Exploring the expression of emotions in children's body posture using OpenPose

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Abstract

Emotions regulate social interactions from early in ontogeny, but are difficult to assess in young children. Previous studies have used body posture as a measure of emotion expressions, employing depth-sensor imaging cameras (e.g., Kinect) in laboratory environments. Advances in artificial intelligence now allow researchers to track posture keypoints from existing video recordings. The studies reported here explored the feasibility of OpenPose to capture children's emotional expressions. In Study 1, we analysed posture data from previous studies and found that children's expressed valence was positively related to changes in their upper-body expansion whereas expressed arousal was related to overall levels of movement. In Study 2, we asked children (n = 64, aged 5 to 10 years) to recall emotional episodes of 'happiness', 'sadness', 'pride', and 'shame'. There were no effects of specific emotion categories on changes in children's posture, but exploratory analyses revealed that recalling positive emotions yielded greater changes in upper-body expansion compared to negative emotions. Together, these results suggest that the valence and arousal of expressed emotions can be captured using OpenPose which may help elucidate how young children conceptualize emotions.

Keywords: Emotions, body posture, OpenPose, Kinect, children

Introduction

I need hardly premise that movements or changes in any part of the body, - as the wagging of a dog's tail, the drawing back of a horse's ears, the shrugging of a man's shoulders, or the dilatation of the capillary vessels of the skin, may all equally well serve for expression.
Darwin, 1872

In his seminal work 'The expression of the emotions in men and animal' (1872), Charles Darwin provided a description of emotions in animals and humans, detailing their physiological expression as well as their communicative function (see van Kleef & Cote, 2022). Social functionalist accounts of emotions posit that both expressing and perceiving emotions fulfills crucial social functions of regulating social interactions (van Kleef & Cote, 2022; Keltner et al., 2022) and developmental theories suggest that emotions serve these functions already from early on in development (Vaish & Hepach, 2020). Because of the prominent role of affective processes for human well-being, behaviour and cognition (Dukes et al., 2021), as well as in interpersonal interactions (Parkinson et al., 2005), the study of emotions has received increasing attention in recent years (Dukes et al., 2021; Pollack, Camras & Cole, 2019).

Emotions are complex constructs with physical, affective, perceptual, appraisal, and functional features (Hoemann, Xu & Barrett, 2019; van Kleef & Cote, 2022). Children first acquire broad categories of positive and negative affect (broad-to-differentiated hypothesis; Widen, 2017), and over the course of development, children construct more specific emotion concepts as an adaptation to their social environment (Hoemann, Xu & Barrett, 2019).

Measuring emotions in young children is challenging. The assumption that the emotion concepts used in self-report questionnaires, for example, are the same for both researcher and participant is not well substantiated (Hepach & Vaish, 2020; Reisenzein, 2022). Such measures are especially not feasible to capture emotions in pre-verbal children (see Vaish, 2019), and they are prone to social desirability biases in older children, but also in caregivers (Weidman et al., 2017). In light of these concerns, more objective measures have been introduced to study emotional arousal (Hepach et

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al., 2015; Ismail et al., 2024) and emotional valence (Wolf, 2015) in young children.

While there exist multiple means to measure arousal, as resulting from autonomic nervous system activity, the majority of studies which captured emotional valence often relied on categorizing facial expressions. However, the reliability and specificity of mapping emotion categories to 'signature' facial movements has been questioned (Barrett et al., 2019). To overcome limitations of individual methods, it is important to additionally explore other measures of emotional valence (e.g., Zeman, 2007; Vaish, 2019),

One such method that has been employed less frequently is the assessment of children's body posture. This measure constitutes an interesting option because already young children can infer emotions from posture (Ross et al., 2012; Zieber et al., 2014; Missana et al., 2015), and de Gelder, de Borst and Watson (2015) concluded from their review of pertinent studies that participants can just as readily identify an emotion from bodily expressions as from facial cues. Emotion understanding is even facilitated by the combination of body posture and facial expressions (Mondloch, 2012; Rajhans et al., 2016; Hock et al., 2017). Beyond, posture is assumed to have played an important role in phylogeny (aan het Rot et al., 2017; Hessen et al., 2023), among other reasons because it can be assessed by observers from some distance (aan het Rot et al., 2017).

Hepach and colleagues used 'body posture' measurements obtained via Kinect-cameras, with a slumped posture indicative of negative valence of affect and a more upright posture reflective of positive emotions. This relation between posture and valence has been confirmed in validation studies with both children and adults (Hepach, Vaish & Tomasello, 2015; Hepach & Tomasello, 2020; Suchodoletz & Hepach, 2021).

