The Role of Motor Representation in Infants' Sensitivity to Emotional Information in Action Kinematics

Lisanne Schröer[1]
In collaboration with: Deniz Çetin[2], Stefania Vacaru[1] and dr. Johanna van Schaik[3]
Supervised by: Prof. dr. Sabine Hunnius[1]

[1]*Donders Institute of Brain, Cognition and Behaviour, Radboud University Nijmegen*
[2]*Institute of Psychology, Leiden University*
[3]*Institute of Education and Child Studies, Leiden University*

Emotional information can be conveyed by deviations in action kinematics (Montepare et al., 1999; Pollick et al., 2001). By 11- to 12-months of age, infants showed sensitivity to the emotional valence of action kinematics (Addabbo et al., in preparation). Whilst the underlying mechanisms of this sensitivity remain unclear, it is widely accepted that our motor system represents observed actions of others. A recent study provided the first evidence that perceived emotional states of others are dependent on our own movement kinematics (Edey et al., 2017). This suggests that infants might become sensitive to emotional information conveyed in kinematics once they have a sufficiently detailed motor representation allowing them to detect deviations in another person's movement kinematics.

This study aimed to understand how young infants become sensitive to emotional information conveyed in kinematics. Firstly, this study examined whether it could replicate the results of Addabbo and colleagues (in preparation) in a large sample. Secondly, this study investigated whether infants who have a more detailed motor representation, indicated by less kinematic variability in their movement, were more sensitive to deviations in kinematics conveying emotional information. Action kinematics of 12- to 13-month-old infants were investigated in two transport tasks using motion capture. Infants' sensitivity to kinematics of angry and happy transport actions was investigated using facial electromyography (EMG), following Addabbo et al. (in preparation). Forty-six infants with sufficient EMG data were included in the analysis to examine whether infants were sensitive to emotional information conveyed in kinematics. Twenty-four infants with sufficient data for both tasks were included in the analysis to investigate whether infants with a more detailed motor representation were more sensitive to emotional information conveyed in kinematics.

The EMG data did not provide evidence that infants this age are already sensitive to emotional information conveyed in action kinematics. The combined data of both tasks indicated a significant correlation between the measurement of motor representation and infants' sensitivity to happy kinematics. However, in contrast to our predictions, infants with higher variability, hypothesized as a less detailed motor representation, showed more zygomaticus muscle activation in response to happy stimulus videos.

This unexpected finding that more variable infants were more sensitive to emotional information (i.e., more zygomaticus compared to corrugator activation to happy stimuli) might be due to expressive infants that were more active and happy overall over both sessions, resulting in more variability in their movement and more zygomaticus activation in the EMG session. There was no evidence for a relationship between the measurement of motor representation and the sensitivity to emotional information conveyed in kinematics. However, it might be that our motor task did not capture the detailedness of the infants' motor representations as assumed. Future research should design an age-appropriate task in order to measure the detailedness of motor representation.

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Corresponding author: Lisanne Schröer; E-mail: l.schroer@bbk.ac.uk

Emotion recognition

Developing the ability to recognize emotions in other persons is essential for infants and young children for successful social interaction (Harms, Martin, & Wallace, 2010). Research has shown that infants become sensitive to emotional expressions during the first year of life. At 3 months of age, infants can already discriminate between facial expressions of surprise and happiness (Young-Browne, Rosenfeld, & Horowitz, 1977), as well as anger and happiness (Barrera & Maurer, 1981) and by 7 months of age, infants can discriminate between facial expressions of fear and happiness (Kotsoni, de Haan, & Johnson, 2001).

Importantly, facial expressions are not the only source of information that can be used for recognizing how another person feels. Information about another person's emotions can also be retrieved from vocal expressions, body posture and body motion patterns (Dael, Mortillaro, & Scherer, 2011; Heberlein & Atkinson, 2009). In particular, body motion patterns are an important source of emotional information for adults. For example, adults were able to identify emotions in body movements and gestures in actors with blurred faces (Montepare, Koff, Zaitchik, & Albert, 1999). In addition, people were capable of recognizing and identifying emotions from gait information (Montepare, Goldstein, & Clausen, 1987). Furthermore, adults could recognize emotions in point-light displays based on motion cues in arm movements (Pollick, Paterson, Bruderlin, & Sanford, 2001), walking movement (Nackaerts et al., 2012) and dance movement (Dittrich, Troscianko, Lea, & Morgan, 1996; Walk & Homan, 1984). Stern (2010) named these emotional actions vitality forms describing the 'how' of an action. In vitality forms, emotions can be detected on the basis of movement dynamics, time profile, force, space or direction (Di Cesare et al., 2014). These emotional actions (e.g., Montepare et al., 1999; Pollick et al., 2001) appeared to deviate in terms of their kinematics compared to normal actions that do not convey emotional information. For example, participants rated angry body movements and gestures as jerkier than happy or sad body movements and gestures, while happy body movements and gestures were rated as smoother (Montepare et al., 1999). An analysis of movement kinematics provided evidence that positive affect in movement kinematics is related to longer duration, slower velocity, slower acceleration and less jerk in arm movements performing drinking and knocking actions (Pollick et al., 2001). In sum, emotional information in action appears to be conveyed by deviations in kinematics.

To date, several researchers have stressed that emotional information in body movement and posture might be even a more important source for emotion recognition than facial expressions (Aviezer, Trope, & Todorov, 2012; de Gelder, 2006). When the emotional cues from the body and the face of an image were mismatched, judgement of the facial expression is limited and is biased into the direction of the emotion expressed by the body (Meeren, van Heijnsbergen, & de Gelder, 2005). This provides evidence that emotional cues from the body bias discrimination of emotional facial expressions in favour of body cues in adults (Aviezer et al., 2012; de Gelder, 2006; Meeren et al., 2005) and in infants (Rajhans, Jessen, Missana, & Grossman, 2016).

However, to date, there has been little research done into how recognition of emotional information in body movement develops in infancy. Using facial electromyography (EMG), a recent study provided the first evidence that infants of 11-to 12-month-old are already sensitive to emotional information conveyed in kinematics of movements. Happy expressions in the kinematics of an action induced a greater response in the zygomaticus major ('smiling muscle'), while angry expressions in the kinematics induced a greater response in the corrugator supercilii ('frowning muscle'), providing evidence that infants of this age show sensitivity to the emotional valence of action kinematics (Addabbo, Meyer, Vacaru, & Hunnius, in preparation).

Action experience

Whilst the underlying mechanisms of this sensitivity remain unclear, it is widely accepted that our motor system represents actions we observe in others (e.g., Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995; Hari et al., 1998; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996; Rizzolatti & Luppino, 2001). Such motor representations of actions become more detailed as experience with that certain action increases. Observed actions that are part of our motor repertoire activated the observer's motor system. However, actions that are outside of our motor repertoire led to little activation in the motor areas (Buccino et al., 2004). Expert dancers trained in either classical ballet or capoeira showed more motor activation when observing movements they had been trained to perform compared to movements they had not (Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2004; Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard, 2006). This motor activation is thought to reflect an internal motor representation that is activated during action observation (Buccino et al., 2004; Calvo-Merino et al., 2004; Calvo-Merino et al., 2006; Hunnius & Bekkering, 2014). Such internal motor representations become more detailed with experience, likewise in infancy. Infants who received motor training with an action with a sound effect showed more motor activation to the sound associated with the learned action compared to a familiar sound not associated with the movement that the infant produced (Gerson, Bekkering, & Hunnius, 2015).

