Cognition 239 (2023) 105571

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/cognit

Do autistic children differ in language-mediated prediction?☆

Falk Huettig[a,b,c,*], Cesko C. Voeten[d,e,f,g], Esther Pascual[h], Junying Liang[c], Florian Hintz[a,i]

[a] Max Planck Institute for Psycholinguistics, Nijmegen, the Netherlands
[b] Centre for Language Studies, Radboud University, Nijmegen, the Netherlands
[c] Zhejiang University, Hangzhou, China
[d] University of Pennsylvania, Department of Linguistics, Philadelphia, PA, USA
[e] University of Pennsylvania, Department of Biology, Philadelphia, PA, USA
[f] University of Amsterdam, Amsterdam, the Netherlands
[g] Fryske Akademy, Leeuwarden, the Netherlands
[h] Institute of Linguistics, Shanghai International Studies University, China
[i] Phillipps University, Marburg, Germany

ARTICLE INFO

Keywords:
Autism
Prediction
Young children
Eye movements

ABSTRACT

Prediction appears to be an important characteristic of the human mind. It has also been suggested that prediction is a core difference of autistic[1] children. Past research exploring language-mediated anticipatory eye movements in autistic children, however, has been somewhat contradictory, with some studies finding normal anticipatory processing in autistic children with low levels of autistic traits but others observing weaker prediction effects in autistic children with less receptive language skills. Here we investigated language-mediated anticipatory eye movements in young children who differed in the severity of their level of autistic traits and were in professional institutional care in Hangzhou, China. We chose the same spoken sentences (translated into Mandarin Chinese) and visual stimuli as a previous study which observed robust prediction effects in young children (Mani & Huettig, 2012) and included a control group of typically-developing children. Typically developing but not autistic children showed robust prediction effects. Most interestingly, autistic children with lower communication, motor, and (adaptive) behavior scores exhibited both less predictive and non-predictive visual attention behavior. Our results raise the possibility that differences in language-mediated anticipatory eye movements in autistic children with higher levels of autistic traits may be differences in visual attention in disguise, a hypothesis that needs further investigation.

1. Introduction

Prediction has become the dominant theoretical framework for explaining the functioning of the human mind (Bar, 2007; Clark, 2013). It is therefore perhaps not surprising that autism, a complex developmental neurodivergent phenomenon characterized by difficulties with social interaction and communication as well as restricted and repetitive behaviors (Frith & Happé, 2005; Lord et al., 2018) has also been related to predictive processing. Sinha and colleagues (Cannon et al., 2021; Sinha et al., 2014), for example, proposed that some typical phenotypes of autism, such as insistence on sameness, sensory hypersensitivities, difficulties interacting with dynamic objects, difficulties with theory of mind, and islands of proficiency (i.e., preserved or enhanced abilities in certain domains, e.g., mathematics, musical performance), can be explained by decreased tendencies to predict. The basic idea is that prediction is a crucial characteristic of human-environment interactions in many seemingly different domains and that reduced predictive processing makes an orderly environment become an overwhelming one. If these ideas are (at least partially) on the right track, and given that psycholinguistic research has established an important role for

☆ The raw data and analysis code can be found on OSF: https://osf.io/qzcd8/

* Corresponding author at: Max Planck Institute for Psycholinguistics, P.O. Box 310, 6500 AH Nijmegen, the Netherlands.
E-mail address: falk.huettig@mpi.nl (F. Huettig).

[1] On reviewer recommendation we use the identity-first language term 'autistic children' rather than person-first language such as 'children with autism' (cf. Bottema-Beutel et al., 2021).

https://doi.org/10.1016/j.cognition.2023.105571
Received 23 August 2022; Received in revised form 20 June 2023; Accepted 19 July 2023

prediction in language in adults and children,[2] one would expect to observe some evidence for differences in prediction in spoken language processing in autistic children.

