Developmental Science

Developmental Science (2016), pp 1–8 DOI: 10.1111/desc.12389

SHORT REPORT

Bodily maps of emotions across child development

Jari K. Hietanen,[1] Enrico Glerean,[2] Riitta Hari[2] and Lauri Nummenmaa[2,3]

1. Human Information Processing Laboratory, School of Social Sciences and Humanities/Psychology, University of Tampere, Finland
2. Department of Neuroscience and Biomedical Engineering, School of Science, Aalto University, Finland
3. Turku PET Centre and Department of Psychology, University of Turku, Finland

Abstract

*Different basic emotions (anger, fear, disgust, happiness, sadness, and surprise) are consistently associated with distinct bodily sensation maps, which may underlie subjectively felt emotions. Here we investigated the development of bodily sensations associated with basic emotions in 6- to 17-year-old children and adolescents (*n = 331*). Children as young as 6 years of age associated statistically discernible, discrete patterns of bodily sensations with happiness, fear, and surprise, as well as with emotional neutrality. The bodily sensation maps changed from less to more specific, adult-like patterns as a function of age. We conclude that emotion-related bodily sensations become increasingly discrete over child development. Developing awareness of their emotion-related bodily sensations may shape the way children perceive, label, and interpret emotions.*

Research highlights

- We illustrate the development of bodily sensations associated with basic emotions in 6- to 17-year-old children and adolescents.
- Bodily sensations associated with emotions are discrete in early childhood, even though they tune towards adult-like patterns over development.
- Our findings suggest that young children have interoceptive awareness of emotion-related bodily states.
- Development of bodily sensation patterns associated with emotions parallels the way children start to use emotion words, suggesting that developing awareness of emotion-related bodily sensations significantly shapes the way children perceive and interpret their environment.

Introduction

Basic emotion theories argue that evolution has shaped a limited set of innate emotions to support different survival functions (Ekman, 1992; Panksepp, 1982). These so-called basic emotions have a discrete neural basis (Hamann, 2012; Kassam, Markey, Cherkassky, Loewenstein & Just, 2013; Saarimäki, Gotsopoulos, Jääskeläinen, Lampinen, Vuilleumier *et al*., 2015) and are associated with distinct and discernible bodily sensations in adults (Nummenmaa, Glerean, Hari & Hietanen, 2014). Such emotion-specific central and peripheral physiological responses may explain the different subjective feelings associated with different emotions (Damasio & Carvalho, 2013).

Children become aware of their emotions in early childhood (Saarni, Mumme & Campos, 1998), yet practically no developmental studies exist on their bodily basis of emotions. As major emotion theories assume that subjective emotional feelings originate from the perception of emotion-related bodily changes (e.g. Damasio & Carvalho, 2013; James, 1884), assessing whether the bodily feeling patterns associated with different emotions are discrete already at early stages of development would be important for resolving the origin of feelings in childhood.

Children have representations of emotions based on sensory, visceral, and kinaesthetic sensations even before

Address for correspondence: Jari Hietanen, Human Information Processing Laboratory, School of Social Sciences and Humanities/Psychology, University of Tampere, Finland; e-mail: jari.hietanen@uta.fi

they can verbally label these experiences (Bucci, 1997). By the age of 2–3 years, children use adult-like emotion labels to describe their subjective feelings, remember past feelings and anticipate future feelings. At the age of 3–4 years, children have an understanding of the typical causes of different emotions, and their receptive and productive vocabulary to describe emotions expands (Thompson & Lagattuta, 2006). Four- to 5-year-old children can name simple internal experiences when asked about how they know they are feeling different emotions (Carroll & Steward, 1984). Children's ability to recognize emotions from other people's expressions is evident at the age of 6 months (Balaban, 1995; Kotsoni, de Haan & Johnson, 2001), and the recognition of emotion expressions develops continuously throughout childhood and adolescence (Herba & Phillips, 2004; Rodger, Vizioli, Ouyang & Caldara, 2015; Widen, 2013). Children's physiological responses also differentiate between different types of neutral and affective stimuli, and autonomic, electroencephalographic, and facial electromyographic responses to affective pictures are adult-like in preschool-aged children (Hajcak & Dennis, 2009; Leventon, Stevens & Bauer, 2014; McManis, Bradley, Berg, Cuthbert & Lang, 2001).

