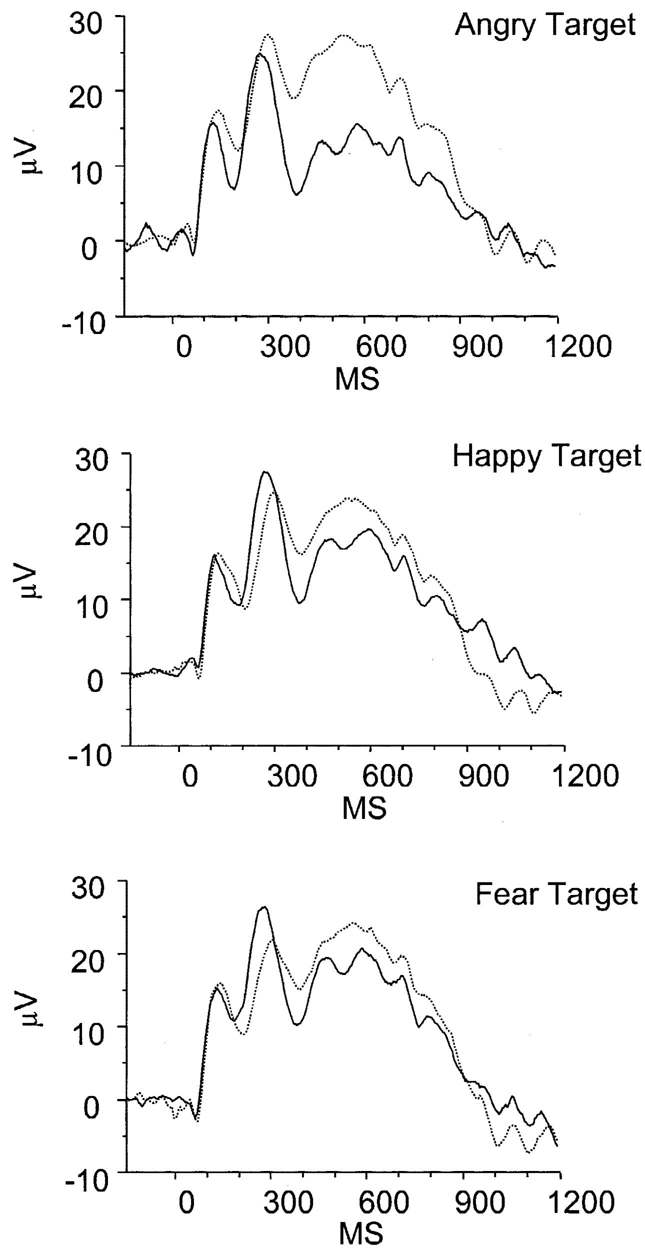

Figure 3. Grand mean event-related potential (ERP) waveforms averaged for the two presentations of each emotion target for maltreated (dashed line) and control (solid line) children at Pz depicting the same effect shown in Figure 1. Stimuli were presented at 0 ms. Relative positivity at the scalp is displayed upward.

Discussion

The present study explored the processing of emotional information in an effort to clarify the mechanisms underlying maltreated children's heightened risk for the development of psychopathology. Behavioral and ERP responses served as measures of the attentional resources invested by children under conditions in which the task salience of different facial displays of emotion was manipulated. Group differences between maltreated and control children were consistent with, and also extended, the results of our previous study (Pollak et al., 1997). Specifically, in an independent sample of maltreated and control children, we found discrepant patterns in the processing of emotional information as a function of maltreatment status. Both behavioral performance and psychophysiological results of this study suggest information processing differences in children with histories of maltreatment. These findings include relatively greater sensitivity and increased accuracy of maltreated children to angry targets. For example, whereas control children made more false alarms and premature responses in the angry condition, maltreated children made fewer errors in this same condition. Both groups combined responded faster to happy as compared to the two negative emotion targets, but no group differences emerged for reaction time.

A late positive-going wave, which peaked a 522 ms, was elicited from children in this paradigm. This wave was maximal at Pz, and sensitive to stimulus significance (target versus nontarget). However, P522 showed limited sensitivity to stimulus probability (rare versus frequent), probably because of the relatively small difference in the frequency of these two stimuli. Based upon its topography and task sensitivity, we interpreted the P522 as P3b, for which we had generated a priori hypotheses. The relationship between P3b and information processing is well established: its amplitude is directly related to the amount of information conveyed by an eliciting event (R. Johnson, 1993). Maltreated children displayed larger P522 waves than did controls to angry targets whereas for happy and fear targets and all nontargets, the two groups were comparable. Although behavioral performance measures indicated differences between groups when contrasting angry versus fear conditions, P522 differences involved contrasts of angry versus happy target conditions. Although it is difficult to account for this inconsistency, both sets of findings reflect differential reactions of maltreated children when angry faces were designated as targets.

