Trajectories and perceptual precursors of intelligence in minimally verbal autistic children from preschool to school age

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Abstract

Background

The question of cognitive prognosis is frequently asked at the time of autism diagnosis, often at preschool age. It remains however difficult to answer this question at such a young age, given the considerable heterogeneity of cognitive development trajectories and the challenges associated with intellectual assessment in autistic children, particularly among minimally verbal children.

Methods

The current prospective cohort study investigated whether early perceptual abilities measured at preschool age could predict later intellectual abilities at school age in a group of 41 autistic (9 girls, 32 boys) and 57 neurotypical children (29 girls, 28 boys). Participants were assessed at three time points during the childhood period (between the age of 2 and 8 years old) using the Wechsler Preschool and Primary Scales of Intelligence – Fourth edition as a measure of full-scale IQ and the Raven's Colored Progressive Matrices as a measure of non-verbal IQ. The performance on two perceptual tests (Visual Search and Children Embedded Figures Test) as well as the frequency of perceptual behaviors served as predictors of later intellectual abilities.

Results

Early performance on perceptual tests measured at preschool age was positively related to later full-scale IQ in both autistic and neurotypical children. Furthermore, both perceptual behaviors and performance on perceptual tests measured at preschool age were associated with later non-verbal IQ in the autistic group. In contrast, only the performance on Children Embedded Figures Test was associated with later non-verbal IQ in the neurotypical group.

Limitations:

The sample size was relatively modest, with some attrition across time points, as expected in a sample including preschool minimally and non-verbal children.

Conclusions

Our findings support the important role of perception in autistic cognition. Early perceptual abilities may be a valid avenue for estimating general intelligence and non-verbal abilities at preschool age, particularly for minimally verbal autistic children.

Introduction

Autism spectrum (AS) diagnosis is often done at preschool age (i.e., 2-5 years) and is characterized by socio-communicative deficits and the presence of repetitive and restricted behaviors and interests (RRBI). The diagnosis must specify both language and intellectual levels (1).

At time of diagnosis, one of the key questions of parents of autistic children is what the future holds for their child in terms of cognitive functioning (2). However, it remains difficult to answer this question given the considerable heterogeneity of cognitive development, particularly during the preschool years (3-6). Previous findings indeed showed a reduction (7, 8), no change (5, 9-11) or increase in IQ from preschool to school age (4-6, 12, 13), with no prevailing pattern. The stability of IQ in autism, especially when assessed during preschool (10), is lower than what is expected in a neurotypical (NT) population (6, 14, 15).

This heterogeneity in autistic preschoolers' IQ has been linked to various factors including compliance with the task, attentional capacities, and disruptive behaviors on the day of assessment, characterizing young children in general (16). Factors inherent to the autistic phenotype also need to be considered. For instance, an important proportion of autistic preschoolers are minimally or non-verbal (17-23) and will only develop language at school age (24), thus making the use of conventional IQ tests impossible or inappropriate with this population (25, 26). In sum, the difficulties evaluators face to properly assess preschool autistic children, as compared to their NT peers, might contribute to the poor prognosis of their IQ scores in longitudinal studies (27). *Consequently, how can one reveal the intellectual potential and predict the cognitive development of these children at the age of diagnosis?*

In NT children, the precursors of intelligence are well established and include language abilities, working memory, executive functions, and processing speed (28-39). However, in minimally or non-verbal autistic children, early indicators of intellectual prognosis remain to be clearly identified. In autism in general, it was proposed that perception plays a greater role in cognition (40, 41). This is reflected in the increased performance of autistic individuals on various perceptual tasks (e.g., 42, 43, 44), a superiority notable as soon as preschool age (42, 45, 46). For example, autistic children have a faster response time in visual search tasks (42, 47, 48), as well as a faster detection time in embedded figure tasks (46, 49). The superiority of perceptual information processing has also been demonstrated in complex non-verbal tasks – assessing abilities to solve novel problems by inferring and integrating rules – such as Raven's Progressive Matrices (25, 44, 50-55).

Previous cross-sectional studies suggest that perceptual abilities are positively correlated to general intellectual abilities in both autistic and NT children and adults (50, 56-58). Interestingly, perceptual and visuospatial abilities appear to be more strongly associated with non-verbal reasoning abilities than to general intellectual abilities in autistic individuals. Moreover, the relation between perceptual skills and non-verbal reasoning abilities appears stronger in autistic individuals versus their NT peers (58-60). These findings may indicate that the precursors of intelligence (or their importance) are different in autistic versus NT children, with a greater role of perception in autistic cognitive development.

Additional arguments for an increased role of perception in autistic cognition is the fact that several RRBIs included in the autism diagnosis are perceptual by nature (41, 61, 62). It has been hypothesized that these RRBIs may represent early explicit manifestations of perceptual strengths (56). For example, fast lateral gaze to objects and faces could be a way for autistic children to optimally capture information, while managing otherwise excessive amounts of sensory input (42, 63).

However, little longitudinal work has formally examined the predictive role of perceptual abilities and behaviors on developmental patterns of change in IQ from preschool to school age in autism. Considering the challenges inherent to conventional intellectual assessment, early perceptual predictors may be useful in estimating intellectual potential among young autistic children when traditional tests cannot be used. Indeed, perceptual abilities have the advantage to be easily observed at preschool age without necessitating a formal evaluation and seem to fit the unique cognitive style of autistic individuals. While perceptual abilities do not constitute a proper measure of intelligence, and thus cannot directly substitute for it, using these abilities to better predict the intellectual potential of autistic children at the age of diagnosis is an avenue worth exploring. Longitudinal studies examining the predictors of IQ trajectories and considering both intra-individual and inter-individual variations across time offer the best hope of unravelling the predictors of intellectual potential from preschool to school age.

Objectives

Our main objectives were to explore 1) whether some perceptual abilities, behaviors and interests measured at preschool age could predict level and change in intelligence at school age, and 2) whether these perceptual predictors are specific to autism or shared with the NT group.

Methods

This study was formally reviewed and approved by the research ethic committee of XXXX Hospital (City, Country). Informed written and verbal consent was obtained from parents prior to participation at each time point.

Participants

Families of children aged under 71 months who received an AS diagnosis at the specialized assessment clinic at XXXX Hospital between January 2014 and February 2020 were invited to participate in this study. Exclusion criteria for this group included having an identified associated genetic disorder or having an important motor delay (equivalent age < 18 months) susceptible to interfere with tests administration. AS diagnosis was based on gold standard instruments and expert clinician judgment. Of the 41 autistic children, 34 were assessed using Toddler Module or Module 1 of the ADOS-2 (64) or ADOS-G (65). Two children were assessed using Module 2 of ADOS-2 and used phrased speech at time of their diagnosis. Five children received an AS diagnosis based on clinical judgment.

NT participants were recruited in daycare centers of the same geographic area. Children in the NT group did not have any diagnosed developmental or neurological condition and did not have any sibling with an AS diagnosis. Participants' characteristics are presented in Table 1.

Measures

Full-scale IQ (FSIQ). The Wechsler Preschool and Primary Scales of Intelligence – Fourth edition (WPPSI-IV: 66) was used to assess FSIQ. It is normed for children aged 2 years 7 months to 7 years 7 months, with a version designed for children under 4 and one for children of 4 years and older. These two versions include respectively 5 (Receptive Vocabulary, Information, Block Design, Object Assembly, Picture Memory) and 6 (Information, Similarities, Block Design, Matrix Reasoning, Picture Memory, Bug Search) core subtests allowing the computation of a FSIQ score in percentiles.

