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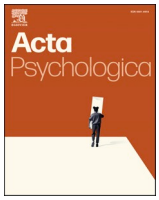

Autistic-like social communication disorders and sensory profile in visually impaired children: Similarity and divergence with autism spectrum disorders

Anna Rita Galiano [a,*], Franclain Mekomedemb [a], Anna Eve Helmlinger [b], Jean-Yves Baudouin [a]

[a] Laboratoire DIPHE (Développement, Individu, Processus, Handicap, Education), Université Lumière Lyon 2, Lyon, France
[b] Université Claude Bernard Lyon 1, CNRS, INSERM, Centre de Recherche en Neurosciences de Lyon CRNL U1028 UMR5292, TRAJECTOIRES, F-69500 Bron, France

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ABSTRACT

This study examined the sensory profile of three groups of children (those with visual impairment, typical development or autism spectrum disorder) aged 3 to 12. The principal aim was to find out whether the Sensory Profile (SP) of children with visual impairment was a good predictor of behaviors typical of ASD. The data was collected through a sensory profile filled out by parents of 37 visually impaired children, 30 with autism spectrum disorder (ASD) and 42 with typical development (TD). To assess the risk of ASD, the Social Communication Questionnaire (SCQ) was also administered. The results indicate that children with visual impairment are at increased risk of exhibiting signs of ASD, and that the sensory profile is a good predictor of risk of autistic signs in children with visual impairment. This study provides for the first time strong evidence for the need to systematically assess the sensory profile in children with visual impairment.

1. Introduction

A longstanding issue in the scientific literature is the relationship between visual impairment and autism spectrum disorder (ASD) (for reviews, see Butchart et al., 2017; Molinaro et al., 2020). The frequent occurrence of autistic-like features in the people with visual impairment was described for the first time by Keeler (1956), who observed autistic patterns and defective communication in blind children (see also Green & Schecter, 1957). The relationship between blindness and ASD was further established in the 1960s (Burlingham, 1965; Fraiberg & Freedman, 1964), becoming a fundamental issue in the field of visual impairment research. One of the questions was to determine the prevalence of ASD in people with visual impairment. Initial estimates indicated rates in the range of 25–50 % (Fraiberg, 1977; Freedman, 1971; Harrison-Covello & Lairy, 1985). Since then, the few publications on the prevalence of ASD in children with visual impairment have reported highly variable rates across studies and countries, from 3.5 % to 11.64 % in the lowest estimates (Baron-Cohen et al., 2009; Fazzi et al., 2019; Gunz et al., 2023; Mukaddes et al., 2007) to 41.6 % to 50 % in the highest estimates (Brown et al., 1997; Jure et al., 2016), a meta-analysis published in 2017 reporting an overall prevalence of ASD in people with visual impairment of about 19 % (Do et al., 2017). Whatever the exact prevalence, the occurrence of ASD in the population with visual impairment is far higher than in the typical population, even at its lowest estimates: in a meta-analysis conducted over the period 1994–2019, the prevalence of ASD was about 0.72 % (95 % CI = 0.61–0.85) (Talantseva et al., 2023).

Beyond the question of prevalence, another issue is the similarity of clinical signs in visual impairment and ASD, with many authors emphasizing the significant overlap between the two populations (Green & Schecter, 1957; Fraiberg & Freedman, 1964; Burlingham, 1965; Blank, 1975; Gense & Gense, 2005; Brown et al., 1997; Hobson et al., 1999; Hobson & Bishop, 2003; Tadić et al., 2010; Galiano et al., 2019). According to the DSM-5® (American Psychiatric Association, 2013), those with ASD have difficulties in two areas: first, persistent deficits in social communication and social interactions across contexts; and second, restricted, repetitive patterns of behavior, interests or activities. A similar phenotype has been reported in visual impairment. For example, children with visual impairment have lower scores on false belief tasks (McAlpine & Moore, 1995; Minter et al., 1998; Peterson et al., 2000; Roch-Levecq, 2006), exhibit socio-affective and repetitive and stereotyped behaviors typical of children with ASD (Brown et al., 1997;

* Corresponding author at: Laboratoire "Développement, Individu, Processus, Handicap, Éducation" (DIPHE), Department Psychologie du Développement, de l'Éducation et des Vulnérabilités (PsyDÉV), Institut de psychologie, Université de Lyon (Lumière Lyon 2), 5, avenue Pierre-Mendès-France, 69676 Bron, France.
E-mail address: anna.galiano@univ-lyon2.fr (A.R. Galiano).

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Hobson et al., 1999; Hobson & Bishop, 2003), as well as exhibit behavioral difficulties and difficulty in managing emotions (Alimovic, 2013; Chennaz et al., 2022; Fazzi et al., 1999; Parr et al., 2010). At the language level, a high rate of verbal imitation (echolalia), verbal routines, formulas and stereotyped speech have been found (Andersen et al., 1984, 1993; Dunlea, 1989; Pérez-Pereira, 1994; Pérez-Pereira & Castro, 1997; Peters, 1987). In addition, a number of children present a delay in and an inversion of personal pronouns (Dunlea, 1989; Fraiberg, 1968; Fraiberg & Adelson, 1973). Children with visual impairment also show significantly lower language use, with particular weakness in the use of language for pragmatic and social purposes (Tadić et al., 2010). A delay in symbolic play has also been identified in several studies (Hughes et al., 1998; Lewis et al., 2000; Tröster & Brambring, 1994).

Another area in which both people with visual impairment and people with ASD have an idiosyncratic profile is the sensory domain. In the few studies that have addressed the question of sensory particularities in populations with visual impairment, it has been found that children with visual impairment exhibit atypical sensory processing beyond their visual impairment, as measured by sensory profile scores (SP: Dunn, 1999) (Houwen et al., 2022). These atypical behaviors can be interpreted as difficulty in assessing or regulating responses to sensory stimuli. For example, Fazzi et al. (1999) reported the presence of stereotyped behavior (body rocking, repetitive handling of objects, hand and finger movements, eye pressing and eye poking, lying face downward, and jumping), which was increased by reduced sensory stimulation. Stereotyped behaviors can also manifest in specific situations such as in arousal or monotony (Tröster et al., 1991). One study has found that blind people show greater tactile sensitivity compared to deaf or unimpaired people (Barbacena et al., 2009). However, another showed that children with optic nerve hypoplasia spectrum exhibit sensory integration dysfunction, with the level of deficit more associated with the severity of autistic symptoms than with visual loss or intellectual level (Jutley-Neilson et al., 2018).

