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Early institutionalized care disrupts the development of emotion processing in prosody

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Abstract

Millions of children worldwide are raised in institutionalized settings. Unfortunately, institutionalized rearing is often characterized by psychosocial deprivation, leading to difficulties in numerous social, emotional, physical, and cognitive skills. One such skill is the ability to recognize emotional facial expressions. Children with a history of institutional rearing tend to be worse at recognizing emotions in facial expressions than their peers, and this deficit likely affects social interactions. However, emotional information is also conveyed vocally, and neither prosodic information processing nor the cross-modal integration of facial and prosodic emotional expressions have been investigated in these children to date. We recorded electroencephalograms (EEG) while 47 children under institutionalized care (IC) ($n = 24$) or biological family care (BFC) ($n = 23$) viewed angry, happy, or neutral facial expressions while listening to pseudowords with angry, happy, or neutral prosody. The results indicate that 20- to 40-month-olds living in IC have event-related potentials (ERPs) over midfrontal brain regions that are less sensitive to incongruent facial and prosodic emotions relative to children under BFC, and that their brain responses to prosody are less lateralized. Children under IC also showed midfrontal ERP differences in processing of angry prosody, indicating that institutionalized rearing may specifically affect the processing of anger.

Keywords: EEG, emotion recognition, ERPs, institutionalized care, prosody

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Children raised in institutionalized care (IC) often experience psychosocial deprivation, leading to physical, cognitive, linguistic, social–emotional, and neural deficits (Chisholm, 1998; Hodges & Tizard, 1989). This type of care covers many people: as recently as 2017, the number of children estimated to be in IC globally was over 2.7 million (Petrowski, Cappa, & Gross, 2017). Social–emotional difficulties are among the most persistent effects of IC and can continue for years after adoption, even when individuals are adopted as infants (Tarullo & Gunnar, 2005). Although these social problems are at least partially driven by disruptions in early attachment (Marcovitch et al., 1997; Roy, Rutter, & Pickles, 2004), another likely mechanism is a reduced ability to process others' social–emotional cues due to limited practice in doing so. The current study examined the effects of IC on the processing of emotional prosody (i.e., tone of voice and rhythm), which has not yet been studied, despite the adaptive significance of emotion recognition for social development (Halberstadt, Denham, & Dunsmore, 2001). We used electroencephalograms (EEG) to examine the effects of IC on the neural mechanisms of prosodic emotional processing in 20- to 40-month-olds, including cross-modal integration of facial and prosodic emotional expressions, recognition of different emotions in prosody, and hemispheric specialization.

The broad effects of institutionalization, including socioemotional issues, support the views of developmental researchers Zigler & Bishop-Josef (2006) who recommend that interventions for underprivileged children should include a focus on socioemotional development using a "whole child" model, rather than solely targeting cognitive abilities and intelligence. Because children under IC receive less caregiver interaction in general and committed caregiver interaction in particular than those under biological family care (BFC) (Windsor, Glaze, Koga, & Bucharest Early Intervention Project Core Group, 2007), they likely have less experience processing others' emotions. Moreover, behavioral research shows that previously institutionalized adopted children tend to be worse at emotion understanding (Tarullo et al., 2016) and worse at recognizing facial expressions relative to their peers under BFC at age 4 years (Hwa-Froelich, Matsuo, & Becker, 2014) and 11 years (Colvert et al., 2008). Consistent with behavioral outcomes, neuroscience studies have found that institutionalized children as young as 5–31 months show occipital event-related potential (ERP) differences relative to those in BFC in response to emotional face stimuli (Moulson, Fox, Zeanah, & Nelson, 2009). Older children who have been under IC also have an N100 ERP that is less sensitive to angry facial expressions at age 8 years, in tandem with deficits in emotion recognition relative to children under

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BFC (Nelson, Westerlund, McDermott, Zeanah, & Fox, 2013). The young age ranges in which some of these effects occur highlight the importance of interventions that take place early in life (Zigler & Finn-Stevenson, 2007).

The studies cited above examined the ability to recognize others' facial expressions following IC. However, how IC influences the ability to recognize emotion in prosody has not been examined, even though prosody is a crucial medium for emotion communication (Frick, 1985; Nygaard & Queen, 2008). Most existing research has instead focused on broader social–emotional outcomes of IC, such as differences in attachment style and friendships (e.g., Almas et al., 2012; Chisholm, 1998; Roy et al., 2004). However, these broader outcomes depend on lower-level abilities such as making eye contact, taking turns in conversation, and processing others' emotional expressions. For example, during social interactions, one often recognizes others' emotional facial expressions and emotions in prosody and responds accordingly. In the following we review how emotional processing typically develops – in particular emotion recognition in facial expressions and prosody as well as visual–auditory emotional integration. Then, we outline previous studies on IC in relation to the development of emotional processing at neural and behavioral levels. We identify a gap in the literature related to the effects of IC on auditory–visual integration and emotion recognition in prosody, which the current study addressed using EEG.

Development of Emotion Processing

Even in their first year, infants are sensitive to facial expressions and prosody at both a neural and a behavioral level, as evidenced through EEG and looking-time studies (e.g., Leppänen, Moulson, Vogel-Farley, & Nelson, 2007). The development of emotional processing, including the ability to recognize different emotions and visual–auditory integration of emotional information, has been studied in nonclinical samples with respect to facial expressions and prosody (e.g., Grossmann, Striano, & Friederici, 2006), providing a framework for typical development under which we could examine the effects of IC on prosody.

