**Understanding, expressing, and interacting: the development of emotional functioning in young children with autism**

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# 2

# CHAPTER 2.

## The early development of emotion recognition in autistic children: Decoding basic emotions from facial expressions and emotion-provoking situations

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## ABSTRACT

Autism has long been associated with struggles in emotion recognition. This four-wave longitudinal study followed the development of three key emotion recognition abilities regarding four basic emotions in preschool autistic and non-autistic children aged 2.5 to 6 years over a period of three years. Behavioral tasks were used to examine whether children could differentiate facial emotion expressions (emotion differentiation), to associate facial emotion expressions to verbal labels (emotion identification), and to attribute emotions to emotion-provoking situations (emotion attribution). The results showed that autistic children experienced more difficulties in discriminating, identifying and attributing emotions than non-autistic peers. These challenges were present early and persistent over time. Remarkably, autistic children showed comparable age-related improvements as non-autistic children. Despite the early presence of difficulties in emotion recognition, autistic children showed the capacity for learning and potential for improvement.

**Introduction**

Emotions have important communicating functions. A happy face signals to another that one is satisfied with the situation and welcomes further interaction, whereas an angry face signals to another that one dislikes the situation and wants to reinstate goals and status (Nikitin & Freund., 2019; Taylor & Barton, 2015). Correctly interpreting the emotional signals of others is crucial for establishing and maintaining positive relationships (Dede et al., 2021). Social communication and social interaction constitute one of the most challenging areas for people with autism (American Psychiatric Association, 2013). The predicament is partly related to their struggles in recognizing others' emotions. There is a plethora of research investigating emotion recognition in autistic individuals (for reviews, see Harms et al. (2010), Uljarevic & Hamilton (2012), Lozier et al. (2014)). They contributed greatly to our knowledge of the intergroup differences. However, due to their cross-sectional designs, little is known about how emotion recognition abilities develop within autistic individuals over time (Rosen & Lerner, 2016). To address this gap and to start from an early life stage, this study examined the development of emotion recognition over a three-year time course in autistic children aged 2.5 to 6 years, in comparison to non-autistic peers.

In typical development, perceiving and discriminating facial expressions marks the first step towards emotion recognition. A-few-month-old infants already show awareness that a happy face is different from an angry face (Grossmann, 2010; Kobiella et al., 2008). By the end of the first year, they can use facial expressions as social references to guide behaviors (Camras & Shutter, 2010; Hertenstein & Campos, 2004). Along with the language development, children start to produce verbal labels for emotions in the second year of life (Dunn et al., 1987; Ridgeway et al., 1985). Labeling emotions enables children to categorize emotions and acquire the scripted knowledge of emotions, which includes not only facial expressions, but also bodily reactions, action tendencies, and importantly, the eliciting events associated with the emotion (Widen & Russell, 2008). Understanding that every emotion is associated with an emotion-provoking situation and being able to predict another's emotion based on situational cues marks another progress towards matured emotion recognition (Rieffe et al., 2017). While toddlers and preschoolers rely primarily on facial expressions, school-aged children reply more often on situational cues for processing emotional information (Herba & Phillips, 2004).

The above-mentioned abilities usually develop without much effort in typically developing children. However, it can be challenging for autistic children. Research showed that autistic children aged between 4 and 17 years encountered more difficulties than non-autistic peers in discriminating facial expressions (e.g., Evers et al., 2015; Fridenson-Hayo et al., 2016; Tardif et al., 2007; Wieckowski et al., 2019; Xavier et al., 2015), labeling facial expressions (e.g., Balconi et al., 2012; Fink et al., 2014; Griffiths et al., 2017; Peterson et al., 2015; Shanok et al., 2019), and attributing emotions to emotion-provoking situations (e.g., Balconi et al., 2012; Fridenson-Hayo et al., 2016; Tell et al., 2014). It was especially challenging when the emotions were of the negative valence such as fear and anger (e.g., Akechi et al., 2010; Wright et al., 2008), with a more complex nature such as shame and guilt (e.g., Heerey et al., 2003; Kotroni et al., 2019), presented in a low intensity (e.g., Song & Hakoda, 2018) or for a short duration (e.g., Clark et al., 2008). Some studies did not find group differences (e.g., Castelli, 2005; Lacroix et al., 2014; Tracy et al., 2011). They usually had groups matched on cognitive abilities such as verbal and global IQ. As pointed out by Harms and colleagues (2010), an uneven IQ profile is phenotypically linked with autism. Removing the effect of IQ might also remove some essential attributes linked with autism. Besides, group differences often disappeared when the recognition of basic emotions were examined in prototypical situations in middle-school-aged autistic children and older (e.g., Jones et al., 2011; Tracy et al., 2011). Possibly, autistic children catch up non-autistic peers in their basic-emotion recognition at older ages.

