Three- and six-year-old children are sensitive to natural body expressions of emotion: An event-related potential emotional priming study

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ARTICLE INFO

ABSTRACT

Body movements provide a rich source of emotional information during social interactions. Although the ability to perceive biological motion cues related to those movements begins to develop during infancy, processing those cues to identify emotions likely continues to develop into childhood. Previous studies used posed or exaggerated body movements, which might not reflect the kind of body expressions children experience. The current study used an event-related potential (ERP) priming paradigm to investigate the development of emotion recognition from more naturalistic body movements. Point-light displays (PLDs) of male adult bodies expressing happy or angry emotional movements while narrating a story were used as prime stimuli, whereas audio recordings of the words "happy" and "angry" spoken with an emotionally neutral prosody were used as targets. We recorded the ERPs time-locked to the onset of the auditory target from 3- and 6-year-old children, and we compared amplitude and latency of the N300 and N400 responses between the two age groups in the different prime–target conditions. There was an overall effect of prime for the N300 amplitude, with more negative-going responses for happy PLDs compared with angry PLDs. There was also an interaction between prime and target for the N300 latency, suggesting that all children were sensitive to the emotional congruency between body movements and words. For the N400 component, there was only an interaction among age, prime, and target for latency, suggesting an age-dependent modulation of this

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component when prime and target did not match in emotional information. Overall, our results suggest that the emergence of more complex emotion processing of body expressions occurs around 6 years of age, but it is not fully developed at this point in ontogeny.

Introduction

Appropriate social interactions require the ability to infer the feelings and intentions of people around us. By adulthood, observers are sensitive to the emotional and social information expressed in other people's body and facial movements. These movements are often unconsciously and spontaneously made. Extensive research has shown that adults are highly sensitive to the fine variations in the biological motion characteristic of other people's body movements (for a review, see Thornton, Wootton, & Pedmanson, 2014). This sensitivity can be demonstrated by presenting human bodies as a small number of moving points of light corresponding to major body parts (e.g., head, wrists, ankles, hips). Despite the absence of many visual form cues (e.g., shape, color), adults readily perceive these point-light displays (PLDs) as a human body when the PLDs are dynamic, but not when they are static (Johansson, 1973). Importantly, adults are able to quickly extract socially relevant information from biological motion, such as sex (Mather & Murdoch, 1994), emotional expressions (Atkinson, Dittrich, Gemmell, & Young, 2004; Volkova, De La Rosa, Bülthoff, & Mohler, 2014a; Volkova, Mohler, Dodds, Tesch, & Bülthoff, 2014b), and psychological traits (Thoresen, Vuong, & Atkinson, 2012), even in the absence of static and dynamic facial information (Bassili, 1979; Willis & Todorov, 2006). Although newborn infants show sensitivity to biological types of motion compared with other types of motion (Simion, Regolin, & Bulf, 2008), it is less clear when the ability to identify emotions from biological motion cues develops, especially when the body expressions of emotion occur in natural settings. Toward this aim, the current study investigated whether 3- and 6-year-old children extract emotional meaning from naturalistic body movements expressed by others. In particular, we focused on young children's neural processing of emotional body movements expressed during naturalistic contexts and depicted as PLDs.

Previous work shows that from infancy to adulthood, observers can use different sensory information—including form (e.g., body postures, static facial expressions), motion (e.g., full body or body part articulations), and auditory (e.g., vocal expressions) cues—to extract emotional and socially relevant information related to emotions (e.g., Bayet, Behrendt, Cataldo, Westerlund, & Nelson, 2018; Crespo-Llado, Vanderwert, & Geangu, 2018a; Crespo-Llado, Vanderwert, Roberti, & Geangu, 2018b; Gao & Maurer, 2010; Geangu, Quadrelli, Lewis, Cassia, & Turati, 2015; Geangu et al., 2016a; Geangu, Quadrelli, Conte, Croci, & Turati, 2016b; Geangu, Roberti, & Turati, 2021; Geangu & Vuong, 2020; Poulin-Dubois et al., 2018; Quadrelli, Geangu, & Turati, 2019; Yeh, Geangu, & Reid, 2016; Zieber, Kangas, Hock, & Bhatt, 2014). These studies used a variety of complementary measures, including behavior, eye fixations, and physiological and electrophysiological responses. Other studies demonstrate that infants as young as 5 months can integrate socially relevant information from multiple senses to recognize emotions (Heck, Chroust, White, Jubran, & Bhatt, 2018; Zieber et al., 2014; for a review, see Bhatt, Hock, White, Jubran, & Galati, 2016). For example, Heck and colleagues (2018) presented 3.5- and 5-month-old infants videos of angry and happy body movements paired with congruent (matching) or incongruent emotional vocalization. The videos were presented upright or inverted. The authors showed that 5-month-olds, but not 3.5-month-olds, preferentially looked at congruent stimuli. This preferential looking occurred only when the videos were upright, which highlights the importance of global biological motion cues.

In the current study, we focused specifically on biological motion cues in the absence of form or other cues, including facial motion. The results from behavioral and neuroimaging studies with infants

and children suggest that both the ability to detect biological motion (e.g., from PLDs; Hadad, Maurer, & Lewis, 2011; Hirai & Hiraki, 2005; Hirai, Fukushima, & Hiraki, 2003; Hirai, Watanabe, Honda, & Kakigi, 2013; Marshall & Shipley, 2009; Pavlova, 2012; Simion et al., 2008) and to accurately identify the emotion expressed (Missana, Grigutsch, & Grossmann, 2014; Ross, Polson, & Grosbras, 2012) have a protracted developmental trajectory. It is believed that for both these functions adults integrate local motion signals from the individual dots across space and time into a global biological motion percept (Giese & Poggio, 2003; Grossman & Blake, 1999). With respect to the detection of biological motion, infants' and children's sensitivity is dependent on the extent to which local motion signals are disrupted. If the local motion signals are profoundly altered, infants can discriminate above chance between coherent biological motion and noncoherent biological motion in which the individual points are temporally or spatially "scrambled" (Bertenthal, Proffitt, & Kramer, 1987; Moore, Goodwin, George, Axelsson, & Braddick, 2007), and by 4 to 6 years of age children are as accurate as adults (Vieillard & Guidetti, 2009). However, if the local motion signals are only slightly altered, children's sensitivity to biological motion continues to improve until adolescence. Even during adolescence, it remains particularly diminished in complex visual displays (Freire, Lewis, Maurer, & Blake, 2006; Hadad et al., 2011).

With respect to children's ability to identify emotions expressed by body movements, Ross et al. (2012) tested 4- to 17-year-old children and adults' ability to identify anger, happiness, fear, and sadness expressed by adult actors explicitly posing these emotions. The stimuli were presented as PLDs and as videos that contained both form and motion cues. Participants were asked to choose the verbal label corresponding to the posed emotion. The accuracy was significantly lower for PLDs than for videos across all age groups and emotions, indicating that children and adults benefited from form cues in identifying emotions. Nevertheless, for both types of stimuli, accuracy improved throughout childhood and adolescence and reached 60% by 8.5 years of age, with the steepest increase from 4 to 8.5 years. Other studies suggest that children's ability to identify emotions expressed by body movements depends on various other factors. When children observe exaggerated body movement videos that extend over longer durations and are associated with dance narrative cues, they are able to identify above chance the emotion at a younger age (Boone & Cunningham, 1998; Lagerlöf & Djerf, 2009). The accuracy of identifying sadness in dance movements tended to be more stable when children were closer to 12 years of age, whereas the accuracy in labeling of happiness, anger, and fear increased as children reached 4 years of age (Lagerlöf & Djerf, 2009). By 5 to 8 years of age, children performed at similar levels as adults in identifying happiness, sadness, anger, and fear, particularly after they obtained training about how body movement can express different meanings (Lagerlöf & Djerf, 2009).