Infants and adults use their own motor representation of actions to predict and interpret actions of others (e.g., Blakemore & Decety, 2001; Gallese & Goldman, 1998; Hunnius & Bekkering, 2014; Sommerville & Woodward, 2005; Southgate, Johnson, El Karoui, & Csibra, 2010; Wilson & Knoblich, 2005). More motor experience with a certain action, and respectively an improved motor representation, enhanced predicting and interpreting of actions in expert sport players (Abernethy, Zawi, & Jackson, 2008; Aglioti, Cesari, Romani, & Urgesi, 2008; Brault, Bideau, Kulpa, Craig, 2012; Diersch, Cross, Stadler, Schütz-Bosbach, & Rieger, 2012; Jackson, Warren, & Abernethy, 2006; Sebanz & Shiffrar, 2009). For example, expert basketball players with high levels of motor experience in a certain action showed an enhancement of perception in discriminating (Sebanz & Shiffrar, 2009) and predicting that certain action (Aglioti et al., 2008).

Hunnius and Bekkering (2014) suggest that action experience is essential for the infants' developing action understanding to form associations between motor representations and the sensory consequences of these actions. For example, the extent of an infant's motor experience with crawling or walking, therefore the detailedness of the infant's motor representation, determined the accuracy of the infant's prediction of another person's crawling or walking action (Stapel, Hunnius, Meyer, & Bekkering, 2016). Movement experience of an infant with a certain action, and therefore a more detailed motor representation of that certain action, improved predicting and interpreting another person's action (Cannon, Woodward, Gredebäck, von Hofsten, & Turek, 2012; Gerson & Woodward, 2014; Sommerville, Woodward, & Needham, 2005; Stapel et al., 2016).

Now, there is the first evidence that such motor representations play a role in deciphering emotions in another person's actions (Edey, Yon, Cook, Dumontheil & Press, 2017). Edey and colleagues (2017) hypothesized that we use our own motor representations of action kinematics to make judgments about the emotional states of others. In their experiment, participants had to judge the emotion of point-light-display walkers on a 10 point scale from not at all happy/angry/sad to very happy/angry/sad. A person who walks with high velocity is generally rated as angry, while a person who walks with low velocity is rated as sad. In addition, the own walking speed of the participants was assessed. There was a relationship between the participants' own walking speed and their judgments about the emotion of the point-light-display walker. Faster walkers rated high velocity point-light-display walkers as less intensely angry, while low velocity point-light-display walkers were rated as more intensely sad. This evidence that perceived emotion in kinematics is dependent on participants' own movement characteristics suggests that we use motor representations of our own movement kinematics to make judgements about emotional states of others (Edey et al., 2017).

Current study

Our own motor experience is essential to improve the motor representation of that specific action. In addition, there is the first evidence that we use the deviations from these motor representations as an indication of emotional states of others (Edey et al., 2017). This would imply that infants become sensitive to emotional information conveyed by kinematics, once they have a sufficiently detailed motor representation that allows them to detect deviations in another person's movement kinematics. Infants are still very variable in the movements they execute, but with practice, movements and their respective motor representations improve (Calvo-Merino et al., 2004; Calvo-Merino et al., 2006; Fetters & Todd, 1987; Gerson et al., 2015; Hunnius & Bekkering, 2014; Konczak, Borutta, Topka, & Dichgans, 1995; Mathew & Cook, 1990; von Hofsten, 1991).

This study aimed to understand how young infants become sensitive to emotional information conveyed in kinematics. We hypothesized that infants need a detailed motor representation in order to become sensitive to emotional information conveyed in action kinematics. Developing a detailed motor representation in infancy is dependent on motor development. Here, we examined whether infants who have a better detailed motor representation of their kinematics were indeed more sensitive to deviations in kinematics conveying emotional information.

In a two-part study, we investigated whether infants' motor representation plays a role in deciphering emotions in another person's actions. In the first session, infant's own motor representation was investigated with the infant moving an object measured by motion capture. Actions conveying emotional information seem to be different in terms of their kinematics compared to normal actions (Montepare et al., 1999; Pollick et al., 2001). Therefore, we decided to measure variability (Cook, Blakemore & Press, 2013) over the infant's own movement kinematics as a measurement of detailedness of motor representation. We hypothesized that infants require a sufficiently detailed motor representation in terms of their kinematics in order to identify deviations in kinematics in observed movement conveying emotional information. In the second session, infants' sensitivity to kinematics of angry and happy actions was investigated by measuring facial muscle activity in response to emotional videos with angry and happy action kinematics in transport movements using facial EMG.

We hypothesized that infants would show activation in the zygomaticus muscle and deactivation in the corrugator muscle for actions with happy kinematics, while they would show activation in the corrugator muscle and deactivation in the zygomaticus muscle for actions with angry kinematics, replicating the findings of Addabbo and colleagues (in preparation). Secondly, we hypothesized that infants with a more detailed motor representation of their own kinematics would display a greater sensitivity to emotional information conveyed in kinematics of observed actions, following the reasoning based on Edey and colleagues (2017).

Methods

Participants

Total sample. A total of eighty-three 12- to 13- months-old infants were tested in this study (Table1). In Figure 1, a flowchart illustrates the participant inclusion and exclusion in the different analyses. Families were recruited from the Baby & Child Research Center database in Nijmegen, a medium sized city in the Netherlands, and its surroundings. Participation in the research was voluntary and parents of the infants were called to see if they wanted to participate with their infant. Parents were informed beforehand about the test procedure and all parents gave written informed consent. Families were given a thank-you gift for participation. All procedures were approved by the local ethics committee.

Sample with sufficient EMG data. Forty-six infants (Table 1) were included in the analysis to test whether infants were sensitive to emotional information conveyed in kinematics. From this sample, twenty-four infants (Table 1) had sufficient data for both tasks to test whether infants with a more detailed motor representation were more sensitive to emotional information conveyed in kinematics (see below). An additional thirty-seven infants (Table 1) were tested, but data was excluded from both analyses, because they did not want to wear the EMG electrodes ($N = 9$), were sick at the second session ($N = 3$), there was a technical error in recording the video during the emotional sensitivity task ($N = 3$), there was a technical error in recording the EMG data (N = 5), they were too fussy (N = 6), they did not watch enough trials (N = 10) or were chewing during the experiment (N = 1). Similar drop-out rates have been reported before in facial EMG research with infants and children (Geangu, Quadrelli, Conte, Croci, & Turati, 2016; Isomura & Nakano, 2016; Vacaru, van Schaik, & Hunnius, under review).