In contrast to the abundant research on the intergroup differences, there is a dearth of developmental data, preventing us from delineating the developmental course of emotion recognition in autism. To the best of our knowledge, only one study used a longitudinal approach. Rosen and Lerner (2016) found that the ability to label basic emotions from facial expressions improved in 11- to 17-year-old autistic children and adolescents over a period of 18 weeks. The age-related improvement was also supported by some correlation studies, which found a positive relation between age and emotion recognition in autistic children aged between 4 to 13 years (Fridenson et al., 2016; Lacroix et al., 2014; Williams et al., 2013; Xavier et al., 2015). Note, however, when looking across the life span, evidence suggests that emotion recognition may develop with a smaller magnitude in autistic people than in non-autistic people. A few cross-sections studies found that non-autistic adults and adolescents outperformed non-autistic children in some emotion-recognition tasks, whereas such age differences were not found in autism (Greimel et al., 2014; O'Connor et al., 2005; Rump et al., 2009). Besides, two meta-analyses, each amalgamating more than 40 cross-sectional studies on emotion recognition in autistic individuals of various ages, found that the difficulties in emotion recognition for autistic individuals did not diminish or disappear with age (Uljarevic & Hamilton, 2012); rather, the intergroup differences in emotion recognition seem to become greater from childhood to adolescence and adulthood (Lozier et al., 2014).

To find out how emotion recognition develops in autistic people and whether their development follows a different trajectory, longitudinal investigations are needed (Harms et al., 2010). Hoping to address this gap, this four-wave longitudinal study examined emotion recognition and its development in 2.5- to 6-year-old children with and without autism. In particular, we examined emotion recognition at three levels: (1) differentiating facial emotion expressions, (2) identifying facial emotion expressions with verbal labels, and (3) attributing emotions to emotion-provoking situations. Based on the previously mentioned literature, we expected that autistic children had more difficulties than non-autistic peers in differentiating, identifying, and attributing emotions. We assumed that all three emotion-recognition abilities improved with age in non-autistic children (Widen & Russell, 2004; Herba & Phillips, 2004). Due to the scarcity of longitudinal data in autism, our hypotheses regarding their development were explorative. We expected that, similar to non-autistic children, autistic children's abilities would improve with age, but probably with a smaller magnitude.

In addition to the effect of age, we also examined the influence of autistic traits on the development of emotion recognition in autistic children. Previous correlational studies found that more accentuated autistic traits were related to more difficulties in emotion recognition (Brosnan et al., 2015; Evers et al., 2015; Xavier et al., 2015; Tell et al., 2014; Williams & Gray, 2013). We explored whether the associations were also present longitudinally.

## Methods

### *Participants and procedure*

This study was part of a larger-scaled longitudinal research on the social and emotional development of preschool children with limited access to the social world, including children with hearing loss, developmental language disorder and autism. The total sample of the larger-scaled research included 73 autistic children (65 boys) and 418 non-autistic children (226 boys). Autistic children met the following inclusion criteria: (1) the child received an autism diagnosis according to the *Diagnostic and Statistical Manual of Mental Disorders* (4$^{th}$ ed.) (American Psychiatric Association, 2000) based on the *Autism Diagnostic Interview-Revised* (Lord, Rutter, & Lecouteur, 1994) set by a qualified child psychologist or psychiatrist at Time 1, (2) parents confirmed three years later that the child retained the autism diagnosis, (3) the child had IQ scores above 70 and no additional clinical diagnoses.

Inclusion criteria for non-autistic children were (1) IQ scores above 70, and (2) no clinical diagnoses or disabilities.

Autistic children were recruited via a specialized institution for diagnosis and treatment of autism, i.e., Center for Autism, Leiden, the Netherlands. Non-autistic children were recruited from day-care centers and mainstream primary schools in the same region. Since the IQ profiles of autistic children were either retrieved from school or collected by the institution, various intelligence tests were used, including the Snijders-Oomen Nonverbal Intelligence Tests (SON-R), Wechsler Intelligence Scale for Children, Wechsler Preschool and Primary Scale of Intelligence, and Wechsler Nonverbal Scale of Ability. Non-autistic children were tested with the SON-R.

The Ethics Committee of Leiden University and Center for Autism granted permission for the larger-scaled research project. All parents provided written informed consent. Children and their parents participated the research once a year for four consecutive years (mean duration between Time 1 and Time 2 = 13.20 months, *SD* = 3.47; between Time 2 and Time 3 = 12.15 months, *SD* = 1.58; between Time 4 and Time 3 = 12.23, *SD* = 1.05). Children were visited either at school or at the specialized institution (for autistic children only), where they finished a series of tasks under the guidance of a trained psychologist. Parents filled out a group of questionnaires to report on children's development. The Social Responsive Scale (SRS; Constantino & Gruber, 2005) was filled out at Time 1, Time 3 and Time 4, where parents reported on the degree of their children's autistic traits. It consists of 65 items with responses on a 4-point scale, where higher scores indicated more accentuated autistic traits. The raw total scores were calculated, based on which the T-scores were generated using the Dutch SRS manual (Roeyers et al., 2011). Since the Dutch norm applies to children aged between four and 17 years, no T-scores were generated for children who were younger than four years.

Due to time constraints, not all children were administered the full test battery. Participants of the larger research project were included in this study if they had data of the emotion-recognition variables on at least one time point (see Supplementary Table 1, 2 and 3 for available data at each time point). The final sample used in the current study included 62 autistic children (7 girls) and 121 non-autistic children (11 girls), aged 32 to 72 months (Mean = 55.86 months).