Certain features of the visual world paradigm method (i.e., rapid integration of linguistic and visual processing, semiautomatic language-mediated looking behavior, providing unequivocal measures of anticipation, see Huettig et al., 2011 for extensive discussion) make it almost ideally suited to study prediction in language in children. Using this method, Mani and Huettig (2012) observed that even 2-year-olds, just like adults, predict upcoming linguistic input that is a thematic fit to familiar verbs. Upon hearing a familiar verb, for example, 'eat' in sentences such as "the boy will eat the …", typically-developing toddlers showed anticipatory eye movements to (semantically appropriate) edible objects, and looked more towards these objects than towards unrelated distractor objects in a visual display. Given these advantages, several recent studies investigated language-mediated anticipatory eye movements in autistic children. Contrary to the prediction deficit account, Brock et al. (2008) however found no reduced effect of sentence context in adolescents with a diagnosis of autism. Similarly, Bavin et al. (2016) and Zhou et al. (2019) observed largely normal language-mediated anticipatory eye movements in autistic children with low levels of autistic traits.

It is noteworthy that these studies included adolescents or children with low levels of autistic traits only. The possibility remains that young children with higher levels of autistic traits show evidence for the (theoretically) predicted differences in language-mediated anticipatory eye movements (cf. Cannon et al., 2021; Sinha et al., 2014). Two recent studies point in this direction. Venker et al. (2019) found evidence for language-mediated anticipatory processing in autistic children, but noted that this effect was weaker in children with lower compared to larger receptive language skills. Similarly, Prescott et al. (2022) observed evidence that young autistic children can engage in predictive processing, but found that the effect was larger in a neurotypical control group and modulated by receptive language skills.

In the present study, we had a fresh look at prediction abilities in autistic children. Specifically, we investigated language-mediated anticipatory eye movements in children with high levels of autistic traits, who were in professional institutional care in Hangzhou, China. Our main question was whether we can detect any difference in language-mediated prediction between autistic children and typically-developing children, and whether the levels of autistic traits modulate any difference in language-mediated eye movements.

2. Methods

2.1. Participants

Thirty-five children previously diagnosed with autism, aged between 3 and 9 years (28 boys, 7 girls), took part in the experiment. All children were enrolled in a professional day care center, specializing in treating children with autism spectrum disorder in Hangzhou, China. Data from seven children could not be analyzed due to extensive track loss (see the Data analysis section). The remaining sample comprised 28 children previously diagnosed with autism (mean age = 5.3, *SD* = 1.4, range = 3–8; 22 boys, 6 girls). All children underwent an assessment of their developmental traits and behavior by completing the Chinese version of the Psychoeducational Profile (PEP-3; Lam & Rao, 1993). The PEP-3 provides composite scores for children's communication and motor abilities, and (adaptive) behavior (see Table 1, higher PEP-3 scores reflect less severely affected individuals).

In addition, 34 typically-developing children, aged between 3 and 9 years (23 boys, 11 girls), were tested. All these children were recruited from pre-school centers and primary schools in Hangzhou, China. One child had to be excluded due to track loss (applying the same criterion as for the autistic children). The final sample comprised 33 children (mean age = 6.3, *SD* = 1.6, range = 3–9; 22 boys, 11 girls). None of the typically-developing children had a history of developmental or neurological disorders (these children did not complete the PEP-3).

Table 1
Overview of the PEP-3 composite scores.

Measure	Autistic children (*n* = 28)	Control children (*n* = 33)
Age	*M* = 5.32 (1.39), *Ra* = 3–8	*M* = 6.33 (1.63), *Ra* = 3–9
Sex	6 female, 22 male	11 female, 22 male
PEP – Communication*	*M* = 47.35 (35.76), *Ra* = 0–97	–
PEP – Motor*	*M* = 43.50 (34.32), *Ra* = 0–98	–
PEP – (maladaptive) Behavior*	*M* = 43.00 (36.19), *Ra* = 0–94	–

Note. Standard deviations provided in brackets. *Eight missing scores due to missing parental consent for sharing PEP3 scores.

The dominant language of all children was Mandarin Chinese. All children were tested at the Hangzhou Autism Center in Hangzhou, China. Ethical approval for the study was granted by the Institutional Ethical Review Board of the Hangzhou Autism Center. Written consent for taking part in the study was provided by the children's caretakers.

