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Sensitivity To Emotional Intensity and Emotion Expression Recognition Abilities in Children and Adults with down Syndrome

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Abstract

The present study aimed to examine the ability to recognize basic facial emotion expressions and sensitivity to low and high intensities of sad and happy expressions. These two components of emotion processing were assessed in 47 individuals with Down syndrome (DS), divided into three age groups. Results showed that young adults (aged 18.15–30.8 years) and middle-aged adults (aged 32.2–42.15 years) had significantly higher identification scores for happiness than the children's group (aged 10.5–16.8 years). Additionally, only the middle-aged group identified anger more accurately than the children's group. High-intensity happiness expressions were more accurately identified than sadness across all groups, while the opposite pattern was observed for low-intensity sadness expressions. Vocabulary level was associated with the recognition of certain emotion expressions, but was not with sensitivity to emotional intensity. Contrary to findings in typical development, no association was found between the two components of emotion processing in this population. Emotion recognition in individuals with DS is influenced by age, emotion type, intensity, and task modality. Deficits may stem from inefficient perceptual strategies, such as focusing on the mouth region, and underdeveloped configural face processing. Vocabulary supports recognition of basic emotions, highlighting the role of semantic knowledge. A positivity bias favors happiness recognition, while negative emotions are often confused, potentially due to attentional and executive control difficulties. Neurological differences, including reduced gray matter and connectivity, likely contribute to persistent impairments. Understanding these complex factors is crucial to develop targeted interventions to improve emotional and social functioning in DS.

Keywords Facial expression · Emotion recognition · Emotion intensity · Children with down syndrome · Adults with down syndrome

Extended author information available on the last page of the article

Introduction

The ability to recognize others' emotional expressions is central to the development of socio-emotional knowledge and social adjustment (Connolly et al., 2018; Finlon et al., 2015; Gabriel et al., 2021; Izard et al., 2008; Shen et al., 2021; Yang & Wang, 2023). Impairments in this ability are considered one of the major causes of socio-emotional disorders and behavioral problems (Castro et al., 2018; Pons & Harris, 2019; Riby et al., 2008; Staff et al., 2022; Yang & Wang, 2023). Emotions can be expressed through various modalities (e.g., facial, bodily, vocal), yet studies suggest that facial emotion recognition plays a dominant role in emotional perception compared to verbal or contextual cues (Liu et al., 2023) and is more directly associated with social interaction and behavioral modulation (O'Brien et al., 2011). Numerous studies report age-related changes in the ability to recognize basic facial emotional expressions (Richoz et al., 2018) is present in the text, but reference is missing in the reference section. Could you please provide the reference or delete the text citation." Resolved="yes"2009), though these vary depending on the type of emotion and task conditions. Children as young as six demonstrate high performance in labeling tasks, whereas similar levels are observed only around age ten in matching tasks (Barisnikov et al., 2020; Bruce et al., 2000; Widen & Russell, 2013). Most studies indicate that happiness is recognized first, followed by sadness and anger, which improve between ages 5 to 7, with surprise recognized between ages 6 and 10, while fear is often recognized even later (Herba & Phillips, 2004; Rodger et al., 2015; Widen, 2013). However, these abilities tend to decline in older adults, particularly for anger, sadness, and fear, with minimal effects observed for happiness and disgust (Hayes et al., 2020; Holland et al., 2019; Richoz et al., 2018; Ruffman et al., 2008). It is notable that most of this research has used photographs of intense facial expressions.

Recent studies have highlighted that sensitivity to subtle (discrete) changes in facial expressions may be more relevant for recognizing complex expressions and for the development of socio-emotional abilities (Finlon et al., 2015; Rutter et al., 2019). These studies used morphing techniques to simulate different levels of facial emotion intensity, gradually adjusting features from a neutral expression in increments of 5% or 10% toward a full, intense expression at 100% or more (Hess et al., 1997). A few studies conducted on neurotypical (NT) children using various intensity levels (4, 5, 11, or even 20) reported that young children experience significant difficulty in decoding subtle expressions (Gao & Maurer, 2009; Herba et al., 2006; Rodger et al., 2018; Thomas et al., 2007). No association between age and different levels of intensity was observed; significant differences appeared only between the lowest and highest intensities for sadness, anger, happiness, fear, and disgust. The authors concluded that using a limited number of intensity levels was sufficient to capture differences in children's perception of emotional intensity. Garcia and Tully (2020) reported notable development in middle childhood (ages 7 to 10) in sensitivity to the intensity of happy, sad, and angry expressions. Participants showed limited accuracy with low-threshold expressions (10%, 20%, and 30%) but significant improvement with medium-intensity expressions (40%, 50%, and 60%), with only minor gains observed at high intensities (70%, 80%, and 90%). Studies have shown that sensitivity to low-intensity sadness and anger expressions continues to develop beyond age

10 and into adolescence (Jenness et al., 2015), while sensitivity to surprise, disgust, and fear tends to develop between ages 5 and 10 (Gao & Maurer, 2010). Additionally, research has demonstrated that recognition of more subtle facial emotional expressions has a slower developmental trajectory than recognition of intense expressions (Barisnikov et al., 2021; Orgeta & Phillips, 2007; Rodger et al., 2018). Barisnikov et al. (2021) also found that the ability to recognize lower-intensity expressions had a greater impact on overall facial expression recognition and served as a mediating factor between age and emotion recognition, a relationship not observed for high-intensity expressions. The difficulty young children face in perceiving low-intensity expressions may interfere with their interpretation of emotional cues during social interactions, potentially impacting behavioral responses and self-regulation of emotions (Denham et al., 2015; Garcia & Tully, 2020; Rutter et al., 2019). A decline in labeling or matching low-intensity facial expressions has also been documented in older neurotypical (NT) adults in their 70s, who were less accurate than younger adults in their 20s (Di Domenico et al., 2015; Orgeta & Phillips, 2007). West et al. (2012) demonstrated that adults in their 60s, 70s and 80s had also significantly lower scores than middle-aged adults in their 30s, 40s, and 50s. These difficulties have been identified as risk factors for functional impairments and the development of psychopathology across the lifespan in the general population (Rocca et al., 2009; Rutter et al., 2019) and individuals with neurodevelopmental disorders (Wingenbach et al., 2017).