Sample with sufficient data for both tasks. Twenty-two infants, who were included in the first analysis, were excluded from the analysis to investigate whether infants with a more detailed motor representation were more sensitive to emotional information conveyed in kinematics, because they had no trials for both motion tasks (N= 13), they had too little trials (less than 3) for the motion task (N = 7), they did not want to wear the motion capture markers (N = 1), or they had no data for the hand marker (N = 1). This left twenty-four infants to be included in the analysis.

Stimuli and procedure

This study consisted of two parts. Infants' motor representation was measured in the first session using motion capture. In the second session, infants' sensitivity to kinematics of angry and happy actions was investigated by measuring facial muscle activity in response to emotional videos with angry and happy kinematics in transport movement using facial EMG. The movement session always occurred first, with the second session measuring emotional sensitivity following preferably within 1 to 10 days. This was done in order to avoid potential biases of the emotional video stimuli on the movement of the infants.

Task on own movement kinematics. Each infant was seated at a table in a baby chair. The parent was seated next to the infant and the experimenter was seated in front of the infant. In order to track the movement of the infant's hand, reflective markers were placed on the infant's preferred hand and corresponding wrist. Parents were asked beforehand about the preferred hand of their infant. If the parent was unable to indicate a preferred hand, the infant was assumed to be right-handed. The experimenter used doubled-sided tape to place one marker on the knuckle of the infant's middle finger (3rd metacarpal) and one marker on the

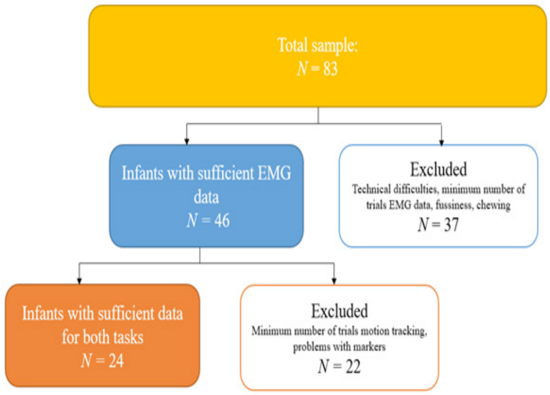

Figure 1. Flowchart of infants included in the different analyses. NB: For testing hypothesis **1**: only EMG data needed and for testing hypothesis **2**: both EMG and motion capture data was required.

Table 1.

Sample size, age in days and months and the mean days between two sessions of the samples.

	Total sample	Sample with sufficient EMG data	Sample with sufficient data for both tasks
Sample size	83 (46 females)	46 (26 females)	24 (9 females)
Age in days at the emotional sensitivity task	389.76 (SD = 11.41; range: 370 - 419)	391.00 (SD = 10.71; range: 375 - 418)	391.50 (SD =11.46; range: 375 - 418)
Age in months at the emotional sensitivity task	12.8 (SD = 0.38; range: 12.1 – 13.8)	12.8 (SD = 0.35; range: 12.3 – 13.7)	12.9 (SD = 0.38; range 12.3 – 13.7)
Mean days between sessions	7.81 (SD = 5.05)	8.30 (SD = 5.90)	7.17 (SD = 5.19)

corresponding location on the infant's wrist. Movements were recorded at 100 Hz using a 3D optical motion capture system (Qualisys AB, Götenborg, Sweden) with eight infrared cameras positioned around the whole table. The session was filmed using the Qualisys system camera at 13 Hz to record the start and the end of each transport movement. Parents were instructed to encourage their infant to play with the balls only using their preferred hand containing the markers.

We used two different tasks to measure the infant's transport movement. The two tasks, one easier and one more difficult, were picked based on the pilot results. These pilot results indicated that the more difficult task was the most appropriate for the age group, therefore it was decided to carry out this task first. The first task (more difficult task) was to transfer a ball from a red block onto a track (see Fig.2A). When the ball was placed on the track, it would roll down the track. The experimenter encouraged the infant verbally and non-verbally to repeat this action at least 10 times. The distance between the red block and the track was 28 cm. Next, the experimenter switched the setup to the second task. The second task (easier task) was to transfer a ball from a red block into a bowl (see Fig. 2B). Again, the infant was encouraged to repeat this action at least 10 times. The distance between the red block and the bowl was 28 cm.

Task on emotional sensitivity. Infants watched stimulus videos portraying actions with happy or angry kinematics. Stimulus videos featured an adult transporting the object (a green donut, a coloured ball, a red bar, a coloured donut or a purple ball) into a tray either from left to right or right to left displaying an angry action or a happy action. The two emotional actions were identical but performed expressing a different emotion (angry or happy). Analysis of the stimuli videos showed that actions with happy kinematics were associated with slower velocity, slower acceleration and less jerk in movement compared to actions with angry

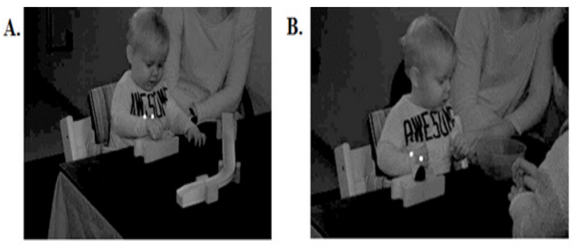

Figure 2. A. The experimental set-up for the transporting task onto the track. **B**. The experimental set-up for the transporting task into the bowl.

kinematics. These stimuli videos were used in previous research (Addabbo et al., in preparation). Four different actors featured in the videos, resulting in a total of 64 different stimuli videos: 32 angry and 32 happy. Only the torso of the actor was visible during the actions, whereas their face was out of view. Videos were presented in a pseudo-randomized way. The pseudo-randomized sequences of videos were created in the program "Mix" (van Casteren & Davis, 2006). The whole experiment consisted of 3 blocks with in total 256 trials: 128 angry and 128 happy trials.

Each trial (see Fig. 3) started with a fixation cross paired with a beep sound to attract the infant's attention to the centre of the screen. The fixation cross was displayed with a varying time between 600 to 1000 milliseconds. This fixation cross was used as baseline. Next, a video depicting either happy or angry emotion conveyed in the kinematics was played with a length of 2800 milliseconds. After each trial, there was a 500 milliseconds inter-trial interval (grey screen) before the beep sound was played again. The fixation cross was displayed 45 to 50 milliseconds later. There was the following constraint: no emotion could occur more than two times successively.

EMG procedure and recordings.

Infants were seated on the lap of the parent, and the parent was asked to hold the hands of their child. First, the infant's face was cleaned with baby skin cleanser and scrubbed lightly with Nuprep Skin Prep Gel to ensure good quality signal recordings from the EMG electrodes. Infants were entertained with nursery rhymes movies or bubbles during the preparation. Conductive OneStep clear gel was placed on the electrodes to improve their impedances. It was aimed to keep impedance below 10 kΩ (following Vacaru et al., under review and Geangu et al., 2016).