Non-verbal IQ (NVIQ). The board form of the Raven's Colored Progressive Matrices (RCPM: 67) was used to measure NVIQ. Raven's Matrices are among the most commonly used cognitive assessments in research studies (68) as this test uses non-verbal material and is relatively independent of culture. The RCPM includes three sets of 12 items (A, Ab, B) of increasing difficulty and complexity within and across sets. Each item presents a pattern or a 2 x 2 matrix that the child must complete by choosing which of the six movable pieces best completes the matrix. The Netherlands norms, from 3 years and 9 months to 10 years and 2 months, were used to derive percentiles from raw scores obtained by participants.

Table 1

Children and Families Sociodemographic Characteristics (N = 98: 38 girls, 60 boys)

Characteristics	*n*		%	
Diagnostic group				
Autistic	41		42	
NT	57		58	
Annual Income ($)				
0 – 29,999	17		17	
30,000 – 49,999	14		14	
50,000 – 69,999	10		10	
70,000 – 89,999	13		13	
90,000 – 119,999	8		8	
120,000+	23		24	
Missing	13		13	
	Mothers		Fathers	
	n	%	*n*	%
Parental level of education				
High school not completed	4	4	2	2
High school	11	11	13	13
College[a]	17	17	18	18
Undergraduate studies	28	29	32	33
Graduate studies	19	17	13	13
Postdoctoral fellowship	3	3	2	2
Missing	16	16	18	18
Parental ethnicity				
Asian	1	1	1	1
Black	11	12	11	12
Latina	4	4	3	3
Middle Eastern countries	18	18	18	18
White	51	52	50	51
Missing	9	9	11	11

[a] Colleges are general and vocational educational institutions that grant two- or three-year postsecondary degrees preparing students for university-level education. NT = Neurotypicals

Perceptual abilities. Perceptual abilities were assessed using two different tests requiring selective visual attention: the Visual Search (VS) Task and the Children Embedded Figures Test (CEFT).

Visual Search Task. The VS was the same as the one in Courchesne et al.'s (50). Children were asked to find a target letter among sets of 5, 15, 25, 50 or 75 distracters. There were two conditions: (a) the feature condition, in which the target letter differed from distracters in shape (e.g., a red T hidden among red Xs and green Ss), and (b) the conjunction condition in which the target had either the color or the shape in common with the distracters, and thus, only the conjunction of attributes defined the target (e.g., a red X hidden among red Ts and green Xs). Each combination of number of distracters (5) and condition (2) was presented six times for a total of 60 trials. Each stimulus (i.e., target among distracters) was printed out on 28 x 21.5 cm plasticized card. Three different target letters were used in the task, and each was printed on thick plasticized cardboard (3 x 2.4 cm), so the children could manipulate it and answer by placing it over the corresponding target letter on the stimulus. The time (in seconds) required to find the target was used as a measure of performance. The number of correct answers was not used as there was an expected ceiling effect on this test.

Children Embedded Figures Test. The CEFT (69) involves finding a target shape camouflaged within a larger design with semantic meaning. The CEFT is made up of 14 practice trials and 25 test trials. To minimize verbal instructions, as it was done in previous studies (Courchesne et al. 2015; 2019), we removed the instruction not to rotate the target shape, which is normally part of the test instructions. We used the number of correct answers on the test, but not response time as it was only recorded for successful items.

Perceptual repetitive behaviors and interests. Perceptual repetitive behaviors and interests were measured using the Montreal Stimulating Play Situation – revised version (70). This standardized play situation is videotaped and lasts approximately 30 minutes. About 40 toys specifically chosen for their perceptual properties (e.g., toys with lights, musical toys, rotating toys) were displayed in a playroom or presented to the child by an experimenter. Undergraduate students were trained over multiple sessions to code repetitive behaviors (e.g., lining up objects) using Observer XT 11 (Noldus Information Technology Inc.) until they reached a percentage of agreement of 90%. Each repetitive behavior was defined in a repertoire, so that each instance could be easily coded. In the context of this study, only the perceptual explorations described below were considered in the analysis.

Perceptual explorations. Perceptual explorations were defined as repetitive behaviors that were atypical by their nature (e.g., lateral glances at objects) or by their intensity (e.g., lining up objects) and had a perceptual component. A perceptual exploration score was calculated for each participant by doing the sum of the frequency of the following repetitive behaviors: grouping objects based on their perceptual characteristics, lining up objects, writing, close gaze at objects, lateral glances at objects, and obstructed gaze at object. Scores were then divided by the total duration of the Montreal Stimulating Play Situation and multiplied by 3600 seconds. The resulting score therefore represented the number of times the child did perceptual explorations per hour.

Covariates. In addition to the child's age at T1, sex and group, family socio-economic status (SES) was computed. Standardized scores (Z-scores) of maternal and paternal years of education, and family income were averaged to create a family SES index.

Procedure

This longitudinal study included three time points. The first time point was at the age of diagnosis during preschool (T1; *M* = 53.38 months, *SD* = 9.53, Range = 26.67 – 70.00). The second and third time points took place approximately 1 year, (T2; *M* = 67.86 months, *SD* = 10.72, Range = 41.00 – 98.00) and 2 years later (T3; *M* = 79.60, *SD* = 10.28, Range = 57.50 – 107.00). During the first time point, participants were exposed to the Montreal Stimulating Play Situation designed to elicit restricted and repetitive behaviors in preschool children. Across all time points, children also had to complete a variety of tasks measuring FSIQ and NVIQ levels as well as perceptual skills.

Among our sample of 98 children, 89 completed the FSIQ assessment at Time 1 (T1), 64 at Time 2 (T2), and 41 at Time 3 (T3). Also, 78 children completed the NVIQ assessment at T1, 65 at T2, and 45 at T3. In all, the 98 children of our sample had available data on at least one of the FSIQ or NVIQ assessment points (i.e., T1, T2 or T3; see Table S1 for information on missing data).

Preliminary Analyses

Attrition analyses suggested that the number of missing data was not associated with family SES, group (i.e., NT or autistic) or performance on perceptual predictors (VS time, CEFT score and perceptual explorations), all *p*s > .05. However, child's age at T1 was significantly associated with the number of missing data, $r = .23$, $p = .02$, such that children who were older at T1 had more missing data. Missing data are considered missing at random when other observed variables are associated with the probability of missingness (71), as it is the case in our study. Consequently, missing data were handled using the robust full-information maximum likelihood (MLR) estimator, as per current best practices, which allows the estimation of model parameters using all available data and increases statistical power (72, 73).

Analytic Strategy

To describe intraindividual trajectories of children's FSIQ and NVIQ levels over time, multilevel growth curves analyses were conducted using Mplus (74). As opposed to structural equation modeling framework, multilevel modeling (MLM) framework can easily handle partially missing data, unequally spaced time points, and data collected across a range of ages within a particular measure point (72, 75, 76). Using MLM also allows for the exploration of intraindividual change over time (level-1; within-subject) as well as inter-individual differences in intercept and slopes (level-2; between-subjects : 77). Furthermore, it allows examining the links between variables of interests and between-subjects' differences in both intercept and slope. Using MLM, adequate statistical power is achieved with as few as 30-50 level-2 units (i.e., 30-50 children : 75). All these attributes make MLM particularly well suited to the methodological design of our study.