Associations between difficulties in facial emotion recognition, low socio-emotional skills, and adaptive functioning have been observed in a range of neurodevelopmental disorders (Evers et al., 2015; Jelili et al., 2021), especially those involving intellectual disabilities. Down syndrome (DS), the most common genetic cause of intellectual disability, is of particular interest in studying these relationships. Despite their pro-social orientation and interest in faces, children and adults with DS exhibit low social-cognitive abilities (Andrés-Roqueta et al., 2021; Pavlova et al., 2018) and significant socio-emotional challenges (Cebula et al., 2010; Fidler, 2006; Jahromi et al., 2008; Kasari et al., 2001). Numerous studies suggest that these challenges may stem from difficulties in recognizing basic facial expressions. Most studies have employed high-intensity expressions (100%) and have documented lower performance in DS populations compared to NT controls, particularly with expressions of fear (Cebula et al., 2017; Kasari et al., 2001; Virji-Babul et al., 2012; Williams et al., 2005), anger (Kasari et al., 2001; Porter et al., 2007), and surprise or neutral expressions (Barisnikov et al., 2020; Wishart & Pitcairn, 2000). These difficulties could hinder the processing of more subtle expressions, which is essential for inferring and understanding others' emotional states, and in turn, may disrupt the development of more complex socio-cognitive skills (Cavioni et al., 2020; Pons et al., 2004). Emotion recognition difficulties in DS populations have been linked to lower performance on tasks assessing theory of mind (Amadó et al., 2024; Comblain & Schmetz, 2020), emotion knowledge (Barisnikov et al., 2022; Bouras et al., 1998; Hippolyte et al., 2009; Kasari et al., 2001), and the matching of emotions with social situations (Barisnikov & Lejeune, 2018; Channell et al., 2014; Kasari et al., 2001).

Surprisingly, few studies have assessed sensitivity to the intensity of facial emotion expressions in individuals with DS. In a comparative study, Cebula et al. (2017)

used photographs depicting two levels of facial expression intensity—veridical (100%) and exaggerated (175%)—across six basic emotions. Participants were asked to match the target emotion either between two photographs or with an emotion label provided by an instructor. Results indicated that children with DS (ages 9–18 years; $M=14.76$, $SD=25.3$) were more accurate in recognizing high-intensity expressions, similar to a control group of NT children (ages 3–6 years; $M=4.68$, $SD=7.4$) and individuals with intellectual disabilities of non-specific etiology. However, children with DS showed particular difficulty in recognizing fear at both intensity levels compared to NT children, while anger posed a challenge for all groups. Additionally, accuracy in emotion recognition correlated with mental age (MA) and vocabulary comprehension (BPVS-II, Dunn et al., 1993) but not with emotion labeling ability. One of the few studies on adults with DS (Hippolyte et al., 2009) employed the Facial Discrimination Task (FDT, Rojahn et al., 1995), designed for individuals with intellectual disabilities, to assess discrimination between low (50%) and high (100%) intensity expressions of happy versus neutral and sad versus neutral faces. The authors found that adults with DS (mean age 34.3 years, $SD=7.1$) differed from NT controls (mean age 5.9 years, $SD=1.6$) only in their recognition of high-intensity sad faces, identifying significantly fewer items than NT controls. Adults with DS performed better with high-intensity happy expressions than with low one, while no differences between low and high-intensity sad expressions were observed. In contrast, NT controls recognized high-intensity happy and sad faces significantly better than low-intensity expressions. Using a modified version of the Face Processing Task (FPT, Bruce et al., 2000), the authors also reported specific difficulties in recognizing basic emotions, particularly sadness, surprise, and neutral faces. but not for happy and angry expressions as found with the original FPT (Hippolyte et al., 2008). Thus, Hippolyte et al. (2009) increased the number of distractors and items for each emotion to moderate the ceiling effect observed in young NT children (Bruce et al., 2000; Hippolyte et al., 2008). Several authors also reported that a low number of items (one or two per emotion) used in some studies in the DS population may be a cause of inconsistency in results and, also limit the possibility to conduct separate analyses for each emotion (see Kasari et al., 2001; Cebula et al., 2010, 2017; Barisnikov et al., 2020).

The literature also suggests that some other methodological aspects, particularly task demands, substantially impact performance in young children and those with intellectual disabilities. Emotion recognition tasks that minimize reliance on language and memory abilities appear more suitable for these populations (Karmiloff-Smith, 2009; Kasari et al., 2001; Morgan et al., 2010). Furthermore, tasks involving several intensity levels may add complexity, challenging attentional capacity and the perception of critical visual information (Blair et al., 2001; Gao & Maurer, 2009; Herba et al., 2008). Tasks using two levels of intensity (low and high) and simplified by reducing the number of response options seem more sensitive to age-related changes (Mienaltowski et al., 2013). It should be noted that comparative studies provide limited information on developmental trends in sensitivity to low-intensity expressions, as children or adults with DS are often compared to much younger NT children. Therefore, to interpret these findings accurately, developmental data from tasks adapted for these populations are crucial. In this context, Barisnikov et al. (2021)

assessed a large sample of NT children (ages 4–12) and a group of adults using the FDT and a modified FPT. Consistent with prior literature, they observed a slower developmental trajectory in decoding low-intensity expressions compared to high-intensity ones. Children ages 4–10 and 12 identified high-intensity emotions significantly better than low-intensity ones. High-intensity happiness was better recognized than low-intensity happiness up to age 11, while children ages 4–12 struggled to distinguish between high and low intensities of sadness. Notably, the results showed that recognition of low-intensity expressions mediated the relationship between age and global emotion expression recognition scores for the six basic emotions.