To summarize, children as young as around 2 or 3 years can detect changes in posed emotional body movements when these have an exaggerated expression and benefit from additional visual and semantic/contextual information. However, it is still unknown at what age children can use people's natural and spontaneous body movements to identify their emotional state. Although young children can be asked to recognize or label these spontaneous body movements, it can be problematic to measure behavioral responses (e.g., word production) to the visually impoverished PLDs, particularly when comparing between 3- and 6-year-old children (Ross & Atkinson, 2020). For instance, the younger children might not understand the task instructions as well as the older children. At the neural level, event-related potential (ERP) studies can reveal developmental changes for processing biological motion (Hirai et al., 2013). Previous studies have shown that developmental changes are present both for ERP components that reflect earlier stages of processing and for those that reflect later stages of processing. The early components are most often associated with extracting low-level properties of PLDs (Hirai et al., 2013; Jokisch, Daum, Suchan, & Troje, 2005), whereas the later components are often linked with attributing a meaning to the perceived biological motion (Jokisch et al., 2005; Krakowski et al., 2011). In the current study, we used ERPs to investigate 3- and 6-year-olds' processing of anger and happiness expressed by naturalistic body movements. Unlike previous studies in which the stimuli were created by explicitly asking adult actors to express specific emotions (e.g., anger), here we used PLDs of spontaneous body movements expressed by adult actors in naturalistic contexts (e.g., narrating a sentence from a fairy tale; Volkova et al., 2014a, 2014b). The actors did not receive any instructions about emotional expressivity per se or about which expressions to use; thus,

the body movements from this database resemble more those produced naturally during similar daily social situations.

We used an ERP priming paradigm (Deacon, Hewitt, Yang, & Nagata, 2000) to test whether children in the two age groups can extract emotional information from naturalistic biological motion cues because it allowed us to exploit the fact that children understand the emotional meaning of the spoken word (Bretherton, Fritz, Zahn-Waxler, & Ridgeway, 1986; Kristen, Fritz, Zahn-Waxler, & Ridgeway, 2014; Li & Yu, 2015; Ridgeway, Waters, & Kuczaj, 1985; Taumoepeau & Ruffman, 2006, 2008) to determine whether they extract emotional information from the PLDs. This priming paradigm is an established method to measure associations between prime and verbal labels without potential task confounds such as the need for behavioral responses. Using this paradigm, we presented either an angry PLD or a happy PLD as a prime followed by the word "angry" or "happy" uttered with emotionally neutral prosody as a target, and we measured ERP responses to the auditory word *target.* Children in both age groups can understand to some extent the semantic meanings of the words (Bretherton et al., 1986; Kristen et al., 2014; Li & Yu, 2015; Ridgeway et al., 1985; Taumoepeau & Ruffman, 2006, 2008). Moreover, the emotional information conveyed visually by the face and body, and conveyed auditorily by the voice, is frequently associated with the corresponding emotion category label and could be learned from very early on. Indeed, at the behavioral level, children as young as 2 years can correctly choose the facial expressions corresponding to the words "happy" and "angry" (Denham et al., 2003). The N300 and N400 are the ERP components primarily shown to differentiate between emotional stimuli that are perceived to be *congruent* or *incongruent* with the emotional context in which they appear (e.g., Bostanov & Kotchoubey, 2004; Goerlich et al., 2012; Paulmann & Pell, 2010; Schirmer, Chen, Ching, Tan, & Hong, 2013; Werheid, Alpay, Jentzsch, & Sommer, 2005; Zhang, Lawson, Guo, & Jiang, 2006). Both components can be elicited during infancy and childhood (e.g., Friedrich & Friederici, 2004, 2005, 2008; Parise & Csibra, 2012; Sheehan, Namy, & Mills, 2007). Moreover, as children mature, the two components may show a reduction in amplitude, a slowing in the latency of the peak response, and a change in hemispheric distribution (Geangu et al., 2021; Holcomb, Coffey, & Neville, 1992; Schapkin, Gusev, & Kuhl, 2000).

The N300 is often reported either independent of or co-occurring with the N400 (Bostanov & Kotchoubey, 2004; Nobre & McCarthy, 1995; Paulmann & Pell, 2010). In children, negativities occurring around 300 ms from stimulus onset have been interpreted to index familiarity effects reflecting the fulfillment of a phonological expectation after seeing the visual depiction of an object. This slightly precedes more advanced cognitive processing of the semantic meaning of the word (Friedrich & Friederici, 2004; von Koss Torkildsen, Syversen, Simonsen, Moen, & Lindgren, 2007). The N300 has also been linked to image processing when the semantic meaning is presented visually (e.g., West & Holcomb, 2000). It has been shown to be modulated by semantic expectations regarding a stimulus membership to a broader category prior to more in-depth semantic processing (Hamm, Johnson, & Kirk, 2002).

The N400 is a negative-going deflection in adults typically observed in central–parietal sites. It is a broadly observed component in language investigations that peaks at around 400 ms after the target word onset in a prime–target paradigm or sentential context (for a review, see Kutas & Federmeier, 2011). A typical N400 effect refers to enhanced negative amplitude to the incongruent condition (i.e., a mismatch between the prime and target); therefore, the N400 is often considered as a sensitive index of cognitive processing (Lau, Phillips, & Poeppel, 2008). It is also elicited when different meaningful stimuli, such as story pictures, action sequences, and music, are paired so that their semantic contents do not match (Aguado, Dieguez-Risco, Méndez-Bértolo, Pozo, & Hinojosa, 2013; Steinbeis & Koelsch, 2008; West & Holcomb, 2000).

Typically in the ERP priming paradigm, a target word that is semantically incongruent with the prime elicits more negative amplitude of N300 and N400 components compared with a word that is semantically congruent with the prime (Amoruso et al., 2013; Deacon et al., 2000; Lau et al., 2008; McPherson & Holcomb, 1999). However, opposite effects have also been reported (Bermeitinger, Frings, & Wentura, 2008), especially for emotional stimuli (e.g., Aguado et al., 2013; Goerlich et al., 2012; Kotz & Paulmann, 2007; Paulmann & Pell, 2010) and in children (Bonte & Blomert, 2004; Holcomb et al., 1992). In addition, variations in the latency of these components as a function of the semantic meaning of the stimuli have been noted (Paulmann & Pell, 2010). These

congruency effects on the N400 latency appear to depend on age. For example, Tiedt, Ehlen, and Klostermann (2020) provided evidence of a congruency effect in the N400 amplitude in young adults but not older adults and in the N400 latency in older adults but not young adults. By manipulating the semantic matching (i.e., congruency) between the prime and the target, we can investigate the development of children's processing of angry and happy emotions expressed through naturalistic biological motion cues. If children can extract to a certain degree the emotional information conveyed by the body movement of the PLD prime and establish the semantic relation with the corresponding target word, we predict differences in the amplitude and/or latency of the N300 and N400 components between the congruent and incongruent prime–target pairs.

