Three- and Six-Year-Old Children are Sensitive to Natural Body Expressions of Emotion:

An ERP Emotional Priming Study

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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 in infancy, processing those cues to identify emotions likely continues to develop into childhood. Previous studies use posed or exaggerated body movements, which may not reflect the kind of body expressions children experience. The present study used an event-related potential (ERP) priming paradigm to investigate the development of emotion recognition from more naturalistic body movements. Point-light displays of male adult bodies expressing happy or angry emotional movements while narrating a story were used as prime stimuli, while 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 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 compared to 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 between age, prime and target for latency, suggesting an age-dependent modulation of this 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 to other people's body movements (for a review, see Thornton et al., 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, and hips). Despite the absence of many visual form cues (e.g., shape, colour, etc.), 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 et al., 2004; Volkova et al., 2014a,b) and psychological traits (Thoresen et al., 2012), even in the absence of static and dynamic facial information (Bassili, 1979; Willis & Todorov, 2006). While new-born infants show sensitivity to biological compared to other types of motion (Simion et al., 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. Towards 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) or auditory (e.g., vocal expressions) cues—to extract emotional and socially-relevant information related to emotions (e.g., Bayet et al., 2018; Crespo-Llado et al., 2018a,b; Gao & Maurer, 2009; Geangu et al., 2015, 2016a,b, 2021; Geangu & Vuong, 2020; Poulin-Dubois et al., 2018; Quadrelli, Geangu, & Turati, 2019; Yeh et al., 2016; Zieber et al., 2014). These studies used a variety of complementary measures including behaviour, 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 et al., 2018; Zieber et al., 2014a,b; for a review see Bhatt et al., 2016). For example, Heck and colleagues presented 3.5-month-old 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-old but not 3.5-month-old infants preferentially looked at congruent stimuli. This preferential looking only occurred when the videos were upright, which highlights the importance of global biological-motion cues.

In the present study, we focused specifically on biological-motion cues in the absence of form or other cues, including facial motion. The results from behavioural and neuroimaging studies with infants and children suggest that both the ability to detect biological motion (e.g., from PLDs; Hadad et al., 2011; Hirai & Hiraki, 2005; Hirai et al., 2003, 2013; Marshall & Shipley, 2009; Pavlova, 2012; Simion et al., 2008) and to accurately identify the emotion expressed (Missana et al., 2014; Ross et al., 2012) have a protracted developmental trajectory. It is believed that for both of 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 non-coherent biological motion in which the individual points are temporally or spatially “scrambled” (Berthenthal et al., 1987; Moore et al., 2007), and by the age of 4- to 6-years 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 in adolescence, it remains particularly diminished in complex visual displays (Freire et al., 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 which 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 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 the age of 8.5 years, with the steepest increase between 4 and 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 were 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 are closer to the age of 2 years, while the accuracy in labelling of happiness, anger and fear increased as children reach the age of 4 years (Lagerlöf & Djerf, 2009). By 5- to 8-year-old, 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 2-3 year-old 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 which 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-impooverished PLDs particularly when comparing between 3-year-old and 6-year-old children (Ross & Atkinson, 2020). For instance, the younger children may 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 et al., 2005), while 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 present study, we used ERPs to investigate 3- and 6-year-old children's 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,b). 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 et al., 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 et al., 1986; Kristen et al., 2014; Li & Yu, 2015; Ridgeway et al., 1985; Taumoepeau & Ruffmann, 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 label without potential task confounds, such as the need for behavioural responses. Using this paradigm, we presented either an angry or happy PLD as a prime followed by the word “angry” or “happy” uttered with emotionally-neutral prosody as a target, and measured ERP responses to the auditory word *target*. Children in both age groups can understand to some extent the semantic meaning of the words (Bretherton et al., 1986; Kristen et al., 2014; Li & Yu, 2015; Ridgeway et al., 1985; Taumoepeau & Ruffmann, 2006, 2008). Moreover, the emotional information conveyed visually by the face and body, and auditorily by the voice are frequently associated with the corresponding emotion category label, and could be learned from very early on. Indeed, at the behavioural level, children as young as 2-year-old can correctly choose the facial expression 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 which 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 et al., 2013; Werheid et al., 2005; Zhang et al., 2006). Both components can be elicited in infancy and childhood (e.g., Friedrich & Friederici, 2004, 2005, 2008; Parise & Csibra, 2012; Sheehan et al., 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 et al., 1992; Schapkin et al., 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 fulfilment 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 et al., 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 et al., 2008). It is also elicited when different meaningful stimuli, such as story pictures, action sequences, or music, are paired so that their semantic content do not match (Aguado et al., 2013; Steinbeis & Koelsch, 2008; West & Holcomb, 2000).