Using posture as a measure of emotional valence, Hepach et al. (2017) showed, for example, that children aged 2.5 to 4.5 years displayed a more baseline-corrected upright body posture, indicating positive affect, when they either helped an adult or retrieved an object for themselves. In the same vein, children displayed an elevated body posture when they watched an adult helping a child who was in greater need than one who was less needy, and even a *de*creased posture when help was directed towards a less needy child (Hepach & Tomasello, 2020). Gerdemann, Büchner & Hepach (2022a) replicated this basic pattern in 6-year-old children. Measuring body posture has also been employed in the study of social emotions, such as shame and guilt (Gerdemann et al., 2022b). When children failed to help others because they could not access the necessary object to finish a tower, Gerdemann et al. (2022a) found a similar emotional response as when they failed to reach their own goal, as indicated in a more slumped posture. Together, these studies illustrate that chest height can index emotional valence in young children.

Studies which measured emotions via posture in adults, mostly using marker-based motion tracking, further found a relation between emotions and speed of walking, with slower walking in conditions that elicited sadness (Gross et al., 2012; Barliya et al., 2013; Kang & Gross, 2015; for a review see Xu et al., 2022), which is consistent with findings that individuals who fullfilled DSM diagnostic criteria of major depressive disorder showed slower walks compared to a control group (Lemke et al., 2000; Michalak et al., 2009).

From a pragmatic perspective, the Kinect technology and marker-based motion tracking also have some shortcomings. Kinect cannot be used to analyse videos obtained with a different camera. Further, Kinect can only detect skeletons from a maximal distance of four meters, restraining applications in more naturalistic settings. Recent advances in artificial intelligence now allow researchers to assess pose keypoints from existing video recordings. OpenPose (Cao et al., 2021) is an open source neural network which outputs 2D pixel coordinates of keypoints from video recordings of humans. OpenPose thus constitutes an alternative method for keypoint detection that enables analysing *existing* video material, and can also be used with data from more naturalistic settings compared to a more controlled experimental lab environment. To date, no study has validated this method to study emotions in young children.

The present studies

Here we conducted two studies to investigate how positive and negative emotions are expressed in young children. In Study 1, we reanalyzed data from previously published work in which changes in 2- to 6-year-old children's body posture were measured in response to positive (e.g., helping others, completing a task; Hepach et al., 2023) and negative (e.g., failing to help others, failing to complete a task) events (Gerdemann et al., 2022b). We processed the body posture data using OpenPose to calculate changes in upper-body posture as well as overall body movement for each child on the respective first test trial they partook in. We compared these values to coders' ratings of the expressed valence and arousal of children. The hypotheses we tested were as follows:

Hypothesis 1.1 (pre-registered): We expect a positive correlation between posture measures obtained via Kinect and via OpenPose.

Hypothesis 1.2 (pre-registered): We explored whether measures as captured via OpenPose are reflective of emotion expressions. Specifically, whether the angle between the shoulders correlates with coder rated valence of emotions, and whether movement correlates with coder rated arousal.

In Study 2, we presented 5- to 10-year-old children with an emotion induction procedure in which we asked them to recall episodes of happiness, pride, sadness, and shame. The procedure was modeled after a procedure previously run with adults (von Suchodoletz & Hepach, 2021) which showed that both a basic (joy) as well as a social (pride) positive emotion resulted in greater upper-body postural elevation compared to a basic and a social negative emotion, of disappointment and shame, respectively. We captured changes in children's posture after they recalled each emotional episode. Our hypotheses were:

Hypothesis 2.1 (pre-registered): We expected a more upright body posture (chest height, as measured by the Kinect) after a positive emotion induction (compared to a negative emotion induction).

Hypothesis 2.2 (pre-registered): We expected a larger expansion angle and more overall movement (as measured via OpenPose) after a positive compared to a negative emotion induction.

Study 1

Method

The study was pre-registered and additional resources such as the analyses scripts and the data are provided here: https://osf.io/kngjr/ .

Participants The data were aggregated from four previous studies (Hepach et al., 2023; Gerdemann et al., 2022b), resulting in a total of 205 participants (131 female), with an age range between two and six years (18 two-year olds, 55 four-year olds, 177 seven-year olds and 11 six-year olds). The data were assembled in the context of a Kinect reanalysis (Gerdemann & Hepach, in preparation).

Data processing For each participant, we processed the first experimental trial as this trial was rated by human coders on valence and arousal (Gerdemann & Hepach, in preparation). We ran the real-time multi-person system OpenPose (Cao et al., 2021) on the recorded videos (.mp4 format) on a local Windows 10 computer. Specifically, we used the body25 model of OpenPose. Individual videos were processed in Powershell:

bin\OpenPoseDemo.exe --video examples\ [path to video] .mp4 --net_resolution "320x320" --part_candidates --write_json [path to output] \ --display 0 --render_pose 0

Processing of videos was automated via a for-loop script in Powershell. OpenPose outputs contained one JSON-file for each frame, with each frame containing all participants captured. The JSON-file outputs were converted to csv files, for further processing in R Studio (version 4.2.3).