Despite the lack of studies on the potential link between sensory particularities and the emergence of autistic signs, a possible link is suggested by the more abundant scientific literature on ASD. Sensory dysfunction has been described in many studies as a characteristic symptom of ASD (Ayres & Tickle, 1980; Baranek et al., 2006; Dellapiazza et al., 2022; Kientz & Dunn, 1997; Leekam et al., 2007; Ornitz, 1974; Osório et al., 2021; Tomchek & Dunn, 2007; Wiggins et al., 2009). Fabbri-Destro et al. (2022) found that sensory profile is strongly correlated with the behavior and emotional problems of children with ASD. Atypical sensory processing such as hyper- or hypo-reactivity to sensory input or unusual interest in sensory aspects of the environment (e.g. apparent indifference to pain/temperature, adverse response to specific sounds or textures, excessive smelling or touching of objects, visual fascination with lights or movement) has been introduced as a diagnostic criterion of ASD (American Psychiatric Association, 2013). It has been shown that the magnitude of differences in sensory processing is larger in children with ASD relative to typically developing (TD) children, and when the gender variable is analyzed, this results in females showing more severe symptoms in certain areas ("Hearing," "Balance" and "Motion" subscales) (Osório et al., 2021). Exploratory longitudinal study results highlight high heterogeneity in the development of sensory processing in children with ASD and the existence of three subgroups based on the course of symptoms (improvement, stable and worsening) (Dellapiazza et al., 2022). In turn, sensory dysregulation affects social functioning (see Thye et al., 2018, for a review). For example, Kojovic et al. showed that a higher intensity of sensory issues is associated with more prominent social difficulties and lower adaptive functioning (Kojovic et al., 2019). Looking at the development of sensory profiles over time, socialization, deficits in day-to-day living skills and maladaptive behavior appeared to be correlated with sensory processes. More specifically, children who show a worsening of these factors with age also show a worsening of the sensory profile (Dellapiazza et al., 2022). A meta-analysis has shown that people with ASD have elevated sensory modulation symptoms across both age and spectrum of severity (Ben-Sasson et al., 2009). An early onset of an extreme sensory profile in ASD has also been reported (Ben-Sasson et al., 2007), suggesting that the sensory phenotype is already present at the first stage of the disorder, and thus could participate in establishing the behavioral profile. Thus, atypical sensory processing is now considered as one of the manifestations of stereotypical and repetitive behaviors in the diagnostic criteria of ASD. These findings prompt an examination of the role of the sensory particularities of the children with visual impairment in the emergence of autistic signs.

In this study, we investigated the potential relationship between sensory profile atypia and the emergence of autistic signs in children with visual impairment. The primary hypothesis was that the particular sensory profile of children with visual impairment would be a good predictor of the emergence of behaviors diagnostic of ASD. To this end, we asked parents of children with visual impairment aged 3–12 to complete the Dunn sensory profile questionnaire as well as the SCQ. These children were compared to a group of neurotypical children and a group of children with ASD to assess (i) whether children with visual impairment differ from the other two groups in any of the domains (sensory profile and autistic behavior) and (ii) whether an atypical sensory profile predicts the severity of autistic behavior, especially in children with visual impairment.

2. Materials and methods

2.1. Participants

The sample included 109 children aged 3 to 12: of these, 37 children had visual impairment (VI) (M_{age} = 7 years 4 months +/− 2.5*SD*; range: from 3 years 2 months to 11 years 5 months; 18 girls and 19 boys), 42 were typically developing (TD) (M_{age} = 7 years 7 months +/− 2.6*SD*; range: from 3 years to 11 years 9 months; 26 girls and 16 boys), and 30 had ASD (M_{age} = 7 years 11 months +/− 2.6*SD*; range: from 3 years to 11 years 9 months; 8 girls and 22 boys). An analysis of variance with the factors "Group" (VI vs. TD vs. ASD) and "Gender" (girls vs. boys) as between-subject variables indicated no effect of age ($Fs < 1$ for all main effects and their interaction). The proportion of boys was greater in the ASD group ($\chi^2(2) = 8.73$, $p = .0127$).

Parents of children with visual impairments or ASD were contacted through medical and social structures that follow this type of child, enabling us to target a population whose deficits have already been identified by medical diagnosis. Parents of typically developing children were contacted by advertisement. The questionnaires were completed by the mother alone (85.3 %), the father alone (10.1 %), or both parents (4.6 %). For children with visual impairment, parents reported that their child had been diagnosed with visual impairment according to the criteria of the International Classification of Diseases 11th Revision (WHO, ICD-11, 2022) criteria. According to these criteria, 24 were diagnosed with moderate or severe visual impairment and 13 with blindness. The parents also declared the visual disorder diagnosis: most children presented a pathology concerning the globe (N = 26) (peripheral visual system), four presented a pathology affecting the optic nerve, five had a cortical damage, and two parents did not specify the pathology. Of the children with visual impairment, parents reported that four children also had an ASD (two children with Leber congenital amaurosis and two with corneal damage). Of the TD children and children with ASD, parents reported no visual impairment other than non-disabling myopia (N = 3), astigmatism (N = 9), hyperopia (N = 9) or strabismus (N = 1). None of the parents of TD children reported any neurological or psychiatric problems.

This research respected the ethical principles for research involving human subjects (World Medical Association Declaration of Helsinki). Parents were informed of the purpose of the study and how their children's data would be used in accordance with ethical principles (General Data Protection Regulation, GDPR).

2.2. Data collection tools

2.2.1. Social communication questionnaire (SCQ)

The Social Communication Questionnaire (SCQ) (Rutter et al., 2003) or its French version (Fremolle-Kruck et al., 2015) is a parental screening questionnaire for ASD that is widely used to study the presence of autistic signs in children (see Berument et al., 1999; Rutter et al., 2003). It has 40 items in a yes/no format divided into three areas: "Reciprocal social interaction," "Language and communication" and "Stereotyped patterns of behavior." The "Lifetime" version (which assesses the child's entire developmental history) was used for this study. The SCQ considers a score of 15 points or greater as an indicator of risk for ASD. However, past research indicates an SCQ score of 11 maximizes sensitivity and specificity in young children (Allen et al., 2007; Lee et al., 2007; Wiggins et al., 2012; Wiggins et al., 2015). For this reason, in this study, an SCQ score of 11 points or higher was chosen as an indicator of risk for ASD.