2.2. Materials

We chose the same spoken sentences and visual stimuli as Mani and Huettig (2012) and included a control group of typically-developing children. Replicating Mani and Huettig (2012) with young Chinese children allowed us to establish the suitability of the materials for Chinese children. A native speaker of Mandarin Chinese translated the German stimulus sentences used by Mani and Huettig (2012) into Mandarin. The materials comprised twelve target nouns embedded in predictive and non-predictive sentence contexts (e.g., the Chinese translation equivalent of 'The boy eats/loves the big cake'; see Appendix). Speech stimuli were produced by a female native speaker of Mandarin. The mean duration of the sentences was 3606 ms (*SD* = 325 ms). Onsets and offsets of verbs and target nouns in the sentences were marked using Praat (Boersma & Weenink, 2002). On average, verbs and target nouns started at 1057 ms (*SD* = 182 ms) and 2722 ms (*SD* = 413 ms), respectively, into the spoken sentences. The time between onset of the verb and onset of the target was on average 1665 ms (*SD* = 381 ms).

The same pictures as in Mani and Huettig (2012) were used. These were photographs of objects commonly known by children aged between 3 and 9. Each item was associated with a picture of the target noun and a distractor picture. Labels for the target and distractor images were semantically and associatively unrelated.

2.3. Procedure

The children were tested individually using an Eyelink 1000 eye-tracker sampling at 1000 Hz. Viewing distance was held constant between 55 and 60 cm. The eye-tracker was calibrated, and the children were instructed to listen to the sentences carefully and asked to not move their eyes off the screen. Such look-and-listen tasks have been successfully used with adults, young children, and clinical populations (Huettig et al., 2011). The spoken sentences were presented through loudspeakers. The 24 sentences were distributed across two experimental lists such that one target only occurred once on each list. The children were randomly assigned to one list and were presented with all 12 trials on that list. Each test trial began with a red dot moving around

[2] A vast amount of research has investigated prediction in language processing. The papers cited in a recent review by Pickering and Gambi (2018) may be a good starting point for the interested reader.

the screen in a circle at 500 ms intervals to capture the children's attention. The dot landed in the center of the screen and, after 1500 ms, was replaced with the two objects (each 250 × 250 pixels), one presented on each side of the screen, 512 pixels apart. Participants had 3 s to inspect the displays prior to the acoustic onset of the verb (cf. Mani & Plunkett, 2010). Areas of interest (300 × 300 pixels) were defined around target and distractor pictures. Eye movements were coded as fixations, saccades and blinks by the algorithm provided in the eye-tracker software.

2.4. Data pre-processing

Data from seven autistic children and one control child were excluded from the analysis due to extensive track loss. These children had >50% of trials with no fixation to one of the objects during the critical analysis period (verb onset to target word onset; cf. Venker et al., 2013). Thus, data from 61 children (28 autistic children, 33 control) were available for analysis.

3. Results

Fig. 1 below shows the fixation proportions of Control (left) and autistic (right) participants. The upper plots represent fixation proportions for target and distractor objects in the predictable, the lower plots in the non-predictable condition. Vertical dotted lines mark the average onset of the spoken verb; time zero (continuous vertical line) indicates the onset of the spoken target. For the control children, Fig. 1 suggests a bias in looks to the target object in the predictable condition emerging shortly after verb onset. In contrast, in the non-predictable condition, more looks to the target than to the distractor were made only after target word onset. Autistic children looked more at the target object than at the distractor *after target word onset* in both predictable and non-predictable conditions but not during the onset-verb–onset-target window (neither in the predictable nor in the non-predictable condition).