Modeling change in FSIQ and NVIQ over time. Intraindividual trajectories in FSIQ and NVIQ level over time were first modeled at level-1 (within-person change over time) and differences between children were then examined at level-2 (between-person change over time). Two unconditional models were specified to ascertain the best-fitting trajectory models in FSIQ and NVIQ levels. The Model A (i.e., fixed linear model) included the fixed effect of children exact age in years, coded such that the intercept represented average FSIQ level or NVIQ level at 5 years (representing school entry in XXXX country) and the slope represented the average yearly change in FSIQ or NVIQ level. The Model B (random linear model) included the random effect of time (i.e., between-subjects variability in individual intercepts and slopes). Using children's exact age enabled us to flexibly handle individually varying time scores and to estimate change in child FSIQ and NVIQ levels from 2 to 8 years.

The log-likelihood (an indicator of deviance) and the Akaike information criterion were used to assess goodness of fit. Lower values indicated better representation of the data by the model (78). The random effects were retained if the model's log likelihood (LL) was significantly lower or remained the same with the addition of the random terms, based on an adjusted chi-square difference test (i.e., adapted to the MLR estimator), or if the model's Akaike information criterion was lowered with the addition of the random terms.

Finally, all continuous predictors were centered at the grand mean so that the intercept represents the estimated initial status (baseline level) for individuals with an average value on each predictor.

Predicting change in FSIQ and NVIQ levels over time. After modeling both FSIQ and NVIQ trajectories, a preliminary condition model was tested, including the effects of the potential covariates (i.e., child's age at T1, family SES, sex) on FSIQ and NVIQ trajectories. Only the covariates significantly associated with the slope, the intercept or with missing data were deemed relevant for our analyses and retained in the final models. Child's age at T1 was included in all final models as it was associated with missing data, as mentioned above. Only these final models were retained to increase parsimony, maximize statistical power, and to reduce the noise that may be caused by the high number of covariates included in the preliminary models (79).

Determining whether the predictors of change in FSIQ and NVIQ levels are the same in both groups. Group was included in the final models because our second objective was to examine whether the same variables predict the slope and intercept in autistic and NT children.

Final predictive models. Final predictive models, including the retained covariates, were estimated for each main predictor (i.e., VS time, CEFT score and perceptual explorations).

Results

Preliminary Analyses

Table S2 displays the descriptive statistics for all continuous variables. All variables were normally distributed (skewness < 3.0; kurtosis < 7.0), except for NVIQ at T2 in the autistic group and NVIQ at T3 in the NT group, that showed high skewness and kurtosis. MLR estimation was used, as it is robust to non-normality.

Zero-order correlations among covariates (i.e., child's age at T1, family SES, sex and group) and main variables (i.e., VS time, CEFT score and perceptual explorations) are shown in Table S3.

Main Analyses

FSIQ level trajectories. An adjusted chi-square difference test using the model's log likelihood revealed that a random linear model (Model B) was not significantly different from a fixed linear model (Model A: see Table 2), $\chi^2(2) = 0.37$, $p = .831$. As described in the analytic strategy, Model B was retained as the fit was not significantly worse than model A. Children started with an average percentile score of 53.75 at 5 years (γ_{00}), and it remained relatively stable over time as children's FSIQ level had a small non-significant decrease of 1.93 percentiles per year (γ_{10}). The covariance between the slope and intercept was not significant, which indicates that children who had a higher FSIQ level at 5 years did not show a faster or slower decrease between 5 and 8 years than those who had lower FSIQ level at baseline.

Table 2

Growth Models of FSIQ Level

FSIQ level (ICC = 0.80)			
	Par	Model A	Model B
Intercept-initial status (5 years)	γ_{00}	53.64 (3.26)***	53.75 (3.29)***
Linear slope (yearly growth)	γ_{10}	-1.95 (1.26)	-1.93 (1.32)
Within-person variance (residual)		226.66 (47.14)***	209.43 (49.31)***
Variance in initial status		891.22 (101.82)***	891.02 (109.81)***
Variance in rate of change		-	12.47 (35.44)
Slope intercept covariance		-	5.34 (25.52)
Goodness-of-fit	LL	-899.40	-899.22
	AIC	1806.79	1810.43

Notes. Standard errors are within parentheses. ICC = Intraclass correlation; Par = Parameters; LL = Log likelihood; AIC = Akaike information criterion. Model A: Fixed linear model; Model B: Random linear model.

VS time, CEFT score and perceptual explorations as predictors of FSIQ level. A preliminary conditional model assessed the links between potential covariates (i.e., child's age at T1, family SES, sex and group) and FSIQ level trajectory parameters (i.e., between-subjects variability in the intercept and slope). This model revealed that family SES (γ_{02} = 12.21, $p < .0001$) and group (γ_{03} = 53.62, $p < .0001$) were significantly related to the intercept. The final model included the relevant covariates (i.e., child's age at T1, family SES and group), each of the perceptual predictors (i.e., VS time, CEFT score and perceptual explorations) and the interaction terms between the group and the selected predictor (see Table 3).

Across all models, it was found that NT children had generally better FSIQ performance compared to autistic children (all *p*s < .01).

Table 3

Final Model FSIQ Trajectory With Predictors

	Par	FSIQ level		
		Pred 1 : VS time	Pred 2: CEFT score	Pred 3 : Perc explo
		B (SE)	*B (SE)*	*B (SE)*
Initial status, π_{oi}				
Intercept (5 years)	γ_{00}	54.21 (2.55)***	52.93 (2.95)***	55.51 (2.95)***
Age at T1	γ_{01}	-10.24 (2.40)***	-6.70 (2.96)*	-2.07 (2.90)
SES	γ_{02}	6.64 (2.68)*	4.84 (2.98)	4.53 (3.23)
Group	γ_{03}	23.67 (6.92)**	38.41 (7.10)***	38.09 (7.13)***
Predictor	γ_{04}	-14.61 (2.91)***	5.56 (2.83)*	-2.66 (2.98)
Interaction (Group X Pred)	γ_{05}	ns	ns	ns
Rate of change				
Child age	γ_{10}	-1.89 (1.50)	-1.46 (1.62)	-1.62 (1.65)
Age at T1	γ_{11}	-1.72 (1.57)	-0.92 (2.28)	-2.81 (2.13)
SES	γ_{12}	-1.98 (1.89)	0.20 (1.55)	0.44 (1.53)
Group	γ_{13}	3.55 (3.84)	0.77 (3.47)	-1.01 (3.52)
Predictor	γ_{14}	-0.12 (1.73)	-2.07 (1.59)	-2.08 (1.07)
Interaction (Group x Pred)	γ_{15}	ns	ns	ns
Within-person variance		219.38 (55.23)***	202.90 (55.77)***	213.84 (59.87)***
Variance in initial status		236.12 (62.54)*	362.39 (84.42)***	384.50 (91.95)***
Variance in rate of change		9.26 (29.28)	9.83 (30.24)	11.55 (32.87)
Slope intercept covariance		-12.42 (24.45)	-2.66 (31.99)	-11.38 (35.97)
Goodness-of-fit	LL	-743.66	-730.49	-679.79
	AIC	1515.31	1488.99	1387.58

Notes. AIC = Akaike information criterion; CEFT = Children Embedded Figure Test; LL = Log likelihood; Par = Parameters; Perc explo = Perceptual explorations; Pred = Predictor; SE = Standard errors; SES = Socioeconomic status; VS = Visual Search. All predictors are centered at their grand mean. *$p < .05$; **$p < .01$; ***$p < .001$.