2.2.2. Sensory profile (SP)

The sensory profile used is a parent-reported 125-item questionnaire about children's responses to sensory stimuli (Dunn, 1999). The SP was published in its French version in 2010 (Dunn, 2010). Parents rate the frequency of each item on a five-point Likert scale from 1 (always) to 5 (never). The items are categorized in 14 subsections, which can be grouped into three main sections ("Sensory processing information," "Modulation" and "Behavioral and emotional responses") or nine factors ("Sensory seeking," "Emotionally reactive," "Low endurance tone," "Oral sensory sensitivity," "Inattention/Distractibility," "Poor registration," "Sensory sensitivity," "Sedentary," "Fine motor/Perceptual"). A lower score indicates a higher frequency of undesirable behavioral responses to sensory events.

Cronbach's alpha as reported in the French manual ranged from 0.71 to 0.90 across different sections and factors for 3 to 11-year-old children (except for five subsections: (E) "Multisensory processing" 0.68, (I) "Modulation of movement affecting activity level" 0.62, (J) "Modulation of sensory input affecting emotional responses" 0.63, (K) "Modulation of visual input affecting emotional responses & activity level" 0.58, and "Items indicating thresholds for response" 0.44; and for two factors: "Poor registration" 0.68 and "Fine motor/Perceptual" 0.64).

2.3. Procedure

The invitation to participate in the research was distributed by the contact networks of various centers specializing in visual impairment or in ASD, through the contact networks of several primary schools in France, and on social networks.

The parents of the selected children were contacted by email to inform them about the study and to determine their interest in it. If the parents showed interest, an information letter, informed consent form, and the questionnaires (SP and SCQ) were emailed to them. Parents also filled out another questionnaire to provide details on their child (age, gender, preterm birth or not) and, for parents of children with ASD and visual impairment, additional clinical information was then requested (etiology, age of diagnosis, degree of visual impairment, any associated disorders, support provided, etc.).

2.4. Data analyses

For the SCQ, missing responses were given a score of 0 (0.28 % of the data). For the SP, missing responses were replaced by the mean score for that question for the other children in the group (0.56 % of the data).

To investigate the effect of group and/or gender on autistic behavior or sensory profile, we applied analyses of variance to the total scores on the SCQ and SP, with the factors "Group" (VI vs. TD vs. ASD) and "Gender" (girls vs. boys) as between-subject factors. For the additional analyses of SCQ subscale scores, the factor "Subscale" ("Communication" vs. "Social interaction" vs. "Repetitive and stereotyped patterns of behavior"; within-subjects) was added to the previous analysis of variance, and we investigated the effects of this new factor in interaction with "Group" and/or "Gender." As the number of items in each subscale was not equivalent, we divided each child's score by the number of items in the subscale before applying the analysis. The same approach was applied for the SP, for which we performed a complementary analysis of variance by adding the factor "Sections" ("Processing of sensory information" vs. "Modulation" vs. "Behavioral and emotional responses"; within-subjects). Greenhouse–Geisser corrections were used when the assumption of sphericity was violated. When the effect of "Group" was significant, the differences between the three groups were further assessed using post-hoc Tukey tests ($p < .05$). Chi-square tests ($p < .05$) were also used to assess whether children with visual impairment displayed a higher risk of ASD than TD children, based on the SCQ score.

The association between sensory characteristics and the occurrence of autistic behavior was studied by considering the SCQ total scores as a dependent variable and then performing simple or multiple regression analyses with, respectively, the total scores on the SP or the scores on the three sections of this questionnaire ("Processing of sensory information," "Modulation" and "Behavioral and emotional responses") as predictive variables. These analyses were first performed on all children, then separately for each group. Fisher's z tests ($p < .05$) were used to test for possible differences between the groups in the correlation between scores on the two questionnaires. Student's *t*-tests ($p < .05$) were used to test for differences in the slope of the regression line.

As four children with visual impairments were also diagnosed with ASD, the analyses were also performed without these children. These analyses indicated exactly the same significant and non-significant effects for the main effects (effect of "Group" on the SCQ and SP score, risk of ASD in children with visual impairment vs. TD children, significant relationships between SCQ and SP scores in simple and multiple regressions when considering all children or only children with visual impairment). As ASD is frequent in children with visual impairment, we decided to keep these four children in our sample to avoid selection bias.

The preliminary analyses showed no relationship between participants' age and SCQ scores (all participants: $R = 0.01$; visual impairment: $R = -0.07$; TD: $R = 0.13$; ASD: $R = -0.02$), or Dunn's SP (all participants: $R = 0.04$; visual impairment: $R = 0.12$; TD: $R = 0.01$; ASD: $R = 0.11$). The factor "Age" was thus not considered in our analyses.

3. Results

3.1. SCQ scores

3.1.1. Group comparisons

The SCQ results are illustrated in Fig. 1. As expected, they show higher SCQ scores for children with ASD than for TD children. Children with visual impairment lay between these two groups. A 2 × 3 analysis of variance with "Group" (with visual impairment vs. TD vs. ASD) and "Gender" (girls vs. boys) as between-subject factors corroborated this visual observation with a significant main effect of "Group" ($F(2,103) = 37.35$, $\eta_p^2 = 0.42$, $p < .0001$). Post-hoc Tukey tests indicated that the mean SCQ score was significantly higher for children with ASD than for children with visual impairment ($p = .0002$), who themselves had a higher mean score that TD children ($p = .0001$).

