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The development of emotion perception in face and voice during infancy

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Abstract. *Purpose:* Interacting with others by reading their emotional expressions is an essential social skill in humans. How this ability develops during infancy and what brain processes underpin infants' perception of emotion in different modalities are the questions dealt with in this paper.
Methods: Literature review.
Results: The first part provides a systematic review of behavioral findings on infants' developing emotion-reading abilities. The second part presents a set of new electrophysiological studies that provide insights into the brain processes underlying infants' developing abilities. Throughout, evidence from unimodal (face or voice) and multimodal (face and voice) processing of emotion is considered. The implications of the reviewed findings for our understanding of developmental models of emotion processing are discussed.
Conclusions: The reviewed infant data suggest that (a) early in development, emotion enhances the sensory processing of faces and voices, (b) infants' ability to allocate increased attentional resources to negative emotional information develops earlier in the vocal domain than in the facial domain, and (c) at least by the age of 7 months, infants reliably match and recognize emotional information across face and voice.

1. Introduction

Infants develop in a world filled with other people, including parents, siblings, other family members, friends, and strangers. Relating socially to others has not only profound effects on what they feel, think and do, but is also essential for their healthy development and for optimal functioning throughout life. Therefore, to develop an understanding of other people is one of the most fundamental tasks infants face in learning about the world.

Interacting with others by reading their emotional expressions is an essential skill for humans. Reading emotional expressions during interpersonal interactions permits us to detect another person's emotional state or reactions, and can provide cues on how to respond appropriately in different social situations. It has been suggested that it may be adaptive for humans to recognize emotional expressions early in development (Darwin, 1872; Nelson, 1987). Thus, although the development of emotion perception expands beyond infancy (e.g. Russell, 1980; 1983; Russell and Bullock, 1986), developmental psychologists have focused on the question of how the perception of emotion develops during the first year of life.

At birth, the infant enters the world well prepared to rapidly develop competencies related to the perception of emotions by extracting relevant information from other's face and voice. Even though neonates' ability to discern fine visual detail is limited (Banks, 1980; Banks and Ginsburg, 1985), they do look preferentially at visual stimuli that are patterned, high-contrast, or moving (Walker-Andrews, 1997). Newborns look longer at face-like stimuli and track them farther than non-face-like stimuli (Goren et al., 1975; Johnson et al., 1991). Not only do newborns look preferentially to faces in general, but also gaze longer at their mother's face specifically, even after very brief exposure to it (Bushnell, 2001; Bushnell et al., 1989; Field et al., 1984).

Neonates are already sensitive to auditory information such as frequency, intensity, and temporal structure, and they prefer human voices to similar non-social auditory stimuli (Ecklund-Flores and Turkewitz, 1996; Hutt et al., 1968). Newborns also prefer their mother's voice over the voice of another newborn's mother (DeCasper and Fifer, 1980). It has been argued that newborns may prefer particular voices because of prenatal experience (Turkewitz et al., 1972). Furthermore, one-month-old infants are able to make fine discriminations among different human speech sounds (Eimas et al., 1971).

Together, this suggests that from very early on, infants are highly attentive to social stimuli such as faces and voices, and they detect information that later may allow for the discrimination and recognition of emotional expressions. What is detected by the infant changes rapidly with the development of the perceptual systems. Thus, the development of emotion perception depends on the interplay of the maturation of perceptual systems, and the developing psychological capacities related to discriminating and recognizing emotional information. In the visual domain, for example, a newborn can only discern a blurry face and distinguish the hairline, eyes, nose, and mouth (Banks and Ginsberg, 1985). Therefore, it seems unlikely that newborns discriminate facial expressions on anything other than feature information. Then, by 6 months of age, visual acuity has improved substantially (Gwiazda et al., 1989), and contrast sensitivity is sufficient to detect most static facial expression contrasts (Hainline and Abramov, 1992). Now infants can detect additional details (e.g. laugh lines) and relational information (e.g. distance between eyebrows and eye) that characterize particular facial expressions. This exemplifies how the postnatal maturation of the sensory systems can constrain the development of processing emotional information at least in the visual domain.

A host of behavioral studies have been conducted to investigate the development of emotion perception during the first year of life. The next sections aim at describing infants' developing abilities in perceiving others' emotional information unimodally from face (2.1), voice (2.2), and multimodally from both face and voice (2.3) by reviewing the empirical behavioral evidence available in these areas.

2. Review of behavioral findings

2.1. Infants' perception of emotion from the face

There is evidence that suggests that even newborns, 36 hours of age, may be able to discriminate between facial expressions (Field et al., 1983; Field et al., 1982). In these studies, newborns were tested with happy, sad, or surprised facial expressions presented by a live female model. One expression was posed repeatedly until the newborn looked at it for less than two seconds, and then the other two expressions were presented. Field and colleagues, (1982) found that infants' looking time increased when the expression changed, and they took this as evidence that newborns were able to discriminate among expressions. However, unlike in other habituation studies, there was no comparison group tested with the same procedure but without a change in expression to support the interpretation that the increased looking time was due to the change in expression (for further critique, see de Haan and Nelson, 1998).

Studies in which control groups did not see a change in expression following habituation (Young-Browne et al., 1978), in which infants were shown novel or familiar stimuli following habituation (Barrera and Maurer, 1981; Schwartz et al., 1985), or in which only infants' visual preference was assessed without habituation (LaBabera et al., 1976) all provide stronger evidence for discrimination of facial expressions in older infants. The results of these studies suggest that by 3 months infants can discriminate between happy and surprised faces (Young-Browne et al., 1978), and happy from angry faces (Barrera and Maurer, 1981). In addition, at the same age infants can also discriminate among different exemplars of the same expression (happy) that vary in intensity (Kuckuck et al., 1986). Studies using the visual preference technique have shown that, by 4 months of age, infants look longer at happy than angry or neutral expressions (LaBabera et al., 1976), and at happy faces with toothy smiles than sad faces (Oster, 1981), but they look equally long at happy faces with closed mouth and sad faces (Oster, 1981). Furthermore, there is evidence that 4-month-olds can discriminate between mild and intense examples of fearful faces (Nelson and Ludemann, 1986, cited in de Haan and Nelson, 1998), and that 6-month-olds reliably discriminated between varying intensities of happy and angry facial expressions (Striano et al., 2002). Then, at 7 months of age, infants look longer at fearful than at happy faces in a visual preferences test (Nelson and Dolgin, 1985). It is important to mention that order effects have been observed at different ages. For example, by 5 months of age, infants can discriminate between interest, sad, fearful, and angry expressions, but only if they are first habituated to angry faces and then tested with fearful, sad, or interest faces (Schwartz et al., 1985). Another example is that 7-month-olds discriminate happy from fearful faces in a habituation procedure, but only if they are first habituated to fear (Nelson et al., 1979).

In sum, the results of these studies suggest that infants are able to discriminate among several facial expressions. There is corroborating evidence that during the first months of life infants can discriminate happy from surprised and angry expressions. It appears that for young infants happy faces may be harder to discriminate from sad faces. Infants' ability to discriminate between other facial expressions has been less extensively studied, and the available findings suggest that the order of presentation influences the ability to discriminate.