The raw data and analysis code can be found on OSF: https://osf.io/qzcd8/. For the analysis, we considered looks to targets and distractors (and track loss as missing data). We divided each trial into three windows of the same size. The 'critical window' started at verb onset plus 233 ms (the approximate time it takes to program and launch a saccadic eye movement in young children, Mani & Plunkett, 2010) and ended at target onset (+ 233 ms). For each trial, we extracted a 'baseline window' of the same size as the critical window, which ended at verb onset (+233 ms), and a 'label window', which started at target onset (+ 233 ms). The goal of this approach was to compare fixation behavior during the baseline window, where no linguistic information about the upcoming target had been provided yet, to fixation behavior during subsequent time windows (the three analysis windows are highlighted through shading in the fixation plots). In comparison to the baseline window, we predicted an increased likelihood of looks to the target compared to the distractor during the label window, as the target object is referred to in the speech. We also predicted more looks to the target than to the distractor during the critical window (compared to the baseline) in the predictable condition, as the information becoming available on hearing the verb could be used to predict the upcoming target.

For each of the three windows, we summed the duration of looks to the target (i.e., target gaze duration). We used beta-regression rather than logistic regression, because multiple target looks within a single trial are not independent of one another, and because this allowed the use of proportions directly without weighting them by window length (i.e., our approach automatically normalized for durational differences among auditory stimuli). Gaze durations were analyzed separately for critical and label windows, using beta regression as implemented in R package glmmTMB (Brooks et al., 2017). As fixed-effect predictors, we included an intercept, 'Group' (treatment-coded such that autistic children = 1 and control = 0), 'Condition' (treatment-coded such that predictable = 1 and unpredictable = 0) and their interaction. In addition, an offset term was included, consisting of the trial-specific (logit-transformed[3]) gaze proportion in the baseline window. We included a maximal random-effects structure (Barr et al., 2013) as long as the model could still converge, assuming a diagonal random-effects covariance structure. Function buildglmmTMB from R package buildmer (Voeten, 2023) was used to find the maximal feasible random-effects structure. In both the critical window and labeling window, the maximal random-effects structure turned out to be feasible and was hence used; this means a by-participants random intercept and random slope for Condition, and a by-items random intercept and random slopes for Group, Condition, and their interaction (Table 2). The analyses statistically confirmed that the autistic children gazed less at the target object than at the distractor in the critical window in the predictable condition compared to the control children (PR = 0.27, $t = -2.25$). Moreover, we observed robust evidence that both autistic and control children fixated the target more than the distractor after target word onset (PR = 2.87, $t = 3.51$). There was also a difference between the groups on predictable trials in the labeling window (most likely a continuation of the same effect observed in the critical window, PR = 0.25, $t = -2.17$; cp. The same effect in the critical window where PR = 0.27.[4]

In post-hoc follow-up analyses, we assessed the extent to which predictive looks by autistic participants correlated with their PEP-3 composite scores. Note that autistic children also looked less (Fig. 1) at the target object than control children in the neutral condition (i.e., the 'label effect', looking at an object once it is mentioned in unfolding speech, which is one of the most robust effects in the psycholinguistic literature). This observation suggests that language-mediated prediction in autistic children may be a general deficit in visual attention. We thus investigated the relationship between looks of autistic children to the target object in the non-predictable condition (labeling window) with the amount of anticipatory looks to the target object during the predictive window (reflecting their prediction skills) and examined whether this relationship was moderated by the children's (1) Communication skills, (2) Motor skills, and (3) (Adaptive) behavior scores on the PEP-3. Model predictions for all autistic children with PEP-3 scores and all items for the non-predictable labelling window and the critical

[3] If a trial had a baseline gaze-duration proportion of exactly zero or one, this was clamped to 0.001 or 0.999, respectively.