Complementary analyses investigating the scores at the subscales of the SCQ were performed by adding the within-subjects factor "Subscale" ("Communication" vs. "Social interaction" vs. "Repetitive and stereotyped patterns of behavior") to the previous analysis of variance. This analysis revealed a significant main effect of subscale ($F(1.54,158.61) = 27.18$, $\varepsilon = 0.77$, $\eta_p^2 = 0.21$, $p < .0001$), with scores that were proportionately significantly higher on the subscale "Repetitive and stereotyped patterns of behavior" and significantly lower on "Social interaction," with all pairwise differences significant after a post-hoc

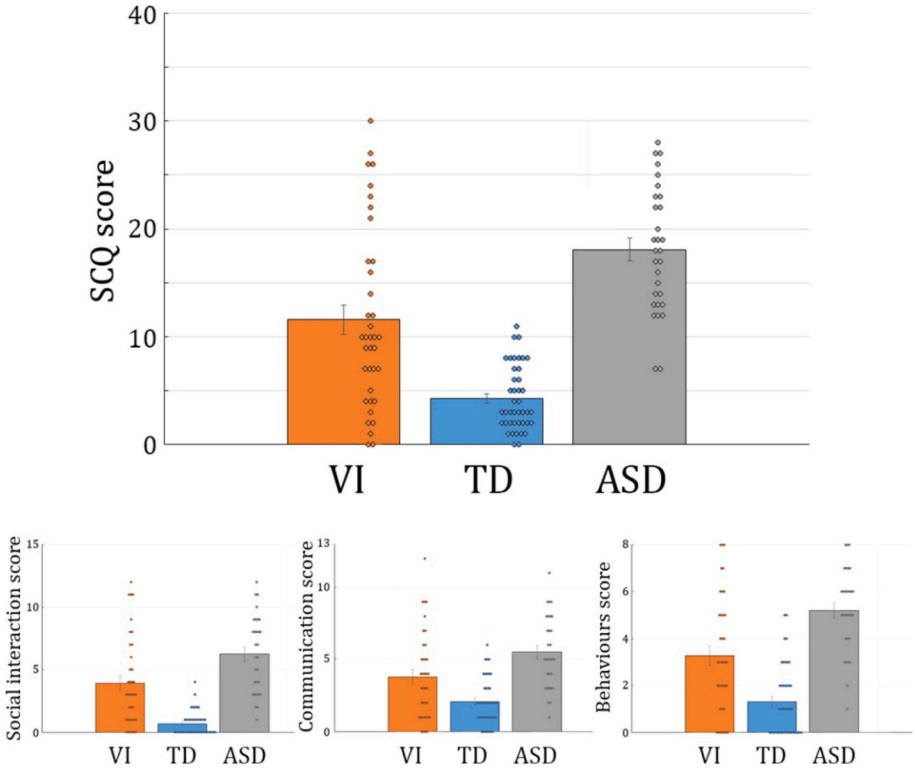

Fig. 1. Top: mean total scores on the SCQ, according to group of children (VI: children with visual impairment, TD: children with typical development, ASD: children with autistic spectrum disorders). Bottom: Mean scores on the three subscales of the SCQ. Error bars show the SE. Individual scores are illustrated by the colored points on the bars.

Tukey test ($p < .0215$). The interaction between "Subscale" and "Group" ($F(3.08,158.61) = 3.90$, $\varepsilon = 0.77$, $\eta_p^2 = 0.07$, $p = .0095$) was also significant; the "Group" effect was similar for the subscales "Social interaction" and "Repetitive and stereotyped patterns of behavior" after complementary linear contrast analyses ($F < 1$). However, it was larger for these two subscales than for the subscale "Communication" ($F(2,103) = 7.44$, $p = .001$ and $F(2,103) = 5.81$, $p = .004$, respectively) (see Fig. 1, bottom graph, for illustration). Post-hoc Tukey tests confirmed that for each subscale, overall, the three groups significantly differed, with a higher score for children with ASD than for children with visual impairment, and TD children obtaining the lowest scores (lowest p value: $p = .0136$).

The visual inspection of individual scores (see colored circles in Fig. 1) further showed a clear cut-off between TD children and children with ASD, with very little overlap between the two groups. For children with visual impairment, however, the variability was much greater, with children ranging along the entire scale, from those with no autistic signs to those with extensive signs. Taking our assumption that a score of 11 or above on the SCQ indicates a risk of ASD (Allen et al., 2007; Lee et al., 2007; Wiggins et al., 2012, 2015), 15 out of 37 children with visual impairment had this risk (40.5 %; including the four children previously diagnosed with ASD), compared to 1 out of 42 for TD children (2.4 %), and 28 out of 30 for children with ASD (93.3 %). Further analysis using the chi-square test indicated that the risk of ASD is significantly greater for children with visual impairment than for typically developing children ($\chi^2(1) = 17.73$, $p < .0001$).

3.1.2. Gender comparisons

In the global analysis (without integrating the "Subscale" factor), neither the main effect of "Gender" nor the interaction between "Gender" and "Group" were significant ($F(1,103) = 2.61$ and $F(2,103) = 0.21$, respectively). When the "Subscale" factor has been added to the analysis, the interaction between "Subscale" and "Gender" was significant ($F(1.54,158.61) = 4.58$, $\varepsilon = 0.77$, $\eta_p^2 = 0.04$, $p = .019$), but not the interaction between "Subscale," "Gender" and "Group" ($F(3.08,158.61) = 1.19$). Post-hoc Tukey tests ($p < .05$) indicated that boys had higher scores than girls on the subscale "Repetitive and stereotyped patterns of behavior" ($M_{boys} = 3.96$ +/− 3.51 SD; $M_{girls} = 2.04$ +/− 2.12 SD; $p < .0001$), with no significant difference for the other two subscales ($p = .1189$ and $p = .1364$, respectively).

3.2. SP scores

3.2.1. Group comparisons

The results for the sensory profile questionnaire are illustrated in Fig. 2. A 2 × 3 analysis of variance with "Group" (with visual impairment vs. TD vs. ASD) and "Gender" (girls vs. boys) as between-subject factors showed a significant main effect of "Group" ($F(2,103) = 29.07$, $\eta_p^2 = 0.36$, $p < .0001$). Post-hoc Tukey tests ($p < .05$) further indicated that the mean score of the SP was significantly lower for children with ASD than for children with visual impairment ($p = .0032$), who themselves had a significantly lower mean score than TD children ($p = .0001$). Complementary analyses investigating the scores on the three sections of the SP were performed by adding the factor "Sections" to the previous analysis of variance. The main effect of "Sections" was significant ($F(1.81,186.42) = 51.25$, $\varepsilon = 0.90$, $\eta_p^2 = 0.33$, $p < .0001$), post-hoc Tukey tests indicating significantly lower proportional scores on "Behavior and emotional responses" than on the other two sections (both $p < .0001$), which did not differ ($p = .9832$).

In contrast to the SCQ, the visualization of individual scores did not indicate greater variability in children with visual impairment compared with other children, whether TD or with ASD (Fig. 2): the variability was consistent between groups, with the exception of two ASD children who scored low on the SP questionnaire (below 300).

The details of the scores of each group in the three sections as well as in the subsections and for the different factors are provided in Table 1.