In order for a facial expression to be useful in communication, infants need to understand that the expression conveys the same 'meaning' across individuals. In addition, infants need to recognize that an emotional expression remains the same despite changes in its intensity. However, the ability to discriminate between facial expressions does not indicate whether infants' responses would generalize beyond the model tested, or whether infants discriminate based on local feature information (e.g. raised vs. lowered eyebrows) or on the invariant configuration of facial features that constitute an emotional expression. These abilities are better tested by assessing infants' abilities to categorize facial expressions. Here, instead of presenting only one exemplar of the category during the familiarization or habituation phase as in simple discrimination tests, multiple exemplars of the same category are presented. Then, infants are tested with a new exemplar of the familiar category or an exemplar from a different category. The assumption is that, even though both stimuli are novel, if infants have formed a category, their looking should only increase to the exemplar of the new category.

In the first study that examined infants' categorization of facial expressions, Nelson, Morse, and Leavitt (1979) familiarized 7-month-old infants to happy expressions posed by two different females. In the test phase infants were shown a new model posing a happy expression and a fearful expression. Infants looked longer at the fearful expression, indicating that despite the change in the model, they detected that the happy expression belongs to the same category whereas the fearful expression is from another category. However, infants did not show categorization abilities when they were first familiarized to the fearful expression. Subsequently, numerous studies (Kotsoni et al., 2001; Ludemann and Nelson, 1988; Nelson and Dolgin, 1985) have replicated and extended these findings. These studies demonstrated that 7-month-olds showed categorization of happy expressions when they first habituated to happy faces posed by multiple male or female models (Nelson and Dolgin, 1985), and that this was also the case when the intensity of the happy expression varied during habituation (Kotsoni et al., 2001; Ludemann and Nelson, 1988). There is evidence from a more recent study that infants only 5 months old can categorize happy facial expressions (Bornstein and Arterberry, 2003). However, it is a consistent observation that 6- to 7-month-old infants do not show evidence of categorizing fear or surprise when first habituated to these emotions and then tested with happy expressions (Caron et al., 1982; Kotsoni et al., 2001; Nelson and Dolgin, 1985; Ludemann and Nelson, 1988). For infants at this age happy faces might in general be more familiar than fearful or surprised faces (Nelson and Dolgin, 1985). It is thus possible that infants are able to categorize the more familiar expression during habituation or familiarization, and then discriminate it from a novel expression, whereas viewing a less familiar expression during habituation might make it difficult for the infants to categorize the expression, and hence, to discriminate it from another expression.

Infants' ability to categorize different expressions into the broader categories of positive and negative expressions has also been examined. In Ludemann's (1991) study, 7- and 10-month-olds were habituated to positive faces (happy and surprise). Following habituation, infants were tested with novel persons portraying positive expressions (happy, surprise) or negative expressions (angry, fearful). Ten-month-olds, but not 7-month-olds, could recognize familiar positive affective tone, indicated by the finding that the older infants dishabituated (i.e. looked longer) only to the novel negative expressions, whereas the younger infants dishabituated in both conditions. These results suggest that, by 7 months of age, infants' ability to categorize expressions according to affective tone may be limited, and that it is not until 10 months of age that they are able to categorize expressions more generally as positive or negative.

By the end of the first year, infants begin to use others' expressions to interpret external events. This phenomenon is called *social referencing*. The development of this skill requires not only that infants discriminate and categorize others' expression, but also that they correctly connect those expressions to environmental events (for a review see Baldwin and Moses, 1996). How infants make use of facial expressions to guide their behavior has been investigated, for example, in the context of the visual cliff (a plexiglas surface providing support over an apparent drop). Sorce, Emde, Campos, and Klinnert (1985) found that if the mother, standing at the opposite side of the cliff, facially posed happiness or interest while the infant looked at her (i.e., referenced), most 12-month-old infants crossed the cliff, whereas if the mother displayed fear or anger, very few infants crossed. Furthermore, in the absence of any depth very few infants referenced the mother, and those who did while the mother was posing a negative expression still crossed the cliff. These findings suggest that others' facial expressions efficiently regulate infants' behavior in the context of threatening/uncertain situations.

In sum, the results of the reviewed studies on infants' perception of facial expressions suggest that (1) although even newborns might react differentially to facial expressions, it is by 3 to 4 months that infants can reliably discriminate among at least some expressions, (2) they are able to form categories of happy expressions by 5 months, although the ability to form categories of other expressions or to form broader categories might not develop until after 7 months of age, (3) by the end of the first year, infants begin to seek out and use others' facial expressions to guide their behavior in uncertain situations.

2.2. Infants' perception of emotion from the voice

Despite the fact that the auditory system is more highly developed at birth than is the visual system (Aslin, 1987; Gottlieb, 1971), relatively few studies have assessed young infants' responses to vocal expressions of emotion. This is even more surprising given that there are a number of studies indicating impressive effects of prenatal auditory experience on newborns' differential responses to auditory stimuli (DeCasper and Fifer, 1980; DeCasper and Sigafoos, 1983; DeCasper and Spence, 1986). There is also converging evidence (Mehler et al., 1978; Moon et al., 1993) showing that postnatal listening preferences are primarily related to infants' sensitivity to prosodic characteristics of speech (i.e., frequency, intensity, rhythm). Mehler and colleagues (1978) found that newborns are able to discriminate speech segments belonging to their native language from those belonging to a non-native language, but they did not discriminate between two non-native languages. This was also the case when the stimuli were filtered to reduce segmental information, so that only the prosodic cues were available. This suggests that as a result of their prenatal experience, newborns might be responsive to prosodic cues typical for their native language. Prosodic cues play an essential role in the perception of vocally communicated emotions (Scherer, 1986). Therefore, newborns listening to their native language might be able to discriminate among emotional speech patterns that differ with respect to their prosodic features.

Indeed, newborn infants respond differentially to different vocal expressions of emotion. Mastropieri and Turkewitz (1999) presented newborns of English- and Spanish-speaking mothers with a range of vocal expressions (happy, angry, sad, and neutral) in their native and non-native language. Newborns showed an increase in eye opening responses following the onset of the presentation of happy vocal stimuli as compared to the other emotions. This form of differential responding was observed in both the English and Spanish group of infants only when listening to the vocal expression in their native language. This suggests that newborns are able to detect distinctive prosodic features characterizing different expressions of emotion in their native language. Given that happy speech is characterized by an increase in fundamental frequency, fundamental frequency range, speech rate, and mean intensity (Scherer, 1986), such speech is likely to cause an increase in infants' level of arousal. However, if the newborns were simply responding to the acoustic properties of the stimuli, then they would have also shown differential mouth opening to the happy expression presented in the non-native language. Since this was not the case, the results obtained in Maestropieri and Turkewitz's (1999) study strongly suggest that the differences in the acoustic properties of the stimuli are not by themselves sufficient to explain newborn's differential responding to emotional speech. The authors suggested a possible mechanism to account for the observed influence of prenatal experience on newborns' vocal discrimination abilities might be the temporal congruity between the prosodic acoustic characteristics of maternal vocal expressions and associated physiological changes experienced by the fetus in the womb (for further discussion see Maestropieri and Turkewitz, 1999).