Despite accumulating knowledge on childhood emotional development, it is surprising that the development of emotion-related bodily sensations – the candidate marker for subjective emotional feelings – has remained unexplored. An evident reason for this is related to lack of appropriate tools of investigation. For example, in self-report questionnaires, such as the Emotion Awareness Questionnaire for children (Rieffe, Meerum Terwogt, Petrides, Cowan, Miers *et al*., 2007), the items measuring bodily awareness of emotions measure the associations between bodily sensations and emotions at a coarse level (e.g. 'When I am scared or nervous, I feel something in my tummy' or 'I can feel my body tensing when I become angry or upset') and do not tap the topographical differences in bodily sensations across emotions. Moreover, as it is still debated whether or not direct psychophysiological recordings can differentiate between discrete emotions (Barrett, 2006; Kreibig, 2010), it is unlikely that the psychophysiological approach would be best suited for addressing the development of emotion-dependent bodily sensations.

We have recently developed a high-resolution topographical self-report method for quantifying bodily sensations associated with different emotions (emBODY; Nummenmaa *et al*., 2014). In this computer-based tool, participants simply indicate bodily regions whose activity they feel increasing or decreasing during different induced or imagined emotions. Different emotions were consistently associated with statistically separable patterns of bodily sensations, suggesting that different emotions have discernible bodily basis. Yet, it remains unresolved whether similar discrete bodily 'fingerprints' for different emotions exist in early childhood (and thus support subjective feelings), or whether they develop gradually and thus provide more fine-grained differentiation between emotions only in adolescents or young adults.

Here we investigated the development of bodily sensations associated with basic emotions in 6-, 8-, 10-, 14-, and 17-year-old children and adolescents. To allow multi-subject testing in a classroom environment with equipment familiar to even young children, we employed a paper-and-pencil version of the emBODY tool. As a nonverbal task, emBODY is well suited for testing children across a wide age range. To compare the children's results with those from adults, we collected normative data from an adult sample using the paper-and-pencil version of the test. We aimed at answering three questions. First, whether basic emotions are associated with distinct bodily sensations maps (BSMs) in early childhood. If so, the result would show that children are able to associate different patterns of bodily sensations with emotions and to discriminate between them in a reliable manner. Second, as we expected that the young children's BSMs would not fully correspond with the adult ones, we aimed at delineating the developmental trends towards adult-like BSMs for each emotion. Third, we also investigated whether the possible developmental trends would differ between basic emotions.

Materials and methods

Participants

Altogether, 331 individuals volunteered for the study. The participants were 48 preschool (mean age 6.1 years, 26 boys, 22 girls), 68 2nd grade (mean age 8.1 years, 34 boys, 34 girls), 91 4th grade (mean age 10.2 years, 43 boys, 48 girls), 42 8th grade (mean age 14.3 years, 15 boys, 27 girls), and 46 high-school (mean age 17.3 years, 9 boys, 37 girls) children and adolescents. They were recruited from local preschools and schools. The sample size was predetermined to be at least 40 participants in each age group based on Nummenmaa *et al*. (2014). Data collection was stopped when the minimum sample was obtained and when data from all volunteers in each contacted preschool and school had been collected. Similar data were also collected from 36 young adults (mean age 23.9 years, 10 men, 26 women) recruited among the students of the University of Tampere. As the

Finnish population is ethnically and socioeconomically rather homogeneous, information about family background was not sought. The Tampere Area Ethics Review Board reviewed the study protocol. Permission to conduct the study in the local preschools and schools was acquired from the city of Tampere.

Data acquisition and analysis

Data were acquired using a paper-and-pencil version of the emBODY tool (Nummenmaa *et al*., 2014; https://git.becs.aalto.fi/eglerean/embody). In this variant, the participants were given an A4-sized paper showing two outlines of a human body (height 10.0 cm) and an emotion word between them. The bodies were abstract and two-dimensional to lower the cognitive load of the task and to encourage evaluating only the spatial distribution of sensations (Figure 1). To discourage responding on the basis of conceptual associations between emotions and specific body parts, the bodies did not contain any pointers to, for example, internal organs.

Participants were asked to read the emotion words (the experimenter also read these aloud; 6-year-old children were not required to read the words themselves) and use a sharpened 4B-grade pencil to colour the bodily regions whose action they typically felt becoming stronger and faster (on the left body) or weaker and slower (on the right body) when feeling each emotion.[1] The procedure was repeated on separate sheets for all six basic emotions plus a neutral emotional state so that the different emotion words were presented in a random order. Memory-based reports were used instead of actually inducing emotions in participants, because in the adult population both techniques result in concordant BSMs (Nummenmaa *et al*., 2014), and because it would have been difficult to match emotion-eliciting stimuli to be equally powerful yet age appropriate across all the age groups tested.