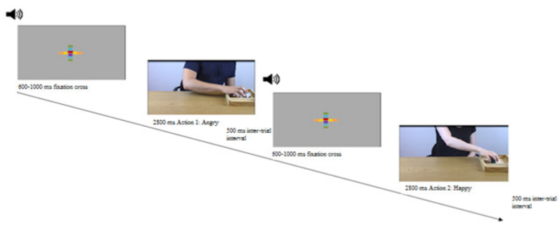

Figure 3. Example frames from the experiment illustrating two successive trials. Trials began with a static fixation cross paired with a beeping sound, followed by an action video, displaying either happy or angry emotion. Next, there was an inter-trial interval of 500 milliseconds before the next beep was played. Markers were time-locked to the onset of each action video.

Electromyography (EMG) was recorded for the zygomaticus major and the corrugator supercilii on the left side of the face with 4 Neuroline EMG Ag/AgCl electrodes in a bipolar configuration with 10 mm inter-electrode distance (see Fig. 4) (Cacioppo, Petty, Losch, & Kim, 1986; Cacioppo, Tassinary, & Berntson, 2007). In previous studies, the zygomaticus major was found to be a reliable indication for differential facial expression for happiness, while the corrugator supercilii was considered a reliable indication for differential facial expression for anger (Addabbo et al., in preparation; Cacioppo et al., 1986; Ekman & Friesen, 1976). Two additional Neuroline EMG Ag/AgCl electrodes were used for the reference and the ground. The reference electrode was positioned on the left mastoid and the ground was positioned just below the hairline in the middle of the forehead (see Fig. 4). The EMG signal was amplified using a Brain Products Amplifier, recorded continuously at a sample rate of 2500 Hz and band-pass filtered (0.016 – 120 Hz) with Brain Vision Recorder (Brain Products GmbH, Munich, Germany).

Infants were shown the stimulus videos on a 17 inch monitor (1280 x 1024 pixels) at a distance of approximately 50 cm from the infant and parent. Infants were monitored by the experimenter in order to determine when they had lost interest. Parents were instructed not to interact with their infant during the videos, except pointing to the screen to reorient the infant's attention to the screen. The experimental session was video-recorded for offline movement and attention coding. The session was ended when the infant became fussy or inattentive. Parents were debriefed after the sessions about the aim of the experiment.

Data-analysis

Motion capture data-analysis. The start and the end of each transport movement for both tasks were determined offline. Trials in which the infant transported the ball with two hands or the non-preferred hand, trials with a different starting point other than the red block, or with a different endpoint other than the track or bowl, or with a pause in the transporting movement were excluded. Furthermore, attempts in which the ball did not reach the end goal position (track or bowl) were excluded. In addition, trials with any missing marker locations for the hand marker were excluded. Lastly, trials in which the parent 'helped' the infant in their movement were excluded.

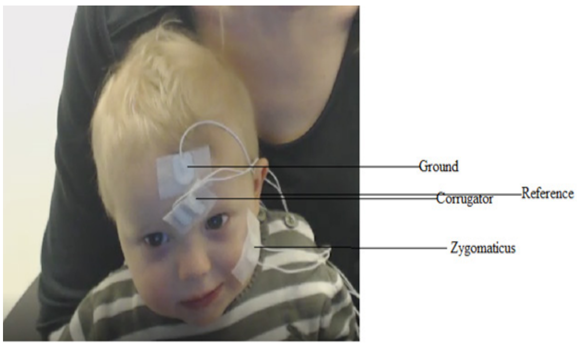

Figure 4. Positions of the EMG electrodes. All electrodes were placed on the left side of the face.

The mean standard error of the mean absolute jerk, acceleration and velocity that were calculated from the movement data can be seen as a measurement of variability in movement kinematics over trials (following Cook et al., 2013). We assumed here that infants with a low variability over trials, meaning better movement control, have a more detailed motor representation.

All pre-processing steps and filters were based on previous research (Cook et al., 2013). Velocity of the movement for each trial was calculated as the square root of the sum of the squared differentials of the x, y, and z vectors of the hand marker[1]. The velocity vectors were low-pass filtered using a Butterworth 1st order filter with a low-pass of 10 Hz, and 10 data points were trimmed from the end of each velocity vector to remove possible artefacts associated with the filter. Acceleration and jerk for each trial were calculated as the first and the second order differentials of these filtered velocity vectors. The distance for each trial was estimated by multiplying the mean velocity of that trial by the number of frames (duration) of that trial. Mean standard error of the mean (SEM) absolute jerk (in mm/frames^3), acceleration (in mm/frames^2), and velocity (in mm/frames) over the first 3 trials were calculated for each participant in analogy to a previous study (Cook et al., 2013). In addition, the mean distance (in mm) and the mean duration (in frames) over the first 3 trials were calculated for each participant (Cook et al., 2013).

However, due to the low number of infants with enough trials (N = 11 with EMG data and 3 or more trials) for the first task (train track task), and no significant correlations of these mean SEM values with the mean SEM values of the bowl task (see Table 2), it was decided not to analyse the data for the first task. The non-significant correlations could indicate that the first task (train track task)

1 The hand marker represented the movement kinematics of the infants better than the wrist marker. Therefore, it was decided to use the hand marker in the analysis.

Table 2.

The correlation of the two tasks in their mean standard error of the mean of the different measurements.

N = 12	Correlation between values of task 1 and task 2
Mean SEM of absolute velocity	$r = .362$ ($p = .248$)
Mean SEM of absolute acceleration	$r = .240$ ($p = .453$)
Mean SEM of absolute jerk	$r = .102$ ($p = .752$)
Mean distance	$r = .345$ ($p = .272$)
Mean duration	$r = .534$ ($p = .074$)

Note: Task 1 is the train track task; task 2 is the bowl task. The correlation is a Pearson correlation, two-tailed.

was not measuring the same concept (in this case detailedness of motor representation) as the second task (bowl task), or that there was too little variance in the first task.

Infants had to have a minimum of 3 trials in the bowl task in order to be included in the final statistical analysis. This inclusion criterion was based on the mode of the trials of all the participants. Infants had a mean number of 10.25 trials (*SD* = 8.00, range: 3-30). There was one left-handed infant included in the final sample. Mean SEM values were always calculated from the hand marker of the preference hand of the first 3 trials of each infant.[2] Given that the velocity, acceleration and jerk scores are related directly through a mathematical operation, a single composite score was calculated to summarize these three variables.

A factor analysis on velocity, acceleration and jerk scores was performed using the regression method calculating the resulting kinematic score. This was done following previous research (Cook et al., 2013).

To investigate whether there is a relationship between the infant's detailedness of motor representation and the infant's sensitivity to emotional information, we aimed to execute a correlation analysis between the kinematic score and the sensitivity scores of the conditions (angry and happy) in the EMG data (see paragraph *EMG data reduction and analysis*). However, tests[3] demonstrated that the kinematic score variable violated the assumptions of most commonly used Pearson correlation analyses.

Therefore it was decided to conduct a non-parametric test, the Spearman's correlation, to determine the relationship since it does not require these assumptions. All statistical analyses were conducted in SPSS statistical software version 25.0 (IBM Corporation, Armonk, New York).