There is more evidence of young infants' ability to discriminate vocal expressions of emotion from a series of experiments by Walker-Andrews and co-workers (Walker-Andrews and Grolnick, 1983; Walker-Andrews and Lennon, 1991). In these studies, infants were habituated to a visual stimulus that was accompanied by a recording of emotional speech. Then, after habituation, only the vocal expression changed while the visual stimulus remained the same. An increase in looking time to the habituated visual stimulus was taken as evidence that infants had detected the change of the vocal expression.

In a first study (Walker-Andrews and Grolnick, 1983), 3- and 5-month-old infants were habituated to a woman's happy or sad voice while a picture of her face was presented posing the same emotion. Three-month-old infants increased their looking to the face only when they heard a change in the voice from sad to happy, whereas they did not show a significant increase in looking time when they heard a change from happy to sad. Five-month-olds were found to dishabituate to changes in the vocal expression for both orders. Walker-Andrews and Grolnick (1983) concluded that at least by the age of 5 months, if not earlier, infants reliably discriminate between happy and sad vocal expressions. However, a closer look at this study raises the question whether infants needed emotional information in the face to detect the vocal change or whether any visual stimulus could have accompanied the vocal expressions.

To further investigate the role of the visual stimuli accompanying the voice, Walker-Andrews and Lennon (1991) conducted another study. In this study, 5-month-old infants were habituated to emotional voices and then tested in four different conditions: a first group of infants saw a facial expression that was affectively matched to the voice heard during habituation, a second group saw a facial expression that affectively matched the voice heard during the test phase, infants in the third group watched a novel facial expression, and another group of infants was shown a checkerboard as a visual stimulus. The results of this study revealed that regardless of whether the face matched the habituated voice, the voice during the testing phase, or did not match either of the voices, 5-month-olds discriminated between happy, angry, and sad vocal expressions. When a checkerboard was presented as a visual stimulus, infants failed to detect the change in the vocal expression. This suggests that seeing a face might help infants to attend to the affective quality of the voice.

Vocal expressions of emotion have also been shown to be powerful modifiers of infant behavior in ambiguous (Mumme et al., 1996) and potentially threatening situations (Vaish and Striano, 2004). In a social referencing paradigm, 12-month-old infants' behavior towards a novel toy was assessed while the mothers provided either facial or vocal emotional cues (neutral, positive, negative; Mumme et al., 1996). Only in the vocal condition, where mothers had their back turned to the infant but could still see the toy, infants responded appropriately to negative vocal cues (i.e. looked longer to the mother, showed less toy proximity to the toy, and expressed more negative affect). Infants did not show differential responses in the face only condition. Therefore, the authors suggested that the voice alone, but not the face alone, is sufficient to guide infants' behavior. This interpretation receives further support from findings of a study of 12-month-old infants' behavior in the potentially threatening context of the visual cliff (Vaish and Striano, 2004). In this study, infants received positive facial-only, vocal-only, or both facial and vocal (bimodal) cues from mothers, and were found to cross the cliff faster when provided with bimodal and vocal cues than with facial cues. Together, the evidence from these studies emphasizes the important and regulating role that vocal expressions of emotion play in guiding infants' behavior in different social contexts at the end of the first year of life.

In summary, the results of the reviewed studies on infants' perception of vocal expressions of emotion suggest that very soon after birth, infants can discriminate among vocal expressions. Moreover, infants reliably detect vocal changes from sad to happy, and happy to sad by 5 months of age. However, this ability seems to depend on the simultaneous presentation of a face. Later, at an age of 12 months, infants seek out and use vocal emotional cues to guide their behavior efficiently in uncertain and threatening situations.

2.3. Infants' perception of emotion from the face and voice

How infants perceive emotional expressions when communicated either by the face or the voice has been extensively studied. However, in most social interactions, emotional information is communicated simultaneously by different modalities such as the face and voice. Unlike in the controlled experimental settings described in the two preceding sections, infants in most social situations do not interact with 'faceless' voices or 'voiceless' faces, but receive multimodal information conveyed by face and voice. This leads to the question of whether and how they integrate visual and auditory emotional information.

This aspect has been typically studied by adapting the use of the intermodal preference technique (Spelke, 1976), in which infants concurrently view two visual displays of filmed facial expressions that are accompanied by an auditory recording of a vocal expression that only matches one of the two facial expressions. Increased looking to the affectively matching facial expression is taken as evidence that infants recognize common affect across modalities.

In a series of four experiments using this technique, Walker (1982) examined 5- and 7-month-old infants' crossmodal perception of emotional expressions. In the first experiment (with happy and neutral expressions), 7-month-old infants were found to detect common affect across modalities by increasing looking time to the emotionally matching face. These findings, however, may have been limited to the particular expression and age. Therefore, in a second experiment 5- and 7-month-olds were tested using happy and sad expressions. Infants at both ages detected the correspondence between face and voice. But this still does not tell us what the invariant information across modalities was that infants responded to. The most obvious invariance might have been the temporal synchrony relations between the filmed faces and vocal recordings. In order to control for that, Walker (1982) conducted a third experiment in which temporal synchrony between visible lip movements and audible speech was eliminated by playing the voice out of synchrony (5 sec.) with the ongoing facial expression. The results revealed that, despite the lack of temporal synchrony relations, 7-month-olds could still detect common affect indicated by an increase in their looking time to the voice-specified facial expression (happy, neutral). To further examine the cues infants use to match face and voice, in a fourth experiment, 7-month-old infants were tested with happy and angry expressions, but this time the facial expressions were presented upright in one condition and upside-down in another. Only the infants that saw the upright face were able to detect common affect across modalities, whereas when the configurational perception was disrupted by presenting the face upside-down the infants failed to show an increase in looking time to the voice-specified facial expression. The finding that, although temporal synchrony information was available, when faces were presented upside-down they did not match facial and vocal expressions lends further support to the interpretation that infants do not use only temporal relation cues to match emotional expressions.

In another study (Walker-Andrews, 1986) following up on the findings of Walker's (1982) original experiments, 5- and 7-month-old infants were presented with filmed facial expressions (happy and angry) in which the lower part of the face was occluded so that infants could not simply match lip movements to the voice. As in previous experiments (Walker, 1982), 7-month-old infants preferentially looked at the voice-specified facial expression. Five-month-olds, however, did not show evidence that they detected common affect across modalities when the mouth was not visible. This suggests that only the older infants, despite the degradation of temporal synchrony, could make use of invariant information to match emotional expressions. Together, the evidence presented (Walker, 1982; Walker-Andrews, 1986) shows that by the age of 7 months an upright orientation of the face, but not temporal synchrony between face and voice, is required for the crossmodal matching process to occur.

In a study with 7-month-old infants, Soken and Pick (1992) examined the role that facial motion plays in the crossmodal perception of happy and angry expressions. In order to do this, infants were presented with point light displays (PLDs) of the facial expression (Johansson, 1973). PLDs reveal only facial motion cues (through the movement of luminous dots) and eliminate facial feature information. In one experiment, temporal synchrony information was controlled for by recording the vocal expression from another woman speaking a different text than the woman filmed for the facial expression. In a second experiment, the vocal expression was simply presented out of synchrony, as in Walker (1982). In both experiments, infants were able to identify the common affect across modalities, showing that infants could detect the congruent affective relation between face and voice based on facial motion information.