Typically in the ERP priming paradigm, a target word which is semantically incongruent with the prime elicits more negative amplitude of N300 and N400 components compared to a word which 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 et al., 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 et al. (2020) provided evidence of a congruency effect in the N400 amplitude in young but not older adults, and in the N400 latency in old 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.

Materials and Methods

Participants

A total of 54 children were tested. The final analysis included 34 children (3-year-old: $N = 17$, 8 females, $M_{age} = 45.82$ months, $SD = 5.60$ months; 6-year-old: $N = 17$, 10 females, $M_{age} = 78.24$ months, $SD = 5.18$ months). The remaining 20 children (3-year-old, $N = 18$; 6-year-old, $N = 2$) 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 [masked for anonymity] University. The main source for this database was from the local hospital. Based on the demographics and geographical region served by the hospital, the majority of the

participants recruited and tested tends to be British white but we did not collect information regarding participants' ethnicity. Moreover, as our study was lab-based, our sample may be biased towards parents who are able and have time to travel to the lab for a research session. Parents gave informed written consent on behalf of their child 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 (the Declaration of Helsinki, 1991) and was approved by the University Ethic Committee. The data is available upon reasonable request to the authors for research and teaching purposes.

Stimuli

The stimuli consisted of PLDs which 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 of the right wrists, 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 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, non-parametric independent samples Mann-Whitney *U* tests showed no differences between the two emotion categories ($ps > .10$, 2-sided).

Table 1

Means and SDs 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 number in the database of the angry PLDs were 549, 644 and 1135. The identification number of the happy PLDs from the database were 523, 544 and 660 (labelled *joy* in the database). The magnitude of optic flow for each PLD was estimated as follows. We first calculated the displacement of 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.

The two target stimuli were 505-ms audio recordings of the words “angry” or “happy” spoken in an emotionally neutral tone by 3 native English-speaking female adults. They were selected from a pool of 30-word utterances recorded in an anechoic chamber by the 3 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 having “neutral” prosody by at least half of 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 which 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 $22.1^\circ \times 22.1^\circ$ (horizontal $\times$ vertical). The experiment was programmed in Matlab (Mathworks, Inc.). EEG was recorded with a 128-electrode HydroCel Geodesic Sensor Net (Electrical Geodesic Inc., Eugene, OR) and amplified using an EGI NetAmps 300 amplifier. A video recorder synchronized with the EEG was used to record participants' during the experiment. The videos were used off-line 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 or Happy) were factorially combined with the two auditory word targets, resulting in four *prime-target* conditions (Figure 1). This factorial design resulted in two congruent conditions in which the prime and target were of the same emotion (Figures 1A and 1C) and two incongruent conditions in which the prime and target were of different emotions (Figures 1B and 1D).

The trial sequence is illustrated in Figure 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 inter-stimulus 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., Geangu et al., 2021; Bristow et al.,

2009). After the offset of the target, a central white fixation cross was presented on a black background for an inter-trial interval (ITI) varying randomly between 1800 and 2000 ms. To maintain participants' attention throughout the task, a non-task-related image (a rainbow-color 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 for a maximum of 27 times. The three different PLDs for each emotion was randomly sampled with replacement on each trial.