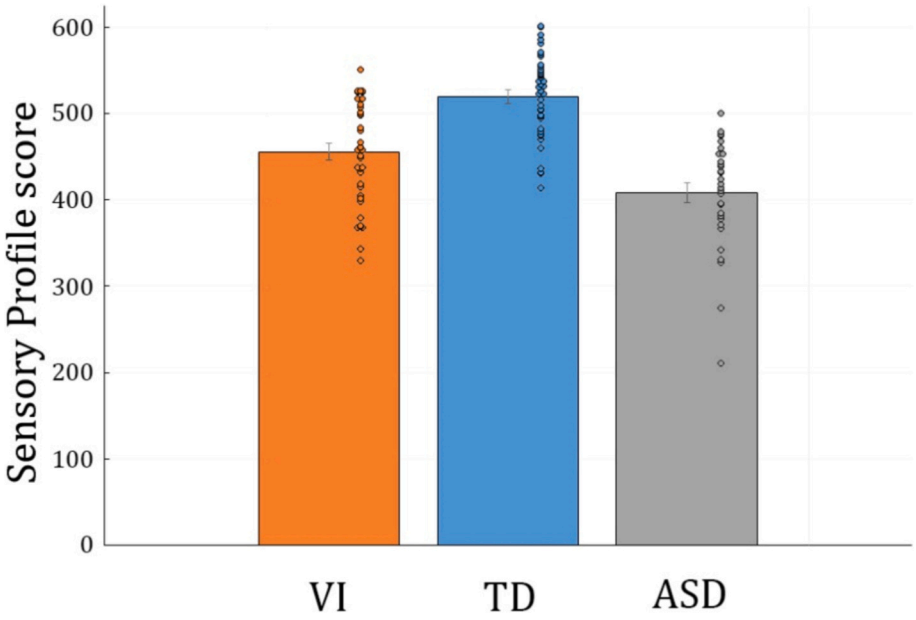

Fig. 2. Mean total scores on the sensory profile questionnaire, according to the group of children. Error bars show the SE. Individual scores are illustrated by the colored points on the bars.

Overall, children with ASD almost always had lower scores than TD children. The scores of children with visual impairment were generally intermediate between those of TD children and those of children with ASD, not differing from children with ASD on some subsections ([B.] "Visual processing," [F.] "Oral sensory processing," [G.] "Sensory processing related to endurance/tone," [H.] "Modulation related to body position and movement," and [K.] "Modulation of visual input affecting emotional responses & activity level") and factors ([1.] "Sensory seeking," [3.] "Low endurance tone," [4.] "Oral sensory sensitivity," [7.] "Sensory sensitivity," [9.] "Fine motor/Perceptual") or from typically developing children in other areas (subsection [I.] "Modulation of movement affecting activity level"; Factors [5.] "Inattention/Distractibility" and [8.] "Sedentary").

3.2.2. Gender comparisons

Neither the main effect of "Gender" nor the interaction between "Gender" and "Group" were significant (both Fs < 1), in the global analysis. After adding the "Section" factor, the interaction between "Sections" and "Gender" was significant ($F(1.81,186.42) = 3.26$, $\varepsilon = 0.90$, $\eta_p^2 = 0.03$, $p = .0455$), with significantly lower scores for boys than girls on the section "Behavior and emotional responses" ($M_{boys} = 84.4 +/- 18.4$ *SD*; $M_{girls} = 95.1 +/- 16.9$ *SD*) after post-hoc Tukey tests ($p = .0005$), and no significant gender effect for the other two sections (($p = .3275$ and $p = .3872$, respectively). This analysis revealed no other significant interactions involving the factors "Gender" or "Sections" (all $p > .225$).

3.3. Regression analyses

To investigate the extent to which autistic signs in children's behavior are related to their sensory profile, we conducted regression analyses with the SCQ scores as the dependent variable and the SP scores as the predictive variable. All children were first considered together, and then regression analyses were conducted for each group separately. The results for the different groups are illustrated in Fig. 3 (top row).

When all children were considered together, a strong relationship was found, with the SP score being a good predictor of the SCQ score ($R = 0.73$; $R^2 = 0.54$; $R^2_{adjusted} = 0.53$; $F(1,107) = 125.21$, $p < .0001$). A similar relationship was observed in children with visual impairment considered alone ($R = 0.68$; $R^2 = 0.46$; $R^2_{adjusted} = 0.44$; $F(1,35) = 29.51$, $p < .0001$). Although this was also significant for TD children ($R = 0.40$; $R^2 = 0.16$; $R^2_{adjusted} = 0.14$; $F(1,40) = 7.44$, $p = .0094$) and children with ASD ($R = 0.48$; $R^2 = 0.23$; $R^2_{adjusted} = 0.21$; $F(1,28) = 8.52$, $p = .007$), the predictive power tended to be less important. While the SP score accounted for 44.2 % of the variation in the SCQ, this proportion dropped to 13.6 % for TD children and to 20.6 % for children with ASD. It should be noted that despite trends in this direction, the correlation coefficient was not significantly higher for children with visual impairment than for TD children ($z = 1.72$) or children with ASD ($z = 1.15$). Nevertheless, as can be seen in Fig. 3, the slope was significantly steeper for children with visual impairment than for TD children ($T(75) = 3.64$, $p = .0005$) or children with ASD ($T(63) = 2.16$, $p = .0346$). It did not differ between children with ASD and TD children ($T(68) = 0.22$). These analyses indicate that the sensory profile of children with visual impairment impacts their autistic-like behavior more than in other children. To illustrate this, a child with visual impairment with an SP that was 10 points lower had an SCQ score that was 0.95 points higher on average, whereas it was 0.23 points higher for a TD child, and 0.44 points higher for a child with ASD. In other words, the negative impact of sensory characteristics was 4.1 times larger for children with visual impairment than for typically developing children, and 2.1 times larger than for children with ASD.