The question one may ask is whether, by means of crossmodal matching, infants distinguish between positive (e.g. happy) and negative (e.g. angry) expressions but not among expressions that share the same emotional tone (e.g. angry and sad as two negative expressions). By testing 7-month-old infants with all paired combinations of happy, interested, angry, and sad expressions, Soken and Pick (1999) could demonstrate that infants at this age also do discriminate between expressions that share the same emotional tone.

Another important question is whether the information conveyed visually through the face and auditorily through the voice contributes to infants' discrimination and recognition processes of the emotion equally or whether one of the modalities is dominant. There is evidence that 6-month-olds, when habituated to a bimodal stimulus (flashing checkerboards accompanied by auditory beeps), detected a change only when the auditory component was changed, but not when the visual component was changed (Lewkowicz, 1988a,b). Older infants (10 months), however, detected both visual and auditory changes. These data suggest that for younger infants, at least for non-social stimuli, auditory information is more potent in evoking a discrimination response than visual information.

In summary, infants by the age of 7 months are able to detect common emotion across modalities. There is a body of evidence that suggests that infants at this age match face and voice based on common affective information even when no temporal cues are available.

2.4. *Event-related potential (ERP) studies of infants' perception of emotion*

How infants' perception of emotional expressions develops has been studied extensively using behavioral methods (see previous section). However, we only poorly understand what the brain processes are that underlie infants' behaviorally exhibited capacities. The major objective of this section is to explore how the infant brain processes emotional information by reviewing some of our own work on this topic.

The focus of this work was a systematic examination of the electrophysiological bases of infants' perception of others' facial and vocal emotional expressions. Therefore, we conducted a series of three ERP studies in which infants' perception of facial emotional information (Grossmann et al., 2007) and vocal emotional information (Grossmann et al., 2005) were examined unimodally, and then, in a third study (Grossmann et al., 2006), the integration of emotional information from face and voice was investigated. All the stimulus material used in this series of infant ERP studies, which is decribed in detail in Grossmann et al. (2005, 2006, 2007), was previously validated in adult experiments. The ERP method is the most commonly used method to study brain function in infancy (for recent reviews concerning infant structural brain development, see Paterson et al., 2006; and for how this relates to EEG/ERP measures, see Csibra et al., 2008).

The main focus of the work was on infants 7 months of age and older. This age group was selected for multiple reasons. First, at this age, infants' visual acuity has improved substantially (Gwaizda et al., 1989), and contrast sensitivity is sufficient to detect most static facial expression contrasts (Hainline and Abramov, 1992) so that they can perceive additional details (e.g. laugh lines) and relational information (e.g. distance between eyebrows and eye) that characterize particular facial expressions. Second, by 7 months, infants are able to detect common emotion across face and voice (see previous section). Thus, in order to be able to examine and compare the underlying brain processes, one age group was chosen at which all three aspects (facial, vocal, and crossmodal information processing abilities) necessary for emotion perception are developed (see previous sections).

2.5. *ERP correlates of emotion processing in the face*

We measured ERPs in 7- and 12-month-old infants to examine the development of processing happy and angry facial expressions (Grossmann et al., 2007). In 7-month-olds, we observed a larger negativity with a maximum at anterior (frontal and central) electrodes in response to happy faces when compared to angry faces (see Fig. 1 and Table 1). However, in 12-month-olds, no ERP differences between emotions were measured at anterior electrodes. In this group of older infants, a larger negativity to angry faces when compared to happy faces was observed at posterior (occipital) electrodes (see Fig. 1 and Table 1). Although the ERP data indicate that infants of both ages are able to discrimnate between the facial expressions, the difference in topography (anterior: 7-month-olds; posterior: 12-month-olds) suggests that different brain systems are involved in processing of the same stimuli depending on the age of the infant. More specifically, the anterior negative component is thought to reflect the allocation of attentional resources during face processing (de Haan, Johnson, and Halit, 2003), suggesting that 7-month-olds allocated more attention to the processing of happy faces. However, at 12 months, enhanced negativity to an angry face at occipital sites might indicate greater sensitivity to angry faces during sensory processing in the visual cortices. In support of this interpretation, ERP findings show that angry compared to happy and neutral facial expressions elicit a larger early posterior negativity at occipital sites in adults (Schupp et al., 2004). This negative ERP component is thought to indicate facilitated sensory processing of emotional cues and appears uniformly also for other experimental designs and stimulus materials (Schupp et al., 2003). Furthermore, a recent fMRI study with adults revealed increased activation of occipital regions for angry versus other facial expressions (Kesler-West et al., 2001). The finding of an adult-like electrophysiological response in 12-month-old infants is also in accordance with recent theoretical accounts that predict an increased sensory specificity through cortical specialization during development (Grossmann and Johnson, 2007; Johnson, 2001). This account of postnatal human brain development proposes that cortical areas will gain increasing functional specialization by se-