For videos of both child and experimenter side by side, the child skeleton was selected according to its location, using the x-coordinate of the chest center.

The output only contains 2D-information of the skeleton, in the pixel units. Thus, as the person moves closer to the camera, the skeleton appears larger (see Fig. 1).

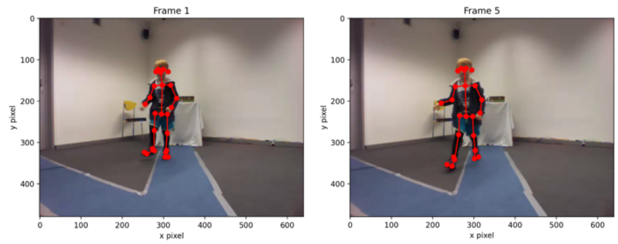

Figure 1: Walk of one child with mapped OpenPose skeletons.

Analyses

Ratings Human coders rated valence and arousal of the test videos on a Likert scale from 1 to 5. Coders were blind to the individual studies' hypotheses and showed a moderate interrater reliability. The intraclass correlation coefficients (ICCs) were .57 for arousal and .7 for valence.

Angle calculations As OpenPose does not contain depth information, x/y values are influenced by the distance of the child from the camera. Angles constitute a depth-invariant measure, as they are not dependent on the scale and centering of the skeleton. Thus, we calculated all possible angles between human limbs, by extracting both vectors pointing away from each skeleton point, and calculating the angle between these two vectors via the dot product:

$$\text{angle} = cos^{-1}\frac{vec1 \cdot vec2}{norm(vec1)*norm(vec2)}$$

Expansion angle Previous studies found a relation of upper body elevation to emotional valence (Gerdemann et al., 2022c). As a corresponding measure of upper body expansion using angles, we calculated the average of the two angles under the shoulders as a measure of upper body expansion, using the angles as calculated above.

Movement calculation Based on anecdotal observations in a previous pilot study (Försterling, 2021) that suggested a relation between movement and emotions, we hypothesized that overall movement relates to arousal. Movement was calculated as the sum of the absolute (frame-by-frame) differences between each angle, averaged across the number of frames.

$$\frac{1}{N_\theta}\frac{1}{N_{Frames}}(\Sigma_i^{N(Frames)-1}\ \Sigma_j^{N(\theta)}\ abs(\theta_{i,j}-\theta_{i+1,j})\ )$$

Similarity measures between Kinect and OpenPose We visually compared OpenPose data to Kinect data.

Analyses of valence and arousal To test our hypotheses, we fitted linear models with the lm function in R (version 4.2.3). The dependent variables were the mean of the expansion angle and the mean of movement as measured via OpenPose (see description above). Per child there was only one data point, from the first test trial of the respective study. We did not include chest height as a dependent measure due to the scaling issue of OpenPose. P-values were calculated using t-tests. Assumption checks of variance inflation factors showed no issues of collinearity for the models. The structure of the models thus was:

lm(Angle_expansion ~ Valence + Arousal + Age + Gender)
lm(Movement ~ Valence + Arousal + Age + Gender)

Results

Correlation We visualized the correspondence between Kinect and OpenPose. Fig. 2a provides an example of an overlaid Kinect and OpenPose skeleton, and Fig. 2b shows the correspondence of OpenPose y values to Kinect y values during one randomly selected walking sequence. Based on visual inspection of the skeletons across multiple individuals and trials, we concluded that Kinect and OpenPose have sufficient overlays.

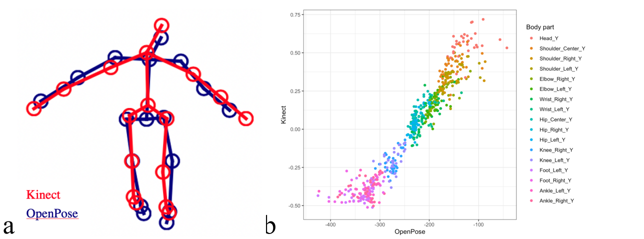

Figure 2: a) Overlay of Kinect and OpenPose skeleton. b) y-values of Kinect and OpenPose for one walking sequence.