VS time. The interaction term (group x VS time) was not significantly associated with the FSIQ intercept nor slope and was therefore removed from the final model. The VS time, measured between 2 and 5 years, was not related to the slope, but it was significantly and negatively associated with the intercept (i.e., FSIQ at 5 years), above and beyond the child age at T1, family SES and group. These results show that in both NT and autistic groups, children who found the targets more quickly on VS had a higher FSIQ level at 5 years, and that they consistently had a higher score than their peers over time (see Figure 1).

CEFT score. The interaction term (group x CEFT score) was not associated with the FSIQ intercept nor slope, therefore it was removed from the final model. In both groups, the raw score on CEFT, measured between 2 and 5 years, was not related to the slope. However, it was significantly and positively associated with the intercept (i.e., FSIQ at 5 years), above and beyond the child's age at T1, family SES and group. These results suggest that children having a higher CEFT score at baseline had a higher FSIQ level at 5 years, and that they consistently had a higher score than their peers over time (see Figure 2).

Perceptual explorations. The interaction term (group x perceptual explorations) was not significantly associated to the intercept (i.e., FSIQ at 5 years) nor slope and was therefore removed from the final model. The frequency of perceptual explorations, measured between 2 and 5 years, was not related to the FSIQ level at 5 years nor to slope. This result indicates that in both groups, children who manifested more frequent perceptual explorations did not demonstrate a higher or lower FSIQ level at 5 years.

NVIQ trajectories. An adjusted chi-square difference test using the model's log likelihood revealed that a random linear model (Model B) was not significantly different from a fixed linear model (Model A), $\chi^2(2) = 4.55$, $p = .103$ (see Table 4). Model B was retained as it was not significantly worse than Model A. On average, children's NVIQ level showed a non-significant decrease of 0.57 percentiles per year (γ_{10}), starting with an average percentile score of 89.30 at 5 years (γ_{00}). The covariance between the slope and intercept was not significant, which indicates that children who had a better NVIQ level at 5 years did not show a faster or slower decrease between 5 and 8 years than those who had a lower NVIQ level at T1.

Table 4

Growth Models of NVIQ level

NVIQ level (ICC = 0.70)			
	Par	Model A	Model B
Intercept-initial status (5 years)	γ_{00}	88.56 (1.99)***	89.30 (1.93)***
Linear slope (yearly growth)	γ_{10}	-0.98 (1.15)	-0.57 (1.26)
Within-person variance (residual)		114.88 (51.46)*	40.60 (28.75)
Variance in initial status		273.21 (133.33)*	285.05 (123.79)*
Variance in rate of change		-	72.21 (47.04)
Slope intercept covariance		-	-55.68 (62.41)
Goodness-of-fit	LL	-793.69	-781.62
	AIC	1595.38	1575.24

Notes. Standard errors are within parentheses. ICC = Intraclass correlation; Par = Parameters; LL = Log likelihood; AIC = Akaike information criterion. Model A: Fixed linear model; Model B: Random linear model.

VS time, CEFT score and perceptual explorations as predictors of NVIQ level. A preliminary conditional model assessed the effects of the potential covariates (i.e., child's age at T1, family SES, sex and group) on NVIQ level trajectory parameters. This model revealed that none of the covariates were significantly related to the intercept, therefore, only the child's age was retained as it was significantly associated with missing data. The final model included the relevant covariates (i.e., child's age at T1 and group), each of the perceptual predictors (i.e., VS time, CEFT score and perceptual explorations) and the interaction terms between the group and the selected predictor (see Table 5).

Across all models, it was found that NT and autistic children had generally similar NVIQ levels (all *p*s > .05).

VS time. The interaction term (group x VS time) significantly predicted both the NVIQ level intercept (i.e., NVIQ at 5 years) and the slope, above and beyond the child's age at T1. The inspection of these significant interactions suggests that 1) the simple effect of VS time on NVIQ level at 5 years is greater in the autistic group and 2) the simple effect of VS time on the slope of NVIQ is greater in the NT group.

Table 5

Final Model NVIQ Level Trajectories With Predictors

	Par	NVIQ level		
		Pred 1: VS time	Pred 3: CEFT score	Pred 4: Perc explo
		B (SE)	*B (SE)*	*B (SE)*
Initial status, π_{oi}				
Intercept (5 y.o.)	γ_{00}	91.56 (1.51)***	89.17 (2.01)**	88.51 (2.23)***
Age at T1		-2.15 (2.36)	-0.89 (2.08)	-1.17 (2.19)
Groupe	γ_{03}	-0.09 (2.67)	8.84 (4.71)	7.23 (4.85)
Predictor	γ_{04}	-8.03 (2.32)**	5.62 (2.01)**	2.91 (1.83)
Autistic	γ_{04}	-13.33 (2.82)***	-	8.10 (3.78)*
NT	γ_{04}	-4.23 (2.87)	-	-0.75 (1,65)
Interaction (Group X Pred)	γ_{05}	9.10 (3.35)**	*ns*	-8.92 (4.27)*
Rate of change				
Child age	γ_{10}	-1.42 (0.94)	-0.45 (1.26)	0.42 (1.84)
Age at T1		-3.09 (1.64)	-2.48 (1.40)	-1.07 (1.43)
Groupe	γ_{13}	1.30 (1.72)	0.01 (3.23)	0.93 (4.18)
Predictor	γ_{14}	-1.13 (2.04)	0.76 (0.89)	-1.00 (1.51)
Autistic	γ_{14}	2.37 (3.18)	-	-
NT	γ_{14}	-3.64 (1.85)*	-	-
Interaction (Group x Pred)	γ_{15}	-6.00 (2.92)*	*ns*	*ns*
Within-person variance		43.29 (32.16)	43.33 (31.89)	41.44 (30.67)
Variance in initial status		171.96 (69.37)*	258.98 (101.73)*	244.65 (109.03)
Variance in rate of change		56.39 (39.10)	63.23 (45.38)	65.84 (53.84)
Slope intercept covariance		-25.38 (29.58)	-52.03 (52.84)	-56.55 (77.83)
Goodness-of-fit	LL	-735.60	-735.12	-667.66
	AIC	1499.21	1494.25	1363.32

Notes. AIC = Akaike information criterion; CEFT = Children Embedded Figures Test; LL = Log likelihood; NT = neurotypicals; Par = Parameters; Pred = predictor; Perc explo = Perceptual explorations; SE =

Standard errors; SES = Socioeconomic status; VS = Visual Search. All predictors are centered at their grand mean. *$p < .05$; **$p < .01$; ***$p < .001$.

Among autistic children, having a shorter VS time (i.e., better performance), measured between 2 and 5 years, was significantly associated with the intercept (i.e., NVIQ level at 5 years), and this relation remained constant over time as there was no effect of VS response time on the slope in this group (see Figure 3a). In contrast, among NT children, a shorter VS time at 2-5 years was not related to a higher or lower NVIQ level at 5 years, but it predicted a faster rate of change in NVIQ level, after accounting for the child's age at T1. For each second faster on VS time, NT children's yearly NVIQ growth was 3.64 percentiles better on average. These results suggest that among NT children, VS time did not predict NVIQ skills at 5 years, but shorter VS time predicted faster growth in NVIQ between 5 and 8 years (see Figure 3b).

