Distribution Agreement

Approval Sheet

The Effect of Emotional Context on Changes in Infants' Neural Response to Novel Objects

By

Jacqueline S. Leventon
Master of Arts

Psychology

____

Patricia J. Bauer
Advisor

____

Jocelyne Bachevalier
Committee Member

____

Robyn Fivush
Committee Member

Accepted:

____

Lisa A. Tedesco, PhD.
Dean of the James T. Laney School of Graduate Studies

____

Date

The Effect of Emotional Context on Changes in Infants' Neural Response to Novel Objects

By

Jacqueline S. Leventon
B.S., University of Maryland, 2008

Advisor: Patricia J. Bauer, Ph.D.

An abstract of
A thesis submitted to the Faculty of the
James T. Laney School of Graduate Studies of Emory University
in partial fulfillment of the requirements for the degree of
Master of Arts
in Psychology
2011

Abstract

The Effect of Emotional Context on Changes in Infants' Neural Response to Novel Objects
By Jacqueline S. Leventon

Around the end of the first year of life, infants develop a social referencing ability- using the emotional information from others to guide their own behavior. Much research on social referencing has focused on changes in behavior in response to emotional information. The present study was an investigation of the changes in neural responses that underlie social referencing behavior, reflected in event-related potential measures (ERPs). Twenty-six 12-month-olds participated in a single-session visit where ERPs were recorded both immediately before and after a behavioral intervention in which infants' caregivers provided positive, negative or neutral information about each of 3 test stimuli. Results indicated that infants devoted more neural resources to processing emotional versus neutral information, as observed in a late positive-going component. Changes in neural responses from the pre- to post-intervention recordings clarify this observation, indicating that there was an increase in neural response in processing negative information, a decrease in processing neutral information, and relatively no change in processing positive information. Taken together, these findings suggest that infants' neural responses are differentially affected by positive, negative and neutral information. Furthermore, the findings highlight the importance of measuring the change in neural responses to better interpret post-experience responses.

The Effect of Emotional Context on Changes in Infants' Neural Response to Novel Objects

By

Jacqueline S. Leventon
B.S., University of Maryland, 2008

Advisor: Patricia J. Bauer, Ph.D.

A thesis submitted to the Faculty of the
James T. Laney School of Graduate Studies of Emory University
in partial fulfillment of the requirements for the degree of
Master of Arts
in Psychology
2011

TABLE OF CONTENTS

The effect of emotional context on changes in infants' neural response to novel objects

Master's Thesis

Jacqueline S. Leventon

Advisor:

Dr. Patricia J. Bauer

Emory University

Thesis Committee:

Dr. Patricia J. Bauer

Dr. Robyn Fivush

Dr. Jocelyne Bachevalier

Abstract

Around the end of the first year of life, infants develop a social referencing ability- using the emotional information from others to guide their own behavior. Much research on social referencing has focused on changes in behavior in response to emotional information. The present study was an investigation of the changes in neural responses that underlie social referencing behavior, reflected in event-related potential measures (ERPs). Twenty-six 12-month-olds participated in a single-session visit where ERPs were recorded both immediately before and after a behavioral intervention in which infants' caregivers provided positive, negative or neutral information about each of 3 test stimuli. Results indicated that infants devoted more neural resources to processing emotional versus neutral information, as observed in a late positive-going component. Changes in neural responses from the pre- to post-intervention recordings clarify this observation, indicating that there was an increase in neural response in processing negative information, a decrease in processing neutral information, and relatively no change in processing positive information. Taken together, these findings suggest that infants' neural responses are differentially affected by positive, negative and neutral information. Furthermore, the findings highlight the importance of measuring the change in neural responses to better interpret post-experience responses.

LIST OF TABLES

LIST OF FIGURES

The effect of emotional context on changes in infants' neural response to novel objects

The ability to identify particular emotions in others has been critical to our survival as a social species. For example, being able to identify and understand the meaning behind an expression of fear in another person allows one to avoid a potentially harmful or even deadly threat. We constantly use social and emotional cues to guide our behavior. This type of emotional intelligence (Mayer & Solovey, 1997) plays a critical role in our survival as a species, and it is also part of the social glue that keeps individuals and groups peacefully together.

If behavior changes with experience, so must the underlying neural activity that governs behavior. Changes in neural activity as it relates to experience, however, has seldom been explicitly examined in the literature. Thus whereas much is known about changes in behavior in response to emotional context, little is known about specific changes in neural activity. We can study changes in neural activity by first measuring the neural response to a stimulus before experiencing the stimulus and then measuring the neural response again to the same stimulus after the experience. In this study we examined the change in infants' neural activity in response to experiencing new objects in an emotional context.

As adults we are readily able to not only identify emotions in ourselves and others, but we also know what kind of responses is appropriate to instances of particular emotions. More specifically, we have expectations for what kinds of behavior are likely to follow particular displays of emotion. Returning to the previous example, if someone expresses a fearful affect toward something, we would expect her to avoid the object, rather than approach it. Such social cognitive processes emerge early in childhood, and continue to develop into adolescence and adulthood (e.g., Wellman, 1990). Critical building blocks of these sophisticated abilities, such as the ability to discriminate and use emotional information for oneself, emerge even earlier in development, beginning in early infancy.

Evidence from behavioral and electrophysiological measures of emotion discrimination suggests that infants as young as 5 months can distinguish between different categories of emotions. In habituation studies, 5- to 7-month-olds demonstrate some ability to distinguish emotion categories in facial expressions (Caron, Caron, & MacLean 1988; Nelson, Morse, & Leavitt, 1979; Schwartz, Izard, & Ansul, 1985). However, only certain emotion pairings and certain orders of exposure to paired emotions elicit differential looking to different emotion types. For example, following habituation to angry expressions, 5-month-olds demonstrate recovery of looking to expressions of fear, sadness and interest, but they do not show recovery of looking to expressions of anger following habituation to expressions of fear, sadness or interest (Schwartz et al., 1985).

In a more simplified looking-time paradigm where two images of different emotional expressions are simultaneously presented, infants have demonstrated an ability to distinguish unique emotions through differential looking times to each of the two images. For example, 7-month-olds show longer looking-times to fearful versus happy expressions (Nelson & Dolgin, 1985). Moreover, infants as young as 4 months of age show different looking patterns to happy versus angry and neutral expressions (LaBarbera, Izard, Vietze, & Parisi, 1976). These mixed findings demonstrate that infants as young as 4 months of age have some ability to distinguish separate emotions.

Although behavioral investigations of social cognitive processes may be more naturalistic, they cannot inform us about the development of neural correlates of emotion processing and social referencing. Brain imaging methods such as functional magnetic resonance (fMRI) and positron emission tomography (PET) are not ideal for studying infant populations. However, an even more direct measure of brain activity is readily available and optimal for use with infants. Many researchers have capitalized on use of electrophysiological methods, such as EEG, as a non-invasive method that directly measures the underlying neural activity in response to a discrete event (i.e., a brief presentation of an image of facial expression). Scalp-recorded EEG signals are time-locked and averaged to become event-related potentials (ERPs) that are representative of underlying neural activity to particular kinds of stimuli. This non-invasive technique does not require participants to sit or lay still (as in fMRI or PET), nor does it involve potentially hazardous procedures such as injecting participants with radioactive traces (as in PET), and as such, the ERP method is ideal for studying neural processes in infant populations (Banaschewski & Brandeis, 2007).