To specify the characteristics of the sensory profile most involved in the emergence of autistic-like behavior, we performed multiple regressions with the SCQ scores as the dependent variable and the total scores on the three SP sections ("Processing of sensory information," "Modulation" and "Behavioral and emotional responses"), considering all children together in a first step, then each group separately. These analyses are summarized in Table 2 (see also the second to fourth rows illustrated in Fig. 3). As in the previous simple regression analyses, the three sections together provided a good prediction of the SCQ score ($R = 0.74$; $R^2 = 0.54$; $R^2_{adjusted} = 0.53$; $F(3,105) = 41.57$, $p < .0001$), with all three sections roughly participating, although "Behavioral and emotional responses" was only marginally significant (Table 2). Quite similar predictive power was also observed when children with visual impairment were considered alone ($R = 0.69$; $R^2 = 0.47$; $R^2_{adjusted} = 0.42$; $F(3,33) = 9.84$, $p < .0001$). Again, although significant, the prediction was less reliable for children with ASD ($R = 0.61$; $R^2 = 0.37$; $R^2_{adjusted} = 0.30$; $F(3,26) = 5.15$, $p = .0063$). In this analysis, it did not reach the significance threshold for typically developing children ($R = 0.41$; $R^2 =$

Table 1
Mean scores on the different sections, subsections and factors of the SP for children with visual impairment (VI), children with typical development (TD) and children with ASD.

	VI		TD		ASD		
	M	(SD)	M	(SD)	M	(SD)	Differences*
Sensory processing information	**242**	**(35)**	**275**	**(28)**	**219**	**(34)**	**TD > VI > ASD**
A. Auditory processing	28	(6)	32	(4)	23	(6)	TD > VI > ASD
B. Visual processing	27	(6)	37	(5)	29	(7)	TD > (VI = ASD)
C. Vestibular processing	45	(7)	48	(5)	41	(8)	TD > ASD
D. Tactile processing	70	(11)	78	(8)	63	(11)	TD > VI > ASD
E. Multisensory processing	28	(4)	30	(3)	25	(4)	TD > VI > ASD
F. Oral sensory processing	44	(12)	50	(7)	40	(10)	TD > (VI = ASD)
Modulation	**125**	**(17)**	**145**	**(12)**	**114**	**(19)**	**TD > VI > ASD**
G. Sensory processing related to endurance/tone	37	(8)	42	(4)	34	(10)	TD > (VI = ASD)
H. Modulation related to body position and movement	38	(5)	44	(5)	37	(8)	TD > (VI = ASD)
I. Modulation of movement affecting activity level	22	(4)	23	(3)	18	(4)	(TD=VI) > ASD
J. Modulation of sensory input affecting emotional responses	14	(4)	18	(2)	12	(2)	TD > VI > ASD
K. Modulation of visual input affecting emotional responses & activity level	14	(3)	17	(2)	13	(3)	TD > (VI = ASD)
Behavior and emotional responses	**89**	**(16)**	**101**	**(15)**	**74**	**(16)**	**TD > VI > ASD**
L. Emotional/ social responses	58	(11)	65	(10)	47	(11)	TD > VI > ASD
M. Behavioral outcomes of sensory processing	19	(5)	23	(5)	16	(5)	TD > VI > ASD
N. Items indicating thresholds for response	12	(2)	13	(1)	11	(3)	TD > VI > ASD
Factors							
1. Sensory seeking	61	(10)	67	(10)	57	(14)	TD > (VI = ASD)
2. Emotionally reactive	52	(11)	59	(11)	40	(10)	TD > VI > ASD
3. Low endurance tone	37	(8)	42	(4)	34	(10)	TD > (VI = ASD)
4. Oral sensory sensitivity	32	(10)	38	(6)	29	(9)	TD > (VI = ASD)
5. Inattention/ Distractibility	25	(5)	27	(4)	19	(5)	(TD=VI) > ASD
6. Poor registration	33	(5)	37	(3)	28	(5)	TD > VI > ASD
7. Sensory sensitivity	15	(4)	18	(3)	15	(4)	TD > (VI = TSA)
8. Sedentary	13	(4)	13	(3)	10	(4)	(TD=VI) > ASD
9. Fine motor/ Perceptual	7	(3)	13	(3)	9	(3)	TD > (VI = ASD)

* After post-hoc Tukey tests ($p < .05$).

0.17; $R^2_{adjusted} = 0.10$; $F(3,38) = 2.55$, $p = .0703$). More importantly, for children with visual impairment, the section that most supported the SCQ score was "Sensory information processing," which was the only section to be significant (Table 2). In contrast, for children with ASD, the section that most supported the SCQ score (and the only statistically significant one) was the "Behavioral and emotional responses" section.

This analysis suggested that sensory processing was involved in the emergence of autistic-like behavior in children with visual impairment. To determine whether this phenomenon was related to the visual modality, we performed a new multiple regression analysis with the SCQ scores as the dependent variable, but this time by entering the different subsections (A, B, C, D, E and F) of "Processing of sensory information" (each section corresponding to sensory processing in a modality). This analysis was performed for the children with visual impairment as well as for all children together and the other two groups separately, for comparison purposes. The summary of these analyses is provided in Table 3. They indicated that the influence of "Processing of sensory information" on the SCQ score was significant only for children with visual impairment, with a strong relationship (the strongest reported in this study) ($R = 0.81$; $R^2 = 0.65$; $R^2_{adjusted} = 0.58$; $F(6,30) = 9.34$, $p < .0001$). This relationship was supported by two subsections, one that involve the visual modality, the other not (i.e. subsections [B.] "Visual processing" and [F.] "Oral sensory processing," which were the only to present significant coefficients). In this regard, restricting the regression analysis to the four subsections that do not involve the visual modality (i.e. introducing subsections A, C, D and F as predictive variables) led to high predictive power, which was almost unchanged ($R = 0.77$; $R^2 = 0.59$; $R^2_{adjusted} = 0.54$; $F(4,32) = 11.43$, $p < .0001$).

4. Discussion

This study examined the sensory profile (as measured by the Dunn test) of three groups of children (with visual impairment, typically developing and ASD) aged 3 to 12. Abnormal sensory profiles in ASD are today recognized in the DSM-5 and are a diagnostic criterion. The main aim of the study was to find out whether the sensory profile of children with visual impairment is a good predictor of behaviors typical of ASD (as measured by the SCQ).

Our results showed that children with visual impairment are at increased risk for signs of ASD. The SCQ scores of children with visual impairment on average approached those of children with ASD, and the proportion of children with visual impairment at risk for ASD was greater than for TD children (40.5 % vs. 2.4 % with a score of 11 points or greater, an indicator of risk for ASD) (see Allen et al., 2007; Lee et al., 2007; Wiggins et al., 2012, 2015). This result corroborates the first observations in relation to sensory profiles of children with optic nerve hypoplasia spectrum (Jutley-Neilson et al., 2018) and in children with visual impairments (Houwen et al., 2022), as well as more general clinical data (Baron-Cohen et al., 2009; Fazzi et al., 2019; Molinaro et al., 2020).