OpenPose measures

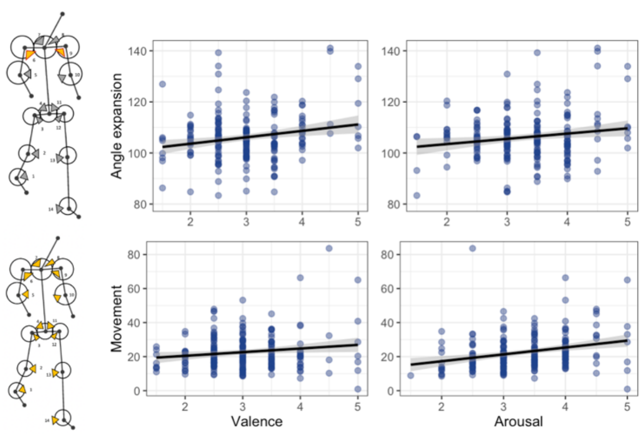

Figure 3: Scatter plots of coder-rated valence and arousal, and expansion angle, as well as overall movement as measured with OpenPose (see angles marked in orange).

Childrens' expansion angle was significantly predicted by coder-rated valence (b = 1.86, t(208) = 2.18, p = .03, R^2 = .03), but not arousal (b = 1.35, t(208) = 1.56, p = .11, R^2= .01). There was no effect of age (t(208) = -0.50, p = .62, R^2= .001), or gender (t(208) = 0.96, p = .34, R^2= .004). Childrens' movement was significantly predicted by arousal (b = 3.85, t(205) = 3.81, p < .001, R^2= .07), but not valence (b = 1.20, t(205) = 0.99, p = .23, R^2= .02). There was no effect of age (t(205) = 0.65, p = .52, R^2= .002), or gender (t(205) = -0.52, p = .60, R^2= .001).

Study 2: Emotion induction study

The individual differences analyses of Study 1 revealed that children who expressed more positive emotions had more expanded upper-body postures whereas children's overall movement was related to their levels of arousal. In Study 2, we followed up on these findings with an experimental paradigm in which children were asked to recall positive and negative emotional episodes while we recorded their upper-body posture expansions and overall movement.

Method

Participants We invited 64 children, aged 5 to 10 years, (M_{age} = 7.22, SD_{age} = 1.71, 26 females) to our research institute. Families were recruited via our local database hosted at the Department of Experimental Psychology and received a book voucher as a small gift for taking part. For this study, we obtained ethical approval from the MSD ethics committee of the University of Oxford. The study was pre-registered on osf.

Design The study utilized a within-subjects design. All participants were presented with all four emotion induction instructions to induce happiness, sadness, pride, and shame. The order of emotion trials was randomized. All children partook in three phases: An initial 'walking phase' in which we captured children's emotional expression while they walked toward the recording camera (following von Suchodoletz & Hepach, 2021). The data reported here are based on this phase. In two subsequent phases, children underwent a similar emotion induction procedure while sitting down and in a final phase, children were presented with a sharing task. The data collected during those two phases are not reported here but are part of broader methodological validations.

Procedure. Families were welcomed to the Babylab by two experimenters. In the study space, parents/guardians signed the consent form and children gave verbal assent. For each emotion induction trial, we combined telling a story with visual stimuli to children and an autobiographical recall procedure for each child (cf. Siedlecka & Denson, 2019). Children were asked to walk towards the camera for a total of six times: Two baseline walks and four walks after each emotion induction. Before the baseline walk, participants were instructed: "In our study, we will ask you to walk towards this table several times. I will stay here, and [E2] will be sitting by the laptop. Do you understand what you have to do? Let's see how this goes. Can you please now walk towards that table there in a calm, natural manner." Participants received four emotion inductions (see Figure 4), presented in randomized order. Participants were then asked to feel that emotion, and walk towards the table: "Now try to feel as [emotion] as you were then. Please keep trying to feel [emotion], and walk towards the table". After each emotion induction, participants were asked by E2 to show on a scale ranging from 'not at all', 'a little', 'middle', 'pretty' to 'very', visualized by circles of increasing size, to rate the intensity of their emotional experience. Thereafter, they were instructed: "Now, let's shake our whole body. Please try to feel relaxed again. You can walk back to the starting point now."

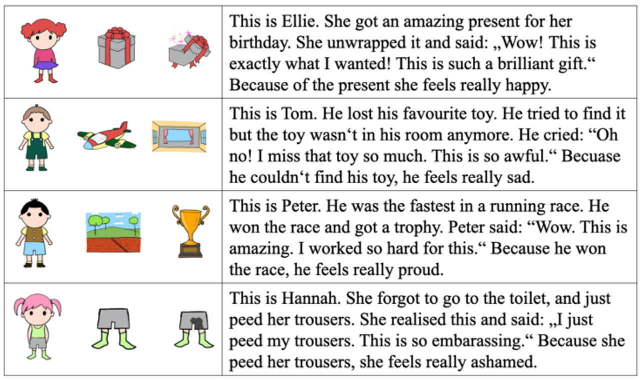

Figure 4: Stories for emotion induction.