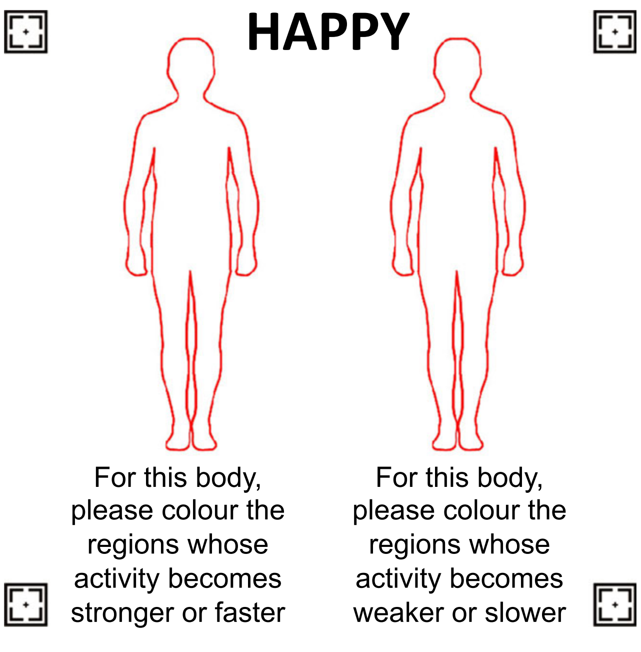

Figure 1 *Paper-and-pencil version of the emBODY tool. Participants used a pencil to colour the initially blank body regions whose activity they felt increasing (left body) and decreasing (right body) during each emotion. Registration marks and the red body outline were used for co-registering the scanned response sheets to the template image. The original texts were in Finnish.*

Subject-wise response sheets were digitized, and analyzed and preprocessed in Matlab R2013a using an in-house analysis toolbox. The analysis stream was similar to that described previously (Nummenmaa *et al*., 2014), and it was accommodated to the paper-and pencil response format. First, all emotion-wise responses were coregistered to a standard body template using Mattes mutual information coregistration and affine transformations. Responses outside the body area were masked, and activation and deactivation maps were combined into single BSMs representing both activations and deactivations. Next, the data were smoothed with a Gaussian kernel with a 15-pixel FWHM to account for uneven pencil traces. Data points with less than 10% of subject-wise maximum intensity were replaced with zeros to account for uneven scan quality. The preprocessed data were then screened manually for anomalous responses (e.g. drawing symbols on bodies or scribbling randomly), but there was no need to remove any data. Final preprocessed bodies were represented by 94,093 pixels each, with intensity values ranging from 0 to 255.

We next generated mean emotion-wise BSMs for each age group. To test whether the bodily sensations of

[1] In order to confirm that the children understood the used emotion labels, we also collected data from a task in which children from the three youngest age groups had to match emotion labels with facial expressions. This task was presented after the emBODY colouring task. Pictures of facial expressions of six basic emotions and a neutral face from three different female models were taken from the Pictures of Facial Affect series (Ekman & Friesen, 1976). The faces were shown one by one printed on a piece of A4-sized paper (for 6-year-olds) or projected onto the screen in the classroom (for 8- and 10-year-olds). For each face, the children had to select one of the seven emotion labels (happiness, anger, sadness, fear, disgust, surprise, and neutral) printed on a piece of paper. The results showed that, in each age group, the children were able to accurately associate emotion labels with the facial expressions (6 yrs: 65.1%, 8 yrs: 67.3%, 10 yrs: 70.0%; t-tests against 14.3% chance level, all $ps < .001$).

emotions are discrete over the lifespan, we employed statistical pattern recognition with linear discriminant analysis (LDA) separately for each age group's subject-wise BSMs. The dimensionality of the dataset was first reduced to 20 principal components with PCA. To estimate generalization accuracy, we employed stratified n/2-fold cross-validation where we trained the classifier to recognize all emotions against all the other emotions (complete classification). To estimate standard deviations of classifier accuracy, the cross-validation scheme was run iteratively 100 times.

Finally, we computed a similarity score between each age group's mean BSM with the corresponding adults' BSM for each emotion. This metric represents how similar the bodily sensations associated with each emotion in each age group are with respect to the corresponding sensations in adulthood. Similarity was computed from the normalized Euclidean distance between the spatial maps with normalized Euclidean distance scaled between 0 and 2 to obtain similarity scores between 1 and –1, i.e. to account for anti-correlated BSMs. Emotion-wise least-squares fitting was next used to test the existence of linear trends in the developmental trajectories toward adult-like bodily sensations.