EMG data reduction and analysis. Videos of the EMG session were coded offline whether the infant was paying attention to the video stimuli or not using ELAN annotation software (Max-Planck Institute for Psycholinguistics, Nijmegen, the Netherlands). Trials in which the infant did not pay attention to the video stimuli were excluded. Two coders coded the first 10 infants, with a good agreement (*Cohen's kappa* = .75).

The EMG data was pre-processed using Brain Vision Analyzer 2.1 (Brain Products GmbH, Munich, Germany). The pre-processing steps were based on previous research (Vacaru et al., under review). The EMG signal was filtered offline using a band rejection filter of 50 Hz with bandwidth of 0.2 Hz and order 4. In addition, an infinite impulse response (IIR) zero phase shift Butterworth filter with a low cut-off filter of 20 Hz and a high cut-off filter of 500 Hz and order 8 was applied on the data. The different scores of the bipolar electrodes of each muscle (zygomaticus and corrugator) were calculated. Next, the data was segmented into trials based on stimulus onset. After excluding the trials based on attention coding (when the infant was not paying attention to the video stimuli), trials with

2 In addition, movement units of each trial were calculated in the MATLAB toolbox TimeStudio (Nyström, Falck-Ytter, Gredebäck, 2016). Movement units consist of an acceleration and deceleration phase, and are often used as measurements of movement control (e.g., Konczak & Dichgans, 1997; von Hofsten, 1991). Filtering values were based on earlier research (Grönqvist, Brodd, & von Hofsten, 2011) and the TimeStudio motion-tracking analysis manual (Gottwald & Ekberg, in preparation). However, there was very little variance (*M* = 1.083, *SD* = 0.177, range: 1.000 – 1.667) in movement units per trial in our sample based on these filtering values. We therefore decided not to look further in movement units.

3 The kinematic score deviated significantly from a normal distribution in a Shapiro-Wilk test ($W = .663$, $p < .001$), and by visual analysis. In addition, the skewness and kurtosis values were not within acceptable range based on Field (2009).

signal noise or motion artefacts contaminated the signal were also discarded based on visual inspection of the data. Lastly, the data was rectified: all values were made absolute values because of our interest in the absolute amplitude of the signal.

Mean activation values were calculated for the baseline (500 ms pre-stimulus onset until stimulus onset) and for the trial interval (700-2800 ms post-stimulus onset). The choice of this trial interval was based on previous research (Addabbo et al., in preparation) and confirmed through visual inspection of the data (see Fig. 5). Activation immediately after the stimulus onset is often seen as a startle response with no difference in activation between the zygomaticus and corrugator muscle activation, and is usually discarded (Addabbo et al., in preparation; Geangu et al., 2016; Isomura & Nakano, 2016). Baseline correction was calculated as the percentage change in activation during stimulus presentation compared to baseline activation during the fixation cross.

Lastly, sensitivity scores were calculated in order to investigate the relationship between the infant's sensitivity to emotional information conveyed in kinematics and the detailedness of their motor representation. The difference between the zygomaticus and the corrugator mean activation in response to happy stimuli was calculated as the happy sensitivity score. The difference between the corrugator and the zygomaticus mean activation in response to angry stimuli was calculated as the angry sensitivity score. Positive values indicated more activation in the corresponding muscle compared to the non-corresponding muscle. This was done in analogy to previous research (Vacaru et al., under review).

Infants had to reach a minimum of 3 trials per condition in order to be included in the final statistical analyses. Forty-six infants were included in the final analyses. The mean number of trials in the happy condition was 12.61 (*SD* = 9.507; range: 3-42) and the mean number of trials in the angry condition was 13.74 (*SD* = 9.733; range: 3-41).

Results

Are infants sensitive to emotional information conveyed in kinematics?

Figure 5 shows the descriptive results of the zygomaticus and the corrugator muscle activation in response to both emotional stimuli over time. First, we tested whether infants were sensitive to emotional information conveyed in kinematics. We hypothesized that infants would show activation in the zygomaticus and deactivation in the corrugator while observing happy actions, and that they would show activation in the corrugator and deactivation in the zygomaticus while observing angry actions, replicating the findings of Addabbo and colleagues (in preparation). We conducted a 2 (Emotion: happy, angry) x 2 (Muscle: zygomaticus, corrugator) repeated measures ANOVA with percentage change score (in the time-window 700-2800 milliseconds; see Fig. 5) from baseline in EMG activation as dependent variable.

The repeated measures ANOVA did not yield a significant interaction between emotion and muscle ($F(1,45) = 0.011$, $p = .916$). This meant that

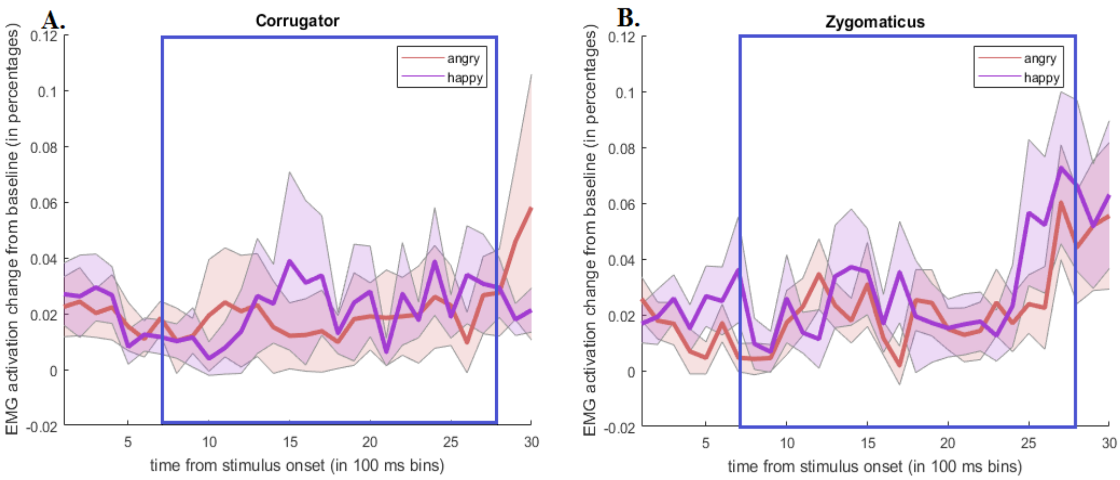

Figure 5. Percentage change EMG activation from baseline (shaded areas indicate the standard error of the mean) for corrugator (**A**) and zygomaticus (**B**) muscle when observing action with happy (purple line) and angry (red line) emotional information conveyed in kinematics. The stimulus presentation lasted 2800 milliseconds. Our time window of interest is indicated by the dark blue square.

Table 3.

Means (and standard deviations) of percentage change in EMG activation from the zygomaticus and corrugator muscle to both emotional expressions in time-window 700-2800 ms.

***N* = 46**	**Corrugator** ***M* (*SD*)**	**Zygomaticus** ***M* (*SD*)**
Angry	0.9762 (3.8380)	1.9460 (4.9344)
Happy	1.1921 (2.6116)	2.2694 (6.3648)

the difference in activation from baseline in the zygomaticus muscle and the corrugator muscle was not significantly different in the happy and the angry condition (see Table 3 and Fig. 6). The absence of the interaction effect between emotion and muscle does not correspond to our predictions, namely, that infants would show activation in the zygomaticus and deactivation in the corrugator during the observation of happy kinematics and would show activation in the corrugator and deactivation in the zygomaticus during the observation of angry kinematics. There were no additional significant effects in the repeated measures ANOVA.