Main Analyses. To test our hypotheses, we fitted linear mixed models with the lme4-package (Bates et al., 2014) in R (version 4.2.3) The structure of the main model, for Kinect-analyses, was:

lmer(chest_height ~ Age_year*Emotion + count + Gender + (1 + count | Participant))

The analyses for the OpenPose data were near identical but lacked the effect of time/distance, both as fixed and random effects, given that the depth information was not available for these data:

lmer(chest_height ~ Age_year*Emotion + count + Gender + (1 + count | Participant))

For the Kinect-data, the dependent variable was the baseline-corrected change in upper-body posture for each emotion (see also Gerdemann et al., 2022; Hepach et al., 2023; scripts available on github). For the OpenPose-data, the dependent variable was the baseline-corrected change in the chest expansion angle, as well as the overall movement (analogous to calculations in Study 1) for each emotion. We tested the main effects of age and emotion by fitting a separate model in which the two fixed effects did not interact. P-values were calculated using likelihood-ratio tests.

Results

Emotion induction

We assessed the understanding of the emotion induction by the recall of stories by children. Table 1 displays the percentages of how many children (a) recalled an event capturing the emotion, (b) recalled an event that had the same valence, but did not capture the specific emotion, or if they only recalled a congruent story in the second trial, and (c) gave no answer, or a wrong answer. Especially the emotion shame was often not shared.

Table 1: Emotion induction check.

Emotion	(a)	(b)	(c)
Happy	58%	9%	33%
Pride	56%	8%	36%
Sadness	53%	5%	42%
Shame	27%	11%	62%

For the answers provided by children, the noun and verbs were (separately) visualized in a word cloud (see Fig 5).

Figure 5: Word clouds of stories told.
Nouns on the left, and verbs on the right.

Main analyses. Children's upper-body posture, as measured by the Kinect, did not systematically vary as a function of children's age and the emotion induced, $\chi^2(3) = 0.49$, $p = .92$. In addition, there were no main effects of age ($\chi^2(1) = 0.38$, $p = .53$), emotion ($\chi^2(3) = 5.27$, $p = .15$), or trial ($\chi^2(1) = 0.04$, $p = .85$). However, our analyses did reveal that boys (M = 0.07cm, SD = 2.63cm) had greater postural elevation than girls (M = -0.09cm, SD = 2.61cm). The identical analyses conducted on the chest angle-expansion measure, as captured by OpenPose, yielded the following results: Children's angle-expansion, as measured by OpenPose, did not systematically vary as a function of children's age and the emotion induced, $\chi^2(3) = 1.08$, $p = .78$. In addition, there were no main effects of age ($\chi^2(1) = 1.28$, $p = .26$), emotion ($\chi^2(3) = 6.36$, $p = .10$), trial ($\chi^2(1) = 0.41$, $p = .52$), or gender ($\chi^2(1) = 4.31$, $p = .11$). The same analyses as for the angle expansion measure were conducted for movement as recorded via OpenPose. Movement did not systematically vary as a function of children's age and the emotion induced, $\chi^2(3) = 1.36$, $p = .72$. In addition, there were no main effects of age ($\chi^2(1) = 1.06$, $p = .3$), emotion ($\chi^2(3) = 4.16$, $p = .24$), trial ($\chi^2(1) = 1.22$, $p = .26$), or gender ($\chi^2(2) = 2.33$, $p = .31$).

Exploratory analyses: Posture. Based on visual inspection of the data, we conducted exploratory analyses by grouping the positive (joy and pride) and negative (sadness and shame) emotions together. We found a significant main effect of valence on the angle expansion measure ($\chi^2(1) = 4.70$, p =

.03); with a larger baseline corrected expansion angle after positive emotion inductions (*M* = 7.93°, *SD* = 22.29) compared to negative emotion inductions (*M* = 6.10°, *SD* = 22.45). We did not find an effect of emotional valence on movement ($\chi^2(1) = 2.54$, $p = .11$), but descriptively in the hypothesized direction (positive: *M* = 1.54, *SD* = 5.07, negative: *M* = 0.74, *SD* = 4.89). We did not find an effect of valence on chest height as measured via Kinect ($\chi^2(1) = 0.34$, $p = .34$), but, descriptively, a trend in the expected direction (positive: *M* = 0.15cm, *SD* = 2.65, negative: *M* = - 0.096cm, *SD* = 2.59).

Discussion

The present studies investigated whether body posture measurements via OpenPose are indicative of young children's emotions. In a reanalysis (Study 1) of four previous studies, we demonstrated that OpenPose and Kinect body keypoints correspond (see Fig 2), and found that higher coder-rated valence of emotions related to a larger expansion angle, and higher coder-rated arousal related to more overall movement (as measured by OpenPose). In Study 2, where we asked children to recall specific emotions, the overall analyses revealed no effect of emotion induction on body posture but in an exploratory analysis aggregating across same-valenced emotions we found a greater expansion angle for positive as compared to negative emotions.