As shown, numerous studies have examined emotion recognition abilities in individuals with DS, generally comparing them to much younger NT controls and frequently highlighting lower performance or atypical patterns in DS populations. The present study exclusively examines individuals with DS, focusing on performance specificities related to age and vocabulary level. We also draw on developmental data (Barisnikov et al., 2021) and existing literature to aid interpretation of our findings. To our knowledge, no research has yet assessed sensitivity to emotion intensity in both children and adults with DS within the same study. Considering the importance of examining both components of facial emotion recognition for understanding emotion processing abilities in individuals with DS, this study aims to assess their ability to (1) recognize basic facial emotion expressions, and (2) discriminate between two levels of expression intensity, through age. Based on developmental data, we hypothesize that better recognition of low-intensity expressions will correlate with higher accuracy in recognizing high-intensity basic emotions. We also expect that chronological age and receptive vocabulary level will positively influence emotion recognition performance.

Method

Participants

A total of 47 individuals with Down syndrome (DS), all with a medical diagnosis of Trisomy 21, participated in the study (22 females and 25 males). They were divided into three age groups: 16 children (ages 10.5–16.8 years), 15 young adults (ages 18.15–30.8 years), and 16 middle-aged adults (ages 32.2–42.15 years) (Table 1). All participants had no significant sensory, psychiatric, or physical disabilities. Only individuals with moderate or mild intellectual disability were included in the study. Nonverbal reasoning abilities were estimated using Raven's Coloured Progressive Matrices (RCPM; Raven et al., 1998), and no significant differences were found between the three age groups ($F(2,46)=1.078, p=.349$). Additionally, adult participants showed no signs of dementia, as assessed by the Dementia Screening Questionnaire (Beciani et al., 2011). Children with DS were recruited from special education schools, while adults with DS were recruited from a sheltered workshop; all had previously attended special schools for individuals with intellectual disabilities. Informed consent procedures were carried out in accordance with ethical guidelines. Written informed consent was obtained from all adult participants who were

Table 1 General characteristics for the three age groups (mean, standard deviation, range)

	Children (<i>N</i> =16)	Young adults (<i>N</i> =15)	Middle-aged adults (<i>N</i> =16)
Sex (n, % female)	8 (50%)	6 (40%)	8 (50%)
Chronological age (years)	13.6 (1.7) Range : 10.5–16.8	23.8 (4.5) Range : 18.15–30.8	36.7 (3.2) Range : 32.2–42.15
PPVT-R raw score	57.1 (14.9) Range : 39–92	75.9 (18.5) Range : 40–117	75.6 (18.5) Range : 39–117
RCPM IQ score	65 (9.8) Range : 45–75	59.6 (11.5) Range : 45–80	61.3 (9.7) Range : 45–75

PPVT-R Peabody Picture Vocabulary Test-Revised (Dunn et al., 1993)

RCPM Raven's Coloured Progressive Matrices (Raven et al., 1998)

able to provide it. For participants who were underage or under legal guardianship, written consent was obtained from their parents or legal guardians, and assent was also sought from the participants themselves whenever possible. The Ethical Committee of the University of Geneva approved the study protocol. All participants were volunteers and could withdraw from the study at any time. The study was conducted in accordance with the Declaration of Helsinki.

Procedure

Two tests adapted from the Face Processing Test battery (Bruce et al., 2000) by Hippolyte et al. (2009), the Facial Discrimination Task (Rojahn et al., 1995), adapted from Erwin et al. (1992) and, the French adaptation of the Peabody Picture Vocabulary Test-Revised (PPVT; Dunn et al., 1993) were administered to all participants. Each participant was assessed individually by an experienced psychologist in a quiet room. Tasks were administered in a random order (counterbalanced across participants), with each session lasting approximately 20 min. Between two to four sessions were needed to complete all tasks, depending on participants' fatigue and motivation.

Recognition of Face Expressions

Two expression processing tasks were adapted from the set of Face processing tests developed by Bruce et al. (2000). Specifically, the emotion identification task and the emotion expression matching task were used to assess recognition of high-intensity facial emotion expressions. Modifications included increasing the number of distractors (from one to two) and adding a neutral expression (following Hippolyte et al., 2009). The expression identification task considered easier to execute than the expression matching task (Barisnikov et al., 2020), also included an additional item per facial expression to enhance task demand. Both tasks assessed five facial expressions: joy, sadness, anger, surprise, and neutral. All stimuli consisted of monochrome photographs (5.5 cm x 4 cm) of children's and adults' full faces (with hair and ears visible), on a uniform grey background. The paper version of the task was administrated.

Emotion Identification Task

This modified task consisted of 20 items (increased from 12), including a trial item, with four items per expression. The task's difficulty was increased by including more distractors (two instead of one) to prevent ceiling effects. Each item consisted of three children's faces (boys and girls) presented side by side and participants were asked to identify the face displaying a specific expression named by the experimenter (happiness, sadness, anger, surprise, or neutral). No time limit was imposed. The number of correct responses was calculated.

Emotion Matching Task

Divided into two parts, the first featuring children's faces (boys and girls) and the second adults' faces (women and men), the task comprised 15 items in the children's part and 12 items in the adults' part, plus one trial item. Participants were shown a target face at the top of the page and asked to match it with one of three faces at the bottom that displayed the same expression (happiness, sadness, anger, surprise, or neutral—neutral only in the children's faces part; three items per expression). All participants completed both parts of the task, and no time limit was imposed. The number of correct responses was calculated.

Expression Intensity Discrimination Task

The Facial Discrimination Task (FDT; Rojahn et al., 1995) was employed to evaluate discrimination between high- and low-intensity emotion expressions. The FDT consisted of 41 black-and-white photographs (13 cm x 18.5 cm) depicting three expressions: happy, sad, and neutral. Items were presented sequentially, and participants were asked to indicate whether a face showed happiness, sadness, or neutrality. If they identified a happy or sad expression, they were asked to distinguish between two intensity levels: Level 1 (low intensity, 50%) for 'a little' happy or sad and Level 2 (high intensity, 100%) for 'very' happy or sad. Participants indicated intensity levels by pointing to either a small column (low intensity) or a large column (high intensity). Following a training session of six items, the test included 35 items: 12 happy faces (9 low intensity, 3 high intensity), 11 sad faces (7 low intensity, 4 high intensity), and 12 neutral faces, presented in a counterbalanced order. The number of correct responses was calculated. For more information on methodological issues, see Rojahn et al. (1995) and Hippolyte et al. (2009).