Figure 1*Example of the trial sequence for the four prime-target pairs*

Note. 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). (A) and (C) are *congruent* prime-target pairs, and (B) and (D) are *incongruent* prime-target pairs.

EEG Acquisition and Pre-processing

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 band-pass filter of .1–100 Hz was applied. Impedances were checked prior to the beginning of the recording and they were considered acceptable if lower than 50 $k\Omega$. The EEG data were further processed off-line using NetStation v 4.5.4 (Eugene, OR). The signal was band-pass filtered (0.3–30 Hz), and segmented from 100ms (baseline) before the onset of the auditory word target to 1000ms after onset for each trial. Segments were baseline corrected. To eliminate artifacts, segmented data were automatically rejected whenever the signal exceeded $\pm 200 \mu V$ 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 pre-processing 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 was 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., Geangu et al., 2021; Bristow et al., 2009; Crespo-Llado et al., 2018a; Hendrickson, Love, Walenski, & Friend, 2019). The average number of included trials as a function of condition and age group is presented in Table 2.

Table 2

Mean numbers of trials (and SD) included in the analysis for each Prime - Target condition, separately for each age group. The maximum number of trials in each condition is 27.

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

Statistical Analyses

Following EEG pre-processing, we conducted statistical analyses on the amplitude and latency of the N300 and N400 components within regions of interest (ROIs). Figure 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 (250-380ms) at the central ROIs, and the N400 (400-550ms) 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; Steinbeis & Koelsch, 2008; Henderson et al., 2011) 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 μ V (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-old, 6-year-old) $\times$ 2 Hemisphere (Right, Left) $\times$ 2 Prime (Happy PLD, Angry PLD) $\times$ 2 Target ("happy" word, "angry" word) mixed analysis of variance (ANOVA), with Age as a between-subjects

factor and the remaining variables as within-subject factors. For significant Prime $\times$ Target interactions, we tested for congruency effects by computing means for congruent (averaging Angry-Angry and Happy-Happy *prime-target* pairs) and incongruent (averaging Angry-Happy and Happy-Angry *prime-target* pairs) conditions 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 $\alpha = .05$.

Figure 2

The location of the electrodes included for the central (blue) and parietal (red) regions of interest (ROIs) in the left and right hemisphere

Results

Central N300

Amplitude. Figures 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 ($M = -3.242 \mu\text{V}, SE = .630 \mu\text{V}$) eliciting a more negative N300 amplitude than when primed by Angry PLDs ($M = -2.096 \mu\text{V}, SE = .694 \mu\text{V}$; Figure 3C). There was no significant difference in N300 amplitude between 3-year-old ($M = -2.575 \mu\text{V}, SE = .856 \mu\text{V}$) and 6-year-old children ($M = -2.762 \mu\text{V}, SE = .856 \mu\text{V}; p = .878$), nor between “angry” ($M = -2.887 \mu\text{V}, SE = .675 \mu\text{V}$) and “happy” word targets ($M = -2.451 \mu\text{V}, SE = .637 \mu\text{V}; p = .399$). All other main effects and interactions were not significant ($ps > .132$). Given that there was no effect or interaction

with Age, Figure 4 shows the ERPs at central scalp ROIs as a function Hemisphere, Prime and Target averaged across Age.

Latency. There was a significant Prime $\times$ Target interaction, $F(1,32) = 9.492, p = .004, \eta_p^2 = .229$ (Figure 3D). Post-hoc t -tests between 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 ($M = 322$ ms, $SE = 2$ ms) compared to the incongruent ($M = 314$ ms, $SE = 2$ ms) conditions (Figure 3D).