Results

Figure 2 shows the bodily sensation maps associated with each emotion. In each age group, the basic emotions are associated with distinct distributions of body areas where activation was felt to either increase (or speed up) or decrease (or slow down). In the adult group, the uniqueness of the BSMs for each emotion is most clear and in agreement with our previous results (Nummenmaa *et al.*, 2014), whereas the maps of the younger age groups show more resemblance across different emotions. However, linear discriminant analysis (LDA) confirmed the independence of BSMs across emotions in all age groups. Average classification accuracy exceeded chance level (0.14) significantly in all age groups (6 years 0.19, 8 years 0.25, 10 years 0.26, 14 years 0.24, 17 years 0.22, adults 0.39; ps < .001). However, the classification accuracy showed emotion-specific differences (Figure 3). Most notably, happiness (and neutral emotional state) was classified reliably in all age groups. Classification exceeded chance level consistently for anger and sadness starting from 8 years of age, and for disgust starting from 10 years of age.

The BSMs shown in Figure 2 also suggest that the resemblance with the adult BSMs increases with increasing age. Thus, we next quantified the developmental trajectory for bodily sensations associated with different emotions. Figure 4 depicts the similarity score between each age group's BSM with the corresponding adults' BSM for each emotion. Linear regression with least-squares fitting showed that for each emotion, the linear model explained on average 74% of the variance in the developmental trajectories toward adult-like representations (significance tests for betas: anger, p = .010; disgust, p = .022; fear, p = .020; happiness, p = .007; sadness, p = .002; surprise, p = .009). Trajectories for surprise, anger, happiness, and fear were relatively similar, and the BSMs for these emotions at the age of

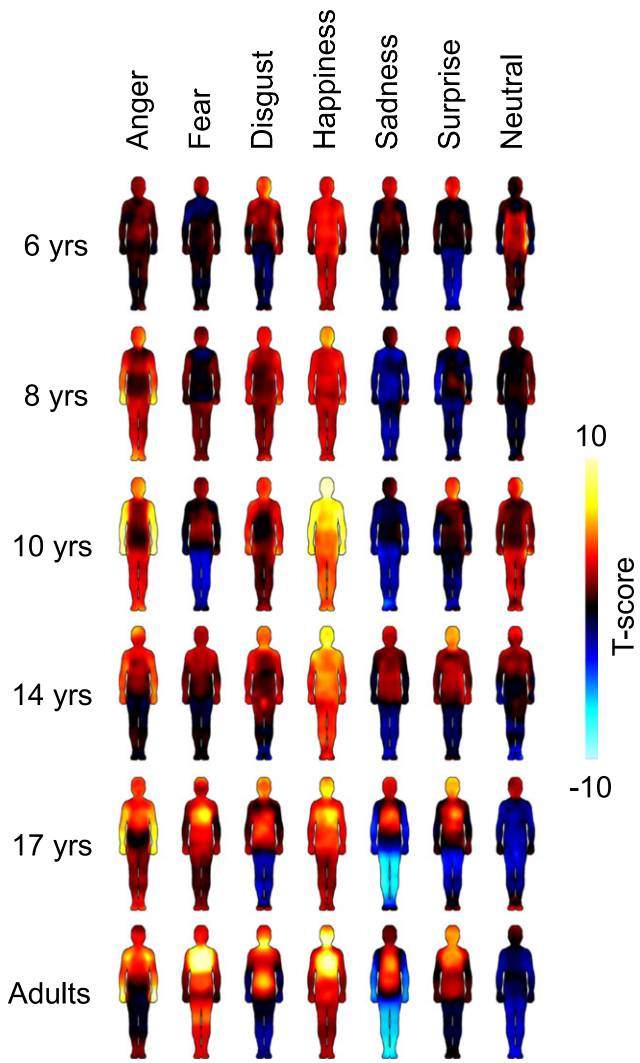

Figure 2 *Bodily topography of basic emotions associated with the six basic emotions and neutral state. The body maps show regions whose activation increased (warm colours) or decreased (cool colours) when feeling each emotion. The colour bar indicates the t-statistic range.*