The ERP technique has been used with infants as young as 6 months of age to investigate processing of face and emotion stimuli. Findings from Nelson and de Haan (1996) suggest that at three different windows during the ERP epoch, infants at this age demonstrate specialized neural processing of fearful and happy facial expressions. During the earliest window, from about 150ms to 400ms following stimulus onset, the happy expression elicited a larger positive peak than the fearful expression. During a middle latency window, from about 400ms to 800ms following stimulus onset, the fearful expression elicited a larger negative peak than the happy expression. And during the late window, from about 800ms to 1400ms following stimulus onset, the happy expression elicited a larger positive peak than the fearful expression. In accordance with previous research (i.e., Nelson, 1994), the differential processing in the middle latency window suggest that infants allocated more attentional resources to processing the fearful versus happy expression, whereas the pattern in the late window suggests that infants devote larger and more continued neural resources to processing the happy versus fearful expression.

Thus, from behavior and EEG, we know that young infants can discriminate emotions. As infants approach the end of the first year of life, a more developed use of emotional information begins to emerge. In ambiguous situations, infants as young as 10 months of age use social referencing (the ability to read and understand the meanings of emotions) to guide their actions. More specifically, social referencing is the use of another's emotional reaction to a particular situation in order to disambiguate its meaning and develop one's own understanding of the situation (Feinman, 1982). For example, when an infant first meets a stranger, she will typically look to her caregiver to help determine if she should approach or avoid the stranger. If her caregiver smiles encouragingly, the infant will likely approach the stranger, whereas if her caregiver seems worried or fearful, the infant may avoid the stranger. Infants' social referencing ability has been examined in several different paradigms, such as the visual cliff paradigm (i.e., Sorce, Embe, Campos, & Klinnert, 1985), stranger paradigm (e.g., Feinman & Lewis, 1983), and the novel-object paradigm (e.g., Mumme & Fernald, 2003). A common finding across these studies is the trend that infants adjust their behavior to negative emotional expressions, but very little or not at all to positive emotional expressions (Hornik, Risenhoover, & Gunnar, 1987; Mumme & Fernald, 2003; Vaish, Grossmann & Woodward, 2008).

In the novel-object paradigm, novel, ambiguous objects (as opposed to pleasant or aversive stimuli) are used because they are maximally effective at eliciting a social referencing response (Gunnar & Stone, 1984). Using this paradigm, Mumme and Fernald (2003) examined how 10- and 12-month-old infants respond to expressions of happiness and fear. Participants watched a video of an actress expressing positive (happy) or negative (fearful) emotion toward one of two objects. The actual objects were in view of the infants during the video, and a presenter pushed them towards the infant when the video presentation ended. As compared to baseline responses (to a neutral expression), 12-month-olds touched the target object much less often after a negative affect and about the same as in baseline after the positive affect as measured by proportion of trials spent touching the target object (about .30 in the negative condition, and about .60 in the positive and neutral conditions). Ten-month-olds did not vary their behavior in response to affect and attention. Notably, the results indicate that even without soliciting such information, infants can use an adult's emotional expressivity to guide their own behavior.

In an investigation of the underlying neural activity governing social referencing behavior, Carver and Vaccaro (2007) employed a combination of a behavioral social referencing paradigm with an ERP paradigm to examine the relations of brain and behavior. Beginning with a typical novel-object social referencing paradigm, 12-month-olds were shown three novel, animated objects. When the infant referenced an adult (either her caregiver or the experimenter) or after a minute elapsed, the adult vocally and facially expressed a happy, disgusted, or neutral expression toward each of the three objects. Infants' behavior and affective response was coded both before and after delivery of the emotional signal.

Immediately following this behavioral paradigm, infants participated in an ERP session during which their neural response to the referenced stimuli was recorded. Images of each of the three stimuli were presented 33 times each, and for 500ms each presentation. Similar to other ERP studies investigating emotion (e.g., Junghofer, Bradley, Elbert & Lang, 2001), there was a trend for larger and more differentiating ERP activity over the right hemisphere than the left. A main effect from this study that was found across infants was that infants showed an increase in ERP activity during a middle latency window, from about 400 to 1200 milliseconds post-stimulus onset, in response to the negative stimulus. Furthermore, infants who were quicker to reference an adult in the behavioral paradigm also showed a greater ERP response in the negative component to the negative stimulus. This finding suggests that the negative emotional signal affected the attention network to a larger degree than the positive and neutral signals, perhaps because negative emotions are more novel to infants than other signals (Vaish et al., 2008). Moreover, it may be that the negative signal rendered the referenced object more salient or important than the other objects, and the differences in the ERP signal are due to differences in attention.

Few differential effects by emotion condition were observed in the behavioral paradigm that preceded the ERP paradigm. Infants as a group showed no reliable pattern in their behavioral response by emotion type in their proximity to the object or the adult, or in their interaction with the object or adult. However, infants' affective response following the adults' emotional signal did vary as a function of emotion condition.

Infants showed an increase in negative emotion following the adults' delivery of the negative emotion signal.

Carver and Vaccaro (2007) represents a significant step forward in the investigation of neural processing underlying social referencing behavior. Although it is informative to examine neural activity following some kind of experience, this approach only provides a snapshot of the neural processing at one point in time. A key component of social referencing investigations is the examination of the *change in behavior* from before to after the introduction of emotional information. ERP investigations have yet to implement this technique. In the present study we examined the *change in neural activity* from before to after the introduction of emotional information, as this has yet to be formally examined in the literature.

In the present study, in order to examine the possible changes in neural activity following the application of emotional information, infants participated in an ERP session both immediately before and after participating in a behavioral novel-object social referencing paradigm. With two measurements of neural activity, one that represents baseline processing and one that represents post-manipulation processing, we can better interpret the meaning of any differences observed in the post-manipulation recording. Specifically, we can identify the *direction* of change that produced any observed post-manipulation effects. For example, if a difference is observed between the negative and neutral conditions in the post-manipulation recording, we can identify whether the source of this difference is an increase in attention the negative object, decreased attention to the neutral object, or some combination of the two effects. Each ERP session followed a similar procedure as Carver and Vaccaro (2007) so that results may be compared across studies. The behavioral paradigm was also modeled after Carver and Vaccaro (2007), but with a few modifications.

Firstly, similar to Carver and Vaccaro (2007), infants' use of positive, negative, and neutral emotional information was investigated. However, instead of using disgust as the negative emotion, we examined the influence of fear on infants' behavior and neural processing. Fear was selected because of its effectiveness at modifying infants' behavior in previous social referencing studies (e.g., Sorce et al., 1985). Furthermore, exploring the influence of fear extends Carver and Vaccaro's (2007) examination of neural processing of emotion signals to a new negative emotion.

Secondly, Carver and Vaccaro (2007) had caregivers and an adult experimenter provide the emotional signals. In contrast, we investigated the influence of emotional information provided by infants' caregivers only. Only caregivers were selected because caregivers represent the prominent source from which infants receive this kind of social information on a daily frequency, and thus the value of emotional information may be greater when expressed by a caregiver versus an unfamiliar adult.

In sum, the present study was an examination of the role of emotional context on infants' neural processing of an event. Behavioral investigations of 12-month-olds' social referencing ability present clear evidence that infants at this age can use an adult's display of emotion to modify their own behavior in accord with specific emotion signals. Moreover, ERP investigations of emotion have found that infants as young as 6 months of age show differential neural processing of particular kinds of emotional expressions. Because others' emotional signals can change 12-month-olds' behavior and emotional stimuli yield differential neural processing in 6-month-olds, we predicted that emotional signals would differentially change 12-month-olds' neural responses to emotionally referenced stimuli.