Peabody Picture Vocabulary Test-Revised (PPVT-R)

To assess receptive vocabulary, the French-adapted PPVT-R vocabulary scale (Dunn et al., 1993) was used. Each participant was shown four pictures and asked to select the one that matched a word spoken by the experimenter. The test was stopped if the participant made six errors over eight consecutive trials. The raw vocabulary score (the item at which the test ended minus errors) was recorded. This measure facilitated comparison with existing literature on emotion processing abilities in the DS popula-

tion (Phillips et al., 2014). Receptive vocabulary is known to be less impaired than other language measures, such as productive vocabulary, in individuals with DS and is generally comparable to nonverbal ability levels (Majerus & Barisnikov, 2018; Næss et al., 2011).

Statistical Analysis

Statistical analyses were conducted using SPSS 29. First, a generalized linear model (GLM) with a binomial distribution and logit link function was conducted to examine the effects of age group (children, young adults, middle-aged adults) and task (identification, matching, discrimination) on participants' response accuracy. The number of correct responses was used as the dependent variable, with the total number of items per task included as a weighting variable. This approach appropriately models the binomial nature of the data by accounting for the number of trials per task.

Second, for each task, we investigated the effects of different facial emotions using separate GLMs with a binomial distribution and logit link function. For the identification and matching tasks, the number of correct responses was entered as the dependent variable, and the number of items for each emotion (happy, sad, angry, surprised, neutral) were used as a weighting variable. Age group (children, young adults, middle-aged adults) was included as a between-subject factor, and emotion (happy, sad, angry, surprised, neutral) as a within-subject factor. For the facial discrimination task, two separate GLMs were conducted. The first model included age group as a between-subject factor and emotion (happy, sad, neutral) as a within-subject factor, using the number of items per emotion (happy, sad, neutral) as a weighting variable. The second model included age group as a between-subject factor, and both emotion (happy, sad) and intensity level (low, high) as within-subject factors. In this model, the weighting variable corresponded to the number of trials for each combination of emotion (happy, sad) and intensity level (low, high).

Before running the correlation analyses, we tested for normality using the Shapiro-Wilk test. Several key variables showed significant non-normality ($p < .05$), which justified using non-parametric methods like Spearman's correlation. Spearman correlation analyses were thus conducted between the total scores for each task and both chronological age and vocabulary level. Additional Spearman correlation analyses were conducted between the scores for each emotion and both age and vocabulary level. The significance threshold was set at 0.05.

Results

Comparison of Age Groups in Individuals with DS

Table 2 presents the number of correct responses by age group and emotion for each task.

Table 2 Number of correct responses (standard deviations) across the three tasks (identification, matching, and discrimination), categorized by age group and emotion

Tasks	Emotions	Children (<i>N</i> =16)	Young adults (<i>N</i> =15)	Middle- aged adults (<i>N</i> =16)	Average
Identification	Happy (/5)	2.44 (0.8)	3.53 (0.6)	3.25 (0.6)	3.06 (0.8)
	Sad (/5)	2.75 (0.4)	2.67 (1.2)	2.94 (1.1)	2.79 (1)
	Angry (/5)	2.75 (14.4)	3.20 (1.08)	3.69 (0.6)	3.21 (0.9)
	Surprised (/5)	2.25 (1)	2.67 (1.2)	2.31 (1.4)	2.40 (1.2)
	Neutral (/5)	1.69 (0.8)	1.87 (1.1)	1.44 (0.8)	1.66 (0.9)
	Total (/20)	11.88 (2.3)	13.93 (3.2)	13.63 (3.2)	13.13 (3)
	Matching	Happy (/6)	5.36 (0.6)	4.53 (1.2)	4.38 (1.2)
Sad (/6)		4.64 (1.5)	4.67 (1.1)	4.25 (1.3)	4.51 (1.3)
Angry (/6)		4.36 (1)	3.33 (1.2)	3.13 (1.5)	3.58 (1.3)
Surprised (/6)		3.79 (1.2)	3.53 (1.5)	3.19 (1.5)	3.49 (1.4)
Neutral (/3)		1.07 (0.6)	1.47 (1.2)	1.25 (1)	1.27 (1)
Total (/27)		19.21 (4.2)	17.53 (3.4)	16.19 (3.6)	17.58 (3.9)
Discrimination		Happy (/12)	4.44 (2.1)	3.93 (1.9)	4.00 (1.8)
	Sad (/11)	4.75 (3)	5.00 (2.6)	5.38 (2.2)	5.04 (2.6)
	Neutral (/12)	6.50 (5)	5.27 (4.3)	6.94 (4.3)	6.26 (4.5)
	Total (/35)	15.69 (7.1)	14.20 (5.5)	16.31 (5.4)	15.43 (6)

Tasks

No significant effect was found for the age group ($Wald \chi^2(2)=0.10, p=.951$). In contrast, a significant effect of the task was found ($Wald \chi^2(2)=176.7, p<.001$), as well as a significant task x age group interaction ($Wald \chi^2(4)=25.30, p<.001$). Pairwise comparisons showed that, for the three age groups, the FDT was significantly more difficult than the other two tasks (all $ps < 0.01$). For the children, the scores for the matching task were significantly better than those for the identification task ($p < .001$). This difference was not observed for the young adults ($p=.184$). In contrast, the middle-aged adults had better scores for the identification task than for the matching task ($p=.020$). Pairwise comparisons were then conducted between age groups for each task. In the identification task, children scored significantly lower than both young adults ($p=.007$) and middle-aged adults ($p=.021$). In the matching task, by contrast, children outperformed both young adults ($p=.035$) and middle-aged adults ($p < .001$).

Finally, in the FDT, young adults scored significantly lower than middle-aged adults ($p=.045$).