CEFT score. The interaction term (group x CEFT score) was not associated with the NVIQ intercept nor slope, therefore it was removed from the final model. In both groups, the raw score on CEFT, measured between 2 and 5 years, was not related to the slope. However, it was significantly and positively associated with the intercept (i.e., NVIQ at 5 years), above and beyond the child's age at T1 and group. These results suggest that both autistic and NT children having a higher score on CEFT at baseline had a higher NVIQ level at 5 years, and that they consistently had a higher score than their peers over time (see Figure 4).

Among autistic children, displaying more frequent perceptual explorations, measured between 2 and 5 years, was significantly associated with a higher NVIQ level at 5 years, and this relation remained constant over time as there was no effect of perceptual explorations on the slope in this group. Hence, autistic children who manifested more perceptual explorations had consistently higher NVIQ level over time (see Figure 5a). In contrast, among NT children, displaying more perceptual explorations between 2 and 5 years was not related to their NVIQ level at 5 years, after accounting for the child's age at T1, and they did not subsequently show faster, nor slower, growth from 5 to 8 years. Therefore, NT children displaying more (or less) perceptual explorations had similar NVIQ level over time (see Figure 5b).

Discussion

This paper set out to 1) examine whether some perceptual abilities or perceptual behaviors and interests measured at preschool age could predict the FSIQ and NVIQ levels and change at school age and 2) determine whether the predictors of change in FSIQ and NVIQ were the same in both autistic and NT groups. Using MLM framework allowed us including in our analyses children for whom evaluators could not complete conventional assessments at preschool age. Taking these children into account, our results showed that the performance on perceptual tests done at preschool age is associated with a higher FSIQ level at 5 years in both autistic and NT children. Furthermore, our findings suggest that both perceptual behaviors and performance on perceptual tests at preschool age are related to a higher NVIQ level at 5 years in autistic children, whereas only CEFT score predicts NVIQ level in NT children.

This longitudinal study builds on a growing body of cross-sectional work suggesting that there are strong associations between perceptual abilities and intelligence, particularly when non-verbal instruments are used as a measure of intelligence (50, 58, 80). Regarding perceptual explorations, howbeit their frequency was independent of FSIQ, there was a significant positive association with NVIQ. This finding contradicts the belief that RRBIs are necessarily associated with intellectual delay. Most importantly, our results support that more frequent perceptual explorations at preschool age underpin better NVIQ abilities at school age in autistic children.

At preschool age, it is often challenging for examiners to properly assess children using conventional assessments (16), but particularly so with minimally and non-verbal autistic children (16–23). In the current study, MLM framework allowed us to include autistic children of all levels of intelligence, adaptive functioning and language abilities in our analyses and to document their FSIQ and NVIQ trajectories, although some of them could not complete the intellectual assessments at some time points. Our results strongly suggest that perceptual skills and behaviors -easier to assess- are valid predictors of FSIQ and NVIQ outcomes for these children.

Our findings are also consistent with the Enhanced Perceptual Functioning model, suggesting a superiority in perceptual information processing as well as a more central role and independence of perceptual processes in autistic cognition (40, 41). In practice, this is reflected in the peaks of abilities often found on perceptual tests or subtests regardless of FSIQ level and in a variety of perceptual behaviors such as lateral glances or lining up objects (25, 50, 63). In line with the Enhanced Perceptual Functioning model, it has been hypothesized that the intellectual potential of preschool autistic children with little or no language could be estimated through simple observations and perceptual tasks such as the manifestation of perceptual explorations, or the performance on VS tasks and embedded figure tests (41, 81). It is coherent with the “p” factor hypothesis, emphasizing that perception is a fundamental component of autistic cognition and intelligence (58). In contrast, the performance of NT individuals on tasks measuring diverse abilities (i.e., language, memory, executive functioning, perceptual skills) would depend more on their general IQ level (82). Consistent with the “p” factor hypothesis, our findings show that perceptual tasks are associated with intelligence in our entire sample, but particularly so in autistic children. Furthermore, among autistic children, early perceptual skills are particularly related to non-verbal intelligence, which seems to better reflect their intellectual potential.

Our results align with those of previous cross-sectional studies showing that the first readily observable intellectual markers in autistic toddlers are simple perceptual indices (50). In the current study, we expanded this finding by showing that perceptual markers can predict what these children will be able to achieve later at school age. Perceptual markers would be particularly useful at preschool age, as intellectual assessment usually becomes easier for examiners as autistic children get older. It is then often possible to complete more complex non-verbal tasks such as Raven’s Progressive Matrices and eventually, more conventional tests such as Wechsler scales (83). Indeed, preschool autistic children are mostly considered minimally or non-verbal (17, 19–21). For these children, it is plausible that a poor performance on a conventional intellectual measure reflects language difficulties rather than limited cognitive abilities. Indeed, most conventional tests rely on the ability of the child to speak or at least to understand verbal instructions. Some autistic children have better intellectual abilities than what is captured during a conventional assessment, due to language difficulties, and would benefit from the use of non-verbal tasks (25, 50, 84).

Overall, the role of perception appears to be particularly important and central in autistic intelligence. In contrast, it has been shown that the role of perception is also important – but not as central – among NT children. Indeed, other intelligence components have been found to underpin FSIQ level in the general population, such as executive functions, working memory, language skills, processing speed, etc. (28, 30, 36, 37). Therefore, examiners have multiple routes to NT children's intellectual level, which generally facilitate cognitive assessment. Our findings suggest that the balance between various components of intelligence is probably not the same in autistic and NT children, with a heavier weight of perceptual skills in autistics.

Limitations And Contributions

The results must be interpreted considering certain limitations. First, our sample size was relatively modest, and we had some attrition across time points. But, we must keep in mind that our sample was composed of autistic children representing the whole spectrum, including minimally and non-verbal children, which constitute an important proportion of autistic preschoolers (17–23). Young autistic children with language difficulties are often excluded from studies as it is usually harder for examiners to assess them (85). Thus, our study constitutes an important step towards documenting intellectual assessment of this underrepresented population. Furthermore, the perceptual predictors were not all measured at the same age across the preschool period. This is because autistic children were invited to take part in this study shortly after their diagnosis, and they received their diagnosis at different ages. We controlled for child age at the time of assessment to minimize the impact of this limitation.

Nonetheless, the longitudinal design of our study coupled with multilevel growth curves analyses considerably contributes to the existing literature. To date, most longitudinal studies have examined change in IQ across time through mean-level consistency and continuity in rank order (i.e., interindividual stability). Although conceptualizing and analyzing change with these approaches is relevant, it does not provide information about intraindividual development patterns of change (i.e., within-person changes across time). Considering the heterogeneity of IQ trajectories in autism, more multiwave longitudinal studies examining intraindividual development change in IQ in the preschool years are needed. Also, this study is the first to use early perceptual abilities as potential predictors of intellectual development, including perceptual explorations during a play situation. Finally, we used the same assessment tools to measure FSIQ and NVIQ levels over time to prevent the impact of the choice of tool on our longitudinal effects.

Conclusions

In conclusion, the present study brings novel understanding of the predictive role of early perceptual abilities in relation to intellectual development in childhood. Our findings support the importance of visual perception in autistic cognition and suggest that intellectual development might be underpinned by perceptual abilities, such as rapid detection time, the ability to find a hidden figure in a more complex image, or the presence of perceptual explorations. The results suggest that measuring early perceptual abilities may be a valid avenue for estimating FSIQ and NVIQ at preschool age, particularly for autistic children. Ultimately, our results may improve assessment and intervention methods, so that they include and focus more on the perceptual strengths of autistic children.