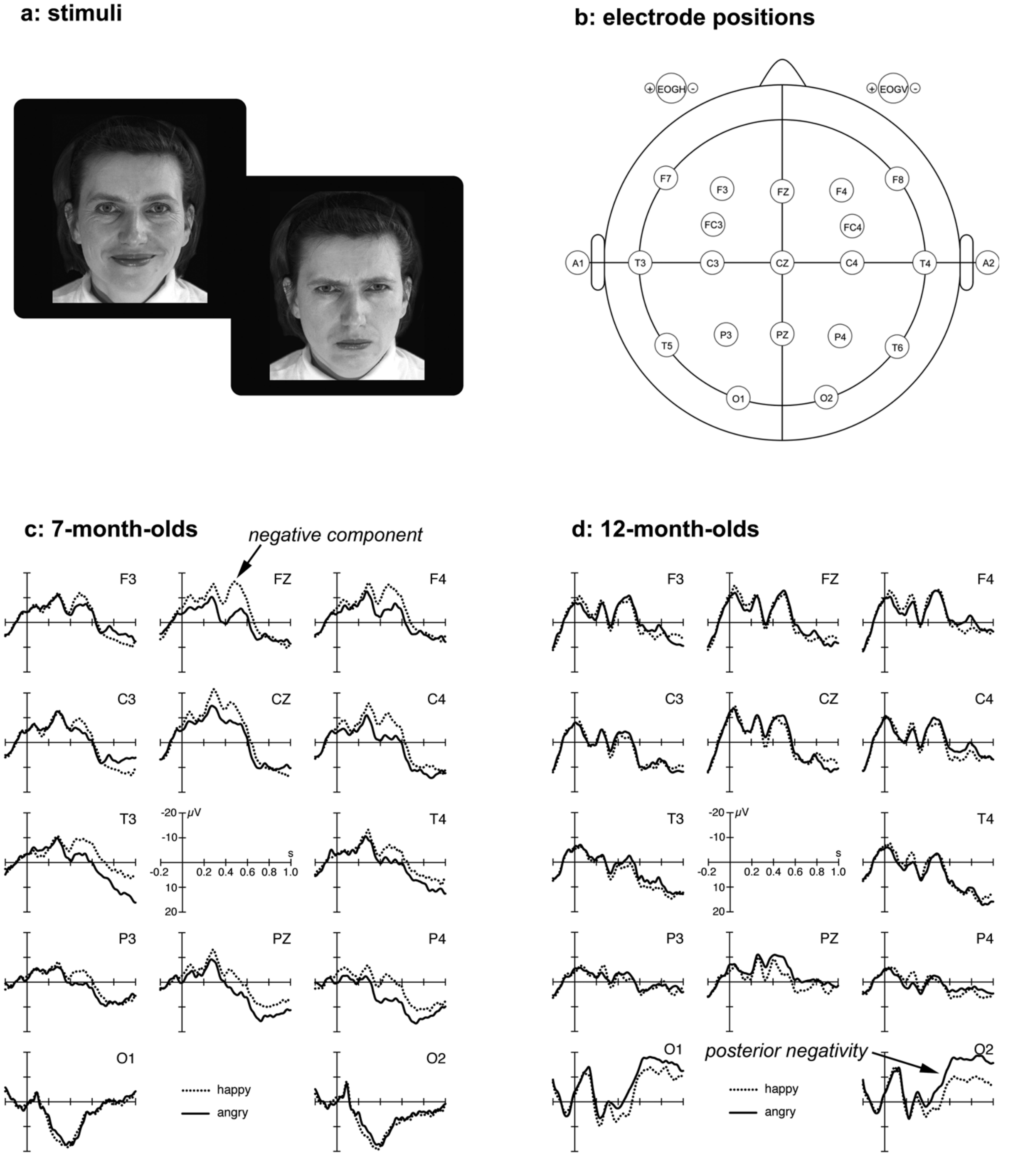

Fig. 1. Processing emotion in the face: a: stimuli pictures of a woman posing either a happy or an angry facial expression, b: electrode positions used in the ERP experiments, c: ERPs in response to happy and angry facial expressions in 7-month-old infants, d: ERPs in response to happy and angry facial expression in 12-month-old infants, (Figure was adapted from Grossmann et al. 2007).

lective loss of synapses and neurons, which might be partly determined by extrinsic (experiential) factors.

One possible developmental account is that although infants can discriminate between both facial expressions at 7 months of age and younger (see Barrera and Maurer, 1981), they still have not had suffcent expo-

Table 1
Overview of the ERP findings on the perception of emotion from the face, voice, and face and voice

Face Grossmann et al. 2007	Voice Grossmann et al. 2005	Face and Voice Grossmann et al. 2006
7 months Anterior negative component Amplitude larger for happy than angry faces -> Index of increased allocation of attention to happy faces	7 months Anterior negative shift Amplitude larger for angry than happy or neutral voices -> Index of increased allocation of attention to angry voices	7 months Anterior negative component Amplitude larger for incongruent than congruent face-voice pairs -> Index of increased allocation of attention to incongruent face-voice pairs (violation of expectation)
12 months Posterior (occipital) negativity Amplitude larger for angry than happy faces (adult-like response) -> Index of increased sensory processing of angry faces	Temporal positive slow wave Amplitude larger for angry and happy than neutral voices -> Index of increased sensory processing of emotional voices (angry and happy)	Anterior positive component Amplitude larger for congruent than incongruent face-voice pairings -> Index that infants recognized common affect across modalities

sure to angry faces to learn the signal value (threat) that an angry expression conveys (Campos et al., 2000). With increased exposure to angry faces towards the end of the first year, infants begin to detect the angry face as a signal of threat that signifies potential negative consequences. In support of this interpretation, following the onset of self-produced locomotion around 10 months of age (Illingworth, 1983), the frequency and quality of emotional communications from the adult to the infant changes. Specifically, self-produced locomotion increases the number of opportunities for caregivers to regulate infant's explorations facially and vocally. Indeed, mothers of locomotor as compared to prelocomotor infants reported a sharp increase in their expression of anger toward their infants (Campos et al., 2000; Campos et al., 1992).

One potential avenue for future research could therefore be to assess inter-individual differences in facial expression processing as a function of locomotion or affective experience. Along these lines, processing of happy and angry faces has been studied as a function of particular experiences such as physical abuse (Pollak et al., 1997; Pollak et al., 2001), and maternal personality (de Haan et al., 2004). In general, these various studies suggest that experiential factors influence the ways that infants and children process facial expressions. It is important to note that the reverse may also be true, i.e., that neural development occurring at the end of the first year (Diamond, 1991, 2000) may impact infant behavior and subsequently infants' experiences with others.

In a behavioral experiment of the study (Grossmann et al., 2007), we examined 7- and 12-month-olds' looking behavior in a visual-paired comparison task in which the two facial expressions were presented side-by-side and looking time to the expressions was measured. Contrary to the ERP data in which we found differences in the processing between ages, the looking time data revealed that both 7- and 12-month-old infants looked significantly longer at happy than angry facial expressions. It is possible that 7-month-olds simply showed a visual preference for the familiar happy face whereas 12-month-olds, who showed an adult-like brain response, avoided looking at the angry face because they perceived it as threatening and therefore preferred to look at the happy face instead. This scenario would result in longer looking to the happy expression at both ages. On a more general note, the phenomon that different neurocognitive processes can result in similar overt behavior underlines the importance of a cognitive neuroscience approach to the study of development. Behavioral looking methods alone would have suggested that there is no development between 7 and 12 months because the looking preferences did not differ but with ERP methods we were able to show that the neural processing differs between 7 and 12 months.

2.6. ERP correlates of emotion processing in the voice

We examined 7-month-old infants' processing of emotional speech using ERP measures (Grossmann et al., 2005). We had infants listen to words with neutral, happy, and angry prosody in order to investigate whether and how ERP correlates differ between (a) neutral and emotionally charged prosody (happy and angry), and (b) positive emotion (happy) and negative emotion (angry).

We found that words with an angry prosody elicited a more negative response in infants' ERPs than did words with happy or neutral prosody. This effect was

