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Development of frontal electroencephalogram (EEG) and heart rate (ECG) responses to affective musical stimuli during the first 12 months of post-natal life

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Abstract

We examined the development of infants' regional electrocortical (EEG) and heart rate (ECG) responses to affective musical stimuli during the first 12 months of post-natal life. Separate groups of infants were seen at 3 ($n = 33$), 6 ($n = 42$), 9 ($n = 52$), and 12 ($n = 40$) months of age at which time regional EEG and ECG responses were continuously recorded during a baseline condition and during the presentation of three orchestral pieces that were known to vary in affective valence and intensity (happy, sad, fear). Overall, there were two important findings. First, we found that although the overall amount of EEG 4–8 Hz power increased between 3 and 12 months, the distribution of EEG power changed across age, with the younger infants (3- and 6-month-olds) showing no difference between frontal and parietal regions, but the older infants (9- and 12-month-olds) showing relatively more activation at frontal than at parietal sites. This development likely reflects the maturation of frontal lobe function. Second, we found that the presentation of affective music significantly increased brain activity at 3 months of age, had seemingly little effect at 6 and 9 months, and significantly attenuated brain activity at 12 months. Findings suggest that there is a clear developmental change in the effect of music on brain activity in the first year, with music having a "calming" influence on infants by the end of the first year of life.

1. Introduction

Children's ability to successfully negotiate a complex social world is highly dependent on the regulation of emotion. For example, infants who are either easily distressed or frustrated in response to the presentation of novel stimuli in the first years of post-natal life and who fail to develop the ability to regulate these affects are known to be at risk for social and emotional problems during the preschool and early school age years (see Schmidt & Tasker, 2000; Segalowitz & Schmidt, 2003).

In a series of studies with infants and young children, Fox and his colleagues (e.g., Fox & Bell, 1990; Fox, Bell, & Jones, 1992; Fox, Calkins, & Bell, 1994) have noted that areas of the prefrontal cortex are involved in the active inhibition of particular motor responses, such as those involved in problem-solving as well as affective behaviors. For example, children who had learned to search for an attractive toy in one particular location were able, by the second year of post-natal life, to inhibit search at that initial location, switch strategies, and search at a different location for the object (Fox & Bell, 1990). Individual differences in the development of these skills may be related to activity of the dorsolateral prefrontal cortex (see Diamond, 1990, for a review).

Fox and his colleagues (Fox et al., 1992; Fox & Davidson, 1987) have also found that the incidence of distress and negative affect in response to mild stressors, such as separation from the mother, decreases during the second year of post-natal life. As well, individual differences in the decline of distress seem to be related to activity of the prefrontal cortex, particularly in the left frontal region. Infants who display greater relative right frontal EEG activation are more likely than those who display left frontal EEG activation to

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exhibit distress to separation or other novel events (Fox et al., 1992).

We know little in terms of the development of emotional regulatory processes in the first year of post-natal life and its psychophysiological basis. Music would appear to be an ideal stimulus for studying early emotional responses because it is closely associated with emotion (Juslin & Sloboda, 2001) and young infants are responsive to music (Rock, Trainor, & Addison, 1999; Trehub & Trainor, 1998; Trainor, 1996). Accordingly, we examined the development of infants' regional EEG and ECG responses to affective musical stimuli during the first 12 months of post-natal life. We chose to use these two physiological measures because (a) both have been implicated on theoretical and empirical levels as brain-based measures of emotional regulatory processes (see, e.g., Fox, 1989, 1991, 1994; Porges, 1991), and (b) tracking the development of these measures may provide a window into the development of emotional regulatory processes in the first year. We employed a cross-sectional design such that separate groups of infants were tested at 3, 6, 9, and 12 months of age. Procedures were identical at each age point.

Regional EEG and ECG responses were continuously recorded during a baseline condition and during presentation of three orchestral excerpts expressing sadness, fear, and joy. We used these musical excerpts because we had used them previously in a study of adults' EEG responses to affective music (Schmidt & Trainor, 2001). From this study, we knew that adults rated them as expressing the intended emotions. As well, we had found that the positively valenced excerpts (joy, happiness) evoked more left than right frontal activation in adults, whereas the negatively valenced excerpts (sadness, fear) evoked more right than left frontal activation. In addition to changes on electrocortical measures, a number of other studies have indexed changes on heart rate measures during the presentation of musical emotions, although the data here are not all that consistent, perhaps due to conceptual and methodological problems (see, e.g., Dainow, 1977). However, in a more recent study than those reviewed by Dainow (1977), Nyklicek, Thayer, and Van Dooren (1997) noted consistent patterns of heart rate change in response to musical emotions. Nyklicek et al. (1997) had participants listen to 2–4 min of musical segments and asked them to judge the strength of the emotion. They found that heart rate decelerated during all of the musical emotion conditions, decelerating least during highly arousing, positively valenced musical segments. They also noted that heart rate decelerated more during negatively than positively valenced musical segments. Here we extend these findings to infants, and report on changes over the first year of life in regional EEG activity and heart rate as infants listened to affective musical stimuli.