Emotion recognition

Infants distinguish between different emotions in the first year, and research on facial expression recognition has shown that emotion recognition continues to develop through adolescence (Batty & Taylor, 2006; Lawrence, Campbell, & Skuse, 2015). EEG research has revealed the effects of different facial expressions on ERPs at age 7 months (Grossmann, 2010). Likewise, by 7 months, the infant brain recognizes different emotions in prosody and shows a larger negative ERP amplitude over frontocentral electrodes at around 450 ms during angry versus neutral or happy prosody, suggesting enhanced attention to angry stimuli (Grossmann, Striano, & Friederici, 2005). The infant brain at 7 months also recognizes when prosody is emotional or not emotional, indicated by a higher positive slow-wave ERP amplitude over temporal electrodes in response to emotional (angry or happy) versus neutral prosody (Grossmann et al., 2005). In school-age children, frontal slow-wave and N170 ERPs are affected by facial expressions (Batty & Taylor, 2006). Some ERP components associated with visual emotion recognition tend to be more lateralized to the right versus the left hemisphere (de Haan, Nelson, Gunnar, & Tout, 1998). In the auditory domain, although lexical–semantic processing tends to be left-lateralized, neuroimaging research has found that processing of prosody is lateralized to right temporal brain regions (Meyer, Alter, Friederici, Lohmann, & von Cramon, 2002). Thus, we predicted that if children under IC in the current study showed decreased ERP responsiveness to different emotions, they might also exhibit lateralization differences in emotion recognition.

The development of emotion recognition is shaped by a child's environment and parental care (Castro, Halberstadt, Lozada, & Craig, 2015; Tarullo et al., 2016). For instance, a history of abuse tends to worsen the overall ability to identify different emotional facial expressions (Pollak, Cicchetti, Hornung, & Reed, 2000) but may enhance the ability to recognize anger (Pollak, Messner, Kistler, & Cohn, 2009). This ability has important social implications; for example, emotion recognition in faces is related to social adjustment during childhood (Leppänen & Hietanen, 2001).

Visual–auditory integration

Infants can also integrate visual and auditory emotional information within the first year. For example, at 5 months, infants look longer at an emotional face when verbal prosody changes (Walker-Andrews & Lennon, 1991). By 7 months, infants also look preferentially to emotionally congruent faces and vocal expressions relative to emotionally incongruent stimuli (Walker-Andrews, 1986). In addition to looking-time studies, visual and auditory integration can be indexed in the infant brain as ERP components distinguish when concurrent facial expressions and prosody are emotionally mismatched (Grossmann, 2010; Grossmann et al., 2006). Although these findings on the integration of cross-modal visual–auditory emotional stimuli are important, to our knowledge, the effects of IC on emotion recognition in prosody and cross-modal visual–auditory stimuli have not yet been studied.

IC and Neural Development

Existing neuroscience research on IC has focused on topics other than emotion recognition in prosody, such as structural brain differences and emotion regulation. For example, IC is linked to increased amygdala volume and decreased gray and white matter (e.g., Mehta et al., 2009; Tottenham et al., 2010). These increases in amygdala volume, along with heightened amygdala reactivity to faces, are associated with decreased emotional regulation and decreased eye contact during social interactions (Tottenham et al., 2011, 2010). However, differences in processing of emotional prosody associated with IC, including emotion recognition in prosody and visual–auditory integration, have not yet been reported in the neuroscience literature.

ERPs

Although processing of prosody has been understudied, individuals with a history of institutionalization have shown differences in ERP studies across multiple other domains. For example, previously institutionalized infants and toddlers have attenuated ERP responses to familiar versus unfamiliar face stimuli in N170, negative component, and slow-wave ERPs (Parker, Nelson, & Bucharest Early Intervention Project Core Group, 2005). Similarly, researchers have found dampened N170 responses in young children who have insecure attachment styles following adverse care experiences (Kungl, Bovenschen, & Spangler, 2017). Research has also found differences in lexical and grammatical processing and spelling: previously institutionalized

Russian adults showed differences relative to typically developing adults in ERPs roughly corresponding to P300 and N400, indicating IC effects on higher-order language processes (Kornilov et al., 2019). One area that some researchers believe IC may not affect is lower-level auditory processing (Pollak et al., 2010), and research has found that infants and toddlers under IC did not show differences in the mismatch negativity with deviant phonological stimuli relative to children under BFC (Ovchinnikova et al., 2019). Therefore, any differences in processing of prosody associated with IC are unlikely to be driven solely by auditory processing deficit differences.

Current Study

As already noted, IC has been associated with reduced social–emotional development in general and differences in ERPs during face processing in particular. However, the effects of IC have not yet been addressed with respect to emotional prosody. We examined this issue by recording EEG while 20- to 40-month-old children observed combined visual and auditory emotional stimuli. Our first hypothesis was that children living in institutionalized baby homes in Russia would have hampered integration of visual and prosodic emotional information, evidenced by midfrontal and lateral slow-wave ERPs that are less sensitive to incongruencies between facial expressions and prosody. We also hypothesized that, consistent with visual face processing research (Moulson et al., 2009), children under IC would have reduced sensitivity to different emotions in prosody relative to those in BFC, evidenced by smaller prosody effects on ERPs at temporal and central electrodes. Another possibility was that children under IC would have increased sensitivity to angry prosody, aligning with findings on increased sensitivity to angry facial expressions following abuse (Pollak et al., 2000). We also examined whether, consistent with research on face processing (Parker & Nelson, 2005), we saw overall attenuating effects of IC on early auditory ERPs over central electrodes. Lastly, we examined whether hemispheric differences in ERPs in response to emotional prosody differed between the BFC and IC groups.