Does motor representation play a role in deciphering emotion in another person's action in infancy?

Secondly, we tested whether infants who had a more detailed motor representation were more sensitive to emotional information conveyed in kinematics of observed action as hypothesized. We conducted a non-parametric Spearman's correlation with the kinematic score and the sensitivity score of both emotions in the EMG data. The kinematic score did not correlate significantly with the angry sensitivity score (r_s = -0.126, N = 24, p = .279, one-tailed), but there was a significant correlation between the happy sensitivity score and the kinematic score (r_s = .368, N = 24, p = .038, one-tailed; see Table 4 and Fig. 7).[4] In addition, there was a significant correlation between the angry sensitivity score and the happy sensitivity score (r_s = -.619 N = 24, p = .001, one-tailed).

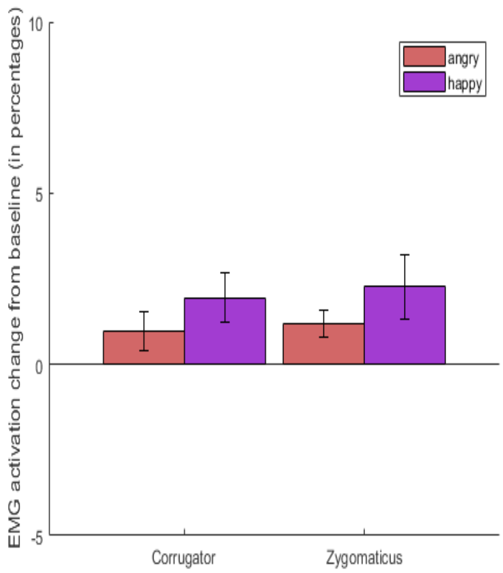

Figure 6. Percentage change EMG activation (error bars represent standard errors) in the time interval 700-2800 ms after stimulus onset compared to baseline in both emotional conditions (angry and happy) in the two muscles (corrugator and zygomaticus).

There was a weak positive relationship between the happy sensitivity score and the kinematic score (r_s = .368). A higher score on the kinematic score, indicated a higher variability in the movements was associated with a higher score on the happy sensitivity score, indicated that these infants showed more activation for the zygomaticus muscle compared to the corrugator muscle in the happy condition. This was in contrast with our hypothesis stating that infants that were more variable in movement (a higher score on kinematic score) were less sensitive to emotional information conveyed in kinematics (had a lower score on the happy score). In addition, there was a moderate to strong negative relationship between the happy and angry sensitivity score (r_s = -.619). A higher sensitivity happy score was associated with a lower angry sensitivity score. Infants with higher activation for the zygomaticus muscle compared to the corrugator muscle in the happy condition, showed lower activation for the corrugator muscle compared to the zygomaticus muscle in the angry condition. This indicates a tendency of infants to activate a similar muscle to a certain extent to both

4 The same analysis was executed excluding the four infants that had more than 10 days in between sessions. However, excluding these infants did not change the results (angry score: r_s = .065, N = 20, p = .393; happy score: r_s = .314, N = 20, p = .089).

video stimuli compared to baseline. This is as well in contrast with our hypothesis, as we expected infants to be sensitive to emotional information conveyed in kinematics, which would result in high angry and happy sensitivity scores, and a strong positive correlation between these scores.

In addition, a Pearson correlation between the sensitivity score of both emotional conditions and the kinematic score was conducted excluding the kinematic score, the happy sensitivity score and the angry sensitivity score outliers[5] in order to control for the potential effects of the outliers on the correlation. Without these outliers, the assumptions of the Pearson correlation were not violated. Outliers can have adverse effects on correlations (Osborne & Overbay, 2004).

5 Outliers with a score above or below 2 standard errors of the mean were excluded. When excluding outliers with a score above or below 3 SD of the mean, the kinematic score still deviated significantly from a normal distribution in a Shapiro-Wilk test ($W = .660$, $p < .001$) and the kurtosis and skewness values were not within acceptable range (based on Field, 2009). It was therefore decided to exclude outliers with a score above or below 2 standard errors of the mean.

The kinematic score correlated significantly with the happy sensitivity score ($r = .434$, $N = 18$, $p = .036$, one-tailed) and correlated marginally significantly with the angry sensitivity score ($r = -.373$, $N = 18$, $p = .064$, one-tailed). Both correlations were weak. In addition, there was a significant negative strong correlation between the angry sensitivity score and the happy sensitivity score ($r = -.744$, $N = 18$, $p < .001$, one-tailed) similar to the previous analysis (see Table 5 and Fig. 7).

A higher score on the kinematic score was associated with higher scores on the happy sensitivity score, and lower scores on the angry sensitivity score. Infants with high variability had higher activation in the zygomaticus muscle compared to the corrugator muscle to observed happy stimuli, and lower activation in the corrugator muscle compared to the zygomaticus muscle to observed angry stimuli. This indicated a tendency for infants with high variability to display more zygomaticus activation to the observed stimuli compared to baseline. This was in contrast with our hypothesis that infants with less variability in movement (low score on kinematic score) were expected to be more sensitive to emotional information conveyed in kinematics.

Table 4.

The correlations between the EMG measurements and the kinematic score

***N* = 24**	**EMG measurements**		**Motion capture**
	Angry sensitivity Score	Happy sensitivity Score	Kinematic Score
Angry sensitivity Score	-		
Happy sensitivity Score	r_s =-.619 (p = .001)*	-	
Kinematic Score	r_s =-.126 (p = .279)	r_s =.368 (p = .038)*	-

Note: The correlation was a Spearman's correlation, one-tailed. * means a significant correlation.

Table 5.

The correlations between the EMG measurements and the kinematic score excluding the outliers

***N* = 18**	**EMG measurements**		**Motion capture**
	Angry sensitivity Score	Happy sensitivity Score	Kinematic Score
Angry sensitivity Score	-		
Happy sensitivity Score	r =-.744 (p < .001)*	-	
Kinematic Score	r =-.373 (p = .064)	r =.434 (p = .036)*	-

Note: The correlation was a Pearson's correlation, one-tailed. * means a significant correlation

Discussion

The current study examined whether infants need a detailed motor representation in order to become sensitive to emotional information conveyed in kinematics. Our first hypothesis was that infants were sensitive to emotional information conveyed in kinematics, showing a differential facial response to both emotional stimuli (replicating results of Addabbo et al., in preparation). Our second hypothesis was that infants with a more detailed motor representation, and therefore less variable movement, would be more sensitive to emotional information conveyed in kinematics.

Are infants sensitive to emotional information conveyed in action kinematics?