2. Method

2.1. Participants

The infants were recruited from a large database that contained the birth records of children born within the McMaster University Medical Center and St. Joseph's Hospital (Hamilton, Ontario). The majority of infants were seen plus or minus seven days of their 3 ($n = 33$), 6 ($n = 42$), 9 ($n = 52$), and 12 ($n = 40$) month birth date. Infants were primarily Caucasian, and all were full-term, healthy and experienced no pre- or post-natal health problems.

2.2. Affective stimuli

The musical stimuli comprised three orchestra excerpts that are known to vary in affective valence and intensity (see Schmidt & Trainor, 2001). The first excerpt, *Adagio* by Barber, reflected sadness; the second, *Peter and the Wolf* by Prokofiev, reflected fear; and the third, *Spring* by Vivaldi (second movement), reflected joy. Musical excerpts were presented with a Sony audio cassette player (Model No. CFD-8/2) and synchronized with the EEG and ECG data collection. Each excerpt played for approximately 30 s.

2.3. Procedure

Upon arrival at the laboratory, the mother and infant were ushered into the testing room. The mother was briefed about the procedures and consent was obtained. The mother was seated in a comfortable chair with her infant on her lap. A lycra EEG stretch cap was put on the infant's head and ECG electrodes were attached to the infant's chest. Mothers were instructed to remain silent and give no emotional cues to the child during psychophysiological recording. EEG and ECG were collected for a 1 min baseline condition, after which time the three musical excerpts were each presented for 30 s with a 30 s pause in between excerpts. Following the psychophysiological testing, the EEG cap and ECG electrodes were detached, and the mother was given a photograph of her child as a token of appreciation for their participation.

2.4. Psychophysiological data collection

2.4.1. EEG recording

EEG was recorded continuously during the baseline and each affective condition using a lycra stretch cap (Electro-Cap), with electrodes positioned according to the International 10/20 Electrode System (Jasper, 1958). Electrode impedances were below 10 kΩ at each site and within 500 Ω between homologous sites.

The EEG was collected and amplified with SA Instrumentation Bioamplifiers from four scalp locations:

left and right mid-frontal (F3, F4) and parietal (P3, P4) sites. These sites represent the left and right hemispheres and anterior and posterior regions of the brain. All electrodes were referenced to the central vertex (Cz) during recording. The EEG data were bandpass filtered between 1 Hz (high pass) and 100 Hz (low pass) and digitized online at a sampling rate of 512 Hz.

2.4.2. ECG recording

ECG was continuously recorded during the baseline and each affective condition using two disposable pediatric electrode patches on the infant's chest. The heart rate signal was collected and amplified by a separate SA Instrumentation Bioamplifier. The ECG data were bandpass filtered between 1 Hz (high pass) and 100 Hz (low pass) and digitized online at a sampling rate of 512 Hz.

2.5. Psychophysiological data reduction

2.5.1. EEG data reduction and analysis

The EEG data were visually scored for artifact due to eyeblinks, eye movements, and other motor movements, using software developed by James Long Company (EEG Analysis Program, Caroga Lake, NY). This program removes data from all channels if artifact is present on any one channel.

All artifact-free EEG data were analyzed using a discrete Fourier transform (DFT), with a Hanning window of 1 s width and 50% overlap. Power (μV^2) was derived from the DFT output in the 4–8 Hz band. This frequency band was chosen as it is thought to represent the infant α band and it contained a majority of the EEG power at all ages. A natural log (ln) transformation was performed on the EEG power data to reduce skewness.

2.5.2. ECG data reduction and analysis

A file of inter-beat-intervals (IBI) was created on each infant. The IBI data were visually edited for artifact and analyzed using software developed by James Long Company (ECG Analysis Program, Caroga Lake, NY). This program calculates the mean heart period (expressed in ms). At 9 months, of the 52 infants, 51 had usable ECG data; at 12 months, of the 40 infants tested, 25 had usable ECG data. ECG data lost were due to the electrodes becoming detached or equipment problems.