Method

Participants

A total of 54 children were tested. The final analysis included 34 children (3-year-olds: $n = 17$, 8 girls; M_{age} = 45.82 months, SD = 5.60; 6-year-olds: $n = 17$, 10 girls; M_{age} = 78.24 months, SD = 5.18). The remaining 20 children (18 3-year-olds and 2 6-year-olds) were excluded due to either technical issues ($n = 3$) or insufficient number of artifact-free trials ($n = 17$). Participants were recruited locally in Northern England from an infant and children database maintained at Lancaster University. The main source for this database was the local hospital. Based on the demographics and geographical region served by the hospital, the majority of participants recruited and tested tend to be British White, but we did not collect information regarding participants' ethnicity. Moreover, because our study was lab-based, our sample may be biased toward parents who were able and had time to travel to the lab for a research session. Parents gave informed written consent on behalf of their children to take part in the study. The children assented to their participation in the study and received a small gift for their participation. The procedure followed the ethical standards of the Declaration of Helsinki and was approved by the university ethics committee. The data are available upon reasonable request to the corresponding author for research and teaching purposes.

Stimuli

The stimuli consisted of PLDs that served as primes and auditory words that served as targets. Six PLDs were selected from the MPI Emotional Body Expression Database (Volkova et al., 2014a): three expressing anger and three expressing happiness or joy. Each PLD consisted of 23 points located at the main joints, head, and spine and captured the natural body movements of male adults while they narrated emotional stories. Importantly, independent adult observers correctly rated all six selected PLDs with respect to their intended category (happy or angry) and valence (positive for happy PLDs and negative for angry PLDs) (see Volkova et al., 2014a, for details). The average speed of the motion of the left and right wrists and duration and consistency of reported emotion labels for each type of the prime stimuli reported in the database are presented in Table 1. Following recommendations from previous research using PLD stimuli (e.g., Geangu et al., 2021), we also calculated the magnitude of

Table 1
Means (and standard deviations) of the measurement of the average speed (of wrist point), magnitude of optic flow, duration, and label consistency for each type of prime.

Prime type	Speed (m/s)	Optic flow (pix/frame)	Duration (s)	Consistency
Angry	0.43 (0.06)	0.048 (0.003)	3.97 (0.50)	0.64 (0.24)
Happy	0.34 (0.02)	0.047 (0.008)	4.67 (0.57)	0.42 (0.10)

Note. The identification numbers in the database of the angry point-light displays (PLDs) were 549, 644, and 1135. The identification numbers of the happy PLDs from the database were 523, 544, and 660 (labeled *joy* in the database). The magnitude of optic flow for each PLD was estimated as follows. We first calculated the displacement of the corresponding PLD dot pixel from frame N to frame $N + 1$ for all consecutive frames using the Lucas–Kanade algorithm implemented in MATLAB (Lucas & Kanade, 1981). We then summed the resulting displacement vectors across frames and divided by the total number of frames.

optic flow of the PLD videos to track the image motion of all 23 dots (including the wrist) across frames. For all the measures reported in Table 1, nonparametric independent-samples Mann–Whitney *U* tests showed no differences between the two emotion categories (*p*s >.10, two-sided).

The two target stimuli were 505-ms audio recordings of the words "angry" and "happy" spoken in an emotionally neutral tone by three native English-speaking female adults. They were selected from a pool of 30-word utterances recorded in an anechoic chamber by the three speakers (15 for "angry" and 15 for "happy"). Ten adult listeners rated each recording in terms of clarity (on a scale of 0–5) and prosody (neutral, angry, or happy). Both target stimuli were rated to be the clearest (clarity = 5) and to have neutral prosody by at least half the raters (happy: 50%; angry: 60%).

Apparatus

Participants were tested individually in a dimly lit room. They sat approximately 70 cm away from a CRT monitor that had a 75-Hz refresh rate. The PLDs were presented on the monitor, and the auditory words were presented via speakers. The PLDs covered a visual field of 22.1° × 22.1° (horizontal × vertical). The experiment was programmed in MATLAB (MathWorks, Natick, MA, USA). Electroencephalogram (EEG) was recorded with a 128-electrode HydroCel Geodesic Sensor Net (Electrical Geodesics Inc. [EGI], Eugene, OR, USA) and was amplified using an EGI NetAmps 300 amplifier. A video recorder synchronized with the EEG was used to record participants' eye movements during the experiment. The videos were used offline to identify eye movements and whether or not participants were looking at the visual stimuli.

Design and procedure

The participants were presented with a PLD prime followed by an auditory word target while we continuously recorded EEG. The two PLD prime categories (angry and happy) were factorially combined with the two auditory word targets, resulting in four prime–target conditions (Fig. 1). This factorial design resulted in two congruent conditions in which the prime and target were of the same emotion (Fig. 1A and 1C) and two incongruent conditions in which the prime and target were of different emotions (Fig. 1B and 1D).

The trial sequence is illustrated in Fig. 1. Each trial began with a PLD prime presented at the center of the screen for its duration. After the offset of the PLD movement, the last static frame of the PLD remained on the screen for the remainder of the trial (~700 ms in total). After 200 ms from the offset of the PLD movement, the auditory word target was presented (concurrently with the static frame). The 200-ms interstimulus interval (ISI) allowed a motion-free baseline for the EEG recording. The continuous presentation of the static PLD during the ISI and target stimulus presentation ensured that the children remained engaged with the trial and that they were less likely to look away from the screen to reduce body and eye movement artifacts in the EEG data (e.g., Bristow et al., 2009; Geangu et al., 2021). After the offset of the target, a central white fixation cross was presented on a black background for an intertrial interval (ITI) varying randomly between 1800 and 2000 ms. To maintain participants' attention throughout the task, a non-task-related image (a rainbow-colored star) was presented before the fixation cross on 40% of the trials. Participants were asked to press a button as soon as they saw the image. The image was presented for 2000 ms irrespective of their response. Each of the four conditions was presented a maximum of 27 times. The three different PLDs for each emotion were randomly sampled with replacement on each trial.