Method

Participants

The original sample included 83 children aged 20–40 months. Of these, 36 were excluded due to (a) technical issues with the EEG recording and/or failure to attend to at least 15 trials in every task condition ($n = 23$), (b) a history of neurological diagnoses or uncorrected vision/hearing disorders ($n = 12$), or (c) low standard scores (<30 T-points) on the visual perception scale of Mullen Scales Early Learning (Mullen, 1995) ($n = 1$). The total number of participants for whom data were analyzed was thus 47 (mean age = 30 months; $SD = 5.6$ months; 24 male participants). The experimental group consisted of 24 children currently living in IC in baby homes in a large industrial center in Russia (mean age = 29.7 months; $SD = 5.6$ months; 11 male). The comparison group consisted of 23 children under BFC who had never received IC (mean age = 30.2 months; $SD = 5.6$ months; 13 male). The two groups did not significantly differ in age (analysis of variance (ANOVA) $F_{(1,45)} = 0.005$, $p > .9$).

Procedure

Written consent for participation was obtained from baby home officials or biological parents. The study procedure was approved by Institutional Review Boards (Ethical Committees) at St Petersburg State University, Russia and Yale University, USA. Prior to testing, children were invited to explore the laboratory space and play with toys for approximately 7 min to familiarize them with the laboratory setting (Hoehl & Wahl, 2012). The researcher then playfully introduced the child to the study procedure by allowing the child to look at the EEG cap and measure the head circumference of a toy. Meanwhile, an experimenter told the caregiver about the study procedure. After the adaptation phase, the child was seated on the caregiver's lap opposite a laptop in a dimly lit, soundproof room.

EEG recording

An elastic cap with 64 Ag/AgCl electrodes connected to an actiCHamp amplifier (Brain Products, Inc.) was positioned on the child's head in accordance with the 10–10 international system. A reference electrode was placed on the mastoid bone behind each ear. Next, a small amount of nonabrasive conductive gel was introduced under each electrode. Electrical impedances for all channels were set below 25 kΩ, with a goal of <10 kΩ. During this procedure, the child could choose to play or watch cartoons on a portable device. The EEG was recorded with a linked mastoid reference during three tasks totaling 35 min with breaks every 8 min. Only data from one task are reported here (total time = 16 min). The EEG data were digitized at 1000 Hz.

Prosody task

To evaluate the processing of emotional information in speech, we used a modified version of the experimental paradigm from Grossmann et al. (2005). The child was presented with images of faces of Caucasian women on a white background expressing angry, happy, or neutral emotions (Warsaw Set of Emotional Expression Pictures; Olszanowski et al., 2015), accompanied by an auditory stimulus – pseudowords spoken by a female voice with happy, angry, or neutral prosodic contours. The pseudowords corresponded to the phonotactic rules of the Russian language and contained two to four syllables with emphasis on the first, half of which belonged to the female grammar (ending with a vowel) and half of which belonged to the male grammar. In addition, the prosodic contour of the auditory stimulus could be congruent or incongruent with the emotion presented in the picture. These stimuli were combined to create five task conditions: two emotionally incongruent conditions (joyful face/angry prosody and angry face/joyful prosody), two emotionally congruent conditions (joyful face/joyful prosody and angry face/angry prosody) and one neutral condition (neutral face/neutral prosody). Each condition occurred 40 times (200 trials in total) in random order.

At the beginning of each trial, the monitor screen turned green for 500 ms. Then, a black fixation cross appeared on a white background for 250 ms, in tandem with a sound (2000 Hz tone, 70 dB of sound pressure level) that was delivered bilaterally via speakers on each side of the laptop in order to attract the attention of the child. The fixation cross was then replaced by a white background for 250 ms. The cross-modal stimulus was then started. An image of a woman's face on the laptop screen appeared and, after 1500 ms, it was accompanied by a pseudoword delivered through the speakers for approximately 400 ms. The picture remained on the screen for an additional 1450–1750 ms (randomized) until the start of the next trial's green screen (Figure 1). When a child appeared inattentive during a trial – as indicated by eyes diverted away from the monitor – the experimenter pressed a button on a

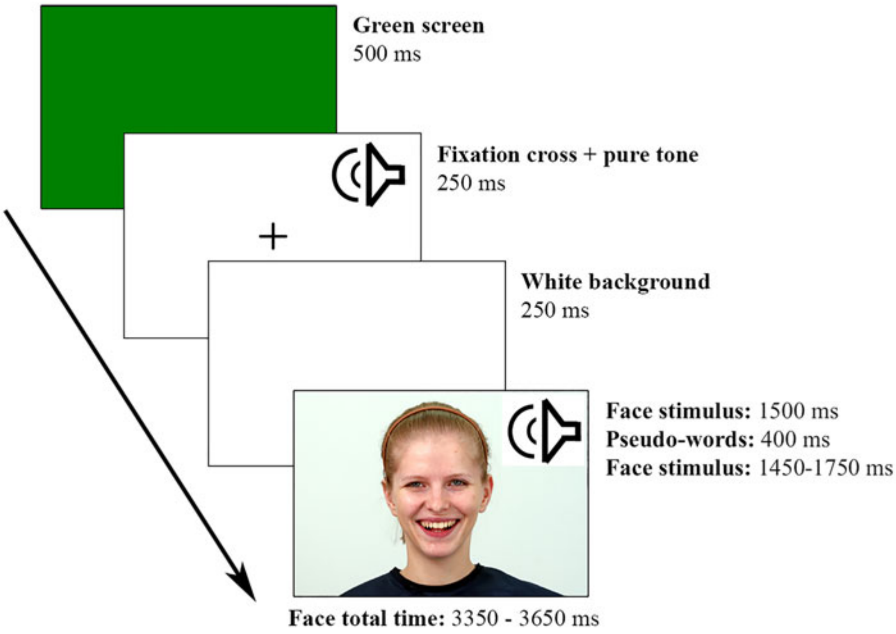

Figure 1. Paradigm illustration. Each trial contained (a) a 500 ms green screen + pure tone, (b) a 250 ms fixation cross, (c) a 250 ms white screen, and (d) a face stimulus (angry, happy, or neutral) which was accompanied after 1500 ms by a 400 ms pseudoword (angry, happy, or neutral prosody) before remaining on screen for 1450–1750 ms (face total time = 3350–3650 ms).