Table 1: Demographic characteristics of participants: means and standard deviations of background variables.

| | | Total participants at Time 1 N = 183 | | | |
|---|---|---|---|---|---|
| | | **Autistic** | N 62 | **Non-autistic** | N 121 |
| **Age in months** | Wave 1 | 56.57 (10.38) | 62 | 55.45 (11.37) | 121 |
| | Wave 2 | 69.18 (10.57) | 44 | 70.16 (11.01) | 51 |
| | Wave 3 | 82.45 (9.45) | 42 | 81.16 (10.69) | 49 |
| | Wave 4 | 95.05 (9.07) | 37 | 93.21 (10.25) | 43 |
| **Male%** | | 88.71% | 62 | 90.91% | 121 |
| **IQ**** | | 99.92 (16.45) | 51 | 110.29 (15.07) | 62 |
| **SRS T score** | Wave 1** | 75.24 (10.86) | 42 | 46.07 (4.18) | 14 |
| | Wave 3** | 78.79 (13.27) | 38 | 47.28 (5.27) | 36 |
| | Wave 4** | 77.91 (11.30) | 23 | 45.70 (5.11) | 27 |
| **Education mother**[a*] | | 3.80 (1.13) | 55 | 4.42 (0.90) | 48 |
| **Education father**[a] | | 3.68 (1.36) | 56 | 4.02 (0.96) | 41 |
| **Net annual income**[b**] | | 2.98 (1.17) | 40 | 3.85 (1.10) | 67 |

[a] Parental education level: 1 = no/primary education; 2 = lower general secondary education; 3 = middle general secondary education; 4 = higher general secondary education; 5 = college/university.

[b] Net household income: 1 = less than €15,000; 2 = €15,000 – €30,000; 3 = €30,000 – €45,000; 4 = €45,000 – €60,000; 5 = more than €60,000.

* $p < .05$ ** $p < .001$

Table 1 shows the descriptive characteristics of the participants. The autistic and non-autistic group did not differ in age ($-.44 < t$s $< .85$, $p$s $> .05$) or gender distribution ($\chi^2$ (1) = .22, $p$ = .636). Autistic children had on average lower IQ than non-autistic children ($t$(117) = 3.49, $p < .001$). They had higher SRS T-scores at Time 1: ($t$(52.71) = 14.49, $p < .001$), Time 3($t$(48.92) = 13.55, $p < .001$, and Time 4 ($t$(29.57) = 12.61, $p < .001$). Mothers of autistic children had on average lower education levels than mothers of non-autistic children ($t$(100.13) = 3.09, $p$ = .003). The average education levels of fathers did not differ between groups ($t(94.89) = 1.47$, $p = .146$). Families of autistic children had lower average income than families of non-autistic children ($t(105) = 3.89$, $p < .001$).

***Measures***

Considering the young ages of the participants, the emotion recognition tasks were designed to place minimal verbal demand on children and involved only four basic emotions, i.e., happiness, anger, sadness, and fear. These tasks were used previously to measure emotion recognition in children with hearing loss (Wiefferink et al., 2012) and with developmental language disorder (Rieffe & Wiefferink, 2017).

Children's ability to discriminate between different facial emotion expressions was measured by the ***Emotion Discrimination Task***. First, a sheet was placed in front of them, where the drawing of one category (e.g., a happy face) was printed on the top left corner, and the drawing of another category (e.g., a sad face) was printed on the top right corner. Next, the experimenter demonstrated how to place two cards with drawings of the two different categories on the sheet, accompanied by a simple oral explanation: "Look, this one should be put here, and this one should be put here". Then, children were given six cards (e.g., three drawings of a happy face and three drawings of a sad face) to do the sorting.

Before sorting out cards of facial emotional expressions, children did two practice tasks, where they first sorted out cards of cars and flowers, and then sorted out cards of similar faces, one with glasses and one with a hat. The two practice tasks were used to familiarize children with the intention and procedure of the tasks. In the testing task, children sorted out facial emotion expressions of different emotional valences (condition 1: happy versus sad) and facial emotion expressions of the same emotional valence (condition 2: angry versus sad). Condition 1 was supposed to be easier than condition 2, because the differences are more prominent in facial emotion expressions between valences than within the same valence. Children scored "1" when placing one card under the correct category and scored maximally "3" for each category.

Children's ability to associate verbal labels to facial emotion expressions was measured by the ***Emotion Identification Task***. The experimenter showed children eight drawings of facial emotion expressions for happiness, anger, sadness and fear (two drawings for each emotion) and asked: "Who looks happy?" Children had to point to the drawing of a happy face. Next, the researcher asked: "Is there anyone else who looks happy?" Children had to point to another drawing of a happy face. The same procedure was repeated for anger, sadness and fear. Children scored “1” for each correctly identified facial emotion expression, and scored maximally “2” for each emotion.