These studies demonstrate the feasibility of body posture tracking using OpenPose for research on emotion development. OpenPose showed good correspondence to the more established Kinect-methodology. Approaches using computer vision can further collaborative efforts as they can be run on pre-existing video recordings, allowing video analyses from more naturalistic recordings, across multiple research sites without required specialized camera equipment. In addition, OpenPose allows multi-person tracking, and is easily accessible as it is open source.

The presented set-up has the limitation of only capturing 2D keypoints, and as we only used one camera located in front of the participant, we only captured the frontal plane. Locating a camera at the side would allow to track posture from the saggital plane. To circumvent the issue of lacking depth information in 2D we explored depth-invariant measures based on angles, instead of the previously used chest height. The larger expansion angle found for positively valenced emotions corresponds to typical displays of 'happy' posture stimuli in the literature (Atkinson et al., 2003; de Gelder & Van den Stock, 2011; Jessen et al., 2011; Ross et al., 2012; Beck et al., 2013; Zieber et al, 2014; Missana, 2015; Martin-Key, 2021).

In the emotion induction, we did not find an overall effect of emotion categories. One explanation for the lack of an emotion induction effect of categorical emotions on children's body posture is that the emotion induction procedure did not work equally well for all children. To address this possibility, we analysed the content of the stories that children recalled as an indicator of how well the emotion induction worked. In less than 60% of cases, the stories recalled were congruent to the emotion induction, with children having most pronounced difficulties in the shame condition. More complex emotions such as shame may be less readily understandable for younger children. This contention is in line with literature suggesting a gradual development of the understanding (and expression) of complex emotions (Conte et al., 2019; Sabato & Eyal, 2022; Blanc & Syssau, 2018; see also broad-to differentiated hypothesis outlined above). A more parsimonious explanation for the low recall of shame stories is that children were simply more "ashamed" to tell a 'shame' story. Note that even if children grasped the emotion concept, it remains unclear whether this understanding corresponded to an emotional experience that lasted for the entire duration of the test trial, especially given that emotions can be relatively short-lived (see Fox, 2018).

The emotion induction study presented here differed from previous studies conducted in laboratory settings (e.g., the datasets which Study 1 is based on), in that children were explicitly instructed to feel a certain emotion whereas in previous studies the experimental manipulation created a situation that elicited certain emotions.

While we did not find an overall effect of emotion category, a follow-up analysis grouping together positive and negative emotions revealed a larger expansion angle in the positive compared to the negative emotion condition. One potential explanation for this pattern is that 5- to 10-year-old children are still in the process of developing understanding and expression of more fine-grained emotional differences (see broad to differentiated hypothesis outlined in the introduction; Widen & Russell, 2008). In an adult study the expression of pride and joy were different in that the social emotion pride led to greater postural elevation than joy (Suchodoletz & Hepach, 2021). At what age children show similar exaggerated effects of social emotions compared to more basic emotions is a question for future research.

Conclusion

Body posture measurements constitute a promising additional assessment method which can contribute to a better understanding of emotions in young children. The current studies introduced a novel approach to capture emotions via body posture using OpenPose. Computer vision provides emotion researchers with new tools to study the development of emotions with more accessible technologies to overcome sampling biases in developmental science (see also Nielsen et al., 2017).

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References

Aan het Rot, M., Enea, V., Dafinoiu, I., Iancu, S., Taftă, S. A., & Bărbuşelu, M. (2017). Behavioural responses to facial and postural expressions of emotion: An interpersonal circumplex approach. *British Journal of Psychology*, *108*(4), 797-811.

Andriluka, M., Pishchulin, L., Gehler, P., & Schiele, B. (2014). 2d human pose estimation: New benchmark and state of the art analysis. In *Proceedings of the IEEE Conference on computer Vision and Pattern Recognition* (pp. 3686-3693).

Atkinson, A. P., Dittrich, W. H., Gemmell, A. J., & Young, A. W. (2004). Emotion perception from dynamic and static body expressions in point-light and full-light displays. *Perception*, *33*(6), 717-746.

Barliya, A., Omlor, L., Giese, M. A., Berthoz, A., & Flash, T. (2013). Expression of emotion in the kinematics of locomotion. *Experimental brain research*, *225*, 159-176.

Barrett, L. F., Adolphs, R., Marsella, S., Martinez, A. M., & Pollak, S. D. (2019). Emotional expressions reconsidered: Challenges to inferring emotion from human facial movements. *Psychological science in the public interest*, *20*(1), 1-68.

Beck, A., Cañamero, L., Hiolle, A., Damiano, L., Cosi, P., Tesser, F., & Sommavilla, G. (2013). Interpretation of emotional body language displayed by a humanoid robot: A case study with children. *International Journal of Social Robotics*, *5*, 325-334.