Emotions

Identification Task A significant main effect of age group was observed ($Wald \chi^2(2)=12.48, p=.002$). Children scored significantly lower in emotion identification compared to both young adults ($p=.002$) and middle-aged adults ($p=.003$). No significant difference was found between the two adult groups ($p=.980$). Results indicated a significant effect of the emotion ($Wald \chi^2(4)=78.10, p<.001$). Neutral faces were less well identified than all the other emotions (all $p_s<0.01$). Surprise and sadness were also significantly less accurately identified than happiness (respectively $p=.004, p=.050$) and anger (respectively $p<.001, p=.005$). There was no other significant difference between the different emotions. A significant emotion \times age group interaction was also found ($Wald \chi^2(8)=18.57, p=.017$). For happiness, the children had lower scores than the young adults ($p<.001$) and the middle-aged adults ($p=.009$). For anger, middle-aged adults performed significantly better than children ($p<.001$) and young adults ($p=.048$). For sadness, surprise and neutrality, there was no difference between the age groups. Figure 1 illustrated these results.

Matching Task Results indicated a significant effect of the emotion ($Wald \chi^2(4)=72.41, p<.001$). Neutral faces were less well matched than all the other emotions (all $p_s<0.05$). Surprise and anger were also significantly less accurately matched than happiness (all $p_s<0.001$) and sadness (all $p_s<0.001$). There was no other significant difference between emotions. A significant main effect of age group was also

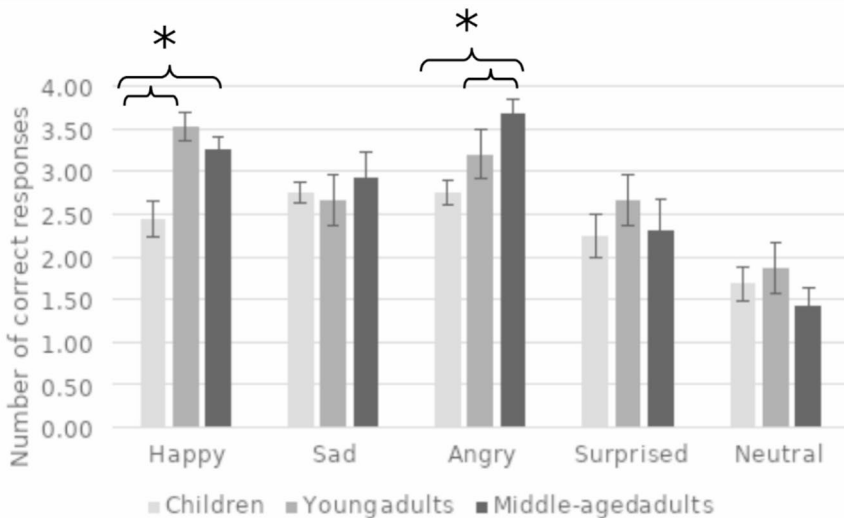


Fig. 1 Number of correct responses for the emotion identification task, presented by emotion type and age group. Error bars represent standard errors

observed ($Wald \chi^2(2)=11.99, p=.002$). Children performed significantly better from both young adults ($p=.049$) and middle-aged adults ($p<.001$), whereas no significant difference was found between the two adult groups ($p=.122$). The interaction between emotion and age group was not significant ($Wald \chi^2(8)=8.32, p=.403$).

Facial Discrimination Task Results indicated a significant effect of the emotion ($Wald \chi^2(2)=36.57, p<.001$). Happy faces were less well identified than sad faces ($p=.009$) and neutral faces ($p=.008$). No significant effect was found for the age group ($Wald \chi^2(2)=4.93, p=.085$), nor for emotion x age group interaction ($Wald \chi^2(4)=5.75, p=.218$).

Results investigating the effect of emotion intensity revealed no significant effect for the with age group ($Wald \chi^2(2)=1.36, p=.508$), nor for the emotion ($Wald \chi^2(1)=0.94, p=.333$). Results indicated a significant effect of the intensity ($Wald \chi^2(1)=73.54, p<.001$), as well as a significant intensity x emotion interaction ($Wald \chi^2(1)=89.12, p<.001$). The participants had a significant better score for faces expressing happiness with high intensity ($M=2.36$ out of 3, $SD=0.9$) than those with low intensity ($M=1.77$ out of 9, $SD=1.8$), ($p<.001$). This difference between the two intensities was not observed for sadness (high: $M=1.74$ out of 4, $SD=1.5$, low: $M=3.3$ out of 7, $SD=2.3$), ($p=.466$). In addition, at a high intensity, happiness was better discriminated than sadness ($p<.001$), while the opposite pattern was observed at a low intensity ($p<.001$). These results are illustrated in Fig. 2, where percentages are presented to facilitate comparison and ease of interpretation, although all statistical analyses were conducted on raw scores (number of correct responses).

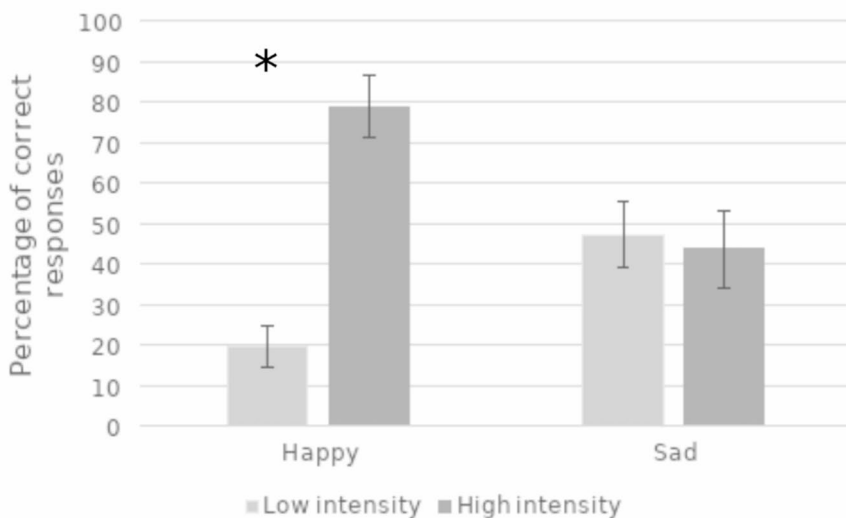


Fig. 2 Percentage of correct responses for the facial discrimination task, presented by emotion type and intensity. Error bars represent standard errors

Correlation Analyses

With Age

The results revealed a significant negative correlation with the matching task ($\rho = -0.343, p = .018$). Additionally, there were two significant positive correlations with the identification scores for happy faces ($\rho = 0.333, p = .022$) and angry faces ($\rho = 0.526, p < .001$). Significant negative correlations were also found with the matching scores for happy faces ($\rho = -0.302, p = .039$) and angry faces ($\rho = -0.363, p = .012$). Finally, no significant correlation was observed between scores for each emotion and intensity and age.