Method

Participants

Twenty-six full-term 12-month-olds (14 girls; *M* = 11.93 months, range: 11.07 – 12.93 months) and their caregivers (25 mothers) participated. Participants were recruited from a database of families who expressed interest in participating in research. An institutional review board approved this study. All parents gave written informed consent for their children's participation prior to the start of the session. At the end of the session, families received a small toy (worth approximately $5) and a $5 gift card to Target as a token of our appreciation for their participation in the study.

An additional five infants participated but were excluded from all analyses due to fussiness (*n* = 4), or refusal to participate (*n* = 1).

Behavioral data were available for 24 of the 26 participants. Data from 2 participants could not be coded due to video recording failures. Twenty infants contributed interpretable ERP data from the first recording, 21 infants contributed to the ERP data from the second recording, and 18 infants contributed to both recordings. In the first recording, data from 6 participants were excluded due to inattention to the trials (*n* = 3), or contaminated recording channels (*n* = 3). In the second recording, data from 5 participants was excluded to inattention to the trials (*n* = 2), contaminated recording channels (*n* = 1), insufficient number of trials (*n* = 1), or fussiness (*n* = 1).

Stimuli and Materials

Three novel objects were used to elicit infant social referencing behavior (see Appendix A for description). Pilot testing indicated that infants at this age respond with neutral or ambivalent interest to the objects. The three objects were counterbalanced so that each object was associated with each emotion equally often. In the behavioral paradigm, the stimuli were presented on a table-top stage one at a time. The stage was an open-faced box draped in black fabric. An experimenter moved the object in random patterns across the stage such that the object appeared to the infant to be self-propelled. In the ERP paradigm, digital images of the objects were presented on a computer monitor. Each of the objects occupied approximately half of the image area.

Infants' caregivers were provided training materials to learn how to accurately present the emotion signals. Training materials consisted of written, picture, and video descriptions of happy, fearful, and neutral expressions. The written and picture descriptions came from a well-cited encyclopedia of emotional expressions (Ekman & Friesen, 1975). Video descriptions were lab-made demonstrations of the parents' expected role in the study. Videos featured an experimenter displaying the emotional signals toward a novel object (one not used in the study proper). All of these training materials were made available via our laboratory website, and participating families were sent electronic messages that directed them to the website.

Procedure

Infants participated in a single session which lasted approximately one hour. After parents provided consent for their infants' participation, the session began. During the visit there were two ERP recordings between which a behavioral intervention was administered. Each part of the session was administered in the same order. First, infants were fitted with an electrode cap and ERPs were collected in response to images of the stimuli. Second, infants were given the opportunity to interact with the stimuli. Infants' caregivers expressed positive (happy), negative (fearful), or neutral expressions to each of the three objects. Infants' behavioral responses to these emotional signals were recorded on DVD and later coded. Third, infants again viewed images of the stimuli while wearing an electrode cap, and ERPs were collected in response to the images.

ERP procedure. Infants were fitted with an Advanced Neuro Technology (A.N.T.) Waveguard cap with 30 shielded EEG electrodes. The site position of the electrodes follows the 10-5 system of electrode placement (see Figure 1). This system is an extension of the widely used International 10-20 System (Jasper, 1958) with the added benefit that the 10-5 system can accommodate a larger number of electrode sites than the 10/20 system. Impedances at each site were kept below 10kΩ, and were generally less than 5kΩ. Images were presented for 500 ms, with a 1750 ms to 2000 ms interval between trials. The sampling rate was 256 Hz.

Insert Figure 1

Data were referenced to the vertex electrode Cz and then was amplified 20,000 times using an A.N.T. high-density amplifier. Following data collection, data were re-referenced offline to an average reference. This referencing method was selected because, in contrast with linked-mastoids reference, it has been shown to yield more powerful results as well as more clearly reveal hemispheric differences in processing (Dien, 1998; Junghofer, Peyk, Flaisch & Schupp, 2006). Furthermore, use of the average reference allows for better comparison of the present findings to those from previous ERP studies which used the average reference method to investigate emotion processing (i.e., Carver & Vaccaro, 2007). A bandpass filter of .1-30 Hz was applied to the collected data to eliminate artifact that was not associated with a biological source.

Infants sat on a highchair or on their caregiver's lap during the presentation of stimulus images. Infants were shown 33 presentations of each of the 3 objects in a randomized order, for a total of 99 picture presentations. An experimenter sat next to the infants during the image presentation and directed their attention to the monitor if they looked away. If the infant failed to attend to the display monitor or became fussy, the image presentation was paused until the infant's attention was refocused on the presentation.

The second ERP recording, which occurred immediately after the behavioral portion of the study, followed the same procedure. Infants viewed a different randomized order of images during the second recording.

Behavioral procedure. Between the two ERP recordings, infants participated in a brief behavioral intervention. Infants were given the opportunity to interact with each of the three stimulus objects. For each object, the caregiver displayed a positive, negative, or neutral expression toward the object.

The seating arrangement of the caregiver-infant-experimenter triad is depicted in Figure 2. Infants were seated in a high chair facing a small table-top stage. The front of the stage was within reaching distance of the infant. The infants' caregivers were seated at the table to the left of the infant, having an angled view of the stage. An experimenter was seated behind the stage, hidden from view of the infant.

Insert Figure 2

The three stimuli were presented on the stage for one minute each. An experimenter (E1) behind the stage moved the object across the stage using a hidden stick that was attached to the back of the object so that each object appeared to have self-propelled motion. Caregivers were signaled to deliver the expression by the backstage experimenter at 3 points during the one-minute presentations (once at 10 seconds, then 30 seconds, then 45 seconds into the presentation). In the positive condition, the caregiver smiled and made comments such as: "What a nice/pretty toy" in a soft, cheerful voice. In the negative condition, the caregiver's facial expression tightened and she made comments such as: "What a scary/frightening toy!" in a tense, rushed voice. In the neutral condition, the caregiver maintained a neutral expression, and made comments such as: "What a simple/ordinary toy" in a calm, non-affective voice. All facial expressions were based on those described in Ekman and Friesen's *Unmasking the Face* (1975), and all tones of voice were based on those detailed in Scherer (1986).

In between the one-minute presentations, a second experimenter (E2) placed a corkboard in front of the stage so as to block it from the infant's view. During this time, caregivers distracted their infants from the stage for a few seconds while the backstage experimenter prepared the stage with the next object. A summary of the stimulus presentations is illustrated in Appendix B.

Behavioral Data Coding

Behavioral coding was a modified version of that used by Carver and Vaccaro (2007). Separate videos were recorded of each the caregiver and the infant. Caregivers' affect was coded to ensure that they were consistent in providing the target emotional signals (see Table 1 for coding of caregivers' affect). Infants' videos were coded for referencing behavior, affect, interest in the stimuli, reaction to the stimuli, and proximity to the stimuli (see Table 2 for coding of affect, and coding of interest in and reaction to stimuli). Infants' interest and reaction to the stimuli was further coded as latency to reach, number of reaches, and distance of closest reach to the object, as well as latency to contact, number of contacts, and duration of contact with the object. Latency to reach and contact were only coded if the infant made at least one reach or contact, respectively. All latency measures are relative to the start of the one minute trial. Proximity to stimuli was measured as the distance of the infants' hand from the front of the presentation stage.. Infants' referencing behavior (i.e., looking toward the caregiver) was coded as latency to reference, duration of referencing, and number of referential looks to their caregiver.