Abbreviations

AS: Autism Spectrum

CEFT: Children Embedded Figures Test

FSIQ: Full-Scale IQ

MLR: Robust full-information maximum likelihood

NVIQ: Non-verbal IQ

NT: Neurotypical

RCPM: Raven's Colored Progressive Matrices

RRBI: Repetitive and restricted behaviors and interests

SES: Socioeconomic status

VS: Visual Search

WPPSI-IV: Wechsler Preschool and Primary Scales of Intelligence – Fourth edition

Declarations

Ethics approval and consent to participate

This study was formally reviewed and approved by the research ethic committee of XXXX Hospital (City, Country). Informed written and verbal consent was obtained from parents prior to participation at each time point.

Consent for publication

Not applicable.

Availability of data and materials

The dataset of the current study is available from the corresponding author on reasonable request, in compliance with the requirements of the institutional ethic review board.

Competing interests

DG, VC, CCP, CJ and IS declare they have no competing interests.

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Authors' contributions

DG contributed to the study design, data collection, analysis, interpretation of the results, manuscript writing, and revisions. VC contributed to the study design, data collection, interpretation of the results and revisions. CCP contributed to data collection and analysis. CJ contributed to the study design and manuscript revisions. IS contributed to the study design, interpretation of the results and manuscript revisions. All authors read and approved the final manuscript.

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Figures

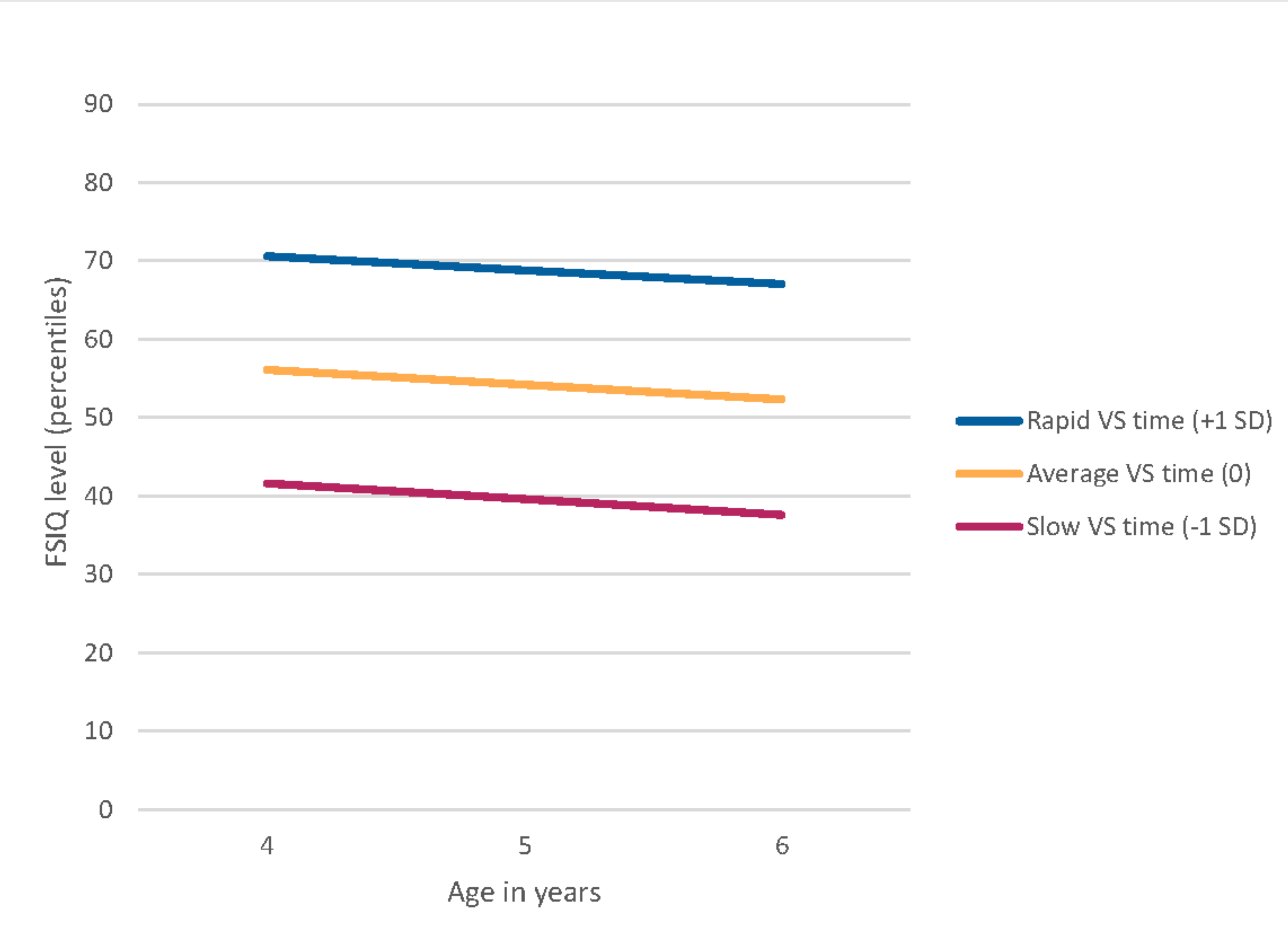


Figure 1

Yearly growth in FSIQ level (percentiles) according to response time (s) on Visual Search in the whole sample.