[4] At the request of an anonymous reviewer, we included both participants' age, and – nested within an interaction with Group – the autistic children's PEP-3 scores to the model. Autistic children's age and their PEP-3 scores were significantly negatively correlated (Communication: $r = -0.54$, $p = .002$; Motor Skills: $r = -0.54$, $p < .001$; Adaptive Behavior: $r = -0.64$, $p < .001$). We assessed whether these correlations led to collinearity in the model by means of generalized variance-inflation factors (gVIFs, computed using function check_collinearity from R package performance). Whereas the gVIFs for the original models were all well below 2 (indicating weak collinearity), those of the model with both age and PEP-3 scores exceeded 20, suggesting a very high degree of collinearity. On the basis of these results and the fact that PEP-3 scores were only available for a subset of 20 autistic children, PEP-3 scores could not be included in the model. The 'critical window' and 'label window' models that contained (mean-centered) age and its interactions with all other terms in the model revealed qualitatively the same results as the main analysis model. That is, in the predictive window, we continued to observe reduced fixations by the autistic children relative to the controls (PR = 0.24, $t = -2.43$), and in the labeling window we continued to observe significant target preferences overall (PR = 2.50, $t = 3.38$) and the same interaction between Group and Condition (PR = 0.14, $t = -3.37$). Age did show an effect in a significant three-way interaction with Group and Condition (PR = 0.40, $t = -2.49$) in the labelling window, such that older autistic children showed a smaller target bias than younger autistic children, which is consistent with the notion that higher levels of autistic traits were more strongly expressed in the older than in the younger children (viz. the negative correlation between age and PEP-3 scores).

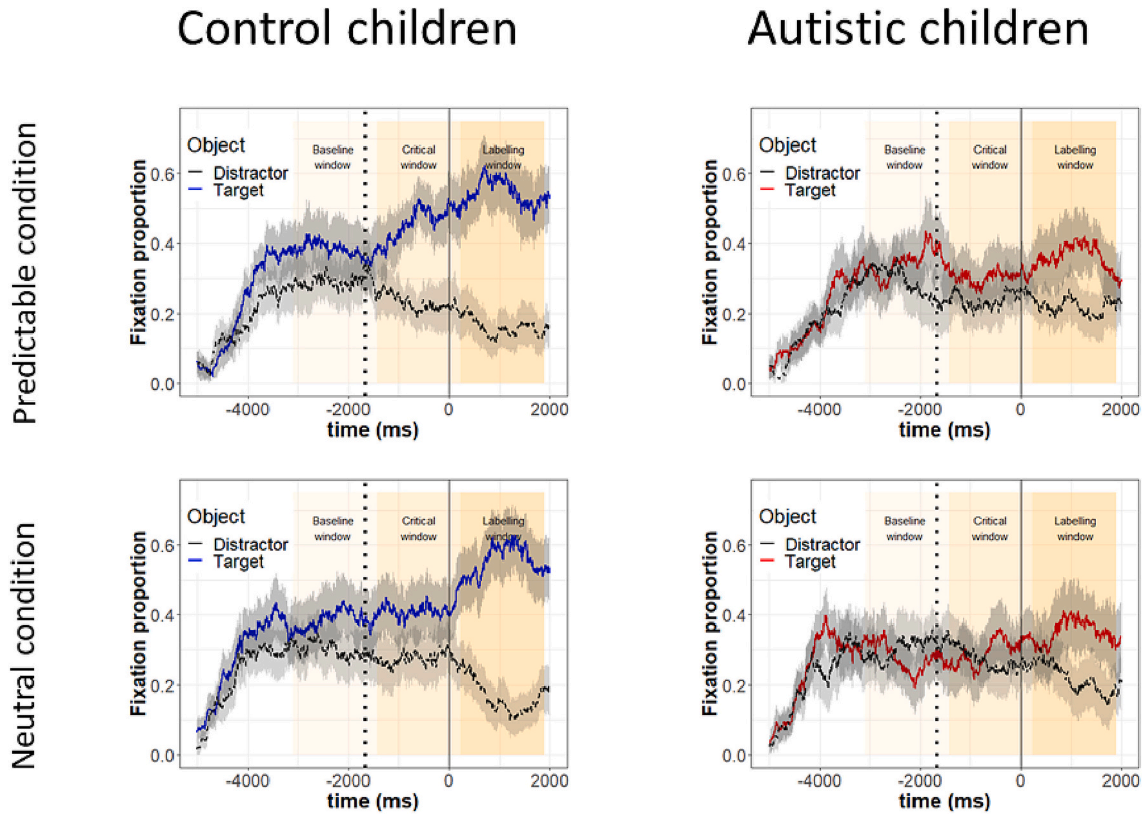

Fig. 1. Fixation proportions of control participants (left) and autistic participants (right). The upper plots depict the fixation proportions for target and distractor objects in the predictable condition. The lower plots depict the proportions of looks to targets and distractors in the neutral condition. Confidence intervals (95%), calculated for each sampling step, are shaded in gray. The vertical line at time zero marks the onset of the target words in the spoken sentences. The dotted line marks the average onset of the spoken verb. The predictive window (onset verb-onset target) was on average 1665 ms.