Figure 3*EEG results for the central N300 component*

Note. ERPs to target words for 3-year-old (A) and 6-year-old (B) children as a function of Hemisphere, Prime (Angry or Happy PLD) and Target (“angry” or “happy” word). The black horizontal line indicates the N300 window. The shaded regions indicate the standard error of the mean. The main effect of Prime for amplitude (C); and the Prime $\times$ Target interaction and congruency effect for latency (D). 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. ** $p = .024$.

Figure 4

EEG results for the central N300 component averaged across 3- and 6-year-old children

Note. ERPs to target words as a function of Hemisphere, Prime (Angry or Happy PLD) and Target (“angry” or “happy” word). The black horizontal line indicates the N300 window. The shaded regions indicate the standard error of the mean.

Parietal N400

Amplitude. Figures 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 ($M = -1.604 \mu\text{V}$, $SE = 1.037 \mu\text{V}$) and 6-year-old children ($M = -2.392 \mu\text{V}$, $SE = 1.037 \mu\text{V}$; $p = .595$); between Angry ($M = -1.800 \mu\text{V}$, $SE = .866 \mu\text{V}$) and Happy PLDs ($M = -2.197 \mu\text{V}$, $SE = .810 \mu\text{V}$; $p = .628$); and between “angry” ($M = -2.100 \mu\text{V}$, $SE = .828 \mu\text{V}$) and “happy” words ($M = -1.897 \mu\text{V}$, $SE = .705 \mu\text{V}$; $p = .662$). There were no Prime $\times$ Target ($p = .127$), nor Age $\times$ Prime $\times$ Target ($p = .897$) interactions. There was a main effect of Hemisphere, $F(1,32) = 6.867$, $p = .013$, $\eta_p^2 = .177$ (left: $M = -1.115 \mu\text{V}$, $SE = .802 \mu\text{V}$; right: $M = -2.882 \mu\text{V}$, $SE = .810 \mu\text{V}$).

Latency. The omnibus ANOVA showed significant main effects of Age, $F(1,32) = 4.357$, $p = .045$, $\eta_p^2 = .120$; and Target, $F(1,32) = 32.094$, $p < .001$, $\eta_p^2 = .501$. The 6-year-old children had earlier N400 latency ($M = 472 \text{ ms}$, $SE = 2 \text{ ms}$) than 3-year-old children ($M = 479 \text{ ms}$, $SE = 2 \text{ ms}$); and all children had earlier N400 latency to “angry” ($M = 469 \text{ ms}$, $SE = 2 \text{ ms}$) compared to “happy” targets ($M = 481 \text{ ms}$, $SE = 2 \text{ ms}$). There was a Hemisphere $\times$ Target interaction, $F(1,32) = 4.274$, $p = .047$, $\eta_p^2 = .118$.

There was a significant Age $\times$ Prime $\times$ Target interaction, $F(1,32) = 5.645$, $p = .024$, $\eta_p^2 = .150$ (Figure 5C). As with the N300, we computed the mean latency for congruent and incongruent conditions to further investigate the 3-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, $F(1,32) = 4.357$, $p = .045$, $\eta_p^2 = .120$, and importantly an Age $\times$ Congruency interaction, $F(1,32) = 5.645$, $p = .024$, $\eta_p^2 = .150$ (Figure 5D). Post-hoc t -tests showed that there was no latency differences between 3-year-old ($M = 476 \text{ ms}$, $SE = 2 \text{ ms}$) and 6-year-old ($M = 476 \text{ ms}$, $SE = 3 \text{ ms}$) children for the congruent conditions, but the older children had earlier N400 latency than

the younger children for the incongruent conditions (3-year-old: $M = 482$ ms, $SE = 3$ ms; 6-year-old: $M = 467$ ms, $SE = 3$ ms; $t(32) = 2.84$, $p = .042$). No other comparisons were significant ($ps > .05$).