EEG acquisition and preprocessing

EEG was recorded continuously at a sampling rate of 500 Hz. For each electrode, the signal was referenced online to the vertex electrode (Cz) and a bandpass filter of 0.1 to 100 Hz was applied. Impedances were checked prior to the beginning of the recording and were considered acceptable if lower than 50 kΩ. The EEG data were further processed offline using Net Station Version 4.5.4 (EGI). The signal was bandpass filtered (0.3–30 Hz) and segmented from 100 ms (baseline) before the onset of the auditory word target to 1000 ms after onset for each trial. Segments were baseline corrected. To
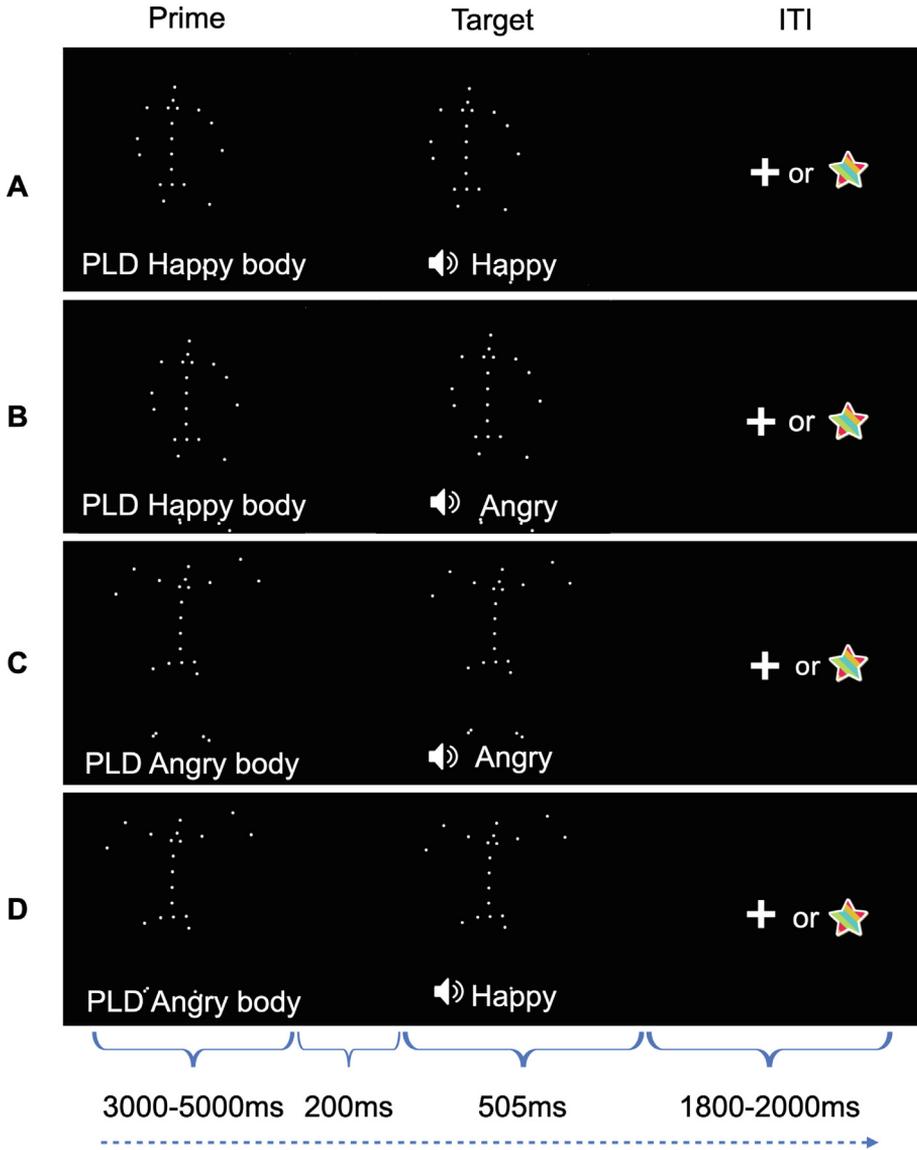
Fig. 1. Example of the trial sequence for the four prime–target pairs. The factorial combination of two primes and two targets resulted in four conditions: happy prime–happy target (A), happy prime–angry target (B), angry prime–angry target (C), and angry prime–happy target (D). Panels A and C are *congruent* prime–target pairs, and Panels B and D are *incongruent* prime–target pairs. ITI, intertrial interval; PLD, point-light display.

eliminate artifacts, segmented data were automatically rejected whenever the signal exceeded ± 200 μV at any electrode. The data were further checked by visual inspection for eye movements, eye blinks, and other body movement artifacts not detected by the automated algorithm. At this stage, trials were excluded if more than 18 bad channels were detected or if participants looked away from the screen during the stimuli presentation (as indicated by the video recording). For the remaining trials after preprocessing the EEG data, the individual bad channels were replaced using spherical spline interpolation. Individual participant averages were computed separately for each

channel across all trials within each condition, and then the data were re-referenced to the average reference. Based on previous studies, we excluded children who did not have a mean of 10 trials averaged across the four conditions (e.g., Bristow et al., 2009; Crespo-Llado et al., 2018a; Geangu et al., 2021; Hendrickson, Love, Walenski, & Friend, 2019). The average numbers of included trials as a function of condition and age group are presented in Table 2.

Statistical analyses

Following EEG preprocessing, we conducted statistical analyses on the amplitude and latency of the N300 and N400 components within regions of interest (ROIs). Fig. 2 shows the two ROIs selected: central (left: 29, 35, 36; right: 104, 111, 110) and parietal (left: 42, 47, 52; right: 92, 93, 98). We focused our analyses on the ERP measures for the N300 (250–380 ms) at the central ROIs and for the N400 (400–550 ms) at the parietal ROIs. The time windows for each component were based on previous literature using similar paradigms with children and adults (Friedrich & Friederici, 2004; Henderson, Baseler, Clarke, Watson, & Snowling, 2011; Steinbeis & Koelsch, 2008) and visual inspection of the data. The amplitude was calculated by taking the average voltage within the time window for each ERP component and each ROI. The latency for each component was calculated using the fractional area method, which is more robust than using the maxima within the time window (Luck, 2014; Tiedt et al., 2020). The latency was defined as the time point at which 50% of the total cumulative area under the ERP component was reached. The ERP was adjusted so that signal fluctuations did not cross 0 μV (i.e., subtracted the voltage at each time point by the maximum voltage). For each component, we submitted the amplitude and latency to a 2 (Age: 3-year-olds or 6-year-olds) × 2 (Hemisphere: right or left) × 2 (Prime: happy PLD or angry PLD) × 2 (Target: "happy" word or "angry" word) mixed analysis of variance (ANOVA), with age as a between-participants factor and the remaining variables as within-participant factors. For significant Prime × Target interactions, we tested for congruency effects by computing means for congruent conditions (averaging angry–angry and happy–happy prime–target pairs) and incongruent conditions (averaging angry–happy and happy–angry prime–target pairs) for each child. We report Bonferroni-corrected p values for post hoc pairwise t tests for six comparisons. The results were interpreted at the significance threshold of α =.05.

Results

Central N300

Amplitude

Fig. 3A and 3B show ERPs at central scalp ROIs as a function of age, hemisphere, prime, and target. There was a significant main effect of prime, $F(1, 32) = 4.477$, $p =.042$, $\eta_p^2 =.123$, with targets primed by happy PLDs ($M = -3.242$ μV, $SE = 0.630$ μV) eliciting a more negative N300 amplitude than when primed by angry PLDs ($M = -2.096$ μV, $SE = 0.694$ μV) (Fig. 3C). There was no significant difference in N300 amplitude between 3-year-old children ($M = -2.575$ μV, $SE = 0.856$ μV) and 6-year-old children ($M = -2.762$ μV, $SE = 0.856$ μV), $p =.878$, or between "angry" word targets ($M = -2.887$ μV, $SE = 0.675$ μV) and "happy" word targets ($M = -2.451$ μV, $SE = 0.637$ μV), $p =.399$. All other main effects and interactions were not significant ($ps >.132$). Given that there was no effect or interaction

Table 2
Mean numbers of trials (and standard deviations) included in the analysis for each prime–target condition separately for each age group.

	Happy–Happy	Happy–Angry	Angry–Angry	Angry–Happy
3-year-olds	13 (3)	13 (3)	14 (3)	13 (3)
6-year-olds	14 (6)	15 (5)	16 (4)	15 (5)