Chronos device (https://pstnet.com/products/chronos/) to digitally mark the trial for removal.

EEG processing

EEG preprocessing was carried out offline using BrainVision Analyzer software v. 2.1 (Brain Products, Inc.). Data were visually inspected and channels containing excessive artifacts were deleted (mean channels removed per subject = 4.13; *SD* = 1.9; max = 8; min = 0). Data were referenced to the cap average. An IIR bandpass filter was applied at 0.1–30 Hz. Ocular artifacts were corrected using the semiautomatic independent component analysis (ICA) tool in BrainVision Analyzer. Independent components that reflected horizontal or vertical eye movements (blinks) were removed from the data. Deleted channels were interpolated using spherical spline interpolation. Data were epoched from −200 to 900 ms around the auditory stimulus onset. Epochs with an amplitude exceeding the absolute value of 110 µV in any of the EEG channels or during which the child looked away from the monitor were removed (mean removed = 53.4/200 trials, *SD* = 36.2). Group membership (IC or BFC) and sex (male or female) had no significant effects on the number of trials removed due to inattentiveness and artifacts in the EEG recording (ANOVA $F_{(1,45)} = 2.79$ and 1.30, p values >.1 and >.25, respectively). The BrainVision Analyzer DC detrend function was used to remove DC drift and a baseline of −200 to 0 ms was applied.

Data analyses

Grand average ERPs were visually inspected for differences that corresponded to hypotheses about group differences in emotional congruency processing, prosody processing, general auditory processing, and lateralization of the response to auditory stimuli. Time windows and regions of interest were initially informed by previous literature (e.g., Grossmann et al., 2005, 2006) and were then adjusted for the participants, who had a different age range, based on visual inspection. ERPs were averaged across these time windows to quantify the data for further statistical analyses, and analyses were conducted on individual electrodes in regions of interest. Data were analyzed using linear mixed effects models with the R lme4 package (Bates, Mächler, Bolker, & Walker, 2015) with participant ID as a random factor on the intercept. Where applicable, Bonferroni-adjusted alpha levels were used for follow-up tests.

Results

Emotional congruency

We first analyzed effects of emotional congruency, where congruent trials contained matched visual and auditory emotional stimuli (e.g., happy face and happy prosody) and incongruent trials contained mismatched visual and auditory emotional stimuli (e.g., happy face and angry prosody). As hypothesized, the BFC group showed greater sensitivity to visual and auditory emotional congruency in midfrontal slow-wave ERPs relative to the IC group. Specifically, a significant main effect of congruency in the 550–850 ms time window at electrode sites Fz and FCz (Wald $X^2 = 7.17$ and 10.15, p values <.01) was qualified by a significant Group (BFC vs. IC) × Congruency (congruent vs. incongruent) interaction at Fz and FCz (Wald $X^2 = 5.22$ and 10.41, p values <.025 and <.01, respectively; Figure 2). Follow-up tests indicated that the BFC group had a higher positive ERP amplitude for congruent relative to incongruent trials at both Fz and FCz ($F_{(1,22)} = 9.05$ and 9.27, respectively, p values <.01). The IC group did not show a significant difference between congruent and incongruent trials in this window at Fz and FCz (p values >.8 and >.1, respectively). This interaction and the main effect of congruency were not statistically significant at AFz, at the central midline electrodes (Cz, CPz, Pz) or at lateral electrodes in regions of interest in which Grossmann et al. (2006) found congruency effects in 7-month-old infants (F3, C3, P3, F4, C4, and P4).

Additional exploratory analyses were conducted based on visual examination of the waveforms, which appeared to have group differences in congruency effects in an earlier ERP component that peaked at around 200 ms at Fz and FCz (Figure 2). We also tested these effects at Cz because this location tends to show maximal effects in auditory ERPs. However, statistical