Children’s ability to attribute emotions to emotion-provoking situations was tested by the ***Emotion Attribution Task***. Children were shown drawings of eight vignettes, depicting two prototypical emotion-provoking situations for happiness, anger, sadness and fear respectively. Meanwhile the experimenter gave a simple oral explanation, such as “Look, the boy sees a frightening dog” (see Supplementary Table 4 for the descriptions of the eight vignettes). Then the experimenter asked: “How does the boy feel?” This required a verbal answer from children (the verbal condition). Considering that some children might not know the word for the emotion, next, the experimenter showed children a sheet with the drawings of a happy, angry, sad and fearful face and asked: “How does the boy look?” This required the child to point to the corresponding face (the visual condition). For both conditions, children scored “2” when assigning the emotion that was intended by the study, scored “1” when assigning an emotion which was not the intended emotion but of the intended valence, and scored “0” when assigning an emotion of the opposite valence. Children’s performances in this task were examined per valence. This was because a prototypical situation might provoke different emotions within the same valence. For example, a child may feel scared when seeing a frightening dog, but it is also possible that the child feels sad. Furthermore, children younger than 3 years tend to mix emotions within the same valence, for example, referring to all the negative emotions as “anger” or “sad” (Widen, 2013).

The drawings used in the tasks were computer generated and in black and white. The facial emotion expressions were drawn based on photos of different four- and five-year-old boys, which were randomly chosen from a large database with photos of various facial emotion expressions. Examples of the drawings can be found in Supplementary Figure 1.

***Statistical analyses***

R (version 3.3.3; R Core Team 2019) was used to make figures (with the package “ggplot2” (Wickham, 2009)). IBM SPSS Statistics for Macintosh (version 27.0; Armonk, NY: IBM Corp.) were used to conduct Linear Mixed Model (LMM) analyses for examining the developmental trajectories of emotion recognition abilities and their associations with symptom severity. LMM can account for the dependency within the longitudinal data (Hox et al., 2010) and is robust in handing missing data when they miss (completely) at random (Twisk et al., 2017). The current data had missing values at every time point. Little’s MCAR tests indicated that the missing patterns could be completely at random ($422.98 < \chi^2$s < 2570.48, *p*s > .05).

We followed a formal model-fitting procedure, i.e., fitting increasingly more complex models to the data step by step. Simpler models with a better model fit were selected over the more complex model. To evaluate model fit, for nested models, the preferred model showed significant less deviance, i.e., lower values of -2 Log Likelihood (-2LL). For non-nested models, the preferred model showed lower Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) values.

To examine the developmental trajectories of emotion recognition abilities, we started with an unconditional means model which included only a fixed and random intercept. Then, age (centered around 32 months, the youngest age of all participants) was added to the model. We examined two models of change: linear and quadratic, respectively. Next, group (0 = non-autistic, 1 = autistic) was added to examine if the levels of emotion recognition differed between the two groups across time. Fourth, we added the interactions between age and group to the model to examine whether the two groups differed in developmental trajectories.

To investigate the role of autistic traits in predicting of the development of emotion recognition abilities in autistic children, we first calculated four composite scores, i.e., the total score of the emotion discrimination task, the emotion identification task, the emotion attribution task verbal condition and visual condition. Next, we calculated the mean score of SRS, i.e., the mean of SRS raw total score at Time 1, Time 3, and Time 4. Third, we started with four separate models which had only age as the control variable and the composite scores of the four emotion-recognition tasks as the dependent variables. Fourth, we added the SRS mean score as a predicting variable to the age-only models.

## Results

***Developmental trajectories of emotion discrimination.*** Table 2 shows the estimates of the fixed and random effects of the best age models for emotion discrimination. The best age models for both conditions were with the fixed effects of linear age and group. As depicted in Figure 1, the abilities to discriminate between facial expressions improved with age in all children, and yet autistic children scored overall lower than non-autistic children in the tasks.

See also Supplementary Table 5 for more information on the model fit of the best age models for emotion discrimination, identification and attribution.

***Developmental trajectories of emotion identification.*** Table 3 provides the estimates of the fixed and random effects of the best age models for emotion identification. For identifying happy and angry facial expressions, the best age models were both with the fixed effects of linear age and group, and their interactions. For both models, adding the random effects of linear age contributed to significant improvements of model fit, indicating that there were substantial unexplained slope variabilities. Autistic children showed greater improvement with age in identifying happy facial expressions ($b$ = .008, $p$ = .006) than non-autistic children ($b$ = .006, $p$ = .002). They also showed greater improvement in identifying angry facial expressions ($b$ = .008, $p$ = .001) than non-autistic children ($b$ = .007, $p$ = .001) (see Figure 2).



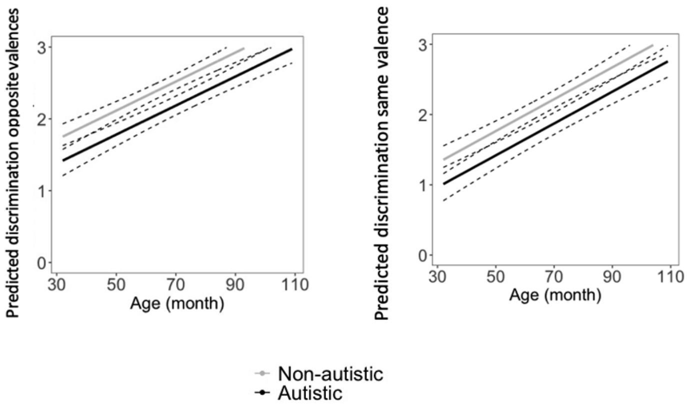


Fig 1. Regression lines depicting the predicted levels of discrimination between emotions of opposite valences (left) and emotions of the same valence (right) with 95% confidence intervals based on the best fitting models with age as the predictor.