Insert Table 1

Insert Table 2

Twenty-five percent of these videos was checked by a second coder to ensure the reliability of the original coding. Coders agreed on 89.02% of the behaviors (range: 86.97 – 91.67%).

Data Reduction and Analysis

Artifacts in the ERP data were excluded from analysis. Trials were excluded when activity exceeded analog to digital values (i.e., values exceeded the maximum of the analog-digital converter). Trials that were contaminated by deflections that exceeded ± 200 μV, due to eye-blinks, eye movements or muscle movements, for example, were excluded from analysis. Individuals' average waveforms were visually inspected to identify contamination by motion artifact. Data that exceeded these limits throughout the recording session were excluded from analysis. Specifically, individual participant data were excluded from analysis if more than 3 channels exceeded the acceptable limits. Thus, individual participant data which had 3 or fewer contaminated channels (10% of recording channels) were included in the final sample. Contaminated channels were removed from the data and subsequent analysis. Thus, for the final sample of data, no more than 10 percent of the recording channels were removed.

After applying these filtering and artifact-detection procedures, the data was baseline-corrected, and artifact-free trials were averaged by condition (positive, negative, neutral). Participants provided at least 8 artifact-free trials per condition were included in the final analysis. In the first recording, participants contributed an average of 24.80 trials in the positive condition (SD = 4.92), 24.65 trials in the negative condition (SD = 4.27), and 25.10 trials in the neutral condition (SD = 4.24). In the second recording, participants contributed an average of 23.24 trials in the positive condition (SD = 6.26), 22.38 trials in the negative condition (SD = 5.86), and 22.86 trials in the neutral condition (SD = 5.56).

ERP components of interest were selected on the basis of visual inspection of individual and averaged data, as well as previous research examining similar social referencing behavior (i.e., Carver & Vaccaro, 2007). Based on these parameters, a negative-going component was identified over frontal and central cites (F3/4, FC1/2, FC5/6, C3/4, Fz, Cz) in a middle latency window (300 – 800 ms post-stimulus onset). Furthermore, a positive-going component was observed at these same sites in a late window (900 – 1500 ms post-stimulus onset). Although this late window was not identified in Carver and Vaccaro (2007), visual inspection of the present data suggested that there was ongoing processing during this time window.

For the middle-latency negative component, mean amplitude and latency to reach peak amplitude were the dependent measures of infants' neural activity. For the late positive component, area scores were used as the dependent measure of neural activity.

Results

Results from the behavioral intervention are discussed first. Then results from the ERP recordings are discussed. Finally, relations between behavior and neural responses are examined. For all follow-up comparisons Bonferroni-corrections were applied, and so all effects are reported at a .0167 level of confidence.

Behavior

Caregiver signaling. A Friedman test was conducted to evaluate differences in caregivers' emotional expressions between emotion conditions. The test was significant: $\chi^2(2, 24) = 42.46$, $p < .001$. Follow-up pairwise comparisons were conducted using a Wilcoxon test and indicated that caregivers' expressions significantly different between all emotion conditions (all *p*s < .001). Moreover, caregivers displayed the appropriate emotional reaction in each condition.

Infant behavior. Descriptive statistics of infants' behaviors are provided in Table 3. During the one-minute trials, infants generally spent most of the trial attending to their caregivers or the objects (M = 51.43 s, SD = 8.20 s).

Insert Table 3

Response to the caregiver. The number of infants' referential looks toward their caregivers significantly differed by emotion condition: $F(2, 46) = 6.58$, $p < .01$. Follow-up planned comparisons indicated that infants made significantly more referential looks in the negative versus positive conditions ($p < .01$). Number of referential looks in the neutral condition did not significantly differ from the number of referential looks in the positive and negative condition. Infants' looking total looking time toward their caregivers significantly differed by emotion condition: $F(2, 46) = 6.83$, $p < .01$. Follow-up planned comparisons indicated a trend that infants' looked longer at their caregivers during the negative versus positive and neutral conditions (ps < .05).

Response to the objects. Infants' total looking time toward the object significantly differed by emotion condition: $F(2, 46) = 16.41$, $p < .001$. Follow-up planned comparisons indicated that infants' spent less time looking at the object during the negative versus positive and neutral conditions (ps < .001). This pattern parallels the referencing pattern, since infants generally directed their gaze toward the object or their caregiver during the one-minute trials.

The number of infants' reaches toward the object differed by emotion condition, approaching significance: $F(2, 46) = 2.99$, $p = .06$. Infants' total time of contact with the object was affected by emotion condition, $F(2, 46) = 4.34$, $p < .05$. Infants spent less time touching the object in the negative condition than in the positive condition, $p = .07$. Furthermore, the number of contacts infants made to the object differed by emotion condition, approaching significance: $F(2, 46) = 3.03$, $p = .058$. Although the effect only approached significance, follow-up planned comparisons suggested a trend that infants made fewer contacts in the negative versus neutral condition ($p < .10$).

Thus, caregivers were reliable emoters and produced accurate emotional expressions that were subsequently rated as distinct emotions. Infants' referencing behavior was affected by emotion condition. Specifically, infants were quicker to reference and spent a longer time looking at their caregivers in the negative condition than in the other conditions. Infants' behavior toward the objects was also affected by emotion condition. Infants spent less time looking at and touching the object in the negative condition than in the other conditions. Furthermore, infants made fewer reaches toward and contacts with the object in the negative condition than in the other conditions.

ERP responses

In order to use all available data, we conducted separate analyses for each ERP recoding (pre- and post-manipulation). In both ERP recordings, we observed a negative-going component in the middle-latency window (300-800 ms post-stimulus onset) and a positive-going component in the late window (900-1500 ms post-stimulus onset) over frontal-central sites. For each component, we used repeated measures analyses of variance to compare activity across the three emotion conditions (negative, positive, neutral). For lateral leads, activity was also compared between hemispheres (left, right). Because they cannot inform the question of interest, effects that involve only pairs of electrodes or individual electrodes will not be discussed. Repeated measures ANOVAs were used to compare differences in activity from the first to second recording. Greenhouse-Geisser corrections were applied in cases of violation of sphericity.

Results from the first recording (prior to the emotion intervention) are presented first, then results from the second recording (post-emotion intervention) are presented. Thirdly, differences in response between the two recordings are discussed.

Responses pre-intervention. No effects of emotion were observed in any measure in either component, at lateral and midline leads. Thus, prior to the emotion intervention, there were no uncontrolled differences by emotion condition.

Responses post-intervention. No effects of emotion were observed at the midline leads. At lateral leads, a 3 (emotion: negative, positive, neutral) x 4 (pair: F3/4, FC1/2, FC5/6, C3/4) x 2 (hemisphere: left, right) repeated measures ANOVA revealed an interaction of emotion x hemisphere for the measure of area score in the late positive-going component: $F(2, 40) = 3.70$, $p = .03$. To follow-up this interaction, we calculated one-way ANOVAs to compare responses in each emotion condition in each hemisphere. An effect of emotion was observed in the left hemisphere: $F(2, 166) = 5.13$, $p < .01$. Follow-up comparisons, Bonferroni corrected, revealed that area scores were significantly larger in the negative (M = 1306.28 μV/ms, SD = 2973.12 μV/ms) versus neutral (37.76 uV/ms, SD = 2546.33 μV/ms) condition ($p < .01$). Differences between the positive (M = 1146.04, SD = 2436.69 μV/ms) versus neutral condition approached significance at the Bonferroni-adjusted level ($p < .05$). No differences between the negative and positive conditions were observed ($p = 1.00$). There was no effect of emotion in the right hemisphere: $F(2, 166) = 1.76$, $p > .10$. Hemispheric differences in effects of emotion are presented in Figure 3.