Note. The maximum number of trials in each condition was 27.
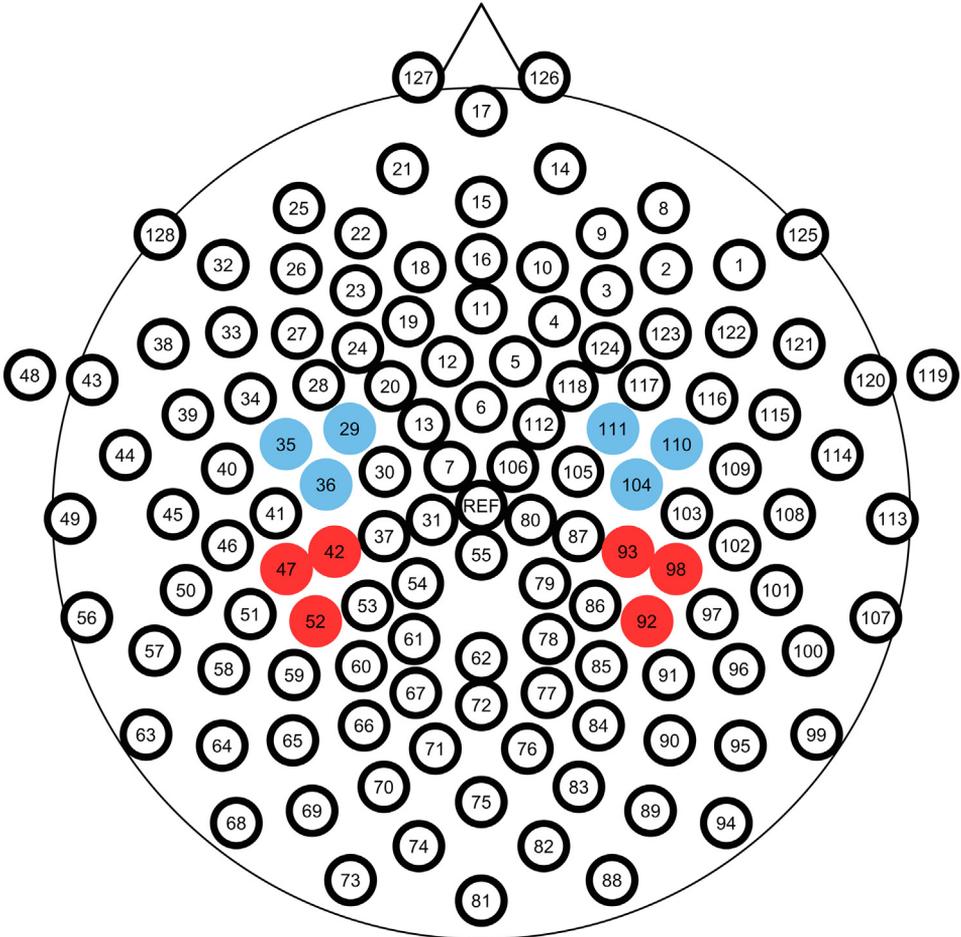
Fig. 2. Locations of the electrodes included for the central (blue) and parietal (red) regions of interest in the left and right hemispheres. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.).

with age, Fig. 4 shows the ERPs at central scalp ROIs as a function of hemisphere, prime, and target averaged across age.

Latency

There was a significant Prime × Target interaction, $F(1, 32) = 9.492$, $p = .004$, $\eta_p^2 = .229$ (Fig. 3D). Post hoc *t*-tests among the four different conditions showed no significant differences ($ps > .078$). As described in the "Statistical analyses" section, we computed the mean latency for the congruent and incongruent conditions for each child. A post hoc *t*-test showed that there was a significant congruency effect, $t(33) = 3.068$, $p = .024$, with a delayed latency for the congruent conditions ($M = 322$ ms, $SE = 2$ ms) compared with the incongruent conditions ($M = 314$ ms, $SE = 2$ ms) (Fig. 3D).

Parietal N400

Amplitude

Fig. 5A and 5B show ERPs at parietal scalp ROIs as a function of age, hemisphere, prime, and target. There was no significant difference in mean amplitude between 3-year-old children ($M = -1.604$ μV,
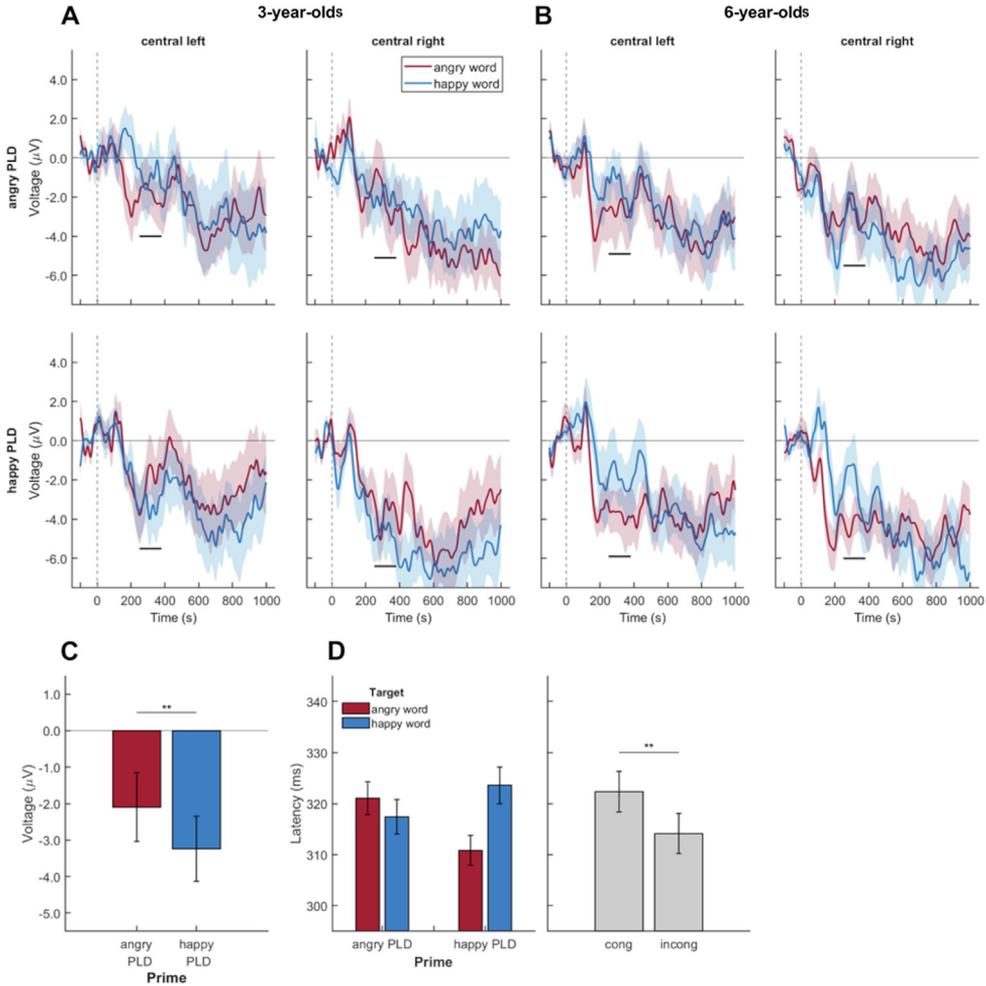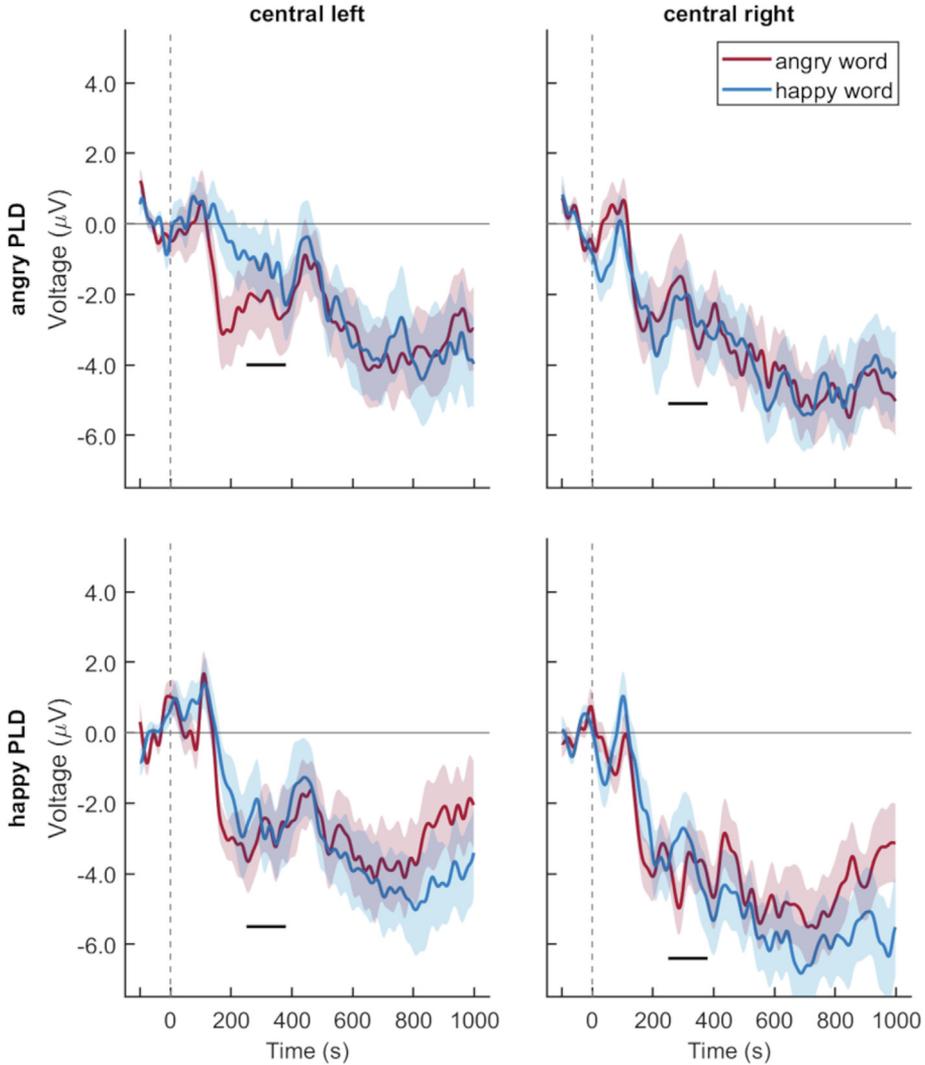
Fig. 3. Electroencephalogram results for the central N300 component. Event-related potentials to target words for 3-year-old (A) and 6-year-old (B) children as a function of hemisphere are shown: prime (angry or happy point-light display [PLD]) and target ("angry" or "happy" word). The black horizontal lines indicate the N300 windows. The shaded regions indicate the standard errors of the means. The main effect of prime for amplitude (C) and the Prime × Target interaction and congruency effect for latency (D) are shown. The congruent (cong) conditions included the angry–angry and happy–happy (prime–target) pairs, and the incongruent (incong) conditions included the angry–happy and happy–angry pairs. **p <.024.