Table 2. Fixed and random effects of the best age models for *emotion discrimination*.

| | ***Positive vs. Negative*** | | | | ***Sad vs. Anger*** | | | |
|---|---|---|---|---|---|---|---|---|
| **Fixed effects** | **Estimates** | **SE** | **CI [low, high]** | | **Estimates** | **SE** | **CI [low, high]** | |
| *Intercept* | 1.75 | .09 | [1.57, 1.93] | | 1.35 | .10 | [1.16, 1.56] | |
| *Age* | .02 | .002 | [.016, .024] | | .02 | .002 | [.02, .03] | |
| *Group* | -.34 | -.09 | [-.51, -.16] | | -.34 | .10 | [-.55, -.14] | |
| **Random effects** | **Estimates** | **SE** | **CI [low, high]** | **Wald's Z** | **Estimates** | **SE** | **CI [low, high]** | **Wald's Z** |
| *Residual* | .49 | .04 | [.41, .57] | 11.89 | .55 | .05 | [.47, .66] | 11.43 |
| *Intercept* | .11 | .04 | [.06, .21] | 3.01 | .18 | .05 | [.10, .32] | 3.45 |

Table 3. Fixed and random effects of the best age models for *emotion identification*.

| | ***Happy*** | | | | ***Anger*** | | | |
|---|---|---|---|---|---|---|---|---|
| **Fixed effects** | **Estimates** | **SE** | **CI [low, high]** | | **Estimates** | **SE** | **CI [low, high]** | |
| *Intercept* | 1.67 | .09 | [1.49, 1.85] | | 1.67 | .09 | [1.48, 1.85] | |
| *Age* | .006 | .002 | [.002, .009] | | .007 | .002 | [.003, .01] | |
| *Group* | -.55 | .15 | [-.85, -.25] | | -.63 | .16 | [-.95, -.32] | |
| *Age*group* | .008 | .003 | [.002, .014] | | .008 | .003 | [.002, .015] | |
| **Random effects** | **Estimates** | **SE** | **CI [low, high]** | **Wald's Z** | **Estimates** | **SE** | **CI [low, high]** | **Wald's Z** |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Residual* | .10 | .01 | [.08, .12] | 9.33 | .09 | .01 | [.07, .10] | 9.61 |
| *Intercept* | .61 | .10 | [.45, .85] | 6.11 | .70 | .10 | [.53, .93] | 6.90 |
| *Slope* | .0002 | .00004 | [.0001, .0003] | 3.90 | .0002 | .00005 | [.0002, .0003] | 5.03 |
| | ***Sad*** | | | | ***Fear*** | | | |
| **Fixed effects** | **Estimates** | **SE** | **CI [low, high]** | | **Estimates** | **SE** | **CI [low, high]** | |
| *Intercept* | .96 | .09 | [.77, 1.14] | | .95 | .09 | [.77, 1.14] | |
| *Age* | .02 | .002 | [.014, .021] | | .02 | .001 | [.014, .021] | |
| *Group* | -.18 | .07 | [-.32, -.03] | | -.17 | .07 | [-.30, -.03] | |
| **Random effects** | **Estimates** | **SE** | **CI [low, high]** | **Wald's Z** | **Estimates** | **SE** | **CI [low, high]** | **Wald's Z** |
| *Residual* | .27 | .03 | [.21, .33] | 9.16 | .26 | .03 | [.21, .32] | 9.23 |
| *Intercept* | .63 | .18 | [.36, 1.09] | 3.54 | .73 | .18 | [.44, 1.19] | 3.98 |
| *Slope* | .0001 | .00009 | [.00003, .0005] | 1.32 | .0001 | .00009 | [.00005, .0005] | 1.74 |

Table 4. Fixed and random effects of the best age models for *emotion attribution*.

| **Positive emotions** | ***Verbal condition*** | | | | ***Visual condition*** | | | |
|---|---|---|---|---|---|---|---|---|
| **Fixed effects** | **Estimates** | **SE** | **CI [low, high]** | | **Estimates** | **SE** | **CI [low, high]** | |
| *Intercept* | 1.01 | .09 | [.84, 1.19] | | 1.47 | .11 | [1.25, 1.68] | |
| *Age* | .02 | .002 | [.01, .02] | | .007 | .002 | [.002, .01] | |
| *Group* | -.23 | .07 | [-.37, -.09] | | -.60 | .18 | [-.95, -.25] | |
| *Age*group* | - | - | - | | .008 | .004 | [.0002, .01] | |
| **Random effects** | **Estimates** | **SE** | **CI [low, high]** | **Wald's Z** | **Estimates** | **SE** | **CI [low, high]** | **Wald's Z** |
| *Residual* | .24 | .03 | [.19, .29] | 9.05 | .19 | .02 | [.16, .24] | 9.25 |
| *Intercept* | .65 | .15 | [.41, 1.03] | 4.25 | .68 | .13 | [.46, 1.01] | 4.99 |
| *Slope* | .0002 | .00007 | [.0001, .0004] | 2.80 | .0002 | .00006 | [.0001, .0004] | 3.37 |