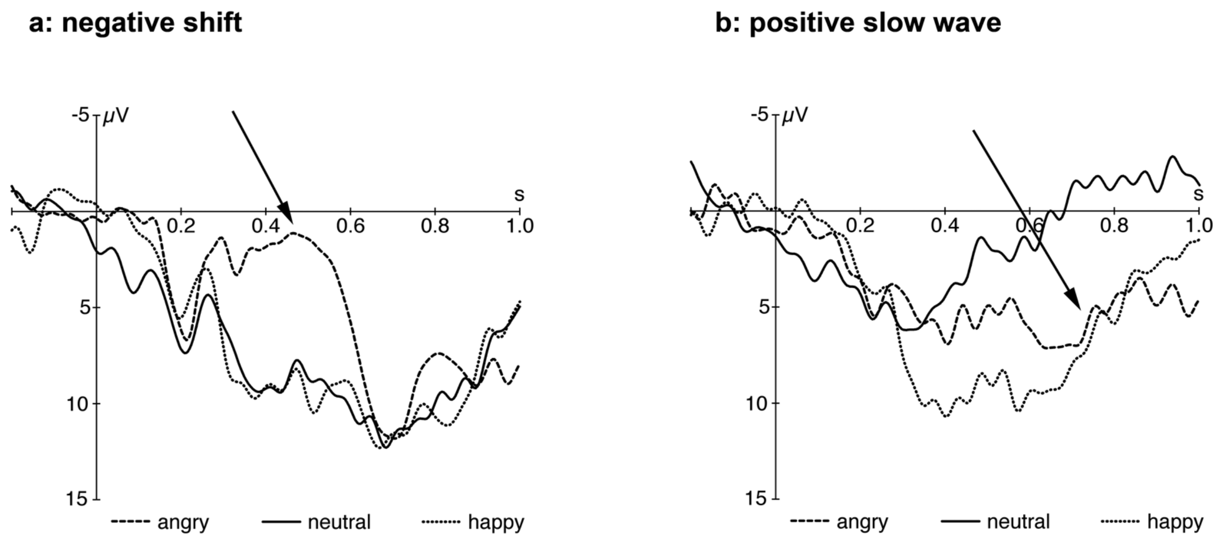

Fig. 2. Processing emotion in the voice: ERPs in response to neutral, happy, and angry emotional prosody in 7-month-old infants, a: negative shift at the central midline electrode (Cz); b: positive slow wave at temporal electrodes (average of T3 and T4), (Figure was adapted from Grossmann et al. 2005).

elicited over fronto-central sites and reached its peak amplitude around 450 ms (see Fig. 2 and Table 1). The negative shift observed in the current study resembles previous ERP work with 4-month-old infants, in which the mother's voice was compared to unfamiliar voices (Purhonen et al., 2004). In that study, 4-month-olds' ERPs revealed a negative shift in response to the mother's voice, while in the current study, angry prosody elicited a negative shift in 7-month-old infants' ERPs. In several infant ERP studies on visual processing it has been suggested that a larger amplitude of a negative component (Nc) indicates increased allocation of attention (de Haan, Johnson, and Halit, 2003). Based on this view, Purhonen et al. (2004) argued that the 4-month-olds in their study allocated more attention to process their own mother's voice compared to unfamiliar voices. Hence, we suggest that the 7-month-old infants in our study allocated more attentional resources to the angry than to the happy or neutral voice.

Furthermore, we found that words spoken with angry and happy prosody elicited a positive slow wave in infants' ERPs, whereas ERPs to words with neutral prosody returned to baseline (see Fig. 2 and Table 1). This effect was observed over temporal electrodes at a latency from 500 to 1000 ms. It has been argued that infants' slow waves reflect more diffuse activation of neural systems (de Haan and Nelson, 1997). It is thus possible that the observed positive slow wave to happy and angry prosody indexes dispersed activation in auditory (temporal) brain structures to affectively-loaded stimuli that is not evoked by neutral voices. This suggests an enhanced sensory processing only of the affectively- loaded auditory stimuli.

Concordant with this interpretation is evidence from ERP and fMRI work in adults showing that emotionally charged words undergo more extensive processing than words with neutral prosody (Alter et al., 2003; Mitchell et al., 2003). For example, relative to neutral prosody, angry prosody evoked enhanced activity in adults' associative auditory cortex, namely, in the middle portion of the superior temporal sulcus (Grandjean et al., 2005). Similarly, an enhancement in the processing of faces was reported in the right midfusiform gyrus for fearful relative to neutral faces (Vuilleumier et al., 2001). Therefore it has been proposed that enhanced sensory responses to emotional facial and vocal stimuli might be a fundamental neural mechanism. It is possible that this mechanism might also account for the observed positive slow wave to happy and angry prosody over temporal sites in the 7-month-olds, indicating an enhanced sensory processing of the emotional stimuli. This enhanced processing, which we have demonstrated on an electrophysiological level, could be linked to the behavioral finding that vocal affect facilitates infants' spoken word recognition (Singh et al., 2004), suggesting a method by which emotional information in the speech signal might help infants develop language comprehension capacities.

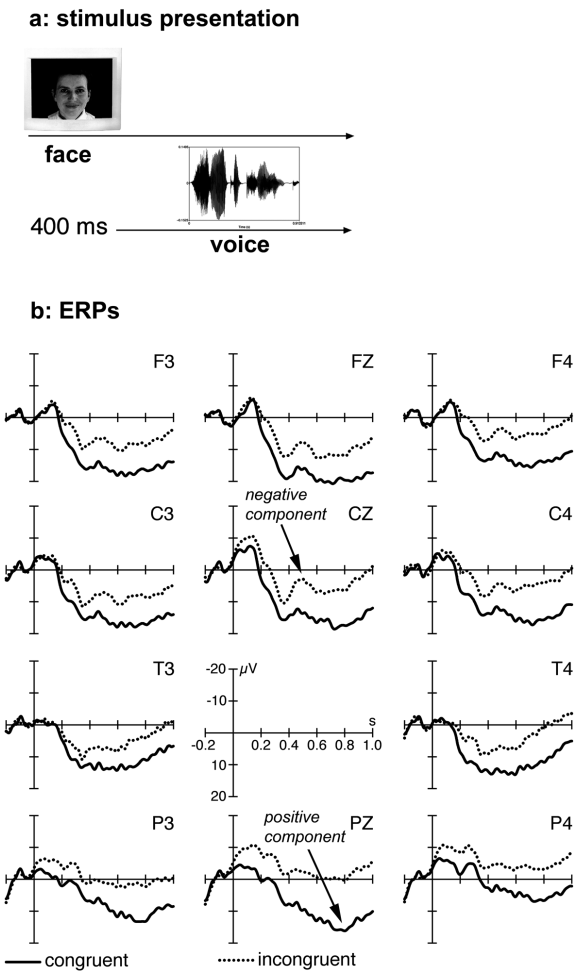

Fig. 3. Processing emotion in face and voice: a: illustration of the stimulus presentation used in the audio-visual experiment, note that the infant first saw the face for 400 ms before the voice stimulus was presented while the face remained on the screen, b: ERPs in response to congruent and incongruent face-voice pairs in 7-month-old infants, (Figure was adapted from Grossmann et al. 2006).

2.7. *ERP correlates of emotion processing in face and voice*

The ERP measure has been found to be sensitive to infants' crossmodal (haptic to visual) recognition of objects (Nelson et al., 1993), and has proven to be a valuable tool in assessing these underlying mechanisms of infants' processing of unimodal emotional information conveyed by the face (Grossmann et al., 2007; Nelson and de Haan, 1996) and by the voice (Grossmann et al., 2005). To extend this work into the domain of multisensory processing we investigated the electrophysiological processes underlying crossmodal integration of emotion in 7-month-old infants (Grossmann et al., 2006). As infants watched a static facial expression (happy or angry), they heard a word spoken in a tone of voice that was either emotionally congruent or incongruent with the facial expression (see Fig. 3). The ERP data revealed that the amplitude of a negative component and a subsequently elicited positive component in infants' ERPs varied as a function of crossmodal emotional congruity. We found that words spoken with a tone of voice that was emotionally incongruent to the facial expression elicited a larger negative component in infants' ERPs than did emotionally congruent words (see Fig. 3 and Table 1). Conversely, the amplitude of the positive component was larger to emotionally congruent words than to incongruent words (see Fig. 3). These findings provide electrophysiological evidence that 7-month-olds recognize common affect across modalities, which is in line with previous behavioral work (Soken and Pick, 1992; Walker, 1982; Walker-Andrews, 1986).