The sensory profile of children with visual impairment followed the same trend of impairment as children with ASD compared to typically developing children, although the former scored higher overall than children with ASD. This exploratory study therefore confirms for the first time that children with visual impairment present atypical sensory profiles very similar to those of children with ASD in several aspects. While it was already known that children with visual impairments have difficulty regulating responses to sensory stimuli (Barbacena et al., 2009; Fazzi et al., 1999; Fazzi et al., 2019; Gal et al., 2009, 2010; Houwen et al., 2022; Jutley-Neilson et al., 2018; Tröster et al., 1991), no previous study had compared the profiles of these children to those of children with ASD.

Regression analyses further showed that the sensory profile predicts the risk of autistic-like behavior in all children. However, the relationship between sensory characteristics and autistic behavior is two to four times greater for children with visual impairment than for others,

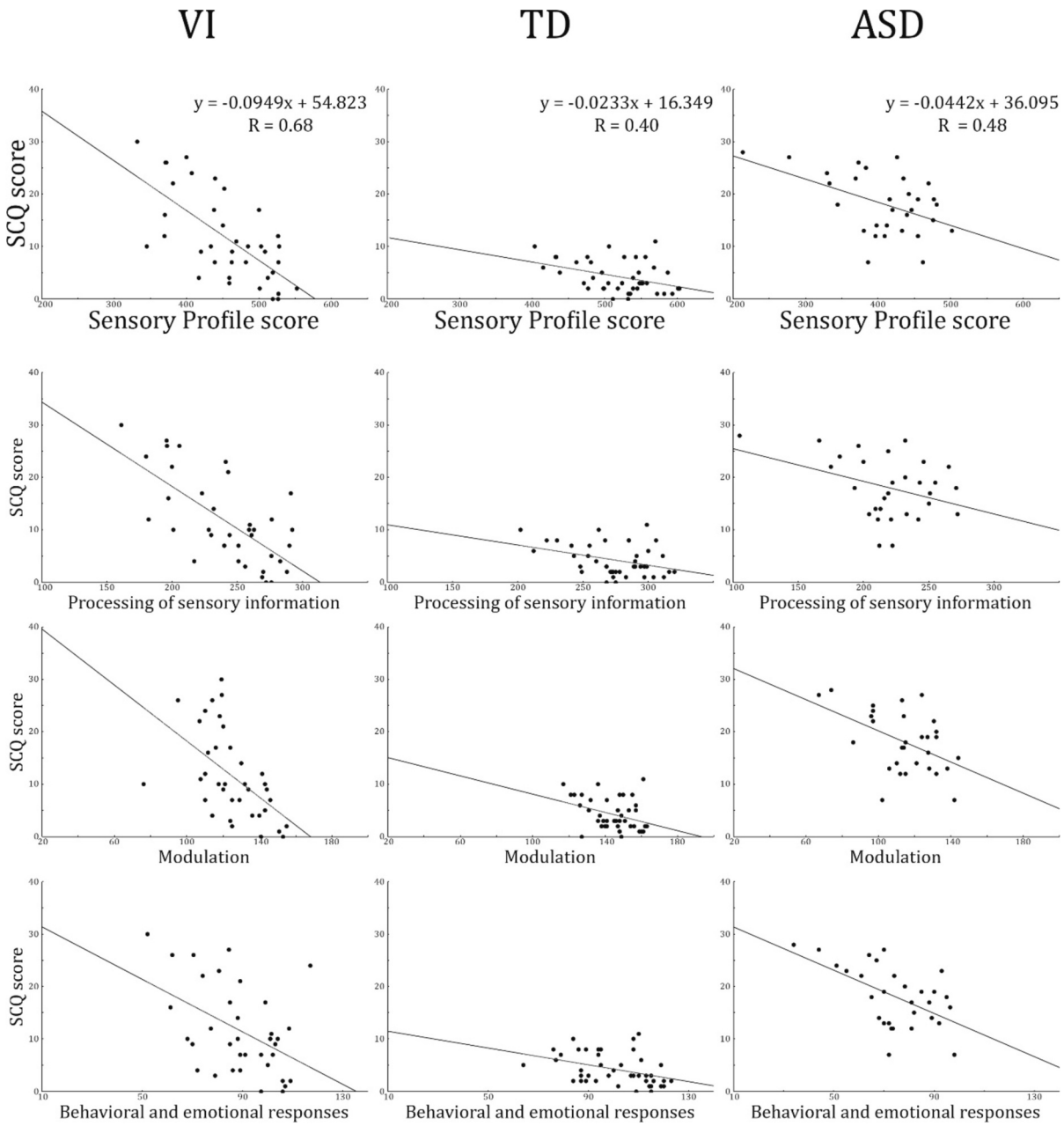

Fig. 3. Scatterplots of SCQ scores and SP scores (top row) and the three sections of the SP (second to fourth rows), according to the group of children.

Table 2
Summary of multiple regression analyses on all children or by group, with SCQ scores as the dependent variable and SP sections as predictive variables.

	All children	VI	TD	ASD
R	0.74	0.69	0.41	0.61
$R^2_{adjusted}$	0.53	0.42	0.10	0.30
F value $^{p\ value}$	41.57 $^{p<.0001}$	9.84 $^{p<.0001}$	2.55 $^{p=.0703}$	5.15 $^{p=.006}$
Standardized coefficients (β):				
Processing of sensory information	−0.28 $^{p=.042}$	−0.57 $^{p=.0062}$	−0.11	0.38
Modulation	−0.30 $^{p=.017}$	−0.10	−0.07	−0.34
Behavioral and emotional responses	−0.21 $^{p=.0705}$	−0.07	−0.27	−0.63 $^{p=.024}$

Table 3
Summary of multiple regression analyses on all children or by group, with SCQ scores as a dependent variable and subsections of the "Processing of sensory information" section as predictive variables.