Cao, Z., Hidalgo, G., Simon, T., Wei, S. E., & Sheikh, Y. (2019). OpenPose: realtime multi-person 2D pose estimation using Part Affinity Fields. *IEEE transactions on pattern analysis and machine intelligence*, *43*(1), 172-186. https://arxiv.org/abs/1812.08008

D'Antonio, E., Taborri, J., Mileti, I., Rossi, S., & Patané, F. (2021). Validation of a 3D markerless system for gait analysis based on OpenPose and two RGB webcams. *IEEE Sensors Journal*, *21*(15), 17064-17075.

Darwin, C. (1872). On the origin of species.

de Gelder, B., & Van den Stock, J. (2011). The bodily expressive action stimulus test (BEAST). Construction and validation of a stimulus basis for measuring perception of whole body expression of emotions. *Frontiers in psychology*, *2*, 9824.

de Gelder, B., De Borst, A. W., & Watson, R. (2015). The perception of emotion in body expressions. *Wiley Interdisciplinary Reviews: Cognitive Science*, *6*(2), 149-158.

Dukes, D., Abrams, K., Adolphs, R., Ahmed, M. E., Beatty, A., Berridge, K. C., ... & Sander, D. (2021). The rise of affectivism. *Nature Human Behaviour*, *5*(7), 816-820.

Ekman, P. (1993). Facial expression and emotion. *American psychologist*, *48*(4), 384.

Försterling, M. (2021). Upright is right: Elevation induced body posture and prosocial behaviour. Master's thesis, University of Oxford.

Gerdemann , S. C., & Hepach, R. (in preparation). Validation of Body Posture as a Novel Measure of Children's Emotion. https://aspredicted.org/9ws52.pdf

Gerdemann, S. C., Büchner, R., & Hepach, R. (2022a). How being observed influences preschoolers' emotions following (less) deserving help. *Social Development*.

Gerdemann, S. C., McAuliffe, K., Blake, P. R., Haun, D. B., & Hepach, R. (2022c). The ontogeny of children's social emotions in response to (un) fairness. *Royal Society Open Science*, *9*(8), 191456.

Gerdemann, S. C., Tippmann, J., Dietrich, B., Engelmann, J. M., & Hepach, R. (2022b). Young children show negative emotions after failing to help others. *PloS one*, *17*(4), e0266539.

Gross, M. M., Crane, E. A., & Fredrickson, B. L. (2012). Effort-shape and kinematic assessment of bodily expression of emotion during gait. *Human movement science*, *31*(1), 202-221.

Hepach, R., & Tomasello, M. (2020). Young children show positive emotions when seeing someone get the help they deserve. *Cognitive Development*, *56*, 100935. https://doi.org/10.1016/j.cogdev.2020.100935

Hepach, R., & Vaish, A. (2020). The Study of Prosocial Emotions in Early Childhood: Unique Opportunities and Insights. *Emotion Review*, *12*(4), 278-279. https://doi.org/10.1177/1754073920939630

Hepach, R., Engelmann, J. M., Herrmann, E., Gerdemann, S. C., & Tomasello, M. (2023). Evidence for a developmental shift in the motivation underlying helping in early childhood. Developmental Science, 26(1), e13253.

Hepach, R., Vaish, A., & Tomasello, M. (2015). Novel paradigms to measure variability of behavior in early childhood: posture, gaze, and pupil dilation. *Frontiers in Psychology*, *6*, 858. https://doi.org/10.3389/fpsyg.2015.00858

Hepach, R., Vaish, A., & Tomasello, M. (2017). The fulfillment of others' needs elevates children's body posture. *Developmental Psychology*, *53*(1), 100. http://dx.doi.org/10.1037/dev0000173

Heesen, R., Kim, Y., Kret, M. E., & Clay, Z. (2024). Perceptual integration of bodily and facial emotion cues in chimpanzees and humans. *PNAS nexus*, *3*(2), pgae012.

Hock, A., Oberst, L., Jubran, R., White, H., Heck, A., & Bhatt, R. S. (2017). Integrated emotion processing in infancy: Matching of faces and bodies. *Infancy*, *22*(5), 608-625.

Hoemann, K., Xu, F., & Barrett, L. F. (2019). Emotion words, emotion concepts, and emotional development in children: A constructionist hypothesis. *Developmental psychology*, *55*(9), 1830.

Ismail, S. N. M. S., Aziz, N. A. A., Ibrahim, S. Z., & Mohamad, M. S. (2023). A systematic review of emotion recognition using cardio-based signals. *ICT Express*.

Jessen, S., & Kotz, S. A. (2011). The temporal dynamics of processing emotions from vocal, facial, and bodily expressions. *Neuroimage*, *58*(2), 665-674.