Extending behavioral findings, the ERP data from Grossmann and colleagues (2006) reveals insights into the time course and characteristics of the processes underlying the integration of emotional information across the senses in the infant brain. Numerous ERP studies in adults have investigated old/new effects in recognition memory tests with a variety of stimuli (for a review, see Rugg and Coles, 1995). The uniform finding across studies is that old (familiar) items evoke more positive-going ERPs than do new (unfamiliar) items. This general old/new effect comprises the modulation of two ERP components: an early negativity (early N400), which consistently shows an attenuated amplitude to old items, and a late positive component or complex (LPC), which shows an enhanced amplitude to old items.

Old (familiar) items have also been found to elicit an attenuated N400 and an enhanced LPC in children's ERPs when compared to new (unfamiliar) items (Friedman, 1991; Friedman et al., 1989; Friedman et al., 1992; Coch et al., 2002). Furthermore, similar effects have been observed in infants' ERPs (Nelson et al., 1998), where old (familiar) items elicited an attenuated early negative component (Nc) and an enhanced late positive component (Pc). Given the similarities in response properties, latency, and topography of these components across ages (infancy to adulthood), it is plausible to assume that the adult and child N400 corresponds with the infant Nc and that the adult and child LPC corresponds with the infant Pc. Thus, a coherent picture begins to emerge about the developmental continuity of recognition memory effects in the ERP.

In Grossmann and colleagues (2006), emotionally congruent face-voice pairs elicited similar ERP effects as recognized items in previous memory studies with infants, children, and adults. This suggests that 7-month-old infants recognize common affect in face and voice. Since the face-voice pairs presented to the infants were novel to them, the ERP data do not only indicate that these infants recognized common affect, but, moreover, that they applied their knowledge about emotions in face and voice to draw inferences about what might be appropriate emotional face-voice associations when encountering novel bimodal events. Multimodal audio-visual events usually make two kinds of information available: amodal and modality specific information (for a detailed discusssion of amodal and modality-specific information processing in infancy see Bahrick, Lickliter, and Flom, 2004). An example of amodal information is that the movements of the lips and the timing of speech share temporal synchrony, rhythm, and tempo, and have common intensity shifts. Since we used static facial expressions, there was no such amodal information available to the infants. Thus, infants could not simply determine that a face and voice belonged together by detecting amodal audio-visual relations; instead, they had to draw inferences based on their prior knowledge.

Another finding from this study was that the amplitude of infants' Nc not only differed between congruent and incongruent face-voice pairs but also between two incongruent conditions. Namely, when a happy face was presented with an angry voice, the Nc was more negative in its amplitude than when an angry face was presented with a happy voice. As mentioned earlier, we know that prior to the onset of crawling (around 10 months), infants have only little exposure to others' expression of anger, whereas happy emotional expressions are ubiquitous in infants' everyday social interactions (Campos et al., 2000; Campos et al., 1992). Based on this observation, it can be assumed that a happy face is more familiar than an angry face (see also Vaish et al., 2008). It is thus possible that the presentation of the more familiar happy face triggered a stronger expectation about the appropriate emotional prosody, causing an especially strong expectancy violation and a larger Nc when the angry voice was presented. This suggests a sensitivity of infants' Nc to familiarity-based processes, confirming previous research on infants' Nc (see Csibra et al., 2008).

2.8. Discussion of ERP findings

Together, the presented ERP findings indicate that infants' perception of emotional expressions in the face and voice elicited both sensory-specific and sensory-unspecific (general) effects in infants' ERPs. The ERP data revealed two sensory-specific effects: (1) a negative component observed over occipital sites to angry faces in 12-month-old infants (Grossmann et al., 2007) and (2) a positive slow wave elicited over temporal sites by emotionally loaded words in 7-month-old infants (Grossmann et al., 2005). These effects are likely to be sensory-specific because their observed scalp topography suggests that the visual (occipital) and the auditory (temporal) sensory processing were specifically affected. Specifically, an enhanced negativity to an angry face at occipital sites in 12-month-olds as shown in Grossmann et al. (2007) might indicate greater sensitivity to angry faces during sensory processing in the visual cortices. Moreover, the observed positive slow wave to happy and angry prosody might reflect sensory-specific proesses in auditory (temporal) brain structures to affectively-loaded stimuli that is not evoked by neutral voices. Based on fMRI work with adults, researchers have proposed that enhanced sensory responses to emotional facial and vocal stimuli might be a fundamental mechanism by which the brain highlights emotionally-loaded information (e.g., Grandjean et al., 2005; Mitchell et al., 2003; Vuilleumier et al., 2001). The reviewed ERP data suggest the early emergence and effectiveness of this mechanism, since infants' enhanced sensory processing of emotional stimuli was demonstrated on an electrophysiological level for vocal and facial cues. More generally, the mechanism of an emotion-induced more elaborate sensory processing of stimuli could also help infants' developing cognitive skills. It is possible that this enhanced processing contributes to the facilitating effects emotion has on infants' learning in different domains (see Malatesta and Haviland, 1982; Singh et al., 2004).

In addition to the sensory-specific ERP effects emotional expressions also elicited sensory-unspecific (general) effects in infants' ERPs. By 7 months of age, happy faces evoked a negative component that was larger than that evoked by angry faces (Grossmann et al., 2007). However, at the same age, angry voices elicited a negative shift that was not observed in response to neutral and happy voices (Grossmann et al., 2005). Both, the negative component in face processing (de Haan, Johnson, and Halit, 2003) and the negative shift in voice processing (Purhonen et al., 2004) are thought to reflect the allocation of attentional resources. Based on this view, a larger amplitude of these components indexes increased allocation of attention. This suggests that 7-month-olds on the one hand allocate more attention to the processing of happy faces, but on the other hand they devote more attentional resources to the processing of angry voice.

These findings thus suggest that infants' ability to show a heightened attentional sensitivity to negative emotional information develops earlier in the vocal domain. Interestingly, it has been suggested that the advantage of the auditory sensory modality might result from the fact that the auditory system in mammals develops much earlier than the visual system (Gottlieb, 1971). The emergence of the different sensory systems begins early in gestation and is sequential, which leads to different amounts and types of sensory experience. The sequential nature of the sensory development is thought to have substantial impact on the development of intersensory function such that the early-developing sensory modalities become functionally differentiated without the competing influence of the later-developing ones, whereas the later-developing ones have to compete with the earlier-developing ones (Turkewitz and Devenny, 1993). The neonate comes into the world with a set of sensory systems that already have had differential sensory experience and that are, therefore, not functionally equivalent. After birth the sensory systems continue to interact with each other, as they did prenatally, but now they do so in a radically different postnatal setting characterized by a new and rich multimodal array of information.