3. Results

3.1. EEG data

Initial analyses showed that there were no significant differences in ln(4–8 Hz EEG power) across the sad, fear, and joy excerpts at any age; nor did this affective difference interact with any other variable. Therefore, in the analyses reported here we collapsed across the sad, fear, and joy excerpts. We performed a separate analysis of variance (ANOVA) at 3, 6, 9, and 12 months of age with Condition (Baseline, Music), Region (Frontal, Parietal), and Hemisphere (Left, Right) as within-subjects factors. The dependent measure was ln(4–8 Hz EEG power). Fig. 1 presents the means and standard

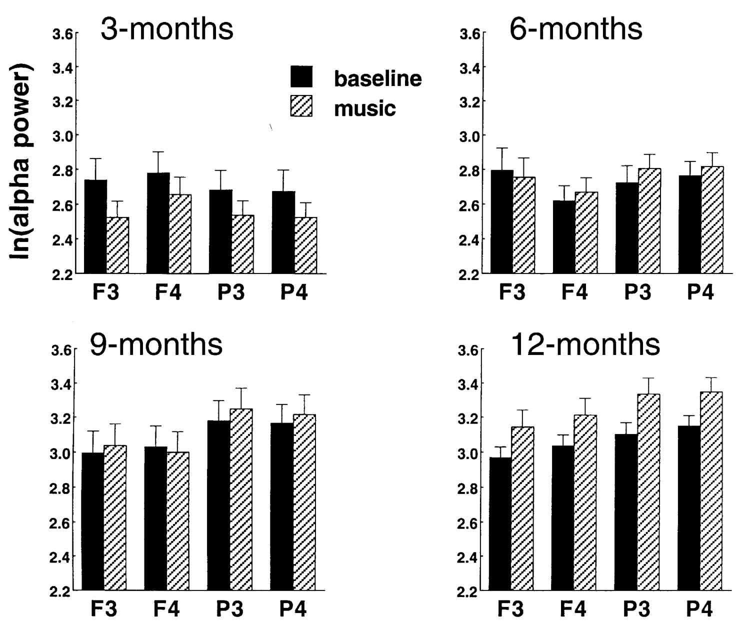

Fig. 1. Differences in frontal and parietal ln(4–8 Hz EEG power) during baseline and in response to affective music at 3, 6, 9, and 12 months of age in human infants. [Note that EEG power is thought to be inversely related to activation (Davidson & Tomarken, 1989), so lower power reflects more activation.]

error bars for ln(4–8 Hz EEG power) across each of the four ages by condition, region, and hemisphere.

3.1.1. Three-months

There was a marginally significant main effect for Condition [$F(1,30) = 3.83, p < .06$]. As can be seen in Fig. 1, there was significantly lower EEG power (i.e., more activation) across all sites during the affective music compared with baseline. Thus, infants exhibited significantly more brain activation in response to the affective music than during baseline. There were no other significant main or interaction effects at 3 months of age.

3.1.2. Six-months

There were no significant main or interaction effects at 6 months of age (see Fig. 1).

3.1.3. Nine-months

There was a significant main effect for Region [$F(1,51) = 31.28, p < .0005$]. As can be seen in Fig. 1, there was significantly lower EEG power (i.e., more activation) in the frontal compared with parietal sites. There were no other significant main or interaction effects at 9 months of age.

3.1.4. Twelve-months

There were significant main effects for Condition [$F(1,39) = 7.81, p < .008$], Region [$F(1,39) = 9.75, p < .003$], and Hemisphere [$F(1,39) = 9.75, p < .003$], and no significant interactions. As can be seen in Fig. 1, there was significantly more power (i.e., less activation) in response to the affective music compared with baseline, significantly lower power (i.e., more activation) in the frontal compared with the parietal sites, and significantly more activation in the left than right hemisphere at 12 months of age. There were no other significant effects at 12 months of age.

3.2. ECG data

Initial analyses showed that there were no significant differences in mean heart period across the sad, fear, and joy excerpts at any age; nor did this affective difference interact with any other variable. Therefore, in the analyses reported here we collapsed across the sad, fear, and joy excerpts. We performed separate pairwise t tests at 3, 6, 9, and 12 months of age, with Condition (Baseline, Music) as a within-subjects factor. The dependent measure was mean heart period (ms). Table 1 presents the means and standard errors for mean heart period (ms) across each of the four ages by condition.

3.2.1. Three-months

Mean heart period was significantly longer during the presentation of the affective music stimuli compared with baseline [$t(32) = 3.23, p < .003$] (see Table 1).