Insert Figure 3

In summary, an effect of emotion emerged in the area scores in the late positive component, specific to sites over the left hemisphere. Area scores were larger in the negative and positive conditions that in the neutral condition.

Change in responses. Repeated measures ANOVAs were used to compare infants' pre- and post-intervention responses in each emotion condition, for each dependent measure. Since the post-intervention results suggested differential processing of emotion between hemispheres, data were collapsed by hemisphere for the following results. Specifically, data from F3, FC1, FC5 and C3 were collapsed to represent processing over the left hemisphere, and data from F4, FC2, FC6 and C4 was collapsed to represent processing over the right hemisphere.

There were no effects of emotion observed in the early window.

For the measure of area score in the positive-going component, a 2 (recording: pre, post) x 3 (emotion: negative, positive, neutral) x 2 (hemisphere: left, right) RM ANOVA revealed an interaction between recording, emotion and hemisphere: $F(2, 113.01) = 5.54$, $p < .01$. To follow up this interaction, RM ANOVAs were calculated for each hemisphere to test recording x emotion. Over the right hemisphere no effects of emotion or interaction of recording and emotion were observed. Over the left hemisphere, an interaction of recoding and emotion was observed: $F(2, 142) = 5.05$, $p < .05$. T-tests were calculated for each emotion to compare pre- and post-manipulation effects over the left hemisphere. Specifically, area scores in the negative condition became larger after the emotion intervention, $t(71) = -2.03$, $p < .05$. Area scores in the neutral condition became smaller after the intervention, $t(71) = 2.69$, $p < .01$. No significant change in area score was observed in the positive condition. Pre- and post-manipulation waveforms from site FC5 illustrate these effects, and are provided in Figures 4 and 5.

Insert Figure 4

Insert Figure 5

In summary, changes in neural responses by emotion condition occurred over the left hemisphere. Following the emotion intervention, neural responses in the positive-going component became larger in the negative condition, smaller in the neutral condition, and remained about the same in the positive condition.

Discussion

In this study, we examined the change in infants' behavioral and neural responses to a novel object when experienced in an emotional context. Findings from the behavioral paradigm mirrored those observed in previous social referencing studies (e.g., Mumme & Fernald, 2003). That is, depending on the emotional context, infants differentially adjusted their attention and behavior. Specifically, when the caregiver produced a fearful expression, infants referenced their caregiver more frequently, and were less likely to approach and touch the target object. When the caregiver produced a happy expression, infants spent more time touching the target object than when the caregiver produced a neutral or negative expression. Although manipulations of behavior via positive affect are not always observed in social referencing paradigms (e.g., Mumme & Fernald, 2003), it appears that in this paradigm, infants differentially regulated their behavior in a positive versus neutral context.

Negative and positive emotion signals not only influenced infants' behavior, but also governed changes in their ERP activity. Specifically, in the post-intervention recording infants seemingly devoted larger and more continued neural resources to processing the objects presented in an emotional (positive and negative) versus a neutral context. Although this finding alone is notable (12-month-olds differentially process emotional versus neutral information), with post-manipulation data alone, we can only speculate as to whether there was an increase in neural resources devoted to the processing of emotion, or a decrease in the processing of neutral information or some combination of both of these effects. This is often the case with ERP studies in which neural responses are sampled at one point in time, post-manipulation (e.g., Carver & Vaccaro, 2007). Critically, in the present study, because we collected a baseline measure of infants' responses to the objects before the emotion manipulation, we were able to compare pre- and post-manipulation responses and elucidate the post-manipulation effects. With this data, we can say that there was an *increase* in infants' neural response to the fearful object, a *decrease* in their response to the neutral object, and responses to the happy object remained about the same.

The present study also differed from Carver and Vaccaro (2007) in the locus of the effect of emotional signaling on neural responses. ERP findings from Carver and Vaccaro (2007) indicated effects of emotion in an earlier component, a middle-latency negative component. In ERP studies more generally, differences in this earlier component have been interpreted as reflecting attentional responses (Nelson, 1994). In contrast, in the present study, effects of emotion were observed in the late positive-going window. Activity during this period of the recording epoch in ERP studies more generally has been interpreted as reflecting updating of a memory trace and recollection processes (Nelson, 1994; Riggins, Miller, Bauer, Georgieff, & Nelson, 2009). Thus differences in this late component may reflect cognitive processes in continuing to process the stimuli, and in this study, perhaps reflecting infants' evaluation of the test stimuli. It is notable to point out the brevity of the intervention that triggered this change in neural response. After only 3 minutes, during which emotional information was provided over three brief moments, noticeable changes in neural responses occurred. These findings indicate that brief exposures to emotional information can have significant effects on the underlying neural response.

The differences in the timing of effects in the present study in comparison to the effects observed in Carver and Vaccaro (2007) may possibly reflect effects of delay. In the present study, there was no delay between in the behavioral intervention and the second ERP recording, and in Carver and Vaccaro (2007) there was an approximately 20-minute delay between these two phases to fit the ERP cap on the infants. Thus different neural processes may be recruited immediately versus after a 20-minute delay after receiving emotional information.

The behavioral and neural findings both suggest that infants are quick to learn and apply new information about the environment. This is a critical ability for infants of this age; they are becoming independent explorers and it is essential to not only pay attention to the environment, but to interpret and appropriately use social information. The present findings suggest that these effects of the emotion manipulation persist for at least ten minutes following the provision of the emotional information (i.e., the time elapsed between the intervention and the end of the post-manipulation ERP recording). Future work could investigate the robustness and duration of this effect. It is important that infants are able to use emotional information to guide their behavior, and thus it is equally important that infants retain this information over a delay to continue to guide their behavior in the future and, for example, categorize safe versus harmful elements in their environment.

Future research using this paradigm could explore the effects of other emotions, such as anger, on patterns of infants' behavior and neural responses. This kind of investigation may explain if these patterns in infants' responses are particular to valence (positive vs. negative) or specific emotion categories (e.g., happiness, fear, etc.).

The findings from the present research indicate patterns of change in neural processes that reflect how 12-month-olds relate emotional information to novel objects. The present results further highlight the importance of using converging brain and behavioral measures to develop a comprehensive picture of the neural underpinnings of behavior. This method could be useful in studies across development to investigate the patterns of *change* in neural processing that reflect behavior and experience.

References

Banaschewski, T., & Brandeis, D. (2007). Annotation: What electrical brain activity tells us about brain function that other techniques cannot tell us: a child psychiatric perspective. *Journal of Child Psychology and Psychiatry, 48*, 415–435.

Caron, A. J., Caron, R. F., & MacLean, D. J. (1988). Infant discrimination of naturalistic emotional expression: the role of face and voices. *Child Development, 59*, 604–616.

Carver, L.J. & Vaccaro, B.G. (2007). 12-Month-Old Infants Allocate Increased Neural Resources to Stimuli Associated With Negative Adult Emotion. *Developmental Psychology, 43,* 54-69.

Dien, J. (1998) Addressing misallocation of variance in principal components analysis of event-related potentials. *Brain Topography*, *11*, 43–55.

Ekman, P., & Friesen, W.V. (1975). *Unmasking the face*. Englewood Cliffs, New Jersey: Prentice Hall.