In contrast to our hypothesis, the findings of Addabbo and colleagues (in preparation) were not replicated in this current study. Our results yielded no indication that infants were sensitive to emotional information conveyed in kinematics as found by Addabbo and colleagues (in preparation). There was no evidence of differential facial response to the two emotional stimuli, meaning that we found no evidence that infants in this age group (12- to 13-months-old) are sensitive to emotional information conveyed in movement kinematics, and there was no evidence that infants were able to differentiate between angry and happy emotional information in

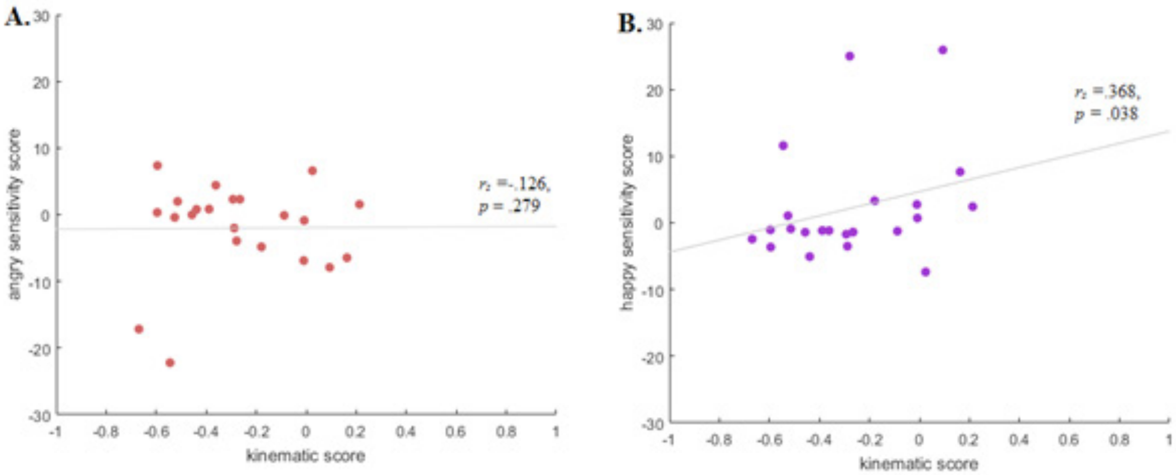

Figure 7. A. Scatterplot depicting the relationship between the kinematic score and the angry sensitivity score. **B**. Scatterplot depicting the relationship between the kinematic score and the happy sensitivity score.

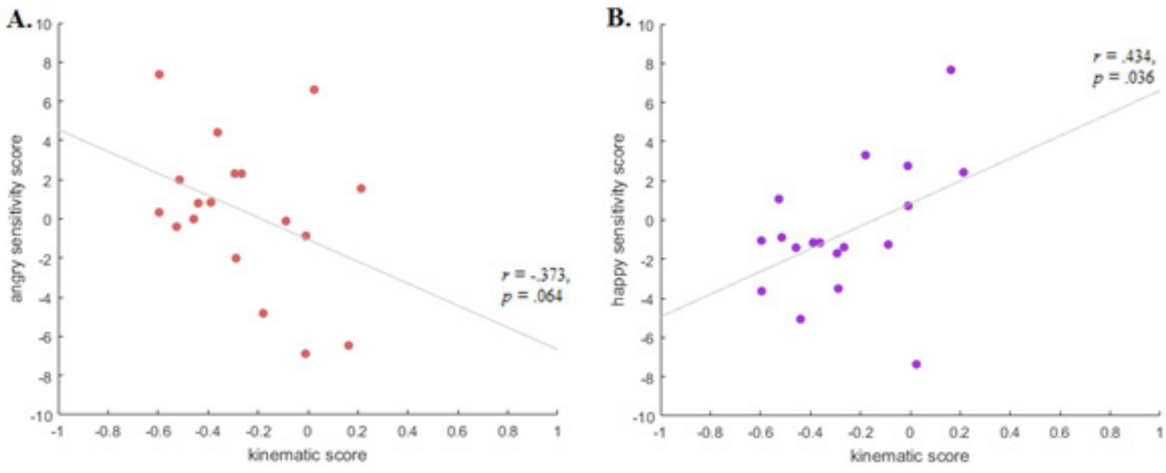

Figure 8. A. Scatterplot depicting the relationship between the kinematic score with the angry sensitivity score excluding the outliers. B. Scatterplot depicting the relationship between the kinematic score with the happy sensitivity score excluding the outliers.

actions. However, we found a negative correlation between the two (angry and happy) sensitivity scores. Infants with more activation in zygomaticus muscle compared to corrugator muscle in the happy condition showed less activation in corrugator muscle compared to zygomaticus muscle in the angry condition. This might indicate a tendency of infants to display a similar response (for example, activate the zygomaticus muscle more) in response to both emotional stimuli. One possible explanation is that some infants found the baseline (the fixation cross) boring and activated their zygomaticus muscle more when the stimuli movies started playing. In sum, our study yielded no evidence that infants are yet sensitive to emotional information conveyed in kinematics.

In the literature, there is some discussion on the muscle reaction to angry stimuli in infants and children. In adults, there is activation in the corrugator muscle in response to angry faces (Dimberg, 1982). In childhood, however, Geangu and colleagues (2016) reported a frontalis muscle (lifts the brows in fear) activation in response to angry faces in 3-year-old children, while Deschamps and colleagues (2012) found an activation in the corrugator muscle to angry dynamic faces in children aged 6 to 7 years. In infancy, 4-months-old infants were found not to show selective facial reactions to any facial expressions (Kaiser, Crespo-Llado, Turati, & Geangu, 2017). 7-months-old infants showed an increased zygomaticus activation to dynamic happy facial expressions, while they did not show a differential response to angry faces (Kaiser et al., 2017), nor was there evidence of a differential corrugator muscle activity (Datyner, Henry, & Richmond, 2016). We based our decision to measure the corrugator muscle response as an indication for sensitivity to angry stimuli on the previous findings of Addabbo and colleagues (in preparation), however, it seems that in infancy and childhood the corrugator muscle activation might not necessarily be the best measurement of differential facial response to angry stimuli. This might explain the lack of differential facial response found for the angry stimuli videos. However, this cannot explain the lack of differential facial response found for the happy stimuli videos.

Isomura and Nakano (2016) suggest a system that elicits facial muscle in response to emotional stimuli that matures over infancy, first only triggered by bimodal emotional information. Later in infancy, when the system is matured, it is as well triggered by unimodal emotional information. It might be that our stimuli did not trigger this not fully matured system to elicit facial muscle in response to emotional stimuli. Isomura and Nakano (2016) found that 4- to 5-month-old infants only show an increased corrugator response to combined audio-visual cries and an increased zygomaticus response to combined audio-visual laughter. These responses were absent for both the visual and auditory unimodal emotion stimuli. They suggested that in infancy a system starts to mature in order to elicit facial muscles responses to emotional stimuli, but that system has not matured yet fully, and motor responses are only generated when multimodal information is present. Future research could look into whether infants are able to display a differential facial response to bimodal stimuli with emotional information conveyed in kinematics, for example combined with vocal or auditory emotional information.