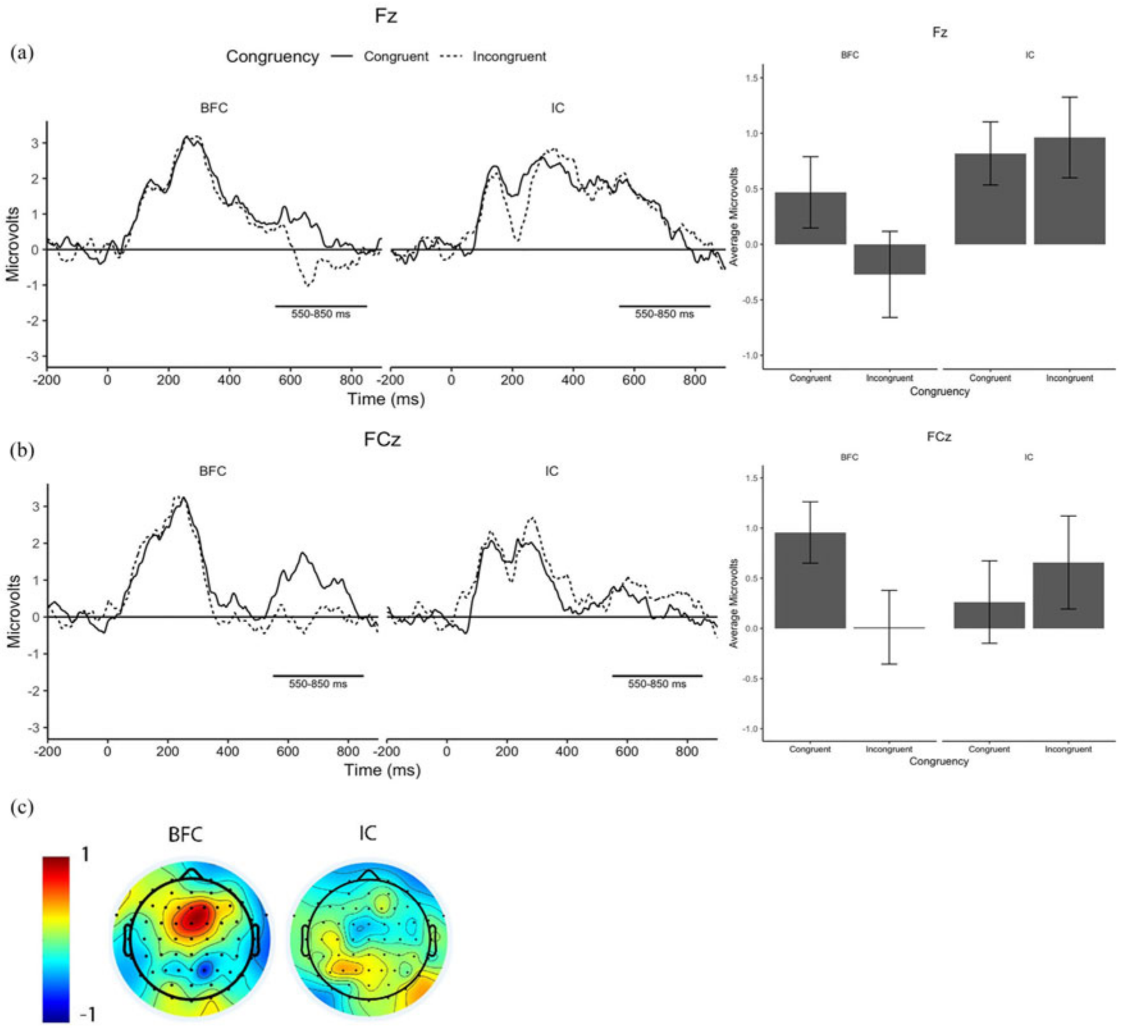

Figure 2. Group (BFC, IC) × Congruency (congruent, incongruent) interaction. (a) Grand average ERPs at Fz and Group (BFC, IC) × Congruency (congruent, incongruent) interaction at Fz in the 550–850 ms time window. (b) Grand average ERPs at FCz and Group (BFC, IC) × Congruency (congruent, incongruent) interaction at FCz in the 550–850 ms time window. (c) Congruent minus incongruent difference scalp maps in each group averaged across the 550–850 ms time window.

analyses revealed no significant Group × Congruency interaction at these locations in the 100–300, 150–250, or 150–350 ms time windows. In addition, we saw no main effect of group on this early ERP component, suggesting that IC may not affect early auditory processing of pseudowords.

Emotional prosody

We next examined group (BFC vs. IC) ERP differences in response to emotional prosody (angry, happy, neutral). In order to address prosody effects without the impact of auditory/visual congruency, only congruent trials are analyzed here. Two mid-frontal electrodes had a main effect of group in the 300–700 ms window, such that children under IC had higher overall ERP amplitudes at AFz and Fz relative to the BFC group (Wald $X^2 = 11.35$ and 5.48, p values <.001 and <.025, respectively). This main effect was qualified by a significant Group (BFC vs. IC) × Prosody (angry, happy, neutral) interaction at AFz and Fz (Wald $X^2 = 8.63$ and 12.65, p values <.025 and <.01, respectively; Figure 3). Follow-up tests revealed that the difference between prosodies at Fz was statistically significant in the IC group ($F_{(2,46)} = 6.87$, $p < 0.01$) but only approached statistical significance for the BFC group ($F_{(2,44)} = 3.09$, $p = .056$). At AFz, the difference between prosodies approached statistical significance in the IC group ($F_{(2,46)} = 2.71$, $p = .077$) and was not significant in the BFC group. Additional follow-up tests showed that the two groups differed significantly in their amplitude for angry trials – not happy or neutral trials – at AFz ($F_{(1,45)} = 10.95$, $p < .01$), and this difference between groups for angry trials approached statistical significance at Fz with a Bonferroni-adjusted alpha level of .0167 ($F_{(1,45)} = 4.29$, $p < .05$). The Group × Prosody interaction and the main effects of group and prosody were not statistically significant at the midline electrode locations FCz, Cz, CPz, Pz, Poz, or Oz or at the lateralized locations F3, F4, C3, C4, P3, P4, T7, or T8.