Kang, G. E., & Gross, M. M. (2015). Emotional influences on sit-to-walk in healthy young adults. *Human movement science*, *40*, 341-351.

Keltner, D., Sauter, D., Tracy, J. L., Wetchler, E., & Cowen, A. S. (2022). How emotions, relationships, and culture constitute each other: Advances in social functionalist theory. *Cognition and Emotion*, *36*(3), 388-401.

Lemke, M. R., Wendorff, T., Mieth, B., Buhl, K., & Linnemann, M. (2000). Spatiotemporal gait patterns during over ground locomotion in major depression compared with healthy controls. *Journal of psychiatric research*, *34*(4-5), 277-283.

Martin-Key, N. A., Graf, E. W., Adams, W. J., & Fairchild, G. (2021). Investigating emotional body posture recognition in adolescents with conduct disorder using eye-tracking methods. *Research on child and adolescent psychopathology*, *49*, 849-860.

Michalak, J., Troje, N. F., Fischer, J., Vollmar, P., Heidenreich, T., & Schulte, D. (2009). Embodiment of sadness and depression—gait patterns associated with dysphoric mood. *Psychosomatic medicine*, *71*(5), 580-587.

Missana, M., Atkinson, A. P., & Grossmann, T. (2015). Tuning the developing brain to emotional body expressions. *Developmental Science*, *18*(2), 243-253.

Mondloch, C. J. (2012). Sad or fearful? The influence of body posture on adults' and children's perception of facial displays of emotion. *Journal of Experimental Child Psychology*, *111*(2), 180-196.

Nielsen, M., Haun, D., Kärtner, J., & Legare, C. H. (2017). The persistent sampling bias in developmental psychology: A call to action. Journal of Experimental Child Psychology, 162, 31-38.

Parkinson, B., Fischer, A. H., & Manstead, A. S. (2005). *Emotion in social relations: Cultural, group, and interpersonal processes*. Psychology press.

Pollak, S. D., Camras, L. A., & Cole, P. M. (2019). Progress in understanding the emergence of human emotion. *Developmental psychology*, *55*(9), 1801.

Rajhans, P., Jessen, S., Missana, M., & Grossmann, T. (2016). Putting the face in context: Body expressions impact facial emotion processing in human infants. *Developmental Cognitive Neuroscience*, *19*, 115-121.

Reisenzein, R. (2022). Tasks for a theoretical psychology of emotion. *Cognition and Emotion*, *36*(2), 171-187.

Ross, P. D., Polson, L., & Grosbras, M. H. (2012). Developmental changes in emotion recognition from full-light and point-light displays of body movement.

Suchodoletz, A., & Hepach, R. (2021). Cultural values shape the expression of self-evaluative social emotions. *Scientific reports*, *11*(1), 1-14.

Vaish, A., & Hepach, R. (2020). The development of prosocial emotions. *Emotion Review, 12*(4), 259–273. https://doi.org/10.1177/1754073919885014

Vaish, A. (2019). Something old, something new: Leveraging what we know to optimize new directions in emotion development research. *Developmental psychology*, *55*(9), 1998.

van Kleef, G. A., & Côté, S. (2022). The social effects of emotions. *Annual review of psychology*, *73*, 629-658.

Weidman, A. C., Steckler, C. M., & Tracy, J. L. (2017). The jingle and jangle of emotion assessment: Imprecise measurement, casual scale usage, and conceptual fuzziness in emotion research. *Emotion*, *17*(2), 267.

Widen, S. C. (2017). The development of emotion recognition: The broad-to-differentiated hypothesis. In J.-M. Fernández-Dols & J. A. Russell (Eds.), *The science of facial expression* (pp. 297–311). Oxford University Press.

Widen, S. C., & Russell, J. A. (2008). Children acquire emotion categories gradually. Cognitive development, 23(2), 291-312.

Wolf, K. (2015). Measuring facial expression of emotion. *Dialogues in clinical neuroscience*, *17*(4), 457-462.

Xu, S., Fang, J., Hu, X., Ngai, E., Wang, W., Guo, Y., & Leung, V. C. (2022). Emotion recognition from gait analyses: Current research and future directions. *IEEE Transactions on Computational Social Systems*, *11*(1), 363-377.

Yu, G. (2021). Emotion monitoring for preschool children based on face recognition and emotion recognition algorithms. *Complexity*, *2021*, 1-12.

Zeman, J., Klimes-Dougan, B., Cassano, M., & Adrian, M. (2007). Measurement issues in emotion research with children and adolescents. *Clinical Psychology: Science and Practice*, *14*(4), 377.

Zieber, N., Kangas, A., Hock, A., & Bhatt, R. S. (2014). The development of intermodal emotion perception from bodies and voices. *Journal of Experimental Child Psychology*, *126*, 68-79.