In the present experimental design, target stimuli recruit the greatest investment of processing capacity; as a result, the cognitive operations reflected by ERPs to these stimuli are impacted the most by the associated facial emotion. When angry faces were designated as nontargets (fear and happy target conditions) the most frequent decision subjects made was to withhold a response rather than initiate a response, making this class of stimuli less salient. The present results suggest that maltreated children allocate more processing resources to angry targets than do control children. The observation that both P522 amplitude and d′ were larger for maltreated than control children in response to angry targets is consistent with this position.

Our data are consistent with the view that information processing, such as heightened resource allocation to anger, is a component of the sociobehavioral difficulties observed in maltreated children. The fact that group differences in P3b amplitude were not comparable across all three emotion targets argues against global emotion information-processing deficits among maltreated children. Rather, stimulus salience and later attentional processes directed toward discrete emotional cues appear central to understanding the information-processing differences between maltreated and control children. Anger displays are a common emotional expression that humans encounter regularly. However, because maltreated children have observed anger that is sometimes within the normative range and at other times followed by traumatic events, the information conveyed by angry faces may convey more uncertainty for them, thereby recruiting more cognitive processing. In addition, the unusual emotional signaling that maltreated children may associate with anger also creates an enormously complex information-processing problem. These children receive a vast amount of important information about the environment in the form of emotional signals, but the emotional communication in maltreating families may be unusually complicated, inconsistent, or distressing. Limited sensory, attentional, and memory capacities dictate that for the developing child, all information from the environment cannot be processed equally (Turkewitz & Kenny, 1982). Thus, if emotional information from the environment exceeds the developing child's information-processing capacity, it follows that children need to be especially selective in what they attend to, favoring some sources of information over others. Similar maturational constraints have been included in models of perceptual (Aslin, 1988) and language (Newport, 1991) development, suggesting that the information that children learn to attend to is potentially determined by the child's experiences.

In the case of maltreated children, successful adaptation depends in part upon the selection of salient social cues to which their available cognitive resources are directed. The absence or presence of many different emotions, conveyed through various channels (others' facial expressions, subjective feeling states), can serve as salient predictors of physical threat. However, displays of anger may recruit a greater proportion of these children's resources because these signals are the strongest—and the most direct—cue to these children, providing them with increased opportunities to alter their behavior in pursuit of increased safety. In this regard, myriad cognitive processes involved in learning are implicated in the mechanisms linking children's early emotional experiences with increased risk for behavioral pathology (for a similar argument, see Miller, 1996).

The present data involve a number of important implications from a developmental psychopathology perspective. The first entails an understanding of the complex relationship between adaptive and maladaptive functioning in maltreated children. Activation of anger-detection systems in threatening contexts would prove adaptive in a maltreating context, with rapidly learned sensitivity facilitating a greater probability of successful behavioral responses. However, when these children are outside of their maltreating environments and interacting with others in more normative social situations, generalization of this coping strategy could lead maltreated children to develop maladaptive response patterns. If such behavioral plasticity exists, it would afford the developing child optimization of adaptation to a particular niche or early environment. But the cost of adapting to an early atypical environment in terms of risk is high. Being sensitive to the expression of others' anger is not inherently pathogenic; in fact, it is a normal and helpful aspect of emotional signaling. Yet, overgeneralized patterns of reactivity or hypersensitivity to perceived anger on the part of maltreated children could result in increased aggressive/hostile attributions to other people or situations in which the likelihood of threat was actually minimal (Dodge, Bates, & Pettit, 1990).

Conclusion

The central question now posed in developmental cognitive neuroscience is no longer *whether* the architecture of the brain can be altered, but rather *how and when* such plasticity and change occurs (see Nelson & Bloom, 1997, for review). The developmental factors that have been proposed to influence brain–behavior relationships include (a) aspects of the external environment that are atypical for most members of a species (M. H. Johnson, 1993), (b) the kind and degree of input received (Greenough, Black, & Wallace, 1987), and (c) specific biases for orienting toward relevant stimuli in the external environment (Turkewitz & Kenny, 1982). In this report we applied these three criteria to the phenomena of child maltreatment and suggest that allocation of attentional resources may be one process through which environmental influences lead to the development of maladaptive behavior. The specificity of maltreated children's responses to anger suggests a nonrandom and relatively specific association between these children's socioemotional experiences and the cognitive processes associated with emotion recognition. Multiple methods and approaches will be necessary to explain the complex interplay between developing persons and their environments. For this reason, interdisciplinary developmental approaches to psychopathology hold enormous promise for understanding the emergence of human behavior and pathology.

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