In addition, it might be that infants in our age group are able to understand emotional information in facial expressions, however, the sensitivity to emotions in bodily expressions and movement develops later in toddlerhood or even childhood, explaining the lack of differential facial response to the different emotions conveyed in kinematics. Geangu and colleagues (2016) found that 3-years-old showed the expected increased response in the zygomaticus muscle to happy facial stimuli, however, they did not show the expected increased response in the zygomaticus muscle to bodily expressions. They explained this finding by suggesting that children fail to associate the emotional body posture of an observed person with the causing emotional state. This ability might develop at a different rate than interpreting emotional facial information.

Furthermore, it might be that infants and young children are not sensitive to actions that are not directed at them personally. In daily life, infants experience many action directed at the infant, such as being picked up or being fed. This may explain the differences between this current study and the studies reporting sensitivity to emotional facial expressions in which stimuli are generally directed at the infant. However, it is generally accepted in the literature that young infants can learn models of actions acquired through observational statistical learning, meaning that they observe someone performing actions not necessarily directed at them (e.g., Hunnius & Bekkering, 2014; Monroy, Gerson, & Hunnius, 2017; Monroy, Meyer, Schröer, Gerson, & Hunnius, 2019). Whether infants can learn emotions in actions from observing actions performed that are not directed at them personally remains unknown. More research with into different age groups (for example, toddlers and children) is necessary in order to be able to understand the development of sensitivity to emotional information in movement kinematics.

Lastly, there is a possible methodological limitation of this study. It might be that our current time window is cut off too soon for the EMG response, resulting in the effect bleeding over in the next trial's baseline during the fixation cross. However, our choice of the time window was based on Addabbo and colleagues (in preparation), who did find an effect in this time window. In addition, previous studies have that facial muscle generally begin to show a differential activation response to facial emotional expressions starting around 500 ms after stimulus onset, and usually decreasing the response 2000 ms after stimulus onset (Beall, Moody, McIntosh, Hepburn, & Reed, 2008; Geangu et al., 2016; Oberman, Winkielman, Ramachandran, 2009).

Does the infant's motor representation play a role in deciphering emotion in another person's action?

Our second hypothesis was that infants with a more detailed motor representation, indicated by less variability in their movements, would be more sensitive to the emotional information conveyed in the kinematics of happy and angry observed actions. However, we only found a significant correlation between the movement variability measure and the sensitivity score to happy stimuli in the EMG data. The relationship between the movement variability score and happy score indicated that infants with higher variability in their movement showed a higher zygomaticus muscle activation compared to corrugator muscle activation to happy stimuli, which is in contrast with our hypothesis. When controlling for outliers, there was also a marginally significant correlation between the movement variability measure and the sensitivity score to angry stimuli. This relationship indicated that infants with higher variability in their movement showed lower corrugator muscle activation compared to zygomaticus muscle activation to angry stimuli. These two relationships between the kinematic score and the emotional sensitivity scores indicated that infants with more variability tended to activate their zygomaticus muscle more during the EMG session. One explanation might be that infants with more expressive and extraverted temperament were overall more active and happy in both sessions, resulting in more variability in their movement as well as more smiling during the EMG session.

These results might indicate that the kinematic score was not capturing the detailedness of motor representations well in our sample. We assumed that infants with more variable movement would have a less detailed motor representation. The mean standard deviation of the mean absolute jerk, acceleration and velocity are described as measurement of movement control (Cook et al., 2013). Movement control and planning itself uses motor representations (Kawato, 1999). Often, motor activation in the motor system during the observation of actions is taken as an indication of motor representation (Buccino et al., 2004; Calvo-Merino et al., 2004; Calvo-Merino et al., 2006). Another possibility of a measurement of motor representations might be motor activation in observation of the neutral action, for example, measured by electroencephalogram (EEG) in infancy and childhood (e.g., Gerson et al., 2015). More motor activation would be an indication of more motor experience, and a respectively improved motor representation (Calvo-Merino et al., 2004; Calvo-Merino et al., 2006). However, with the current methods, it is still impossible to measure motor representations directly in infancy.

Unfortunately, our movement task was too difficult for many infants. This resulted in several infants who did not have any trials for the bowl task (N = 13) or too few trials (N = 7), who we were not able to include in our analysis. These infants generally showed less competent movement control, consisting of pausing in movements, putting the ball first in the mouth before moving to the bowl, or using a different start- or endpoint. It might be that our task therefore measured in a lesser extent the detailedness of the infants' motor representation. Future research should design a more appropriate motor task for this age. Infants in this age group have very limited motor abilities and often still mouth stuff. A good movement task aiming to get an idea of the detailedness of the infant's motor representation should be able to tolerate for pauses in movement and be more flexible in order to include infants with 'less competent' movement.

Based on piloting, we used two tasks to measure infant's variability in movement. However, the first task (train task) was very hard to execute by the infants. Infants required fine control in order to place the ball on the train track to make it roll. The bowl task was more flexible with an endpoint that was not a small precise location. There was more variance in the standard error of the mean velocity, acceleration and jerk in the bowl task compared to the train task. In addition, very few infants in this age group were able to do the train task (N = 11). It might be that the few infants that were able to do the train track task were very competent in their movement, resulting in low variability, and therefore low variance within the included group. However, most of the infants in our sample were not able to do this task. An easier task would therefore be more appropriate for this age group.

Conclusion

This study investigated how young infants become sensitive to emotional information conveyed in kinematics. We had two hypotheses in this study: first, we hypothesized that infants of this age (12- to 13-months) are sensitive to emotional information conveyed in kinematics (replicating Addabbo et al., in preparation) and second, we hypothesized that infants with a more detailed motor representation would be more sensitive to emotional information conveyed in kinematics, based on the idea of Edey and colleagues (2017) that we use our own motor representation to make judgments about the emotional states of others.

In our results, we were unable to replicate the results of Addabbo and colleagues (in preparation). This study did find a relationship between the angry and the happy sensitive score, indicating that infants showed a similar activation pattern in response to both stimuli (such as smiling in a certain extent to both angry and happy action kinematics). Our research did not provide evidence that infants of 12- to 13-months-old are sensitive to emotional information conveyed in action kinematics.

In our second analysis, we found a correlation between the infants' variability in movement and their sensitivity to emotional information conveyed in kinematics when observing happy actions (and only when controlling for outliers, a marginal significant correlation when observing angry actions). Infants with a higher variability score tended to activate their zygomaticus muscle more in response to the happy and angry stimuli. It might be that more expressive, extraverted infants are overall more active and comfortable during the experiment, showing more variability in the motion task and smiled more during the emotional sensitivity task. It might be that our kinematic score does not provide us with a measurement of the detailedness of the infant's motor representation to the full extent. In addition, our motor task also excluded infants with less competent movement kinematics. Future research should use a more appropriate movement task to investigate whether infants need a detailed motor representation to become sensitive to emotional information conveyed in kinematics.

In sum, this study did not provide evidence that infants of 12- to 13-months-old are yet sensitive to emotional information conveyed in action kinematics, and nor did it provide evidence that this sensitivity is related to the infant's own motor representation.

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