Table 2
Results of the statistical analyses.

Critical window			
Factor	Estimate (SE)	Proportion ratio	*t*
Intercept	1.39 (0.30)	4.00	4.61*
Group	1.25 (0.53)	3.48	2.37*
Condition	0.23 (0.32)	1.26	0.73
Group × Condition	−1.29 (0.58)	0.28	−2.25*
Label window			
Factor	Estimate (SE)	Proportion ratio	*t*
Intercept	1.06 (0.30)	2.87	3.51*
Group	0.90 (0.52)	2.45	1.74
Condition	0.07 (0.35)	1.07	0.19
Group × Condition	−1.37 (0.63)	0.25	−2.17*

window in the predictable condition were obtained, resulting in 240 data points (20 participants, 12 items) that fully represent the model fit for those children. Then, for each of the three PEP-3 composite scores of Communication, Motor Skills, and (Adaptive) Behavior, we performed a median split, resulting in six subsets stratified by PEP-3 score type and high/low performance on that PEP score. For each of these, we computed the correlation between the predictions from the critical window and those in the labelling window, resulting in six correlation coefficients. The correlations were computed using repeated-measures correlations,[5] based on R package rmcorr (Bakdash & Marusich, 2022). Items[6] were included in the correlations as random factor. Bonferroni corrections were applied to correct for the increased family-wise error rate in the *p*-values from these repeated tests (Table 3). Fig. 2 provides a visualization of the correlations. In this figure, the random effect for Item has been partialed out.

The overall correlation between the fixation behavior in both windows was $r = 0.30$, $F(1,227) = 22.62$, $p < .001$, suggesting that in the autistic children, prediction ability (critical window) correlated positively and moderately with visual attention to the labeled target object (labeling window) in the non-predictable condition. Importantly, this relationship was moderated by the children's performance on the PEP-3: The correlation between prediction and visual attention to the (non-

Table 3
Correlations between predictions of the statistical analyses (autistic children only), stratified by PEP-3 scores.

PEP-3 domain	Median split	*r*	df	*p*
Communication	Low	0.19	107	0.28
Communication	High	0.45	107	0.001
Motor Skills	Low	0.15	107	0.69
Motor Skills	High	0.49	107	<0.001
(Adaptive) Behavior	Low	0.20	107	0.21
(Adaptive) Behavior	High	0.45	107	<0.001

[5] We thank an anonymous reviewer for suggesting to adopt this mixed-effects approach in our correlation tests.

[6] It was not necessary, and in fact not possible, to also include participants as a random factor in these correlations, as the PEP-3 scores we tested are all between-subjects, and hence would be partialed out if in addition a by-participants random effect had been included.