SE = 1.037 μV) and 6-year-old children ($M = -2.392$ μV, SE = 1.037 μV), p =.595, between angry PLDs ($M = -1.800$ μV, SE = 0.866 μV) and happy PLDs ($M = -2.197$ μV, SE = 0.810 μV), p =.628, or between "angry" words ($M = -2.100$ μV, SE = 0.828 μV) and "happy" words ($M = -1.897$ μV, SE = 0.705 μV), p =.662. There was no Prime × Target interaction (p =.127) or Age × Prime × Target interaction (p =.897). There was a main effect of hemisphere, $F(1, 32) = 6.867$, p =.013, η_p^2 =.177 (left: $M = -1.115$ μV, SE = 0.802 μV; right: $M = -2.882$ μV, SE = 0.810 μV).

Latency

The omnibus ANOVA showed significant main effects of age, $F(1, 32) = 4.357$, p =.045, η_p^2 =.120, and target, $F(1, 32) = 32.094$, p <.001, η_p^2 =.501. The 6-year-old children had earlier N400 latency (M = 472 ms, SE = 2 ms) than the 3-year-old children (M = 479 ms, SE = 2 ms), and all children had

Fig. 4. Electroencephalogram results for the central N300 component averaged across 3- and 6-year-old children. Event-related potentials to target words as a function of hemisphere are shown: prime (angry or happy point-light display [PLD]) and target ("angry" or "happy" word). The black horizontal lines indicate the N300 windows. The shaded regions indicate the standard errors of the means.

earlier N400 latency to "angry" targets (M = 469 ms, SE = 2 ms) compared with "happy" targets (M = 481 ms, SE = 2 ms). There was a Hemisphere $\times$ Target interaction, $F(1, 32)$ = 4.274, p =.047, η_p^2 =.118.

There was a significant Age $\times$ Prime $\times$ Target interaction, $F(1, 32)$ = 5.645, p =.024, η_p^2 =.150 (Fig. 5C). As with the N300, we computed the mean latency for congruent and incongruent conditions to further investigate the three-way interaction. We submitted the mean latency to an Age $\times$ Congruency ANOVA. There was no main effect of congruency (p =.581). There was a main effect of age, $F(1, 32)$ = 4.357, p =.045, η_p^2 =.120, and importantly there was an Age $\times$ Congruency interaction, $F(1, 32)$ = 5.645, p =.024, η_p^2 =.150 (Fig. 5D). Post hoc t-tests showed that there was no latency differ-
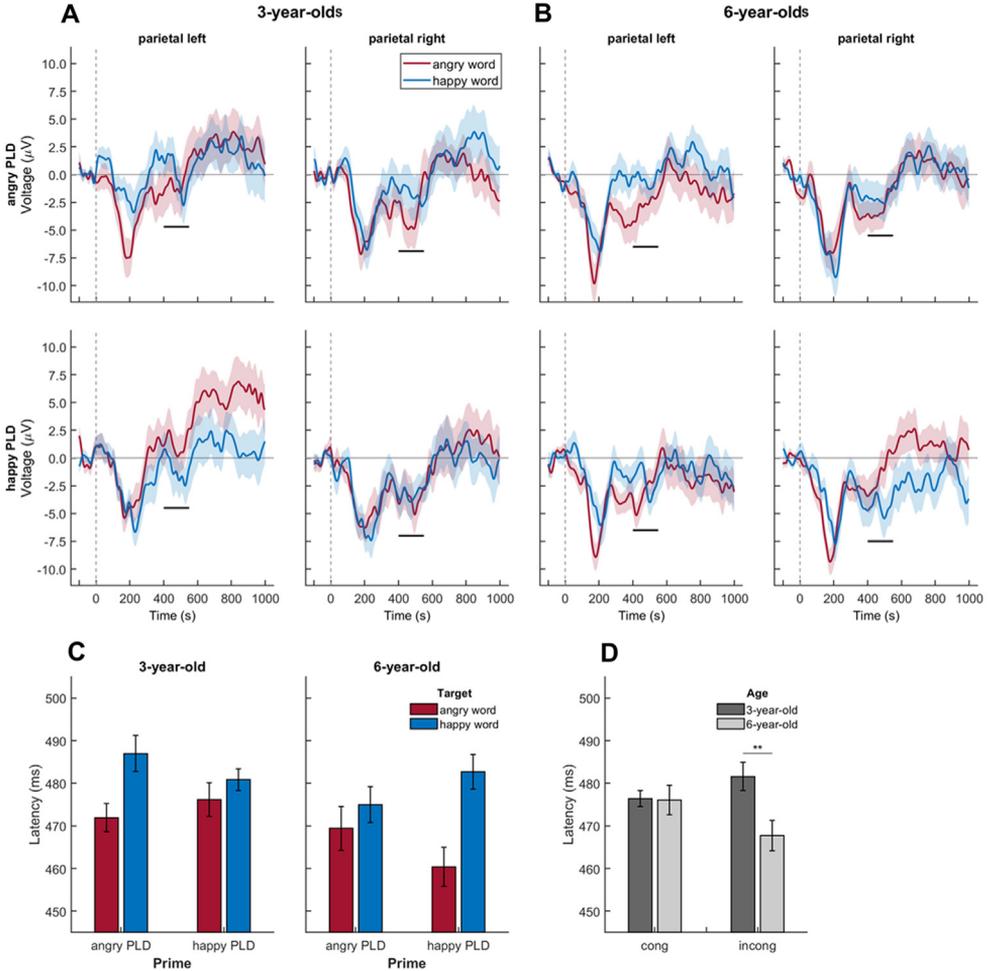
Fig. 5. Electroencephalogram results for the parietal N400 component. Event-related potentials to target words for 3-year-old (A) and 6-year-old (B) children as a function of hemisphere are shown: prime (angry or happy point-light display [PLD]) and target ("angry" or "happy" word). The black horizontal lines indicate the N400 windows. The shaded regions indicate the standard errors of the means. The Age × Prime × Target interaction for amplitude (C) and the Age × Congruency interaction for latency (D) are shown. The congruent (cong) conditions included the angry–angry and happy–happy (prime–target) pairs, and the incongruent (incong) conditions included the angry–happy and happy–angry pairs. **p <.042.