| **Negative emotions** | ***Verbal condition*** | | | | ***Visual condition*** | | | |
|---|---|---|---|---|---|---|---|---|
| **Fixed effects** | **Estimates** | **SE** | **CI [low, high]** | | **Estimates** | **SE** | **CI [low, high]** | |
| *Intercept* | 1.04 | .05 | [.94, 1.14] | | .90 | .06 | [.77, 1.02] | |
| *Age* | .003 | .001 | [.001, .005] | | .009 | .001 | [.006, .01] | |
| **Random effects** | **Estimates** | **SE** | **CI [low, high]** | **Wald's Z** | **Estimates** | **SE** | **CI [low, high]** | **Wald's Z** |
| *Residual* | .10 | .01 | [.08, .11] | 11.08 | .14 | .02 | [.11, .17] | 9.30 |
| *Intercept* | .19 | .03 | [.14, .25] | 6.79 | .28 | .07 | [.17, .47] | 3.78 |
| *Slope* | - | - | - | - | .0001 | .00004 | [.00004, .0002] | 2.36 |

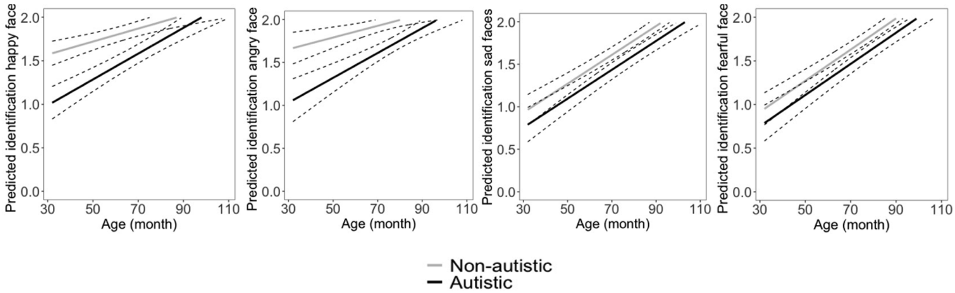


Fig 2. From left to right: regression lines depicting the predicted levels of identifying happy, angry, sad and fearful facial expressions with 95% confidence intervals based on the best fitting models with age as the predictor.

The best age models for identifying sad and fearful facial expressions were both with the fixed effects of linear age and group. Adding the random effects of linear age contributed to significant improvements of model fit, indicating that, for both models, there were substantial unexplained slope variabilities. Autistic children scored overall lower than non-autistic children in these tasks. However, all children showed age-related improvement in identifying sad and fearful facial expressions.

***Developmental trajectories of emotion attribution.*** Table 4 provides the estimates of the best age models for emotion attribution. The best age model for attributing positive emotions in the verbal condition was with the fixed effects of linear age and group, showing that this ability improved in all children, and autistic children scored overall lower in this task. The best age model for attributing positive emotions in the visual condition was with the fixed effect of linear age, group and their interaction. While autistic children had overall lower scores, they showed greater improvement ($b$ = .008, $p$ = .045) than non-autistic children ($b$ = .007, $p$ = .003) (see Figure 3). For both conditions, adding the random effects of linear age contributed to significant improvements of model fit, indicating that there were substantial unexplained slope variabilities.

The best age model for attributing negative emotions in the verbal condition was with the fixed effect of linear age, and in the visual condition was with the fixed and random effect of linear age. This indicates that children's abilities to attribute negative emotions increased with age. In the visual condition, there was also substantial unexplained slope variability. Adding group did not contribute to a better model fit, showing that autistic children did not differ from non-autistic children in attributing negative emotions.

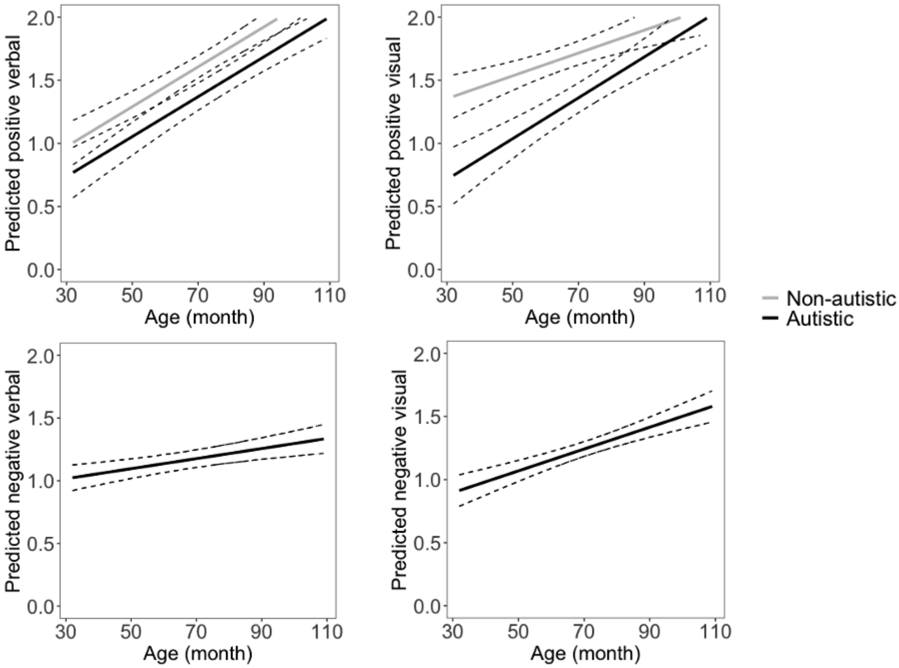


Fig 3. Upper left and right: regression lines depicting the predicted levels of attributing positive emotions in the verbal and visual condition with 95% confidence intervals based on the best fitting models with age as the predictors. Lower left and right: regression lines depicting the predicted levels of attributing negative emotions in the verbal and visual condition with 95% confidence intervals based on the best fitting models with age as the predictor.