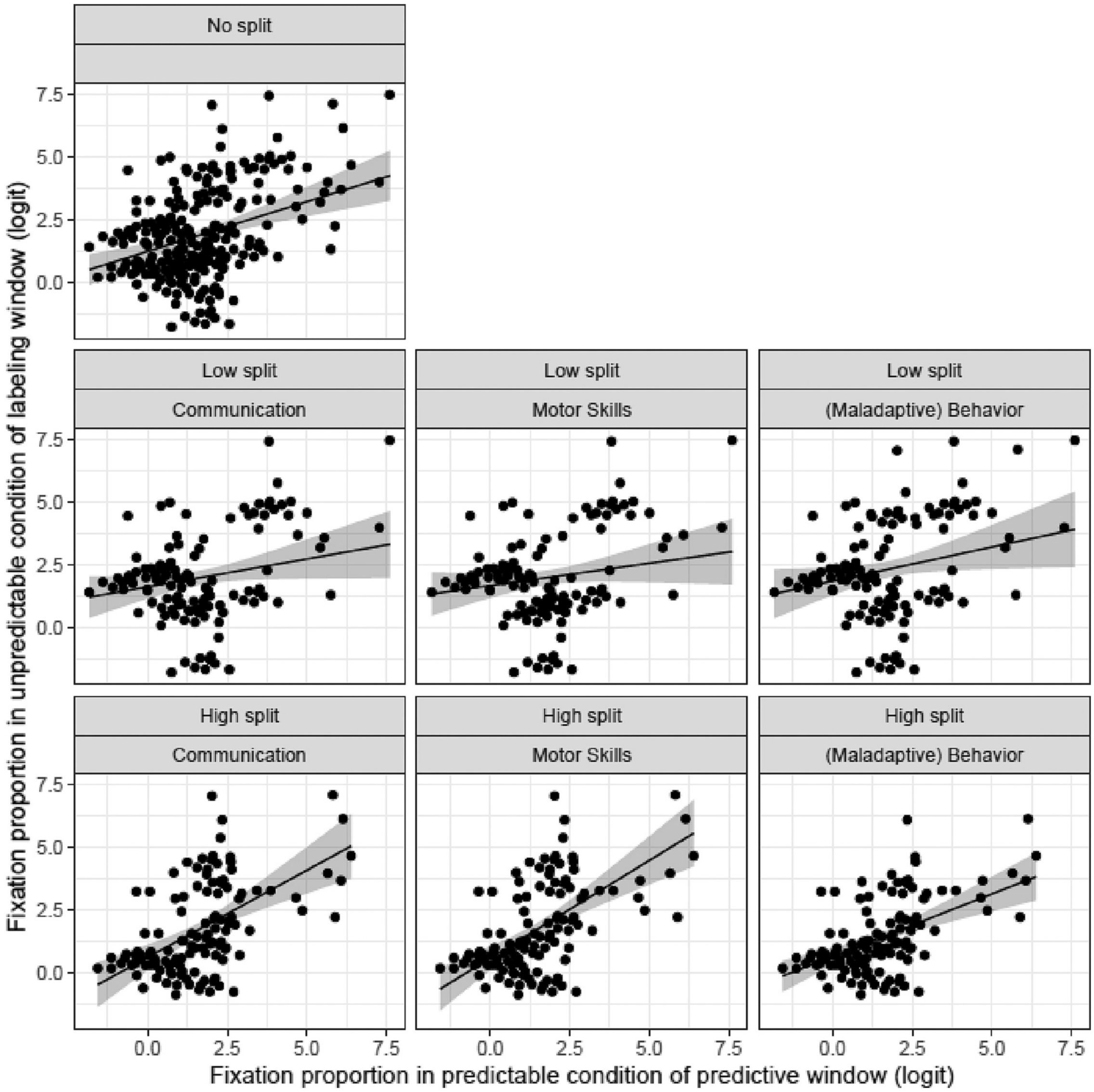

Fig. 2. Repeated-measures correlations between looks in the predictable condition of the critical window and looks in the labeling window in the non-predictable condition of the labeling window, for the autistic children for whom PEP-3 scores were available. The first panel visualizes the 'raw' correlation ($r = 0.3$, $p < .001$). The other panels show low and high median splits of each of the three PEP scores, as indicated by the two labels above each panel. The shaded area around the trend line indicates the 95% CI.

predictable) target was statistically significant and relatively strong in the children with higher Communication, Motor Skills, and (Adaptive) Behavior scores, and not statistically significant and relatively weak in children with lower scores.