Figure 5

EEG results for the parietal N400 component

Note. ERPs to target words for 3-year-old (A) and 6-year-old (B) children as a function of Hemisphere, Prime (Angry or Happy PLD) and Target (“angry” or “happy” word). The black horizontal line indicates the N400 window. The shaded regions indicate the standard

error of the mean. The Age $\times$ Prime $\times$ Target interaction for amplitude (C), and the Age $\times$ Congruency interaction for latency (D). 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. ** $p < .042$.

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., colour or 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 meaning 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 fulfilment (within context) of visual and auditory stimuli, proceeding 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). We therefore 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 determine when this ability emerges.

We found that both age groups showed larger negative N300 amplitudes to words preceded by happy than 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 expression

and word 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 the body expression and word 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 in childhood.

N300 at central scalp locations

We found a prime effect for the amplitude the N300 component. Both 3- and 6-year-old children showed increased negative N300 amplitude in response to target words preceded by happy compared to angry body movements. This prime effect is consistent with previous studies which show that the N300 response precedes more advanced cognitive processing of semantic meaning 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. As we used different exemplars of angry and happy body movements these findings suggest that by at least the age of 3 years, children are able to extract and represent subtle motion features of the PLDs specific to each emotional category. The 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 (Angry-Angry or Happy-Happy *prime-target* pairs) compared to the incongruent (Angry-Happy or Happy-Angry) conditions. This finding is consistent with previous studies which showed 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 (3-5s) 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 to 1000 ms; Daltrozzo et al., 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, nor 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” compared to “happy” target words, providing evidence that children can extract meaning from the words. The earlier latency to angry compared to happy target word may reflect the activation of threat-related representations; for example, angry facial expressions can signal a potential threat to the individual (e.g., Dennis et al., 2009).

These main effects were qualified by a 3-way interaction between age, prime and target. This interaction reflected an age-dependent modulation of the congruent 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). While the presence of a prime stimulus which does not match the target often elicits increased N400 amplitude compared to 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 3-way interaction between age, prime and target is consistent with these latter findings on the N400 latency. Furthermore, the 6-year-old children showed earlier N400 response 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 word compared to younger children (Dawson et al., 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 compared to the right hemisphere. For the N400 latency, there was an interaction between hemisphere and target. These findings were not the focus of the present study but they are consistent with previous works (e.g., Friedrich & Friederici, 2004; Geangu et al., 2021; Vogel et al., 2012; West & Holcomb, 2002). The developmental trajectory of hemispheric effects in 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 which suggest 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 & Guidetta, 2009;). Our interpretation of the present results is also consistent with Ross et al. (2012), who found that children's ability to recognize PLDs shows the steepest improvement between 4 and 8.5 years, with accuracy reaching 60% by 8.5 years of age (chance = 25%, adult performance = 80%).

While 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 meaning of the words may be slower compared to older children, possibly due to having less experience observing and using body-movement information (Boone & Cunningham, 1998; Nelson & Russell, 2011). Three-year-old children 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 present study were motion-captured from adult actors expressing them under a naturalistic setting (i.e., narrating a story). It is thus possible that younger children may need to watch the entire emotional PLD prime to extract the relevant information. In this case, the optimal level of activation of the corresponding emotional representation may be reached towards 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 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 or 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., Deschamp et al., 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 et al., 2013). Collectively, these EMG studies suggest that 3-year-old children may 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 they 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 to older children. These EMG studies focused on observers' facial muscles. Huis In 't Veld et al. (2014a,b) 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 build a more complete picture of how children process subtle biological-motion cues to infer emotions at different age groups.

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 present study (Volkova et al., 2014a,b), 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 favour 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 component 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 are dependent on cultural and socio-economic contexts (e.g., Parkinson, Walker, Memmi, & Wheatley, 2017). Considering that our sample may be biased towards 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 socio-economic 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) but, to the best of our knowledge, none have investigated emotion processing of facial and/or body expressions.

Conclusions

In summary, the present 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 the age of 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 $\times$ 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 expressions ability seems to occur around 6 years of age.

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