Emotional intensity

We next examined the effect of emotional intensity (happy/angry vs. neutral prosody) on a later slow-wave ERP. We chose lateralized and temporal electrodes T7, T8, C3, C4, C5, and C6 to overlap with the temporal locations analyzed by Grossmann et al., (2005). A time window of 600–800 ms was selected based on visual inspection of the waveforms and in order to partially

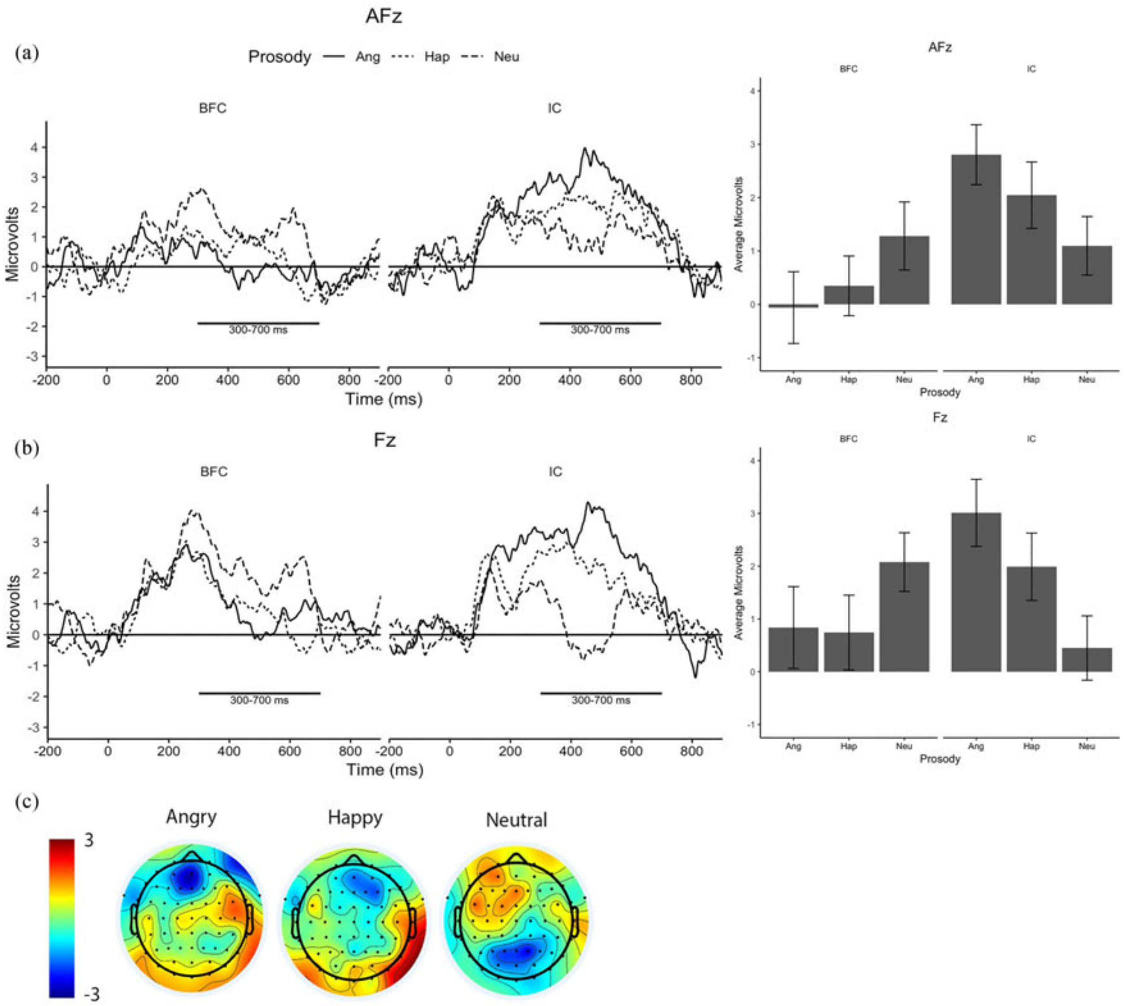

Figure 3. Group (BFC, IC) × Prosody (angry, happy, neutral) interaction. (a) Grand average ERPs at AFz and the Group (BFC, IC) × Prosody (angry, happy, neutral) interaction in the 300–700 ms time window. (b) Grand average ERPs at Fz and the Group (BFC, IC) × Prosody (angry, happy, neutral) interaction in the 300–700 ms time window. (c) BFC minus IC group difference scalp maps in each prosody condition averaged across the 300–700 ms time window.

overlap with slow-wave time windows that showed effects in Grossmann et al. (2005). As before, only congruent trials are analyzed here. We found no significant main effect of emotional intensity or the Group (BFC vs. IC) × Emotional Intensity interaction for slow-wave ERPs in the 600–800 ms time window. Additional exploratory analyses showed no effects of emotional intensity at the electrode locations and window averages that showed prosody effects in the section above.

Lateralization

The next analyses considered right hemisphere specificity in the processing of prosody at temporal locations. Linear mixed effects models revealed significantly higher right versus left amplitudes in the 300–550 ms averaged time window at T8 versus T7 (Wald $X^2 = 11.90$, $p < .001$), TP8 versus TP7 (Wald $X^2 = 11.86$, $p < .001$), FT8 versus FT7 (Wald $X^2 = 12.82$, $p < .001$), and FT10 versus FT9 (Wald $X^2 = 14.66$, $p < .001$; Figure 4a). At T7 and T8, this main effect was qualified by a significant Group (BFC vs. IC) × Laterality (left vs. right) interaction (Wald $X^2 = 4.00$, $p < .05$), revealing greater right-lateralization for BFC children relative to IC children (Figures 4b–d). Follow-up tests revealed no significant difference between BFC and IC amplitudes on the left (T7) and a significantly higher ERP amplitude for the BFC group on the right (T8) ($F_{(1,45)} = 6.45$, $p < .025$). This interaction approached statistical significance at TP7/TP8 (Wald $X^2 = 3.78$, $p = .052$). However, there were no significant main effects of Prosody and no Group × Prosody interaction at these electrodes (see also the section "Emotional prosody" above).