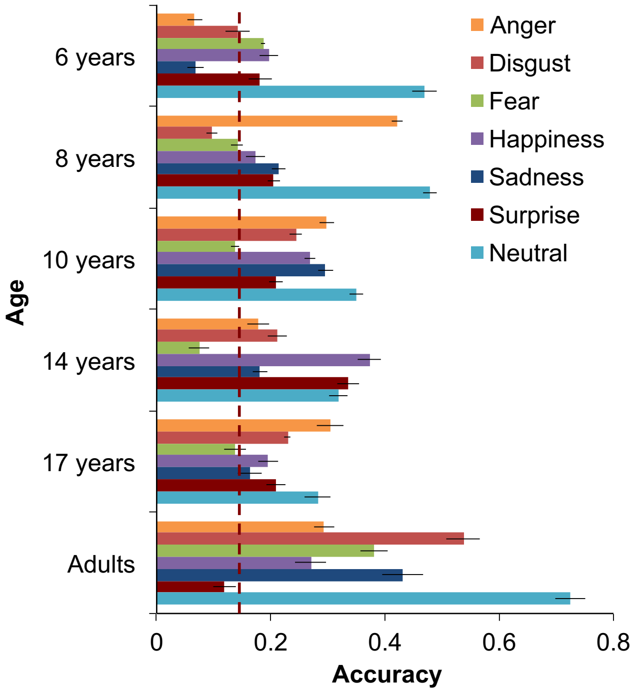

Figure 3 *Mean (± SD) emotion-wise classification accuracy across age groups. The dashed vertical line denotes the chance level (0.14).*

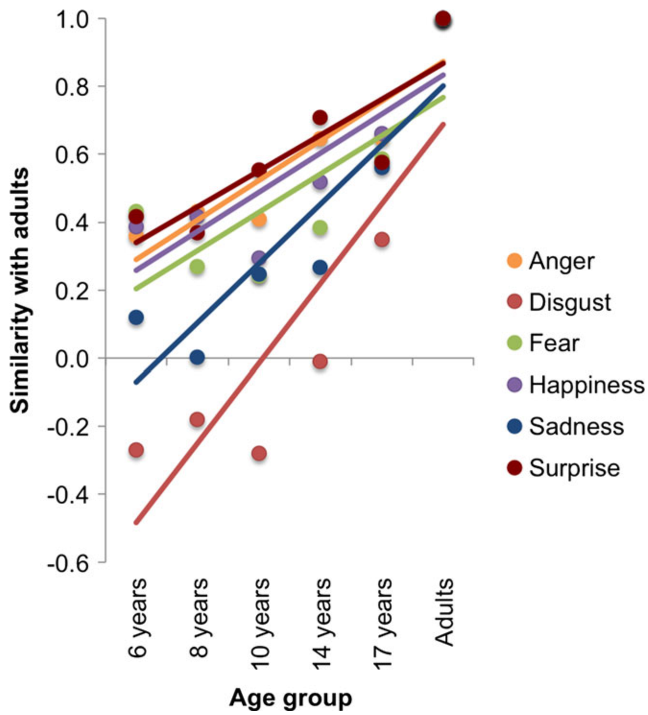

Figure 4 *Developmental trajectories for the emotion-wise bodily sensations. Each dot shows how similar an emotion in that age group is with respect to the corresponding bodily sensations in adults. Adults constitute the reference group with which other age groups are compared.*

6 year were closer to the corresponding adult ones. On the contrary, BSMs for sadness and disgust showed a more prolonged development towards the adult-like sensation patterns, with disgust being experientially distant from the corresponding adult sensation until early adulthood.

Discussion

Using a high-resolution topographical mapping tool we showed that preschool and young school-aged children associate discrete patterns of bodily sensations with specific basic emotions. Emotion-wise BSMs were most discrete in the adult participants and least unique in the 6-year-old children, with a linear developmental trend towards adult-like representation across the age groups. Linear discriminant analysis revealed that discrete bodily signatures for emotional neutrality and for two positive emotions – happiness and surprise – start to emerge around 6 years of age. Thereafter, development of discrete bodily sensations of other emotions follows, disgust being the last one to become adult-like. Thus, we were able to demonstrate a clear developmental trend from less to more specific emotion-related BSMs as a function of age.

Emotion-wise developmental trajectories differed across emotions. BSMs for surprise, anger, happiness, and fear were most similar to the adult maps for children as young as 6 years of age, and they all showed a relatively similar gradual development across childhood. Most notably, the developmental trajectories for BSMs associated with sadness and disgust clearly differed from the other emotions. The 6-year-olds' BSMs for sadness and disgust bore little similarity with the corresponding adult ones. However, both showed a steep developmental slope and, by the age of 17 years, the BSMs for sadness had reached an equal level of similarity with fear. For disgust, the 17-year-olds' BSMs were still different from those of adult participants.