Table 1
Differences in mean heart period (ms) during baseline and in response to affective music at 3, 6, 9, and 12 months of age in human infants

Age	Measure	Condition	
		Baseline	Music
		Mean heart period (ms)	
Three-months ($n = 33$)	*M*	408.29	421.47
	SE	7.51	7.30
Six-months ($n = 42$)	*M*	415.57	430.55
	SE	5.23	5.01
Nine-months ($n = 51$)	*M*	440.40	431.59
	SE	5.13	4.97
Twelve-months ($n = 25$)	*M*	457.76	462.07
	SE	6.38	6.60

Note that mean heart period is inversely related to heart rate, so lower values reflect a higher heart rate.

3.2.2. Six-months

Mean heart period was significantly longer during the presentation of the affective music stimuli compared with baseline [$t(41) = 4.24, p < .0005$] (see Table 1).

3.2.3. Nine-months

Mean heart period was significantly shorter during the presentation of the affective music stimuli compared with baseline [$t(50) = 2.04, p < .047$] (see Table 1).

3.2.4. Twelve-months

There were no significant differences between baseline and affective music presentation on mean heart period [$t(24) = 1.06, p > .05$] (see Table 1).

4. Discussion

4.1. Development of frontal EEG across the first year of post-natal life

There were three main changes in EEG responses to affective musical stimuli between 3 and 12 months of age. First, the presentation of affective music significantly increased brain activity at 3 months of age, had seemingly little effect at 6 and 9 months, and then significantly attenuated brain activity at 12 months. This developmental trend was not specific to the frontal sites, but was also found in the parietal sites. In contrast to adults, differences in the valence of the emotion expressed in the orchestral experts did not affect brain activation patterns. Rather, compared to baseline, all musical excerpts increased general brain activation at 3 months and decreased general brain activation at 12 months.

The second clear development concerns the relative activation of frontal and parietal regions. Although the overall amount of EEG power increased between 3 and 12 months, at 3 and 6 months there was no difference between frontal and parietal regions. However, by 9 and 12 months there was relatively more activation at frontal than at parietal sites, likely reflecting the maturation of frontal lobe function.

Third, there were no hemispheric differences in activation at 3, 6, and 9 months. However, by 12 months, there was greater overall left than right activation at baseline and in response to the music stimuli. This pattern of hemisphere asymmetry is not necessarily at odds with the expected right frontal EEG activation observed during the presentation of affective stimuli in infants, particularly negatively valenced stimuli (e.g., Fox, 1991, 1994 for a review) for two reasons. First, we collapsed across musical excerpt so our measure of music contained both positively and negatively valenced emotion. Second, the pattern of greater left frontal EEG activation during baseline and in response to the music in combination with the former two findings described above (i.e., the frontal lobe coming "online" between 9 and 12 months and a decrease in frontal activity at 12 months relative to earlier months in response to the music) is suggestive of the notion that this pattern of asymmetry may be reflective of the emergence of emotion regulatory processes by the end of the first year.

4.2. Development of ECG across the first year of post-natal life

Similar to the EEG results, there was a clear developmental shift in autonomic patterning from 3 to 12 months. At 3 and 6 months, the presentation of the affective musical stimuli resulted in a slowing of heart rate compared with baseline, possibly reflecting infants' interest in these stimuli, since heart rate deceleration is known to occur during orienting. At 9 months, the presentation of the affective musical stimuli resulted in a higher heart rate compared with baseline, possibly reflecting re-organization and the emergence of emotions that are known to develop at 9 months. Third, at 12 months, there were no differences in heart rate during baseline compared with the presentation of the affective musical stimuli, suggesting that infants at this age may be regulating their arousal and responses to emotional stimuli. This interpretation is consistent with the maturation of the frontal lobe and the pattern of EEG responses involved in the regulation of emotion at 12 months.

4.3. Implications and limitations

The development of emotion regulation is undoubtedly a complex process that involves maturation, learning, and their interaction. The findings from the present study suggest that there are significant developmental changes that occur on central and autonomic levels that may underlie emotion regulatory processes in the first year of post-natal life. Few studies have examined the neural basis of emotion regulation during the first year of post-natal life using multiple psychophysiological indices. As well, still fewer studies have examined the auditory modality in infant emotional development. Although we failed to find significant hemisphere differences across valence using affective auditory stimuli, it may have been that our stimuli (i.e., orchestral pieces) were too complicated for infants to understand. The studies to date that have found differences on frontal EEG asymmetry (Schmidt & Trainor, 2001) and heart rate (Krumhansl, 1997) measures in response to different musical emotions have been with adults. Given that (1) the auditory modality is important to emotion and develops earlier than the visual sense, and (2) previous studies on infants' reactions to music show that as young as 2 months of age infants already show a preference for consonance over dissonance (Trainor, Tsang, & Cheung, 2002), future studies should examine emotional development in a more "naturalistic" context, such as with infant-directed speech and singing.

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