Lewkowicz (1988 a,b) designed studies on sensory dominance, and put forward a theory of early auditory dominance. In these studies, infants 6 and 10 months of age were habituated to flashing checkerboards (visual information) accompanied by beeps (auditory information). The younger infants dishabituated only to audio-visual or auditory changes. At 10 months infants also dishabituated to visual changes, but overall infants at both ages were more sensitive to the auditory change than to the visual change. However, these data are limited to socially irrelevant stimuli. Based on evidence indicating that when infants are not yet showing consistent differential responsiveness to positive and negative facial expressions, they are responding differentially to positive and negative vocal expressions (Fernald, 1992), it has been proposed that in early development, emotional information in the voice is more powerful than in the face (see, Vaish, Grossmann, Woodward, 2008; Vaish and Striano, 2004). The ERP data presented here suggests that infants' ability to show a heightened sensitivity to negative emotional information develops earlier in the vocal domain when compared to the visual domain, are consistent with this view.

Another finding in the present studies was that 7-month-olds can recognize common emotion in face and voice (Grossmann et al., 2006). This finding seems surprising, given that infants at the same age do not recognize anger by looking only at a facial display (Grossmann et al., 2007). A developmental sequence has been proposed in which infants learn to discriminate and recognize emotional expressions based on multimodal, then vocal, and finally, as visual acuity improves, facial cues (Walker-Andrews, 1997). This notion that emotion discrimination and recognition occurs earlier in multimodal contexts is supported by the current ERP findings when multimodal context (Grossmann et al., 2006) is compared to unimodal facial context (Grossmann et al., 2007). It has been shown that the perception of multimodally specified events appears to be generally more efficient, because multimodal cues confer a significant advantage over unimodal cues both in perception and discriminative learning across a variety of species (Rowe, 1999). Moreover, the availability of multimodal information in the current study might have had advantageous multiplicative effects (Stein, Meredith, and Wallace, 1994) on infants' perceptual abilities that cannot be anticipated by simply adding their performances in the unimodal contexts. In other words, although 7-month-olds failed to exhibit the ability to detect facial anger unimodally, they discovered commonalities across face and voice that allowed them to recognize the congruent emotion.

It has been suggested that through the detection of intermodal invariants in multimodal contexts, infants also discover the meaning of emotional expression (Walker-Andrews, 1997). However, note that although infants might first recognize the affective expressions of others as a unified multimodal event, and only later begin to recognize the same emotional information unimodally, this does not necessarily mean that infants also discover the meaning of emotional expressions through this process. Infants' ability to match facial and vocal expressions of emotion might merely be based on learning to associate a certain facial expression with the vocal expression that consistently accompanies it. This ability can be expressed by the infant without the appreciation of the meaning of the emotional expression. Thus, although the presented ERP data (Grossmann et al., 2006) suggest that 7-month-olds detect common affect in the face-voice pairs presented, it cannot be concluded that they also discover the meaning of these emotional expressions.

It is important to note that many mother-infant studies using live interaction suggest that infants recognize the emotional expressions of their own caregivers and respond to them meaningfully as early as 2 to 3 months (Cohn and Ellmore, 1988; Malatesta and Haviland, 1982). For example, 10-week-old infants respond differentially and contingently to their mothers' live presentation of happy, sad, and angry emotional expressions (Haviland and Lelwica, 1987). When mothers expressed happiness, infants expressed more joy and interest. When mothers presented sad expressions, infants expressed less joy, and they also showed increased mouthing behavior and gaze aversion. To maternal expressions of anger infants responded with increased anger and their movement appeared to freeze. This and other studies suggest that infants as young as 3 months of age have a wide repertoire of emotional expressions and respond effectively to their mothers' emotional expression.

As opposed to studies using live interactions, findings from the reviewed ERP studies and other experimental investigations examining infants' recognition of emotional expression suggest that only at around 7 months of age infants match facial and vocal expressions of the same emotion (Soken and Pick, 1992; Walker-Andrews, 1986) or recognize that different examples of the same emotion belong to the same category (Ludemann and Nelson, 1988). This apparent age difference might be due to several differences between live interaction and experimental studies. First, in most experimental studies, the emotional expressions presented are restricted to either the visual or the auditory domain, whereas in interaction studies, infants are provided with multimodal presentation of the emotion in face, voice, gesture, and touch. Second, in most experimental studies the emotional expression is displayed by an unfamiliar actress, whereas in interaction studies they are typically displayed by infants' mothers. Indeed, 3-month-old infants are better at discriminating among facial expressions when the expressions are portrayed by their own mother than by a stranger (Barrera and Maurer, 1981). Furthermore, Kahana-Kalman and Walker-Andrews (2001) found that infants presented with familiar faces and voice were able to recognize common affect across modalities at 3.5 months of age, whereas infants tested with unfamiliar faces and voices did not recognize common affect across modalities until 7 months of age (Walker-Andrews, 1986). Kahana-Kalman and Walker-Andrews (2001) propose that maternal emotional responses are not only more familiar to a young infant, but also more informative with respect to ensuing actions. Infants may have been more motivated to attend to the emotional expressions of their mothers because these may foreshadow more specific outcomes to them. For example, maternal smiles are likely to be followed by positive caretaking interactions, whereas maternal negative expressions may frequently be followed by experiences were the infant is left alone.

Based on these findings, which underline the prominent role of maternal expressions of emotion for infants' developing understanding of others' emotion, what are the implications for the presented ERP studies? In general, it can be stated that the findings described in these studies are limited to perception of emotional expressions displayed by strangers, and previous work seems to suggest that the abilities observed here might well be observable at an earlier age when investigated with maternal expressions. Therefore, for future studies it seems promising to examine the role of experience and familiarity on the electrophysiological correlates of infants' perception of emotion by using maternal stimuli.

The presented ERP work has provided insights into how the human brain processes emotional information very early in development. The systematic investigation of the electrophysiological correlates of perceiving facial, vocal, and multimodal emotional cues provided empirical data on the brain mechanisms guiding infants' emerging understanding of emotional expressions.

It is my hope that this paper might stimulate future work that extends these findings on four levels. First, it seems worthwhile to test infants at other ages to further examine the roles maturation and experience play in the development of processing emotional information. Specifically, one important issue that has not been addressed is the question of how infants' own production of facial and vocal expressions relates and possibly shapes their understanding and processing of emotional expressions in others. This question seems particularly pertinent because there is much debate about the role of the so-called human, Mirror-neuron-system' (Rizzolatti and Craighero, 2004) in the understanding of emotion and action in adults. According to the mirror neuron system view, infants are not expected to show an understanding of other people's actions or emotions before they can perform the action or express the emotion themselves. Indeed, there is some first evidence from studies on action understanding to support this hypothesis (Falck-Yttr et al., 2006; Sommerville et al., 2005), but whether this also holds for emotional expressions remains to be seen. Second, this line of electrophysiological work should be extended to other emotions in order to understand the emotion-specificity of the found effects (see Kobiella et al., 2008). Third, it is crucial to identify the neural sources that are involved in infants' processing of emotional information by using methods that can localize brain activity in the infant (such as near-infrared spectroscopy; see Grossmann et al., 2008). Fourth, once we know how the typically developing brain processes emotional and social information it might be possible to examine how this differs from the processing in atypically developing infants. By this comparison we might gain knowledge about atypical brain indices that, in conjunction with other measures, can contribute to an early diagnosis of the specific deficit (see Elsabbagh and Johnson, 2007). An early diagnosis allows early intervention and may therefore help the affected children and families.

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