***Symptom severity and the development of emotion recognition.*** Table 5 provides the fixed and random effects of the predicting models with the SRS mean score as the predictor. Adding the SRS mean score improved the model fit for all models (see Supplementary Table 6 for detailed information on model comparisons). Nonetheless, none of the fixed effects of the SRS mean for predicting emotion recognition abilites among autistic children was significant.

Table 5. Fixed and random effects of the predicting models with SRS mean as the predictor in the autistic group.

| | ***Emotion discrimination*** | | | | ***Emotion identification*** | | | |
|---|---|---|---|---|---|---|---|---|
| **Fixed effects** | **Estimates** | **SE** | **CI [low, high]** | | **Estimates** | **SE** | **CI [low, high]** | |
| *Intercept* | 1.94 | .36 | [1.21, 267] | | .91 | .31 | [.29, 1.54] | |
| *Age* | .02 | .003 | [.01, .03] | | .02 | .002 | [.01, .02] | |
| *Mean SRS* | -.006 | .003 | [-.01, .001] | | -.001 | .003 | [-.006, .005] | |
| **Random effects** | **Estimates** | **SE** | **CI [low, high]** | **Wald's Z** | **Estimates** | **SE** | **CI [low, high]** | **Wald's Z** |
| *Residual* | .39 | .05 | [.30, .51] | 7.42 | .16 | .02 | [.12, .21] | 7.43 |
| *Intercept* | .16 | .06 | [.07, .33] | 2.57 | .16 | .05 | [.09, .28] | 3.51 |
| | ***Emotion attribution*** | | | | | | | |
| | ***Verbal condition*** | | | | ***Visual condition*** | | | |
| **Fixed effects** | **Estimates** | **SE** | **CI [low, high]** | | **Estimates** | **SE** | **CI [low, high]** | |
| *Intercept* | .55 | .30 | [-.06, 1.15] | | .82 | .31 | [.19, 1.44] | |
| *Age* | .01 | .002 | [.009, .02] | | .01 | .002 | [.006, .02] | |
| *Mean SRS* | .001 | .003 | [-.004, .007] | | .0002 | .003 | [-.006, .006] | |
| **Random effects** | **Estimates** | **SE** | **CI [low, high]** | **Wald's Z** | **Estimates** | **SE** | **CI [low, high]** | **Wald's Z** |

2

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Residual* | .19 | .03 | [.15, .25] | 7.39 | .20 | .03 | [.15, .26] | 7.35 |
| *Intercept* | .14 | .04 | [.07, .25] | 3.18 | .15 | .05 | [.08, .28] | 3.19 |

**Discussion**

This study contributed unique insights into the levels and early development of three emotion recognition abilities (i.e., discrimination, identification, and attribution) in 2.5- to 6-year-old autistic children, in comparison to non-autistic children. First, in line with the literature, we found that autistic children had more difficulties than non-autistic children in discriminating, identifying facial emotion expressions and in attributing positive emotions to emotion-provoking situations. The group differences were present throughout the three-year course of measurements. However, autistic did not differ from non-autistic children in attributing negative emotions. Second, it was revealed for the first time that in early childhood, like non-autistic children, autistic children's abilities to recognize basic emotions improved with age. Noteworthy, some abilities increased with greater magnitudes in autistic children than in non-autistic children. Furthermore, we did not find the expected association between autistic traits and emotion recognition in autistic children.



First, we found that the challenges in emotion recognition for autistic children were present across modalities and across emotions. This provides supporting evidence that their struggles in emotion recognition are universal rather than task- or emotion-specific (Uljarevic & Halmilton, 2012; Lozier et al., 2014). Some studies on older autistic children and adults proposed that the challenges were emotion specific, as autistic people had difficulties only in recognizing one or a few negative emotions (Uono et al., 2011; Ashwin et al., 2006; Humphreys et al., 2007). Our findings showed that young autistic children were also less accurate in recognizing positive emotions. Despite the challenges, their abilities to recognize emotions all improved with age. Conceivably, autistic children would catch up non-autistic peers at older ages in some aspects of emotion recognition such as recognizing positive emotions.

We expected that autistic children would develop at slower rates than non-autistic children. However, the magnitudes of development were by and large the same between the groups, and autistic children showed even greater improvements than non-autistic children in identifying happy and angry facial expressions and in attributing positive emotions to emotion-provoking situations. Protracted developments were suggested by cross-sectional and meta-analysis studies (e.g., Greimel et al., 2014; Rump et al., 2009; Lozier et al., 2014), which compared between children, adolescents and adults. Although these studies shed insight into the development of emotion recognition throughout the whole life span, the development within each developmental phase and of each discrete emotion can be dynamic and different. The only longitudinal study we were aware of also found age-related improvement in autistic children and adolescents (Rosen & Lerner; 2016). However, this study did not involve a control group, so it remains unknown whether non-autistic peers developed at a similar or faster rate. Future research adopting a longitudinal design and involving a control group can provide more information in this regard.