Discussion

Psychosocial deprivation during IC leads to numerous physical, motor, neural, cognitive, emotional, linguistic, and social deficits relative to BFC (e.g., Albers, Johnson, Hostetter, Iverson, & Miller, 1997; Fries & Pollak, 2004; Marshall, Fox, & Group, 2004; Muhamedrahimov et al., 2014; Windsor et al., 2007). Although delays in various aspects of social–emotional development and emotion regulation have been well documented among infants and children raised in IC (Tarullo et al., 2016), the specific effects of IC on recognizing emotions in prosody have remained understudied.

In this study, we found that institutionalized 20- to 40-month-old children had midfrontal ERPs that were less sensitive to emotional congruency relative to children living under BFC. In

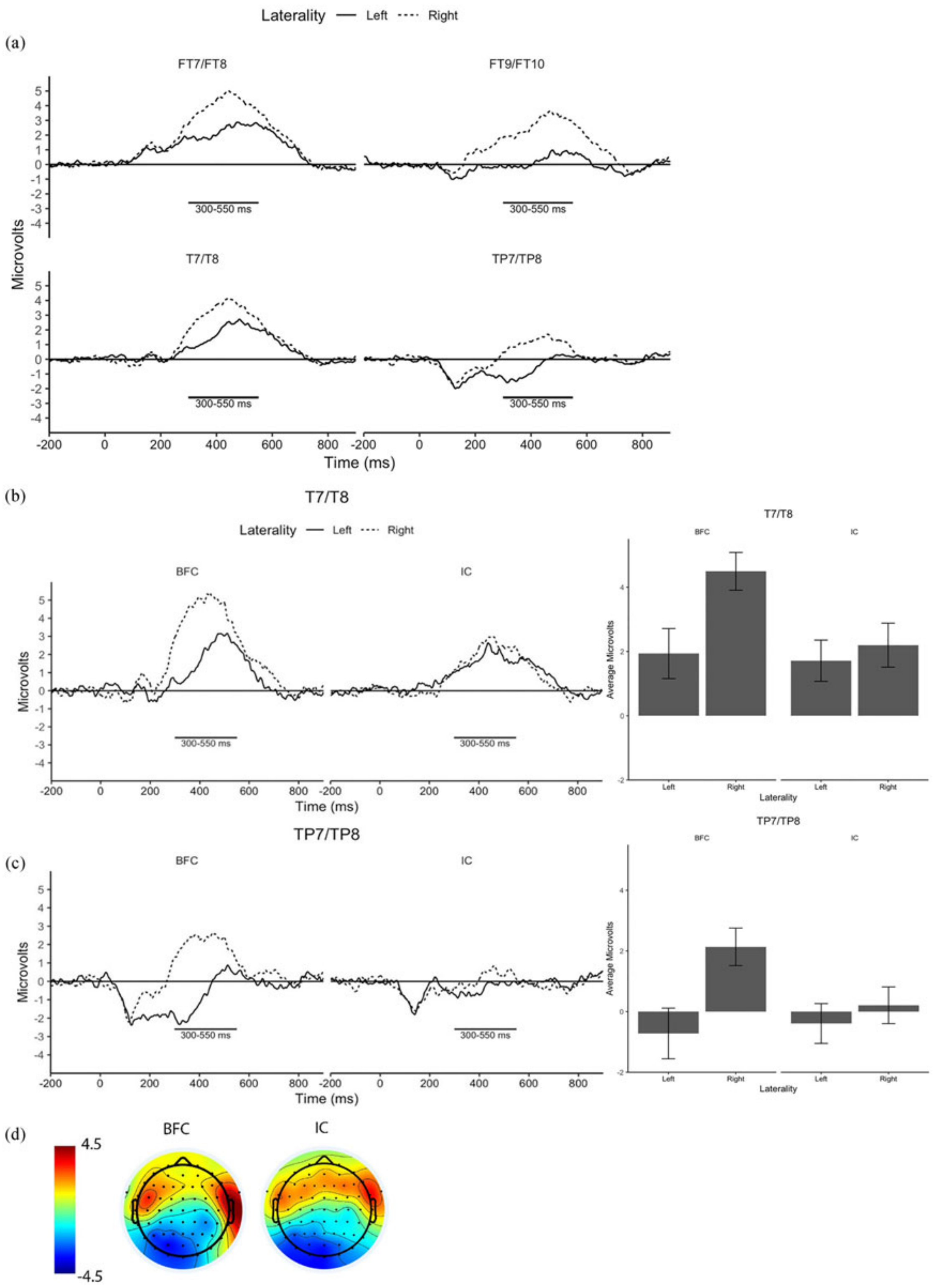

Figure 4. Lateralization of ERPs. (a) Left versus right grand average ERPs at lateralized electrodes FT7, FT8, FT9, FT10, T7, T8, TP7, and TP8. (b) Left versus right grand average ERPs at T7 versus T8 in each group and the Group (BFC, IC) × Laterality (left, right) interaction in the 300–550 ms averaged window. (c) Left versus right grand average ERPs at TP7 versus TP8 in each group and the Group (BFC, IC) × Laterality (left, right) interaction in the 300–550 ms averaged window. (d) Scalp maps averaged across the 300–550 ms window for BFC and IC groups.

addition, children under IC had midfrontal ERP differences in response to angry prosody relative to children under BFC, as well reduced lateralization of ERP responses to pseudoword stimuli. Taken together, these results suggest that IC may be associated with deficits in processing of emotional prosody and with increased sensitivity to angry prosody.