	All children	VI	TD	ASD
R	0.73	0.81	0.37	0.56
$R^2_{adjusted}$	0.51	0.58	−0.02	0.14
F value $^{p\ value}$	19.54 $^{p<.0001}$	9.34 $^{p<.0001}$	0.94	1.76
Standardized coefficients (β):				
A. Auditory processing	−0.38	−0.19	−0.16	−0.42
B. Visual processing	0.08	0.28 $^{p=.0406}$	0.00	0.25
C. Vestibular processing	−0.09	−0.12	−0.03	−0.42
D. Tactile processing	−0.16	−0.19	−0.09	0.13
E. Multisensory processing	−0.02	0.12	−0.08	−0.10
F. Oral sensory processing	−0.28	−0.65 $^{p=.0003}$	−0.08	0.01

suggesting a greater weight of the sensory profile in this type of behavior in these children. We also found that different aspects of the sensory profile were affected in children with visual impairment and in those with ASD. Whereas in children with ASD the expression of autistic behavior (as measured by the SCQ) is associated with "Behavioral and emotional responses" in the SP questionnaire, for children with visual impairment it is associated with "Processing sensory information," including processing non-visual sensory information. These findings indicate that deficits in the processing of sensory information (auditory, balance, tactile, multisensory and oral) strongly predict the presence of autistic-type behavior in children with visual impairment.

The observation of a dissociation between children with visual impairment and children with ASD in terms of the aspect of their sensory profile most closely associated with the emergence of autistic behavior ("Processing of sensory information" or "Behavioral and emotional responses," respectively) suggests that what underpins these behaviors is at least partially distinct in the two populations. In children with ASD, "Behavioral and emotional responses" is the area in Dunn's sensory profile that corresponds most directly with what the SCQ measures (i.e. communication skills and social functioning): both measure behaviors related to deficits in social communication and social interactions, a central aspect of ASD. The association of autistic-like behaviors with sensory information processing in children with visual impairment suggests that these behaviors develop along a different developmental pathway that is more due to their sensory particularities (see, for example, Brambring, 2011). It has been suggested that social adaptation disorders in autism are linked to difficulties in integrating interpersonal understanding mechanisms, such as joint attention, triadic interactions and theory of mind (e.g. Baron-Cohen et al., 2001). In people with visual impairment, the absence of vision is obviously a major barrier to the early development of these social abilities (e.g. Bigelow, 2003; Hobson, 1990). Their acquisition consequently rests on the ability of the child and his/her caregivers to enlist the other senses to support it (see Molinaro et al., 2020). This thus depends to a large extent on the integrity and proper functioning of these other senses, and on the ability of caregivers to engage them to support their child's cognitive and social development.

Indeed, a key finding of our study is that the emergence of autistic-like behavior is closely associated with deterioration in the quality of sensory processing in areas other than the visual modality. In our findings, the predictive power of the SCQ score was strongest for children with visual impairment when the sensory information processing score was considered alone, with or without the visual modality. The more atypically the child processes sensory information, whatever its origin, the more frequent autistic-type behavior will be. Thus, despite the major influence of visual impairment on the difficulties faced by children suffering from this, our results showed that the risk of developing autistic-type syndromes is also related to the ability of other sensory modalities to compensate for this deficit. In other words, it is not solely related to the extent of visual impairment.

This link with sensory information processing also calls into question using the presence of autistic behaviors in childhood as an indicator of a diagnosis of ASD in children with visual impairment; at least, the results urge caution before qualifying these behaviors as indicative of ASD. The hypothesis that autistic behavior is more closely linked to the loss of vision in early visual experiences than to a neurodevelopmental trait has previously been put forward (e.g. Brambring & Asbrock, 2010; Hobson & Lee, 2010). In some cases, children with visual impairment met the clinical criteria for ASD when children, with the diagnosis being withdrawn when they reached adolescence (Hobson & Lee, 2010). This is unusual for sighted children with ASD. Thus, some autistic-like behaviors may be more related to a sensory processing response that is unique to the presence of visual impairment than to the presence of a true autistic syndrome. This nuance can be important when it comes to providing the most appropriate therapeutic care: for example, by focusing more specifically on sensory information processing responses in patients with visual impairment.

5. Limitations and future directions for research

Some limitations concerning this study should be noted. First, the evaluations (whether responses to questionnaires on children's behavior or clinical condition) were based on parental reports (mainly mother's reports) and not on the children's clinical records or direct observation by a clinical professional or a researcher. This, combined with the relatively small sample, limit the impact of our study and prevented us from considering some potential important factors. In particular, we did not consider the severity or the cause of visual impairment (e.g. peripherical or central), nor the age of onset. It would be of interest to enlarge the sample to carry out more powerful analyses that take into account the degree of visual impairment. Studies have shown that children most at risk of developmental problems are those with a more severe visual impairment (Dale & Sonksen, 2002; Hatton et al., 2007; Mukaddes et al., 2007). Likewise, several studies have reported a link between ASD and the type of visual impairment. This link has been found in certain ophthalmological diseases such as Leber congenital amaurosis (Fazzi et al., 2005; Rogers & Newhart-Larson, 1989), Norrie disease (Goodyear et al., 1989) and retinopathy of prematurity (Ek et al., 1998). The prevalence of autistic-like behavioral disorders also depends on whether the visual disturbance is peripheral or cerebral in nature, with the former more prevalent and the latter more compatible with a diagnosis of ASD (Fazzi et al., 2019; see also Mukaddes et al., 2007; Molinaro et al., 2020). The presence of cerebral dysfunction could also be a factor hindering development of the other senses. It would therefore be valuable to carry out analyses taking into account the severity and the type of pathology, as well as whether the damage is peripheral or central. It would also be important to study larger cohorts to investigate the role of factors such as the child's developmental or intellectual quotient, and the influence of the social environment (parental education and socio-economic status, siblings, for example).

6. Conclusion

There is a high association between ASD and visual impairment. Because of the similar behavioral traits associated with both visual impairment and ASD, the ASD diagnosis in children with visual impairment is complex. The DSM-5 recommends the systematic assessment of sensory profiles at an early stage during clinical evaluations. For children with visual impairment, the evaluation of sensory profiles to detect children at risk of developing ASD is almost non-existent. This study provides strong evidence to support the need to make this evaluation systematic for children with visual impairment.

CRediT authorship contribution statement

Anna Rita Galiano: Writing – original draft, Methodology, Conceptualization. **Franclain Mekomedemb:** Investigation. **Anna Eve Helmlinger:** Investigation. **Jean-Yves Baudouin:** Writing – original draft, Methodology, Formal analysis.

Declaration of competing interest

The authors declare no conflict of interest.

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Data availability

Data will be made available on request.

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