Feinman, S. (1982). Social referencing in infancy. *Merrill-Palmer Quarterly, 28*, 445-470.

Feinman, S., & Lewis, M. (1983). Social referencing at 10 months: a second-order effect on infants' responses to strangers. *Child Development, 54*, 878–887.

Gunnar,M. R. & Stone, C. (1984). The effects of positive maternal affect on infant responses to pleasant, ambiguous and fear-provoking toys. *Child Development*, *55*, 1231–1236.

Hornik, R., Risenhoover, N., & Gunnar, M. (1987). The effects of maternal positive, neutral, and negative affective communications on infant responses to new toys.

Child Development, 58, 937-944.

Jasper, H.H. (1958). The 10-20 electrode system of the International Federation. *Electroencephalography and Clinical Neurophysiology, 10*, 371–375.

Junghofer, M., Bradley, M. M., Elbert, T. R., & Lan, P. J. (2001). Fleeting images: A new look at early emotion discrimination. *Psychophysiology*, *38*, 175-178.

Junghofer, M., Peyk, P., Flaisch, T., & Schupp, H.T. (2006) Neuroimaging methods in affective neuroscience: selected methodological issues. *Progress in Brain Research, 156*, 123-143.

LaBarbera, V. D., Izard, C. E., Vietze, P., & Parisi, S. A. (1976). Four- and six-month-old infants' visual responses to joy, anger, and neutral expressions. *Child Development, 47,* 535–538.

Mayer, J. D., & Salovey, P. (1997). What is emotional intelligence? In P. Salovey & D. Sluyter (Eds.), *Emotional development and emotional intelligence: Implications for educators* (pp. 3–31). New York: Basic Books.

Mumme, D.L., & Fernald, A. (2003). The infant as onlooker: Learning from emotional reactions observed in a television scenario. *Child Development, 74,* 221-237.

Nelson, C. A. (1994). Neural correlates of recognition memory in the first postnatal year of life. In G. Dawson & K. Fischer (Eds.), *Human development and the developing brain* (pp. 269-313). New York: Guilford Press.

Nelson, C.A. & de Haan, M. (1996). Neural correlates of infants' visual responsiveness to facial expression of emotion. *Developmental Psychobiology, 29*, 577–595.

Nelson, C. A. & Dolgin, K. G. (1985). The generalized discrimination of facial expressions by seven-month-old infants. *Child Development*, *56*(1), 58–61.

Nelson, C. A., Morse, P. A., & Leavitt, L. A. (1979). Recognition of facial expressions by seven-month-old infants. *Child Development*, *50*, 1239-1242.

Riggins, T., Miller, N. C., Bauer, P. J., Georgieff, M. K., & Nelson, C. A. (2009). Electrophysiological indices of memory for temporal order in early childhood: Implications for the development of recollection. *Developmental Science, 12*, 209-219.

Scherer, K.R. (1986). Vocal affect expression: A review and model for further research. *Psychological Bulletin. 99*(2), 143-165.

Schwartz, G.M., Izard, C.E., & Ansul, S.E. (1985) The 5-month-old's ability to discriminate facial expressions of emotion. *Infant Behavior and Development*, *8,* 65–77.

Sorce, J.F., Embe, R.N., Campos, J., & Klinnert, M.D. (1985). Maternal emotional signalings: Its effect on the visual cliff behavior of 1-year-olds. *Developmental Psychology. 21(1),* 195-200.

Vaish, A., Grossman, T., & Woodward, A. (2008). Not all emotions are created equal: The negativity bias in social-emotional development. *Psychological Bulletin, 134,* 383–403.

Wellman, H.M. (1990). *The Child's Theory of Mind*. (p. 61-91). Cambridge, Massachusetts: MIT Press.

Table 1

Scoring criterion for caregivers' affect

Score						
1	**2**	**3**	**4**	**5**	**6**	**7**
Very negative (exactly like the training video)	Mostly negative	Somewhat negative	Neutral (no affect, exactly like the training video)	Somewhat positive	Mostly positive	Very positive (exactly like the training video)

Table 2

Scoring criterion for infants' behavioral responses

	Score				
Measure	1	2	3	4	5
Affect	Clear negative emotion (i.e. crying)	Apparent negative emotion (i.e. fussy)	Neutral emotion	Positive, smiling, minimal vocalization	Very positive, laughing, vocalizing
Interest in stimuli	Ignores	Looks occasionally, does not track	Tracks toy for less than 5 s	Tracks toy for 5-10 s	Very interested, tracks toy for more than 10 s
Reaction to stimuli	Withdraws from object	Ignores object	Looks or points at object	Approaches or reaches for object	Touches or explores object

Table 3

Descriptive statistics of caregivers' (C) affect and infants' behaviors toward C and the object (O) during the behavioral component

	Emotion condition					
	Negative		Positive		Neutral	
Behavior	*M*	*SD*	*M*	*SD*	*M*	*SD*
C Affect	2.50	1.29	6.50	0.51	4.08	0.50
Affect	2.96	0.62	3.25	0.74	2.92	0.78
Interest	5.00	0	4.96	0.20	5.00	0
Reaction	3.96	0.69	4.13	0.80	4.04	0.86
# looks to C	3.33	2.18	2.00	1.84	2.38	1.72
latency to look at C	16.68	10.49	25.4	12.79	20.85	14.11
Duration at C	10.00	10.45	4.92	6.28	5.21	4.25
Duration at O	38.96	11.01	47.38	9.63	47.83	7.56
# reaches to O	2.42	1.89	3.21	2.36	2.21	1.62
Latency to reach to O	15.00	11.53	14.7	12.82	20.85	16.78
Closest reach to O	3.44	3.75	3.80	5.05	4.80	5.85
# of contacts to O	0.38	0.88	1.21	1.98	1.29	2.37
Latency to contact O	25.60	16.35	20.80	7.15	24.44	15.36

Duration of contact	1.04	2.24	6.21	10.68	3.28	6.52

Duration and latency measures are in seconds (s). Closest reach measure is in centimeters (cm) from front of stage.

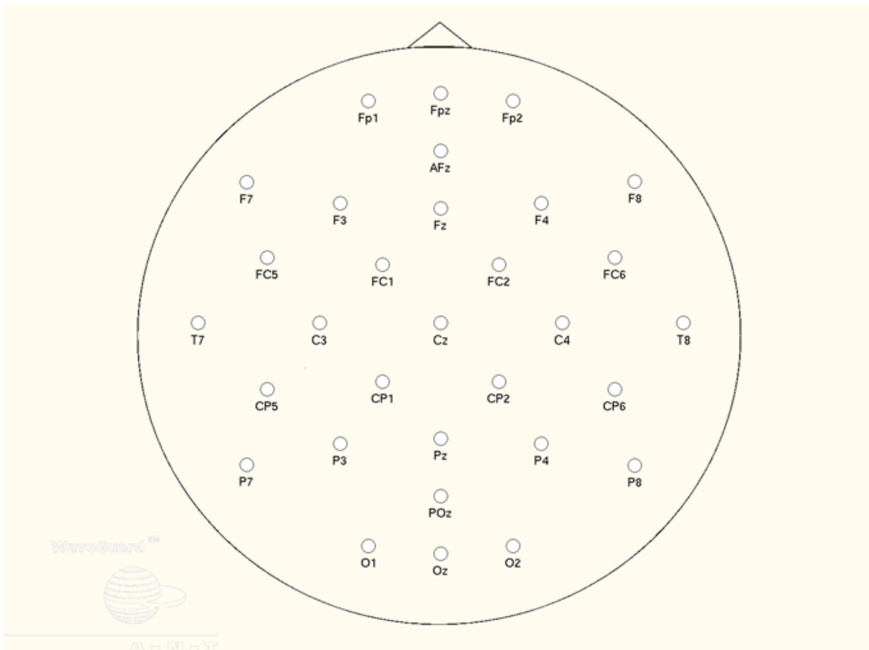


Figure 1. Electrode configuration following the 10-5 system of placement.