These results accord with findings that 2- to 4-year-old children start to use emotion labels in describing facial expressions or stories of emotional events in a systematic order. The first label they are likely to use is happiness. This is followed either by sadness or anger, and then either fear or surprise. The last one to emerge is disgust. It has been suggested that differential use of emotion labels reflects the development of children's categorization of emotions (for a review and results, see Widen & Russell, 2010). Thus, it is possible that the differences between emotion-wise developmental trajectories observed in the present study reflect the way a general emotional categorization system develops in children rather than differences in the way children can associate bodily sensations with different emotions as such. However, there are also some discrepancies in the developmental paths between children's use of emotion labels and those observed in the present study. For example, children start to consistently use emotion label for disgust before 4 years of age (Widen & Russell, 2010), and yet the present results showed that a unique BSM associated with disgust was not apparent before the age of 10 years. Thus, it may be that the present findings do reflect differences in the way children can associate bodily sensations with different emotions rather than development of general emotion categories. In future studies, the present methodology may offer a way to investigate the relationship and direction of causality between the development of a general emotional categorization system and changes in the accuracy with which children can access and report their emotion-related bodily sensations.

The present results differ from the recently reported developmental trajectories of the recognition of facial expression. Rodger *et al.* (2015) measured perceptual thresholds for discrimination of facial expressions of basic emotions in children from 5 years of age up to adulthood. The recognition was best for happiness and worst for fear but, for both emotions, no significant improvement was observed from 5 years of age to adulthood. For other basic emotions, recognition was between that for happiness and fear, and it improved over development. For sadness and surprise, the improvement was modest across childhood and adolescence, but steeper for disgust and anger. In sum, the patterns of developmental trajectories of basic emotions differ between recognizing others' expressions versus one's own emotion-dependent bodily changes. This is hardly surprising considering that the recognition of facial expressions largely depends on perceptual information and on the corresponding neural mechanisms – rather than on affective information and feelings (for a review, see Calvo & Nummenmaa, 2015) – and that these mechanisms are likely to follow a different developmental trajectory from those involved in bodily sensations.

The present results do not allow us to disentangle whether developmental trends in emotion-wise BSMs reflect changes in the actual bodily sensations associated with different emotions, or changes in the accuracy of accessing and reporting these sensations. It is possible that children's bodily reactions in emotions are different from those in adults. Compared with adults, children's less discrete emotion-wise BSMs could also reflect greater inter-individual variability in children's bodily reactions leading, thus, to less unique mean emotion-wise BSMs. However, based on theoretical views that emphasize the innate origin of bodily reactions in emotions (e.g. Damasio & Carvalho, 2013), we are inclined to interpret our results to reflect changes in the accuracy with which children can access and report these bodily sensations. Although we cannot in the present setup rule out age-related differences in the memory of bodily sensations, it is known that children's interoceptive awareness as measured by accuracy in detecting their own heart beats – a prominent response associated with multiple emotions – is still inferior to that of adults at 8–11 years (Eley, Stirling, Ehlers, Gregory & Clark, 2004). Furthermore, if the emotion-related bodily sensations as such were shaped by developmental experiences one would expect to observe differences in these sensations across people coming from different cultures. However, this is not the case in adult populations: BSMs are concordant across considerably different West European (Finland) and East Asian (Taiwan) cultures (Nummenmaa *et al.*, 2014). BSMs thus seem to reflect sensation patterns triggered by activation of the emotion systems, and the developmental changes likely reflect changes in the recognition/reporting accuracy of these sensations. The paper-and-pencil version of the emBODY tool proved to be suitable to be used by children and, thus, offers an accessible method for investigating patterns of bodily sensations associated with emotions. Due to its visual and motor nature, the task is appealing for children, and it relies minimally on verbal skills. The BSMs observed in the adult participants using this paper-and-pencil version of the emBODY tool corresponded well with existing data on adults using a computerized version of the same tool (Nummenmaa *et al.*, 2014) and, thus, provide support for the reliability of this method.