With Vocabulary Level

The results showed two significant positive correlations: one with the identification task ($\rho = 0.725, p < .001$) and one with the FDT ($\rho = 0.396, p = .006$). Additionally, four significant positive correlations were observed between vocabulary level and identification scores for happy faces ($\rho = 0.381, p = .008$), angry faces ($\rho = 0.556, p < .001$), surprised faces ($\rho = 0.629, p < .001$), and sad faces ($\rho = 0.332, p = .023$). There were also two significant positive correlations with matching scores for surprised faces ($\rho = 0.330, p = .023$) and neutral faces ($\rho = 0.445, p = .002$), as well as one significant negative correlation with the matching score for angry faces ($\rho = -0.314, p = .032$). Finally, there was one significant positive correlation with the FDT for faces expressing happiness with high intensity ($\rho = 0.485, p < .001$).

Discussion

The ability to recognize emotional expressions is a fundamental aspect of social functioning, with significant implications for interpersonal communication and emotional well-being. In individuals with Down syndrome (DS), this capacity is often marked by specific deficits rather than generalized impairments, reflecting the unique interplay of cognitive, perceptual, and neurodevelopmental factors. The present study aimed to assess the sensitivity to emotion intensity and recognition of basic emotion expressions. More precisely it is sought to elucidate the influence of task modality, age, and emotion type on these abilities in children, young adults, and middle-aged adults with DS. Our findings reveal that while developmental improvements occur for some emotions, recognition patterns remain distinct from typically developing NT populations. By exploring these patterns, this discussion aims to situate the current findings within the broader body of research, highlighting their implications for developmental trajectories and practical applications.

Impact of Task Modality on Performance

The present study confirmed significant effects of task modality on the ability to recognize emotional expressions, particularly highlighting that the discrimination

task presented greater challenges for participants compared to the identification and matching tasks. Across all groups, performance variability suggests that task demands influence recognition strategies. Discrimination tasks require more refined perceptual differentiation between intensity of expressions, engaging more complex cognitive processing and greater attentional resources. Nevertheless, improvement with age was observed, as the middle-aged adults achieved significantly higher scores than young adults, suggesting a slower developmental trend. In the identification task, children scored significantly lower than both adult groups. The performances of our middle-aged adults are consistent with the work of Hippolyte et al. (2008, 2009), who demonstrated that adults with DS rely on verbal labeling processes. In contrast, children with DS outperformed both adult groups in matching tasks, while no difference was found between the two adult groups. This may reflect an age-specific reliance on visual information in children with DS, possibly favoring a configural processing strategy, as suggested by Kasari et al. (2001) and Barisnikov et al. (2020). Young adults, however, exhibited relatively consistent performance across task modalities, which may indicate a transitional stage where visual and verbal processing capacities are more balanced.

This pattern diverges from one observed in NT individuals, where verbal-based strategies tend to dominate in children aged 4 and 6 (Widen & Russell, 2013). Children typically achieve comparable performance across tasks by the age of 10, suggesting a potential developmental delay in DS populations. Prior research has documented that their task modality preferences and recognition accuracy with age remain influenced by developmental differences in specific cognitive and perceptual processing abilities (Andrés-Roqueta et al., 2021; Carvajal et al., 2012; Hippolyte et al., 2010). Furthermore, the observed correlations between receptive vocabulary and performance on identification and discrimination tasks underscore the importance of language abilities in emotion recognition tasks that involve verbal labeling or differentiation. These findings align with existing literature indicating that expressive and receptive language deficits in DS significantly contribute to socio-cognitive challenges (Carvajal et al., 2012; Cebula et al., 2017).

Emotional Expression Recognition Patterns

Our results also revealed that the recognition of specific emotion expressions was differently impacted by task modality, chronological age, and vocabulary level. Neutral expressions were more difficult to identify and match than the other four emotions. Surprise and sadness were significantly less accurately identified than happiness and anger. While surprise and anger were significantly less accurately matched than happiness and sadness. However, the identification score showed improvement with age for certain emotions. Thus, young adults (aged 18.15–30.8 years) and middle-aged adults (aged 32.2–42.15 years) had significantly higher identification scores for happiness than the children's group (aged 10.5–16.8). The middle-aged group identified anger significantly better than the children's and young adult's groups. Correlation analyses supported these results, showing a significant positive relation between chronological age and identification of happy and angry expressions, but a negative correlation for matching these expressions.

These findings align with several studies reporting difficulties in identifying basic facial emotion expressions in individuals with DS compared to NT controls matched on vocabulary level (Barisnikov et al., 2020; Cebula et al., 2017; Kasari et al., 2001; Porter et al., 2007). Difficulties in recognizing neutral faces persist in adults with DS, with higher scores for recognizing happiness compared to other basic emotional expressions (Andrés-Roqueta et al., 2021; Hippolyte et al., 2008, 2009; Virji-Babul et al., 2012). Low scores in recognizing surprise in children with DS (Barisnikov et al., 2020) and the lack of improvement with age (Wishart & Pitcairn, 2000) also persist into adulthood (Hippolyte et al., 2008, 2009). Similarly to most of these studies, our results show a positive correlation between vocabulary level and identification scores for happy, sad, angry, and surprise expressions. Additionally, these correlations were also observed in the matching scores for neutral and surprise expressions, which are particularly difficult for individuals with DS. These results further demonstrate the importance of vocabulary for emotion recognition abilities over chronological age in the DS population (Pochon & Declercq, 2014; Roch et al., 2020).

Furthermore, the results of our study and those cited above suggest that the DS population may not follow the typical developmental trajectory. Most studies report that the identification of happiness develops earlier, followed by sadness and anger between ages 5 and 7, with surprise developing between ages 6 and 10 (Richo et al., 2018; Widen, 2013). More specifically, Barisnikov et al. (2021) reported that happiness is recognized better than all other emotions at ages 4, 5, and 6, while at age 5, surprise is better recognized than neutral expressions. Furthermore, young NT children had better identification than matching scores for neutral expressions at age 5, for surprise at ages 4 and 6, and for anger at ages 4, 5, and 6. The difference for anger disappeared by age 7.