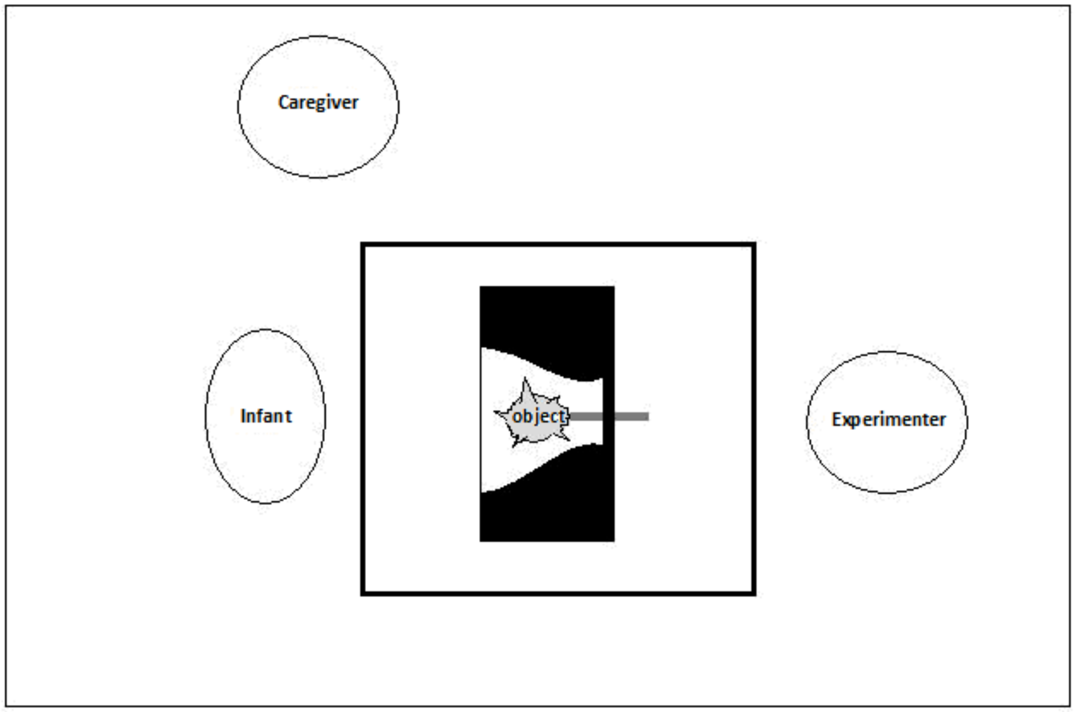


Figure 2. Depiction of seating arrangement in the behavioral paradigm.

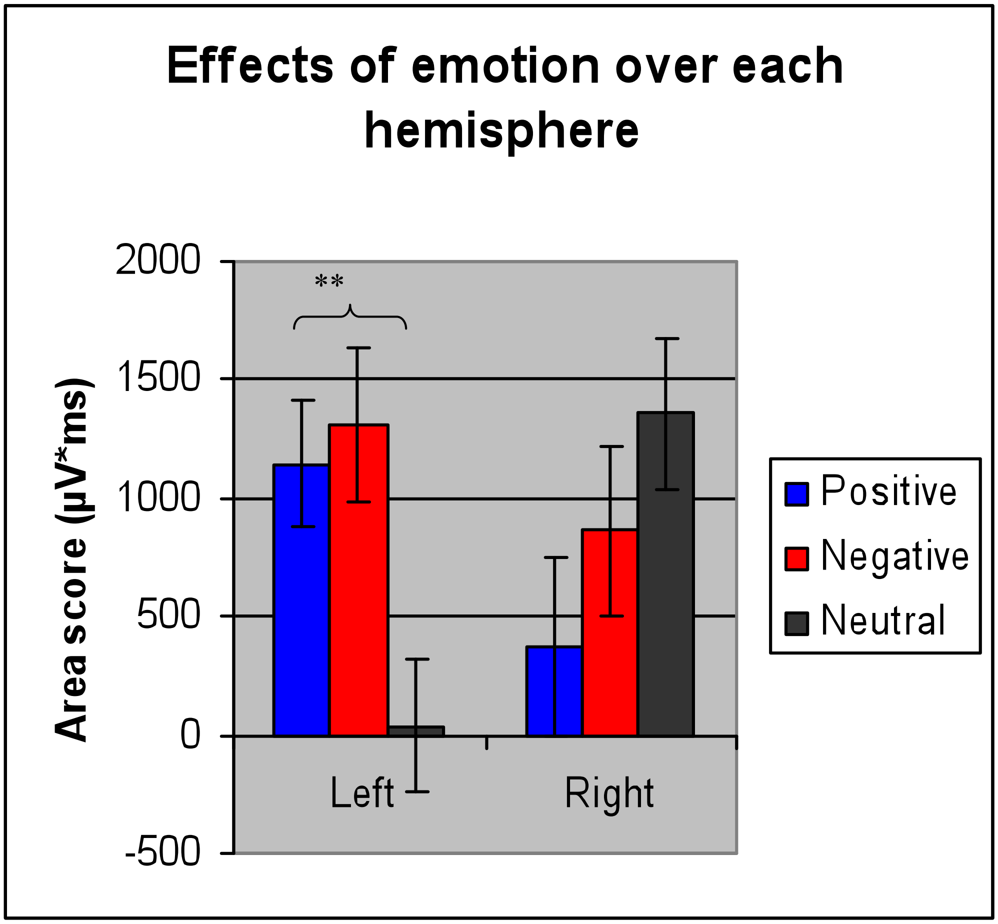


Figure 3. Differential effects of emotion over each hemisphere as reflected in area scores in the post-manipulation recording. Error bars represent ±1 standard error. **indicates significance at the level of $p < .01$.