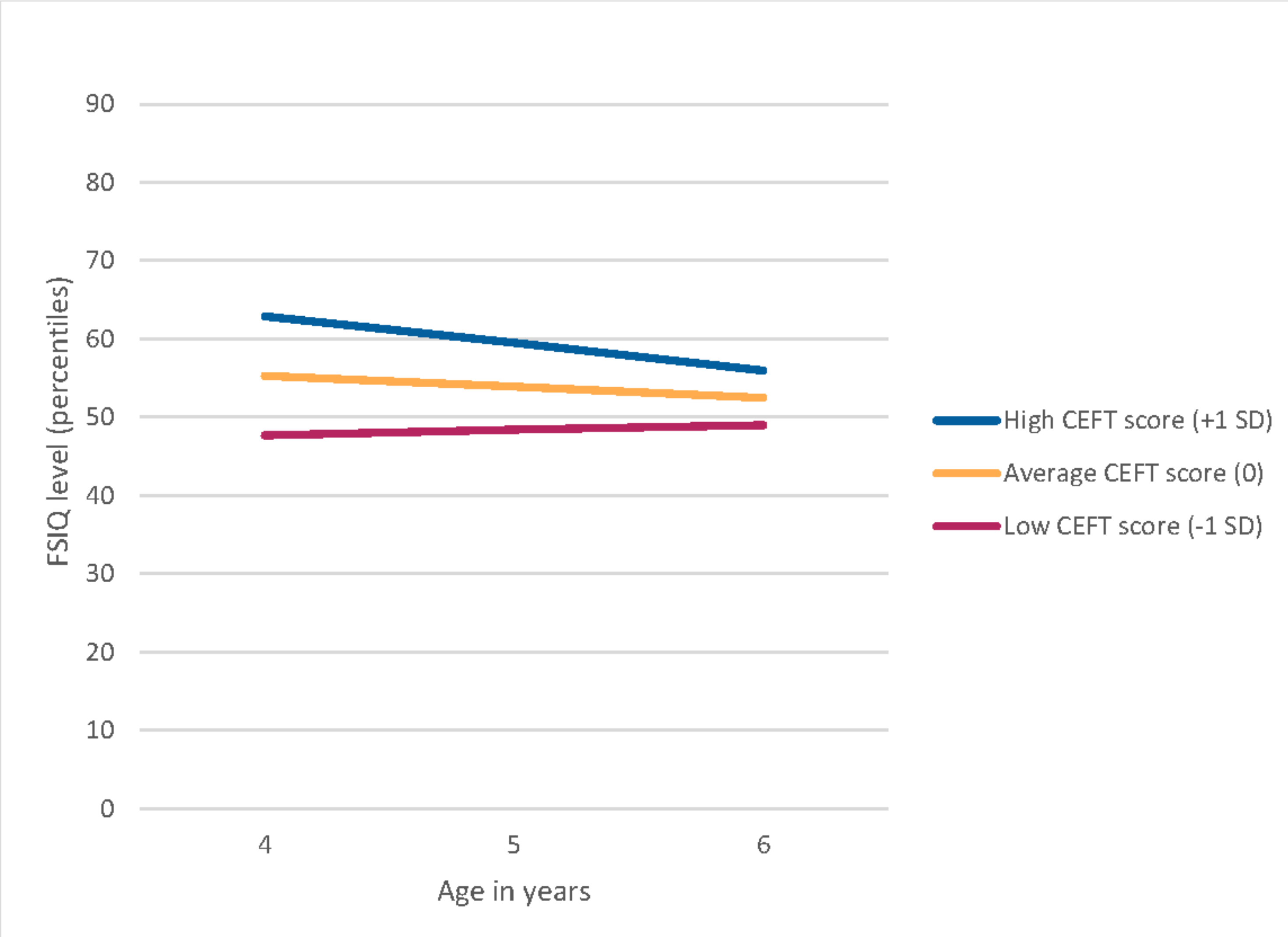
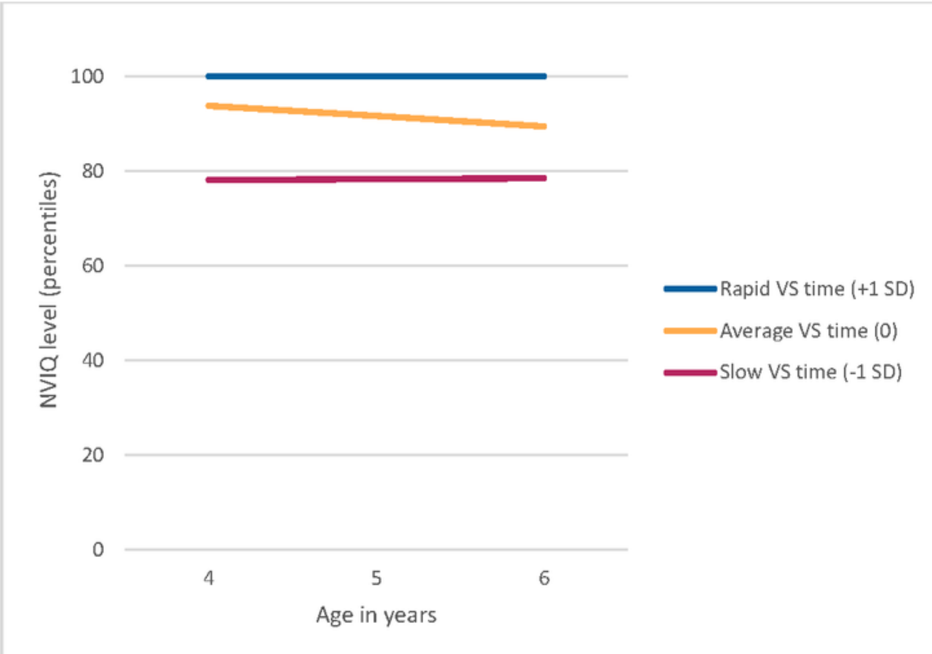
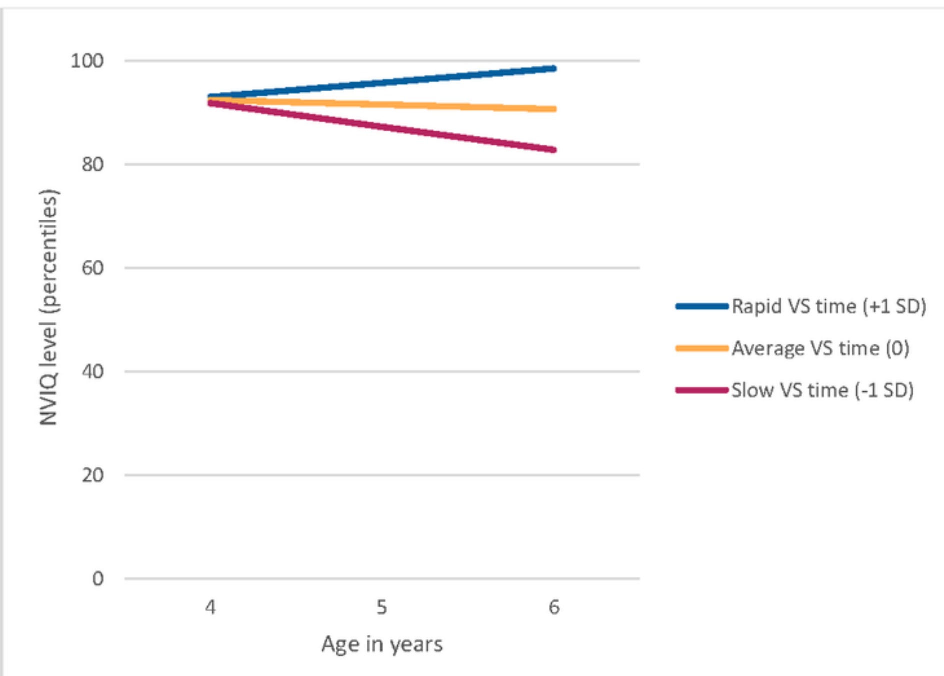


Figure 2

Yearly growth in FSIQ level (percentiles) according to performance on CEFT in the whole sample.



a) Associations between response time (s) on Visual Search and yearly growth in NVIQ level (percentiles) among autistic children



b) Associations between response time (s) on Visual Search and yearly growth in NVIQ level (percentiles) among NT children

Figure 3

See image above for figure legend.