It is important to note that the difficulties our participants had in recognizing certain emotion expressions, such as sadness, surprise, and neutral, did not improve with age and may be considered specific recognition deficits. In contrast, the recognition of happiness and anger expressions improved throughout adulthood, suggesting a developmental delay (see Figure X). Although not significant but visually apparent (Figure X), middle-aged adults showed slightly lower scores for recognizing happy, neutral, and surprise expressions, which warrants further examination by including older adult groups. Studies on life-span emotion recognition have reported a decline in older NT adults aged 60, 70, 80 years old, in recognizing anger, sadness, and fear, with only a marginal effect for happiness (Hayes et al., 2020; Richoz et al., 2018; Ruffman et al., 2008).

Role of Emotional Intensity

Overall, the discrimination task was significantly more difficult for our participants than the other two tasks. No significant age group effects were observed, but a significant effect of emotion and expression intensity was found. Our participants performed better on high-intensity happiness expressions compared to low-intensity ones, whereas no such difference was found for sadness. High-intensity happiness was identified more accurately than high-intensity sadness, while the reverse was true for low-intensity expressions. No other study, to our knowledge, has examined sensi-

tivity to emotion intensity in both children and adults with DS. The study by Cebula et al. (2017), which assessed two intensities (100% and 175%), found that children with DS (aged 9–18) were more accurate in recognizing higher-intensity expressions similar to NT children (aged 3–6). However, their results are not directly comparable to ours, as we used 100% and 50% intensities, therefore (consequently), our study is the first to assess sensitivity to low intensity expression in children with DS. Nevertheless, Cebula et al. also observed that emotion recognition accuracy correlated with mental age and vocabulary comprehension, but not with emotion labeling ability.

In line with our study, Hippolyte et al. (2009) reported that adults with DS (mean age 34.3 years) discriminated high-intensity happy expressions significantly better than low-intensity ones, with no differences for sad expressions. This contrasted with their NT control group (mean age 5.9 years), who performed better on both high-intensity happiness and sadness. Barisnikov et al. (2021) found that sensitivity to emotion intensity, especially for happiness and sadness, improves with age in NT children, with better recognition of high-intensity expressions in children aged 4 to 12. Children are generally less sensitive to lower-intensity expressions than adults, with performance reaching adult levels around age 10 (Gao & Maurer, 2009; Rutter et al., 2019).

For sadness, our results showed low recognition scores for both high and low-intensity sadness expressions in all groups, which may indicate a persistent difficulty in perceiving sad expressions that does not improve with age (Hippolyte et al., 2009). Sensitivity to low-intensity sadness expressions develops later and typically requires a more intense expression for accurate recognition (Barisnikov et al., 2021; Gao & Maurer, 2010; Garcia & Tully, 2020) noted that children aged 4 to 12 had difficulty discriminating high and low-intensity sadness, unlike adults, whose sensitivity improved beyond age 10. In their life-span study, Rutter et al. (2019) presented pairs of faces to participants aged 10 to 85 years, asking them to judge which face appeared more angry, fearful or happy. The results revealed that sensitivity to low-intensity expressions of these emotions increased during adolescence and early adulthood. However, sensitivity to anger and fear declined in older NT adults from their 70s onward, with only a marginal decline for happiness. The major meta-analyses examining age-related effects have consistently reported a significant decline in recognition of reduced-intensity expressions in older NT adults over the age 65, compared to younger and middle-aged adults. This decline is most pronounced for anger, fear and sadness, with smaller declines for happiness and surprise (Gonçalves et al., 2018; Hayes et al., 2020; Ruffman et al., 2008).

Finally, contrary to expectations, no significant relationship was found between age and sensitivity to intensity of happy and sad expressions. However, a significant positive correlation with high intensity happy expression was found among our participants. Therefore, future research should include older adults to assess potential age-related changes in sensitivity to emotional intensity. It would also be important to examine other emotions, such as anger, given the significant improvement in its recognition among our middle-aged participants.

Nevertheless, vocabulary level was associated with the global discrimination score and recognition of certain basic emotions. Despite extensive studies on the recognition of high intensity expressions in DS, questions remain about how individuals

with DS process facial emotion information. A better understanding of these findings could improve methodological approaches elaborating future hypotheses and more targeted intervention.

Conclusions

As seen above, unequal performances in emotion expression recognition in our participants were related to task modality, age, emotion type and expression intensity. However, a clear explanation for their emotion recognition difficulties remains elusive as they could be attributed to several factors, which will be discussed below.

Inefficient perceptual processing strategies have been identified as contributing to deficits in face and emotion processing in children and adults with DS (Barisnikov et al., 2020; Carvajal et al., 2012; Hippolyte et al., 2008). For example, adults with DS have been shown to focus on the regions around the mouth, which helps distinguish happy from sad expressions but may lead to confusion when decoding surprise and fear (Carvajal et al., 2012). Recognizing these emotions requires processing both local and configural face information, which is underdeveloped in young children and those with DS (Barisnikov et al., 2020). A deficit in recognizing neutral faces, which serve as a reference point for identifying a subtitle change in face allowing to recognize low-intensity emotional expressions, is particularly relevant. Improving perceptual strategies to identify local changes and integrate them into configural face processing could enhance emotion recognition abilities in individuals with DS.

Receptive vocabulary level is often associated with the recognition of basic emotion expressions in individuals with DS, but not with their general language or non-verbal reasoning abilities (Hippolyte et al., 2010; Pochon et al., 2017). Study in NT children reported the positive relation between vocabulary level and emotion recognition but not to non-verbal reasoning abilities (Albanese et al., 2010). The crucial role of semantic representation (e.g., emotional vocabulary) in emotion recognition, which develops with age, was demonstrated by several studies (Pons et al., 2003; Reed & Steed, 2015; Widen, 2013). Nevertheless, emotion recognition and understanding rely on both visual and verbal abilities. To improve these abilities in individuals with DS, rehabilitation programs should integrate visual (e.g., facial expressions) and verbal (e.g., emotion-related words) cues (Pochon et al., 2022; Roch et al., 2020; Vicari et al., 2000).