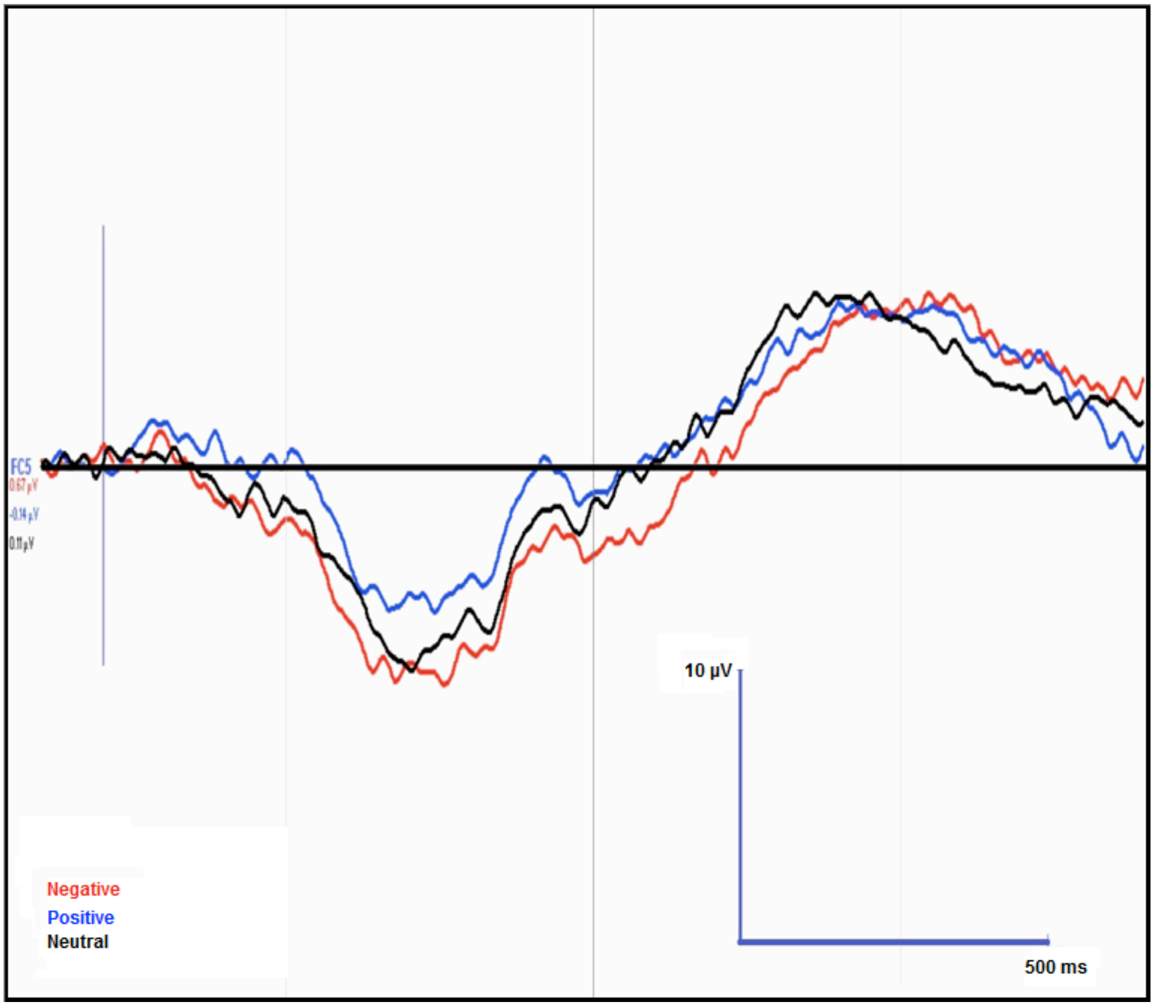


Figure 4. Pre-manipulation ERP waveforms at site FC5.

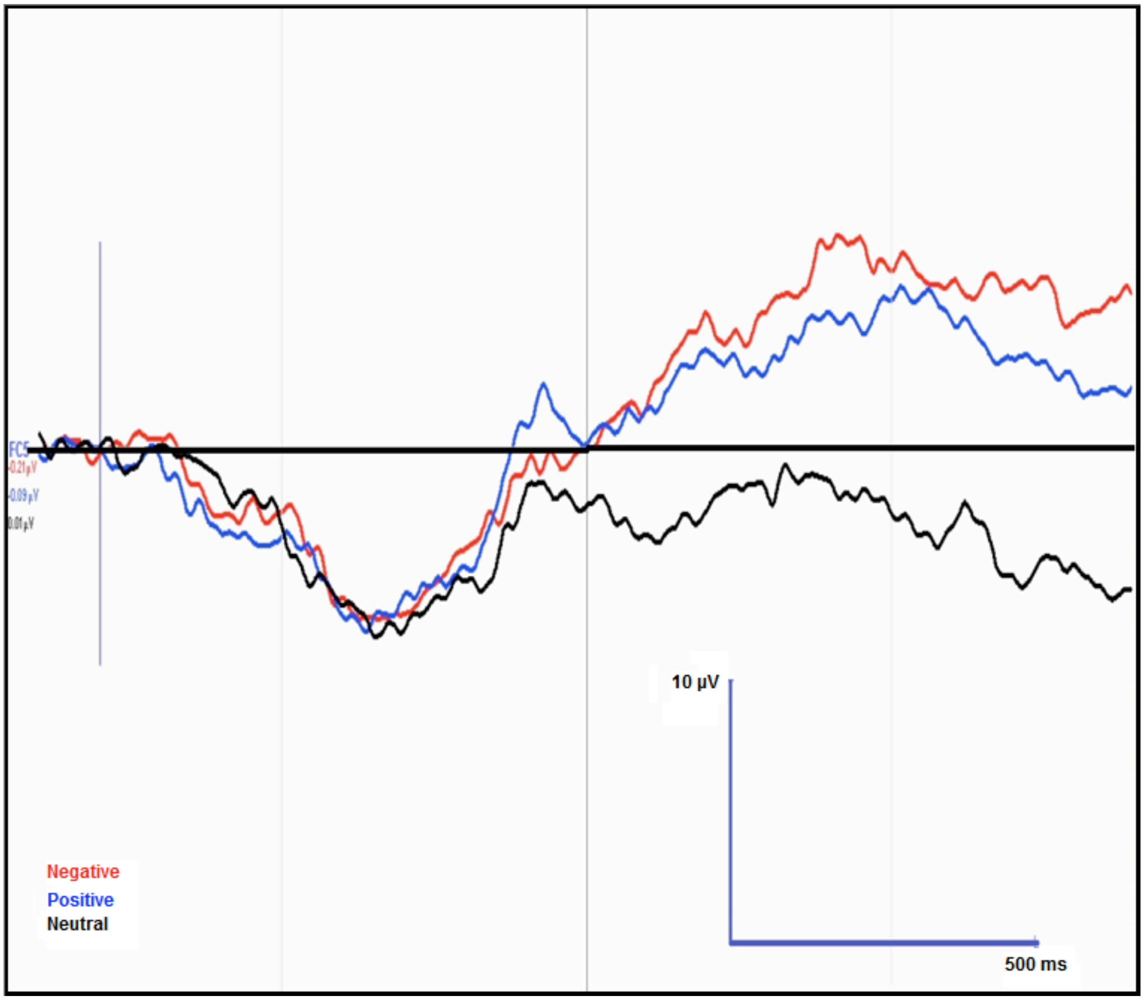
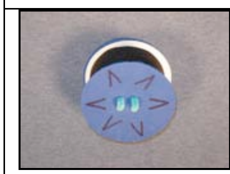
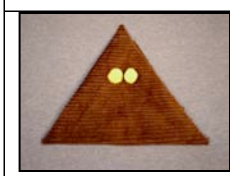


Figure 5. Post-manipulation ERP waveforms at site FC5.

Appendix A

Description of stimuli

Object	Dimensions	Description
	9 x 6 x 6 cm	Red rubber ball with two horns on top and two short feet on bottom
	4 x 7 x 7 cm	Black and blue foam wheel with short, fuzzy antennae
	.5 x 12 x 12 cm	Brown corduroy triangle with two yellow eye-spots

Appendix B

Sequence of trials during behavioral procedure

Time (min:sec)	**Event**	**Caregiver (C) behavior**
0:00-1:00	Introduction of Object 1	C provides emotional signal when E2 signals C
1:00-2:00	Introduction of Object 2	C provides emotional signal when E2 signals C
2:00-3:00	Introduction of Object 3	C provides emotional signal when E2 signals C