It was also found that the 20- to 40-month-olds under IC had midfrontal slow-wave ERPs that were less responsive to emotional congruency relative to the children under BFC. This suggests that IC may be associated with less efficient integration of facial and prosodic expressions of emotion in this age range. Compared with the work of Grossmann et al. (2006), who showed effects of emotional congruency at frontal, central, and parietal midline and lateralized locations in 7-month-olds, the congruency effect in this study occurred over a smaller area of the scalp and in an earlier time window in our 20-to 40-month-old sample. The 550–850 ms timing of the ERP window in which we saw congruency effects was overlapping, but somewhere in between the window showing this effect in typically developing infants (Grossmann et al., 2006) and adults (Föcker & Röder, 2019), further expanding knowledge on the developmental trajectory of this brain response.

The midfrontal location of the congruency effect in this study comports with extensive adult literature showing frontal midline ERPs and activation in the anterior cingulate cortex (ACC) and prefrontal cortex (PFC) in response to stimulus congruency in a variety of emotional and non-emotional contexts (Kerns, 2006; Töllner et al., 2017; West, Bailey, Tiernan, Boonsuk, & Gilbert, 2012; Zhu et al., 2018). Although results have been mixed, some research has shown thickness differences in the ACC of children who have experienced maltreatment (Kelly et al., 2013) and researchers have also found differences in prefrontal areas in children who have experienced institutionalization (McLaughlin et al., 2014). Considered together, previous research and the electrode locations for the current results suggest that the ACC and PFC may be neural sources of ERP differences during the processing of facial–prosodic emotional congruency following IC.

In addition to the effects of emotional congruency, we also saw group differences in the effect of emotion in prosody over midfrontal electrodes. Children under IC had higher ERP amplitudes in response to angry prosody relative to children under BFC, and the two groups did not significantly differ in response to neutral or happy prosody. Although we expected to find reduced differentiation among the different emotions in the IC group – mirroring visual studies that found worse recognition of facial expressions (Colvert et al., 2008; Hwa-Froelich et al., 2014) and less neural responsivity to facial expressions associated with IC (Moulson et al., 2009) – we did not see a larger effect of prosody emotion on ERPs for the BFC group relative to the IC group. However, previous research also suggests enhanced emotional reactivity following institutionalization (Batki, 2018) and greater responsiveness to negative stimuli following abuse (Pollak et al., 2009). Therefore, one possible explanation for our result could be that institutionalization may be associated with increased sensitivity to anger in prosody rather than reducing the ability to process emotion in prosody across all emotions. Future work may further look for differential effects of abuse characterized by anger versus indifference, as well as differences in processing of emotional expression across additional emotions.

Unlike Grossmann et al. (2005), who studied 7-month-olds, we did not find an effect of emotional intensity over temporal electrode locations. However, the time course and topography of the effect of different facial expression emotions change across the second half-year after birth (Grossmann, 2010). Therefore, it is possible that the topography of ERPs associated with emotional intensity shifted before and during our age range of 20–40 months, making it less consistent across individuals in this age range and more difficult to detect effects. (Although it should be noted that exploratory analyses also did not reveal effects of emotional intensity at frontal midline electrodes.) Future research could test the development of ERP responses to emotional intensity longitudinally or cross-sectionally with a larger sample size spanning infants and young children.

Another finding of the current study was that, consistent with imaging research on emotion processing in adults (Meyer et al., 2002), right-lateralized temporal ERPs were more responsive to pseudoword stimuli than left-lateralized ERPs. This effect was present for children under BFC but not for those under IC, suggesting that IC may result in decreased or delayed lateralization of brain responses to speech. However, because these ERP components did not appear to be sensitive to different emotions in prosody, the conclusions we can draw about implications for the specific cognitive processes they reflect remain unclear. The differences found here are unlikely to be tied to low-level auditory processing deficits because their 350–550 ms time course occurred after early auditory ERP components such as the N100 (Nunez & Srinivasan, 2006). Moreover, previous studies have found that post-institutionalized children have normal auditory processing skills (Pollak et al., 2010) and no difference in a phonological mismatch negativity relative to children under BFC (Ovchinnikova et al., 2019). We suggest that our results reflect neural differences in language or prosody processing associated with IC. However, future work could address this question more directly in an older sample of children under IC who would be capable of following task instructions to examine the link between behavioral prosody identification and hemispheric specificity.

One limitation of the current study is that the research cited in this article mainly included mixed samples from Europe, Asia, and North America, while our sample consisted entirely of Russian (ethnically Slavic) children. Therefore, it is important to note that, while our results point toward IC as detrimental for brain development, they (as well as others' results) may not generalize to all samples. In addition, institutional and residential care options for children are not homogenous. Some programs have better outcomes than others (Kendrick, 2015) and, in some cases, IC may be preferable to residential family care in some less wealthy countries (Whetten et al., 2009). Future research could address whether our results occur following IC in different countries.

Conclusions

IC has widely been associated with adverse outcomes, yet, as recently as 2017, the number of children estimated to be in IC globally was still over 2.7 million (Petrowski et al., 2017). This study suggests that, by at least 20–40 months of age, IC disrupts brain development associated with the processing of prosody in speech. These findings align with researchers' suggestions that discrepancies in the quality of early care can lead to an achievement gap that begins at a young age, even before children are old enough to enter school (Zigler & Finn-Stevenson, 2007). The implications may be reduced social understanding and, in turn, social difficulties throughout development. These results should direct policymakers to continue to move toward alternate forms of care, such as family-based models like foster care, and highlight the importance of social competence as a focus of early interventions (Zigler & Styfco, 1997). Taken together, our results and many other findings support the movement toward keeping children out of IC (Marshall, Reeb, Fox, Nelson, & Zeanah, 2008; Vanderwert, Marshall, Nelson, Zeanah, & Fox, 2010), although approaches to this goal should still be evaluated on a case by case basis.

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Conflicts of Interest. None.

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