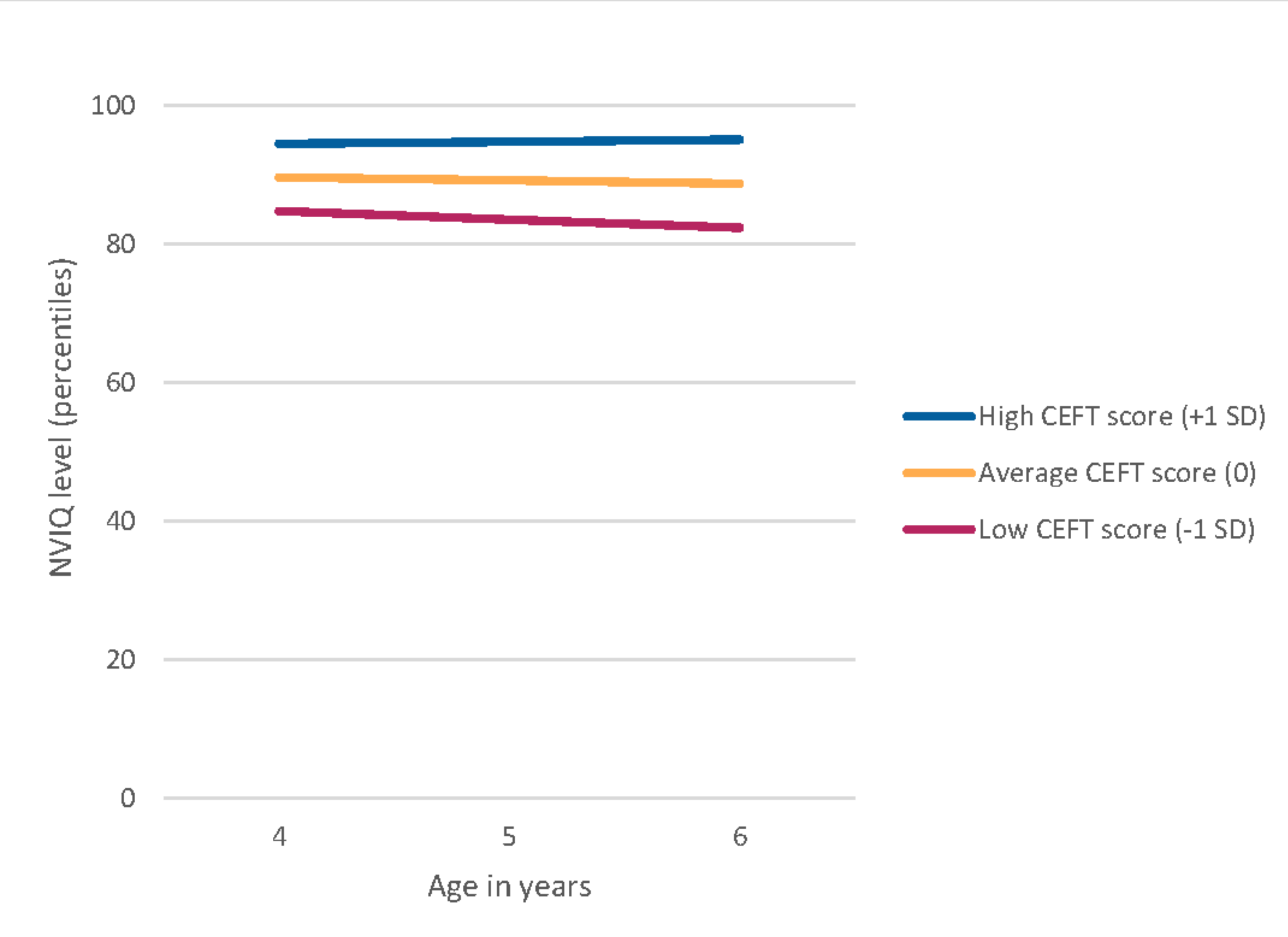
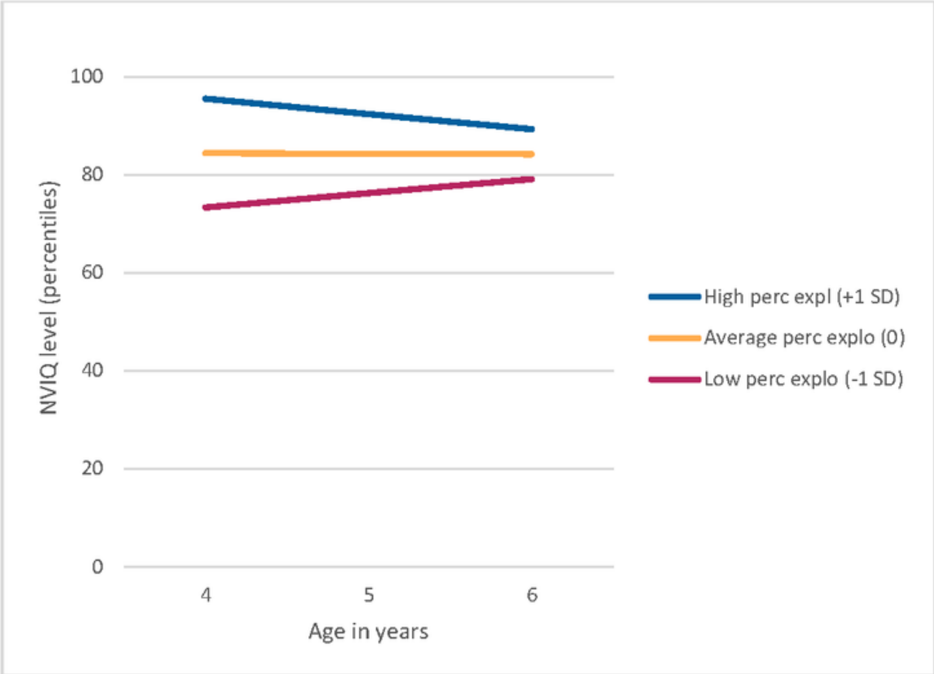
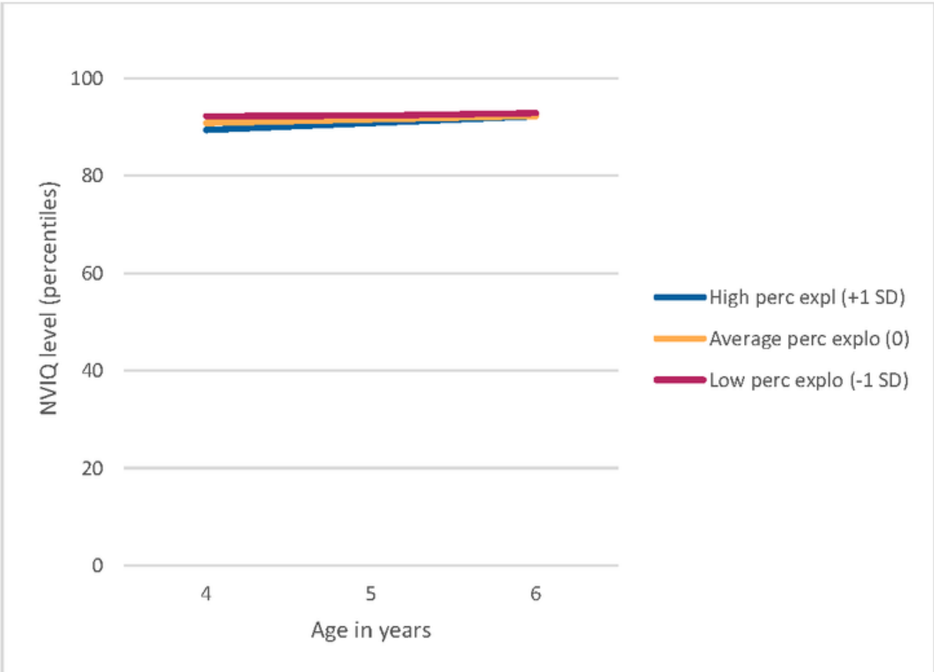


Figure 4

Yearly growth in NVIQ level (percentiles) according to performance on CEFT in the whole sample.



a) Associations between the frequency (#/hour) of perceptual explorations and yearly growth in NVIQ level (percentiles) among autistic children



b) Associations between the frequency (#/hour) of perceptual explorations and yearly growth in NVIQ level (percentiles) among NT children

Figure 5

See image above for figure legend.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Additionalfile1.docx