ences between 3-year-old children (M = 476 ms, SE = 2 ms) and 6-year-old children (M = 476 ms, SE = 3 ms) for the congruent conditions, but the older children had earlier N400 latency than the younger children for the incongruent conditions (3-year-olds: M = 482 ms, SE = 3 ms; 6-year-olds: M = 467 ms, SE = 3 ms), $t(32)$ = 2.84, p =.042. No other comparisons were significant (ps >.05).

Discussion

The aim of our study was to investigate the developmental changes during early childhood in the sensitivity to adults' body expressions of emotion during natural settings using an ERP priming paradigm. We focused on biological motion per se in the absence of both form cues (e.g., color,

body parts) and facial motion cues. Both the N300 and N400 ERP components have been shown to be sensitive to the mismatch between the semantic meanings of visual and auditory stimuli (e.g., Aguado et al., 2013; Bostanov & Kotchoubey, 2004; Goerlich et al., 2012; Paulmann & Pell, 2010; Steinbeis & Koelsch, 2008; West & Holcomb, 2000). The N300 can reflect processing of familiarity and semantic expectation fulfillment (within context) of visual and auditory stimuli, proceeding to more advanced cognitive processing (e.g., Friedrich & Friederici, 2004; von Koss Torkildsen et al., 2007; West & Holcomb; 2000). The N400 component has been systematically shown to reflect advanced semantic processing (Lau et al., 2008). Therefore, we hypothesized that children's ability to extract emotional information from PLDs of naturalistic body movements would modulate N300 and N400 components. Differences in modulation of the amplitude or latency of these components between 3- and 6-year-old children can help to determine when this ability emerges.

We found that both age groups showed larger negative N300 amplitudes to words preceded by happy body expressions than by angry body expressions, but there was no prime effect for the N400 amplitude. We also found that all children had earlier N300 latency when body expressions and words did not match (i.e., incongruent trials) than when they matched (i.e., congruent trials), but older children had earlier N400 latency than younger children when body expressions and words did not match. Taken together, our results suggest that the emergence of more complex emotion processing of body expressions may occur after 3 years of age and around 6 years of age. In what follows, we present the findings and discuss their implications for understanding the development of emotional body movement processing during childhood.

N300 at central scalp locations

We found a prime effect for the amplitude of the N300 component. Both 3- and 6-year-old children showed increased negative N300 amplitude in response to target words preceded by happy body movements compared with angry body movements. This prime effect is consistent with previous studies showing that the N300 response precedes to more advanced cognitive processing of semantic meanings of words (Friedrich & Friederici, 2004; von Koss Torkildsen et al., 2007); in our case, this would be emotion processing. There were no target effects on the N300 amplitude. Because we used different exemplars of angry and happy body movements, these findings suggest that by at least 3 years of age, children are able to extract and represent subtle motion features of the PLDs specific to each emotional category. These findings also suggest that the PLDs were effective primes, eliciting differential N300 amplitudes.

We found an interaction between the prime and target for the latency of the N300 component. This interaction reflected a congruency effect; the latency was delayed by ~ 8 ms for the congruent conditions (angry–angry and happy–happy prime–target pairs) compared with the incongruent conditions (angry–happy and happy–angry prime–target pairs). This finding is consistent with previous studies showing that N300 latency is related to extracting a certain level of semantic meaning from the stimuli (e.g., Paulmann & Pell, 2010). However, other studies found congruency effects on the N300 amplitude in infants and adults (Friedrich & Friederici, 2005; Holcomb & Neville, 1990; Nobre & McCarthy, 1994; von Koss Torkildsen et al., 2007). The variation in effects on amplitude and latency across studies may be due to experimental parameters such as the long stimulus duration (3–5 s) affecting the duration between the onset of the prime and the onset of the target, which is typically much shorter in previous semantic priming studies (0–1000 ms) (Daltrozzo & Schön, 2008; Friedrich & Friederici, 2005; Henderson et al., 2011). Future work will be needed to determine more precisely which parameters drove these differences.

N400 component at parietal scalp locations

For the amplitude of the N400 component, there were no effects of age, prime, target, or their interactions. By comparison for the latency of the N400 component, we found that 6-year-old children had earlier latency than 3-year-old children. We also found that all children had earlier N400 latency for

"angry" target words compared with "happy" target words, providing evidence that children can extract meaning from the words. The earlier latency to "angry" target words compared with "happy" ones may reflect the activation of threat-related representations; for example, angry facial expressions can signal a potential threat to the individual (e.g., Dennis, Malone, & Chen, 2009).

These main effects were qualified by a three-way interaction among age, prime, and target. This interaction reflected an age-dependent modulation of the congruency effect; the 6-year-old children showed an earlier N400 response than the 3-year-old children by ~14 ms for incongruent conditions, whereas there was no age difference in N400 latency for congruent conditions. Research suggests that the N400 component reflects the integration of current information with any representations activated by a prime stimulus, which relies on more developed semantic processing (Hamm et al., 2002; Kutas & Federmeier, 2011; Maguire, Magnon, Ogiela, Egbert, & Sides, 2013). This integration is usually indexed by changes to the N400 amplitude (Friedrich & Friederici, 2004; Paulmann & Kotz, 2008; Paulmann & Pell, 2010). Whereas the presence of a prime stimulus that does not match the target often elicits increased N400 amplitude compared with congruent prime–target pairs (Amoruso et al., 2013; Deacon et al., 2000; Lau et al., 2008; McPherson & Holcomb, 1999), the opposite effects (Bermeitinger et al., 2008) or variations as a function of stimulus affective valence (Aguado et al., 2013) and individual characteristics (Bermeitinger et al., 2008; Bostanov & Kotchoubey, 2004; Goerlich et al., 2012; Paulmann & Kotz, 2008; Schirmer et al., 2013; Werheid et al., 2005; Zhang et al., 2006) have been reported as well. Studies have also shown that prime–target congruency can affect not only amplitude but also the latency of the N400 component in children and adults (Friedrich & Friederici, 2004; Tiedt et al., 2020; West & Holcomb, 2002). Our three-way interaction among age, prime, and target is consistent with these latter findings on the N400 latency. Furthermore, the 6-year-old children showed earlier N400 responses than younger children when PLDs and words were semantically incongruent, suggesting that the older children can extract the emotional information from body movements sooner before the onset of the words compared with younger children (Dawson, Webb, Carver, Panagiotides, & McPartland, 2004; Dennis & Hajcak, 2009).