The emBODY tool may have significant potential in supporting and advancing the positive development of children. For example, emotion-regulation skills – that are among the most important developmental milestones in childhood – comprise the ability to be aware of emotions, the ability to identify and label emotions, and the ability to identify emotion-related bodily sensations correctly (Eisenberg & Morris, 2002). Thus, simple tools allowing measurements of emotion-related sensations in the whole body could be used, for example, in training children's emotion-regulation skills and in helping children to become aware of their emotion-related bodily sensations. Aberrant developmental trends might also be detected. In children, impairments in emotion awareness are associated with more serious internalizing problems that are typical, for example, in depression, anxiety, and somatic complaints (Rieffe & De Rooij, 2012; Rieffe, Oosterveld, Meerum Terwogt, Novin, Nasiri *et al.*, 2010; Van der Veek, Derkx, de Haan, Benninga & Boer, 2012). The emBODY tool could also be suitable for studies of children having difficulties in verbalizing their emotions and internal states, as in autism (Samson, Hardan, Podell, Phillips & Gross, 2015) and alexithymia (Jellesma, Rieffe, Meerum Terwogt & Westenberg, 2009).

Conclusions

We conclude that bodily sensations associated with emotions show rudimentary differentiation at preschool age, and that these interoceptive representations between different emotions become increasingly discrete during development toward adolescence. This development parallels the way children start to use emotion words when describing different emotional events, suggesting that the development of awareness of their own emotion-related bodily sensations significantly shapes the way children perceive and interpret their environment.

Acknowledgements

We thank Anne Engdahl, Jonne Hietanen, Helena Hokuni, and Karoliina Manninen for their help in data collection. This research was supported by the Academy of Finland MIND program grants #266187 to JKH and #265915 to LN, ERC Starting Grant #313000 to LN, and an aivoAALTO grant from Aalto University.

References

Balaban, M.T. (1995). Affective influences on startle in five-month-old infants: reactions to facial expressions of emotions. *Child Development*, **66**, 28–36. doi:10.2307/1131188

Barrett, L.F. (2006). Are emotions natural kinds? *Perspectives in Psychological Sciences*, **1**, 28–58. doi:10.1111/j.1745-6916.2006.00003.x

Bucci, W. (1997). Symptoms and symbols: a multiple code theory of somatization. *Psychoanalytic Inquiry*, **17**, 151–172. doi:10.1080/07351699709534117

Calvo, M.G., & Nummenmaa, L. (2015). Perceptual and affective mechanisms in facial expression recognition: an integrative review. *Cognition and Emotion*. doi:10.1080/02699931.2015.1049124

Carroll, J.J., & Steward, M.S. (1984). The role of cognitive development in children's understandings of their own feelings. *Child Development*, **55**, 1486–1492. doi:10.2307/1130018

Damasio, A.R., & Carvalho, G.B. (2013). The nature of feelings: evolutionary and neurobiological origins. *Nature Reviews Neuroscience*, **14**, 143–152. doi:10.1038/nrn3403

Eisenberg, N., & Morris, A.S. (2002). Children's emotion-related regulation. In R. Kail (Ed.), *Advances in child development and behaviour* (Vol. **30**, pp. 190–229). San Diego, CA: Academic Press.

Ekman, P. (1992). An argument for basic emotions. *Cognition and Emotion*, **6**, 169–200. doi:10.1080/02699939208411068

Ekman, P., & Friesen, W. (1976). *Pictures of facial affect*. Palo Alto, CA: Consulting Psychologists Press.

Eley, T.C., Stirling, L., Ehlers, A., Gregory, A.M., & Clark, D.M. (2004). Heart-beat perception, panic/somatic symptoms and anxiety sensitivity in children. *Behaviour Research and Therapy*, **42**, 439–448. doi:10.1016/S0005-7967(03)00152-9

Hajcak, G., & Dennis, T.A. (2009).Brain potentials during affective picture processing in children. *Biological Psychology*, **80**, 333–338. doi:10.1016/j.biopsycho.2008.11.006

Hamann, S. (2012). Mapping discrete and dimensional emotions onto the brain: controversies and consensus. *Trends in Cognitive Sciences*, **16**, 458–466. doi:10.1016/j.tics.2012.07.006

Herba, C., & Phillips, M. (2004). Annotation: Development of facial expression recognition from childhood to adolescence: behavioural and neurological perspectives. *Journal of Child Psychology and Psychiatry*, **45**, 1185–1198. doi:10.1111/j.1469-7610.2004.00316.x

James, W. (1884). What is an emotion? *Mind*, **9**, 188–205.