Surprisingly, autistic children did not differ from non-autistic peers in attributing negative emotions to emotion-provoking situations. No group differences were found in the levels nor in the developmental trajectories. This is unexpected, because compared to emotion discrimination and emotion identification where we did find group differences, emotion attribution is a more advanced ability and developed usually at later stages. One possibility is that autistic children were better at recognizing emotions through situational cues than through facial expressions. Past research found that autistic people experience more difficulties in processing facial information (Weigelt et al., 2012). Many autistic people tend to avoid looking at the faces of others, and when they do look at the faces, they often show atypical face scanning patterns (Chawarska & Shic, 2009). To find out whether the task performances of autistic children were indeed influenced by the type of task stimuli, we conducted post-hoc analyses to check children's performances in the two practice tasks of the emotion discrimination task. The first practice task asked children to discriminate between two objects (a car vs. a flower), and the second asked children to discriminate between two faces which did not differ in emotion expressions but in appearances (wearing glasses vs wearing a hat). If autistic children were less skilled in processing facial information, they would be outperformed by non-autistic peers in the face condition but not in the object condition. The post-hoc analyses showed that at wave one autistic children performed less well than non-autistic children in both conditions, and at wave two autistic children performed less well only in the face condition. No group differences were found in either condition in the following two waves (see Supplementary Table 7 for the statistical outcomes). It seems that autistic children caught up non-autistic peers in discriminating both objects and non-emotional facial features. However, the group differences in discriminating and identifying facial emotion expressions did not disappear with age. This suggests that the persistent difficulties in recognizing facial emotion expressions in autistic children might be related to but not limited to their struggles in processing facial information.

Note that autistic children had more difficulties in attributing positive emotions. This again indicates that the absence of group difference in attributing negative emotions was not only due to autistic children's difficulties in processing facial information. Possibly, autistic children were especially sensitive and alert to situations that could provoke negative emotions, and thus they performed better in attributing negative emotions than positive emotions. Another possibility is that non-autistic children's abilities to attribute negative emotions were still unfolding. In typical development, children first learn to recognize positive emotions and to distinguish situations that provoke positive emotions from those that provoke negative emotions. While toddlers already have the general knowledge that unpleasant events would lead to the arise of negative emotions, fine distinguishments among discrete negative emotions are not well developed until the school age (Widen & Russell, 2008). The emotion-attribution abilities were probably at the starting phase of development, and thus the effect of autistic traits on their development was yet to be seen.



Some correlation studies found that more accentuated autistic traits were related to more difficulties in emotion recognition in autistic children (e.g., Brosnan et al., 2015; Evers et al., 2015). However, we did not find this relation with our longitudinal data. The lack of strong association between symptom levels and the development of emotion recognition might be partly due to the measurement chosen in the study. The Social Responsive Scale (SRS; Constantino & Gruber, 2005) was used to measure the autism symptom severity in autistic children. The SRS is most appropriate for use with children from four to 18 years of age. Yet, many participants of this study were younger than four years. Therefore, the SRS might not be sensitive to detect symptom levels in such a young sample.

This study has the advantages of using a longitudinal approach to unravel the development of multiple emotion recognition abilities in autistic children at a relatively young age. However, limitations should also be noted. First, the testing materials were the drawings of faces with pronounced emotion expressions. The drawings of facial expressions were easier to detect than facial expressions encountered in daily life, where the emotions are expressed often more subtly, with a lower intensity and in a dynamic way. Despite the relatively low ecological validity of the testing materials, autistic children were still outperformed by non-autistic peers, indicating that emotion recognition was a real challenge for them. Second, the autistic sample included in this study did not have intellectual disabilities. Also, the autistic participants and their parents were involved regularly in supporting programs. The positive outcomes found in this study might at least partly result from the supports that the participants received. Caution is warranted when generalizing our findings to other autistic groups. Third, autistic girls were underrepresented in this study, so as in the general population with autism. Although much fewer girls are diagnosed with autism, it does not mean that the predicament is of a lesser extent for autistic girls than for autistic boys. Future research should make more efforts to understand the unique challenges and difficulties that autistic girls face and provide them gender-tailored support. Last but not least, our findings only reflected the average performances and abilities of autistic children. As indicated by the significant random age effects found in most models, the development of emotion recognition abilities differed greatly among children. Autistic children are as heterogeneous and diverse as non-autistic children. The findings of this study should not be used to label them. Instead, when interacting with an autistic child, we should try to understand his or her characteristics, strengths and needs, and treat each of them as a unique human being.

To conclude, this study confirmed previous findings that challenges in emotion recognition were present already at young ages for autistic children and persisted over time. Nonetheless, autistic children displayed potential for developing emotion recognition skills. Understanding the challenges that autistic children face and acknowledging their potentials can make a positive step towards supporting autistic children in the right way. Future research should look into factors that facilitate and promote emotional development in autistic children, such as the impacts of providing extra supports inside and outside family, and creating an inclusive and respectful social environment, where autistic children can develop at ease and to their full potential.

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