Lastly, we found hemispheric effects for the amplitude and latency of the N400 component. We found a main effect of hemisphere with more negative-going ERP responses in the left hemisphere compared with the right hemisphere. For the N400 latency, there was an interaction between hemisphere and target. These findings were not the focus of the current study, but they are consistent with previous works (e.g., Friedrich & Friederici, 2004; Geangu et al., 2021; Vogel, Monesson, & Scott, 2012; West & Holcomb, 2002). The developmental trajectory of hemispheric effects during early childhood can be investigated in more detail in future work.

Developmental trajectory for processing naturalistic emotional body movements

Overall, our results suggest that the emergence of more complex emotion processing of body expressions occurs around 6 years of age, but it is not fully developed at this point in ontogeny. Considering that the naturalistic body movements we used have subtle motion differences between emotions (see Table 1), our findings are in line with previous studies suggesting that when biological motion cues are only slightly changed, 4- to 6-year-old children's sensitivity to these subtle manipulations continues to improve until adolescence (Freire et al., 2006; Hadad et al., 2011; Vieillard & Guidetti, 2009). Our interpretation of the current results is also consistent with Ross et al. (2012), who found that children's ability to recognize PLDs shows the steepest improvement from 4 to 8.5 years of age, with accuracy reaching 60% by 8.5 years (chance = 25%; adult performance = 80%).

Although 3-year-old children can extract the emotional information from the body movement as demonstrated by the prime effect on the N300 amplitude, their ability to relate the information to the meanings of the words may be slower compared with older children, possibly due to having less experience in observing and using body movement information (Boone & Cunningham, 1998; Nelson & Russell, 2011). Three-year-olds may also need more visual information for processing the emotional meaning of the body movement (Geangu et al., 2016b; Geangu & Vuong, 2020; Ross et al., 2012), particularly given that the body movements used in the current study were motion captured from adult actors expressing them under a naturalistic setting (i.e., narrating a story). Thus, it is possible that younger children may need to watch the entire emotional PLD prime to extract the relevant informa-

tion. In this case, the optimal level of activation of the corresponding emotional representation may be reached toward the end of the body movement and thus shortly before the word target (Aguado et al., 2013; Goerlich et al., 2012; Schirmer et al., 2013; Steinbeis & Koelsch, 2008). By comparison, 6-year-old children can infer emotional states based on fewer body movement cues or can process them more efficiently. Consequently, the optimal level of activation of the corresponding emotional representation may be reached sooner, well before the end of the body movement. With a longer delay before the onset of the target word, the activation of the emotional representation by the prime may diminish and not delay N400 responses when PLDs and spoken words are incongruent.

Beyond differences in processing naturalistic body movements to infer emotions, there may also be a developmental trajectory for children's ability to simulate motor plans associated with different emotional expressions (for a review of sensorimotor simulation models, see Ross & Atkinson, 2020). These trajectories may differ for different emotion expressivity (i.e., faces, bodies, voices). To address this, previous studies with children and adults used electromyography (EMG) to measure covert facial muscle activity in response to viewing static facial expressions (e.g., Deschamps, Schutte, Kenemans, Matthys, & Schutter, 2012; Geangu et al., 2016b; Hess & Blairly, 2001). These studies showed similar selectivity in muscle activity to specific emotions for all age groups (e.g., increased activity of the zygomaticus major when viewing a happy face). For bodies, however, 3-year-old children did not show selective facial muscle activity when they viewed static bodily expressions (Geangu et al., 2016b), whereas adults can sometimes show selectivity (Tamietto & de Gelder, 2008; Kret, Roelofs, Stekelenburg, & de Gelder, 2013). Collectively, these EMG studies suggest that 3-year-olds might not be able to link the body expression to the event causing their emotional state. This leads to an inability for sensorimotor simulation. Children's simulation abilities may also depend on whether the children need to *discriminate* different emotions or *recognize* them (i.e., identify or label the emotion). The latency difference in the N400 component reported here further suggests that younger children may be slower at extracting emotional information from body expressions, which may make it more difficult for them to simulate or recognize emotions compared with older children. These EMG studies focused on observers' facial muscles. Huis In 't Veld, Van Boxtel, and de Gelder (2014a, 2014b) measured EMG from non-face muscles related to emotion expressivity in adults, but there are no similar studies with children. Thus, future EMG studies along these lines can help to build a more complete picture of how children process subtle biological motion cues to infer emotions at different ages.

Lastly, there are limitations in the current study that can be addressed in future studies. First, we did not directly measure young children's ability to explicitly recognize the emotion expressed by the PLDs used in the current study (Volkova et al., 2014a, 2014b), which may have implications for understanding their priming effects on the target stimuli. It is important to note, however, the significant main effect of the prime on the amplitude of the N300 for both 3- and 6-year-old children. This indicates that the information extracted from the happy and angry PLD primes modulated the response to the target words, which speaks in favor of their effectiveness as prime stimuli. Furthermore, as noted by Ross and Atkinson (2020), there are potential developmental trajectories in terms of children's ability to simulate and/or articulate different expressions. Thus, there can be methodological challenges in asking children to rate or categorize these PLDs; for example, there may be difficulties and age differences in understanding the rating scale or the categorization task rather than emotion processing per se. It is worth noting that adults also do not consistently categorize these PLDs (see Table 1). To address our aim, we used the ERP priming paradigm to measure young children's ability to extract emotional meaning from naturalistic body movements. A second limitation is that it can be difficult to interpret age differences on the latency of ERP components due to maturational changes with age. A potential avenue for future research is to measure structural brain differences (e.g., using magnetic resonance imaging) between different age groups of children and test whether these differences correlate with latency and/or amplitude differences. A third limitation is that the development of auditory processing may affect how children process the prime stimulation. Our focus in this study was developmental changes in how children extract emotional information from naturalistic body movements. That said, children's ERP response to only neutrally spoken emotion words without any prime would be a possible future direction. Lastly, it is important to note that emotional expressivity in adults is dependent on cultural and socioeconomic contexts (e.g., Parkinson, Walker, Memmi,

& Wheatley, 2017). Considering that our sample may be biased toward British White participants from families who have the possibility to travel to the lab and dedicate time to participating in research, the generality of the current findings beyond this group may be limited. Thus, another avenue for future research is to investigate the developmental trajectory in other cultural or socioeconomic groups. Related to this future direction, it may be an important next step to consider children who experience abuse or trauma that can affect emotion processing of body expressions. There are ERP studies on facial emotion expressivity in children who grew up in environments characterized by violence or who suffered social neglect from a young age (e.g., Pollak & Tolley-Schell, 2003); however, to the best of our knowledge, none has investigated emotion processing of facial and/or body expressions.

Conclusions

The current study is one of the first to investigate the development of children's neural response underlying the emotion inferred from the unconscious and spontaneous body movements expressed by adults during naturalistic settings. Using the ERP priming paradigm, our findings suggest that children from as young as 3 years can extract the emotional information from naturalistic body movements (i.e., the prime effect for N300 amplitude and the congruency effect for N300 latency). By 6 years of age, children may begin to have more developed processing of the emotional relationship between naturalistic body movements and words (i.e., the Age × Congruency interaction for N400 latency), leading to faster ERP latencies in response to biological motion that may be semantically incongruent with spoken words. Thus, the emergence of more complex emotion processing of body expression ability seems to occur around 6 years of age.

CRediT authorship contribution statement

Han Ke: Conceptualization, Methodology, Formal analysis, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Quoc C. Vuong:** Methodology, Formal analysis, Writing – original draft, Writing – review & editing, Visualization. **Elena Geangu:** Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing, Visualization, Supervision.

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