A positivity bias was also observed, with participants showing significantly better recognition of happiness compared to other emotions. Similar findings have been reported for children (Kasari et al., 2001; Williams et al., 2005) and adults with DS (Andrés-Roqueta et al., 2021; Hippolyte et al., 2008), suggesting a preferential attention toward positive emotions with relation to attention and inhibition difficulties. Similarly, a positivity bias has been observed in NT children (Garcia & Tully, 2020) showing low miss rate and higher false alarm rate for happiness than for sadness and anger. Studies also report that individuals with DS tend to confuse neutral expressions with happiness and may incorrectly attribute happiness to a sad expression (Andrés-Roqueta et al., 2021; Hippolyte et al., 2009). Additionally, studies indicate that sensitivity to happiness remains high with age, while sensitivity to negative emotions, such as anger and fear, declines in older TD adults ((Hayes et al., 2020). Some

studies, however, did not find higher performance for happiness in individuals with DS, which may stem from methodological differences. The use of a limited number of stimuli and distractors in clinical and older populations could create a ceiling effect for happy expressions (Kasari et al., 2001; McKone et al., 2012), leading to misinterpretations in emotion recognition tasks.

Confusion between negative emotions (e.g., sadness, anger, fear) has also been observed in adolescents (Pochon et al., 2017) and adults with DS (Andrés-Roqueta et al., 2021). It has been suggested that these errors, along with the positivity bias, may be related to deficits in selective attention (Hippolyte et al., 2008; Rowe et al., 2006), executive control (Amadó et al., 2016; Lanfranchi et al., 2010), or working memory (Andrés-Roqueta et al., 2021), rather than mental age (MA) or level of intellectual disability (Cebula et al., 2017; Williams et al., 2005). These errors may also affect the development of internal (mental) representations of emotion, influencing social interactions and contributing to social-adaptive and emotional difficulties in population with DS (Barisnikov & Straccia, 2019; Dykens, 2007; Foley et al., 2016; Jahromi et al., 2008). Nevertheless, low sensitivity to emotional expressions may be particularly relevant, as in daily life, one is more exposed to less intense facial expressions. Difficulties in processing low-intensity emotions in NT children seem to lead to misinterpretation of emotional cues. This, in turn, could cause maladaptive behavioral responses and emotion regulation problems (Denham et al., 2015; Garcia & Tully, 2020).

Low emotion processing abilities alongside their prosocial behaviors, may contribute to challenges in emotion regulation and handling negative social interactions (Jahromi et al., 2008), as well as increased social withdrawal and isolation (Foley et al., 2016) and a higher incidence of depression in older individuals with DS (Straccia et al., 2014). Recognition difficulties for negative emotions are linked to various psychopathological disorders in NT populations (Rocca et al., 2009) and behavioral adjustment issues (Fischer & Manstead, 2016), as well as in these with neurodevelopmental disorders (Wingenbach et al., 2017). In older NT adults, the intensity of sadness tends to increase, while anger decreases (Charles et al., 2003; Hasse et al., 2012), with changes in emotion recognition abilities likely related to age-related modifications in brain areas involved in emotion processing (Adolphs, 2002, 2009).

Neurological factors could explain deficits or declines in emotion recognition, particularly for negative emotions, in older NT adults (Jernigan & Gamst, 2005; Vuilleumier & Pourtois, 2007). Individuals with DS are known to have smaller gray matter volume (e.g., orbitofrontal cortex) and reduced connectivity between frontal and limbic systems (e.g., amygdala), which decline significantly in adulthood (Koran et al., 2014). These neurological features likely contribute to persistent difficulties in emotion recognition and social cognition (Carvajal et al., 2012; Jernigan et al., 1993; Gunbey et al., 2017).

In conclusion, understanding emotion recognition in individuals with DS remains complex, and developmental data cannot be directly applied to their results. Further research is needed to investigate the cognitive processes underlying these performances (see Roch et al., 2020), as well as the interplay between cognitive abilities, personality traits, and environmental factors. This could inform more effective interventions from an early age to improve or maintain emotion and social skills in the DS population.

Limitations and Future Directions

A limitation of the current study is the sample size of the three groups, which was relatively small and may limit the generalizability of the findings. Some potential predictors (e.g., low expression recognition) did not reach significance, possibly due to insufficient statistical power. A post hoc power analysis indicated that the study had limited power (approximately 55%) to detect medium effect sizes, further emphasizing the need for cautious interpretation of the results. Larger samples may yield different results, as Hippolyte et al. (2009) found a strong relationship between discrimination scores and neutral face recognition scores in a face processing task. Future studies should assess sensitivity to low-intensity expressions of other emotions, such as anger, whose recognition seems to improve with age. Further research should examine the use of neutral faces as response options, considering their persistent deficit in the DS population. Studying emotion recognition abilities alongside sensitivity to expression intensity and investigating the impact of specific cognitive abilities (e.g., visual perception, selective attention) could provide new insights for the development of emotion processing abilities in individuals with DS. Understanding these mechanisms is crucial for the development of socio-emotional skills and the prevention of behavioral problems in TD children and adolescents (Crivelli & Fridlund, 2018; Finlon et al., 2015; Izard, 2011; Lemerise & Arsenio, 2000; Liu et al., 2023).

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Author Contributions KB contributed to the study conception and design, as well as material preparation, data collection. Analysis was performed by FL. The first draft of the manuscript was written by KB and FL. All authors read and approved the final manuscript.

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Data Availability The raw data, analysis code, and materials used in this study are not openly available but are available upon request to the corresponding author.

Declarations

Ethical Approval The Ethical Committee of the University of Geneva approved the study protocol. All participants were volunteers and could withdraw from the study at any time. The study was conducted in accordance with the Declaration of Helsinki.

Informed Consent Written informed consent was obtained from all adult participants who were able to provide it. For participants who were underage or under legal guardianship, written consent was obtained from their parents or legal guardians, and assent was also sought from the participants themselves whenever possible.

Competing Interests The authors declare no competing interests.

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