Jellesma, F.C., Rieffe, C., Meerum Terwogt, M., & Westenberg, M. (2009). Do I feel sadness, fear or both? Comparing self-reported alexithymia and emotional task-performance in children with many or few somatic complaints. *Psychology and Health*, **24**, 881–893. doi:10.1080/08870440801998970

Kassam, K.S., Markey, A.R., Cherkassky, V.L., Loewenstein, G., & Just, M.A. (2013). Identifying emotions on the basis of neural activation. *PloS ONE*, **8**, e66032. doi:10.1371/journal.pone.0066032

Kotsoni, E., de Haan, M., & Johnson, M.H. (2001). Categorical perception of facial expressions by 7-month-old infants. *Perception*, **30**, 1115–1125. doi:10.1068/p3155

Kreibig, S.D. (2010). Autonomic nervous system activity in emotion: a review. *Biological Psychology*, **84**, 394–421. doi:10.1016/j.biopsycho.2010.03.010

Leventon, J.S., Stevens, J.S., & Bauer, P.J. (2014). Development in the neurophysiology of emotion processing and memory in school-age children. *Developmental Cognitive Neuroscience*, **10**, 21–33. doi:10.1016/j.dcn.2014.07.007

McManis, M.H., Bradley, M.M., Berg, W.K., Cuthbert, B.N., & Lang, P.J. (2001). Emotional reactions in children: verbal, physiological, and behavioral responses to affective pictures. *Psychophysiology*, **38**, 222–231. doi:10.1111/1469-8986.3820222

Nummenmaa, L., Glerean, E., Hari, R., & Hietanen, J.K. (2014). Bodily maps of emotions. *Proceedings of the National Academy of Sciences of the United States of America*, **111**, 646–651. doi:10.1073/pnas.1321664111

Panksepp, J. (1982). Toward a general psychobiological theory of emotions. *Behavioral and Brain Sciences*, **5**, 407–422. doi: http://dx.doi.org/10.1017/S0140525X00012759

Rieffe, C., & De Rooij, M. (2012). The longitudinal relationship between emotion awareness and internalising symptoms during late childhood. *European Child and Adolescent Psychiatry*, **21**, 349–356. doi:10.1007/s00787-012-0267-8

Rieffe, C., Meerum Terwogt, M., Petrides, K.V., Cowan, R., & Miers, A.C. et al. (2007). Psychometric properties of the Emotion Awareness Questionnaire for children. *Personality and Individual Differences*, **43**, 95–105. doi:10.1080/00223891.2010.482003

Rieffe, C., Oosterveld, P., Meerum Terwogt, M., Novin, S., & Nasiri, H. et al. (2010). Relationship between alexithymia, mood and internalizing symptoms in children and young adolescents: evidence from an Iranian sample. *Personality and Individual Differences*, **48**, 425–430. doi:10.1016/j.paid.2009.11.010

Rodger, H., Vizioli, L., Ouyang, X., & Caldara, R. (2015). Mapping the development of facial expression recognition. *Developmental Science*, **18**, 926–939. doi:10.1111/desc.12281

Saarimäki, H., Gotsopoulos, A., Jääskeläinen, I.P., Lampinen, J., & Vuilleumier, P. et al. (2015). Discrete neural signatures of basic emotions. *Cerebral Cortex*. doi:10.1093/cercor/bhv086

Saarni, C., Mumme, D.L., & Campos, J.J. (1998). Emotional development: action, communication, and understanding. In W. Damon & N. Eisenberg, (Eds.), *Handbook of child psychology: Social, emotional and personality development* (5th edn., Vol. **3**, pp. 237–309). New York: Wiley.

Samson, A.C, Hardan, A.Y., Podell, R.W., Phillips, J.M., & Gross, J.J. (2015). Emotion regulation in children and adolescents with autism spectrum disorder. *Autism Research*, **8**, 9–18. doi:10.1002/aur.1387

Thompson, R.A., & Lagattuta, K. (2006). Feeling and understanding: early emotional development. In K. McCartney & D. Phillips (Eds.), *The Blackwell handbook of early childhood development* (pp. 317–337). Oxford: Blackwell.

Van der Veek, S.M.C., Derkx, H.H.F., de Haan, E., Benninga, M.A., & Boer, F. (2012). Emotion awareness and coping in children with functional abdominal pain: a controlled study. *Social Science and Medicine*, **74**, 112–119. doi:10.1016/j.socscimed.2011.10.023

Widen, S.C. (2013). Children's interpretation of facial expressions: the long path from valence-based to specific discrete categories. *Emotion Review*, **5**, 72–77. doi:10.1177/1754073912451492

Widen, S.C., & Russell, J.A. (2010). Differentiation in preschooler's categories for emotion. *Emotion*, **10**, 651–661. doi:10.1037/a0019005

Received: 26 June 2015
Accepted: 3 November 2015