4. Discussion

In the present study, typically-developing young children showed a large prediction effect, replicating Mani and Huettig (2012) with young Chinese participants and Mandarin materials. In contrast, autistic children (as a group) did not anticipate the target (but directed preferential looks at it once it was mentioned). This finding does not necessarily contradict previous studies that found evidence for anticipatory eye gaze in autistic children, because these studies were carried out with adolescents or autistic children with low levels of autistic traits. Our autistic participants were young children who differed in the severity of autistic traits and were in professional institutional care. Autistic children in our study also looked less at the target (e.g., the cake) than control children when it was mentioned in the non-predictable condition ("The boy loves the big cake"). Most strikingly, autistic children with higher scores for Communication, Motor Skills, and (Adaptive) Behavior were the ones with a higher tendency of both predictive eye gaze and overt visual attention to non-predictable targets.

Do some autistic children show reduced language-mediated anticipatory eye-movements? Superficially the answer is yes. As a group, autistic children in the present study showed strikingly less anticipatory eye gaze in a task where typically-developing young children strongly anticipated. Looking more closely at our results, however, it becomes clear that the underlying relationship between autism and (language-mediated) prediction is a very complex one. First, and perhaps unsurprisingly, it makes little sense to lump all autistic children together. When it comes to language-mediated anticipatory eye movements not all autistic children are alike. The tendency to engage in anticipatory eye movements appears to be related to the severity of autistic traits in communication, motor skills, and (adaptive) behavior. Second, and even more informative, is the finding of a possible link between general-mediated attention (looking at the cake when the word 'cake' acoustically unfolds) and language-mediated prediction (looking at the cake when hearing the word 'eat'). The higher the autistic traits of the autistic children according to their communication, motor, and (adaptive) behavior scores, the less they tended to engage in typical predictive as well as non-predictive visual attention behavior. The finding that not only communication skills but also motor and (adaptive) behavior scores showed such a correlation raises the possibility that it reflects more than a receptive language difference (cf. Prescott et al., 2022; Venker et al., 2019): apparent differences[7] in language-mediated anticipatory eye movements in autistic children with higher levels of autistic traits may at least partly be differences in visual attention in disguise.[8] Another useful direction for further research would be to explore to what extent the anticipation differences in autistic children are a secondary consequence of differences in the efficiency of processing of the speech signal (Fernald et al., 2006, 1998). Given the challenges inherent in research with autistic children, we suggest that further investigation with a longitudinal design (cf. Goswami, 2015; Huettig et al., 2018) and collaborative efforts involving many labs (cf. Frank et al., 2017) would prove most fruitful.

CRediT authorship contribution statement

Falk Huettig: Conceptualization, Methodology, Investigation, Project administration, Data curation, Writing – original draft, Writing – review & editing. **Cesko C. Voeten:** Formal analysis, Visualization, Writing – review & editing. **Esther Pascual:** Conceptualization, Project administration, Data curation, Writing – review & editing. **Junying Liang:** Project administration, Writing – review & editing. **Florian Hintz:** Methodology, Formal analysis, Visualization, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

None.

Data availability

Our data are freely available at the OSF long provided on the title page.

Acknowledgements

We would like to thank all the children and their caretakers for taking part in this study and Fan Bai for helping with preparing the Mandarin materials.

Appendix A. Spoken and picture stimuli

Spoken Sentence	Target Picture	Distractor Picture
The girl rides (sees) the brown horse.	horse	bread
The boy eats (sees) the big cake.	cake	bird
The boy washes (likes) the new trousers.	trousers	bee
The boy bathes in the (sees the) big bathtub.	bathtub	hat
The girl drinks (likes) milk.	milk	sun
The girl cuts (loves) the pretty paper.	paper	window
The boy paints (loves) many pictures.	pictures	glass
The girl reads (likes) only new books.	books	shirt
The girl sits on (looks at) the blue chair.	chair	boot
The boy throws (loves) the green ball.	ball	table
The girl strokes (likes) the little cat.	cat	bottle
The boy drives (has) my old car.	car	phone

References

Bakdash, J., & Marusich, L. (2022). rmcorr: Repeated measures correlation. R package version 0.5.4. https://CRAN.R-project.org/package=rmcorr.

Bar, M. (2007). The proactive brain: Using analogies and associations to generate predictions. *Trends in Cognitive Sciences, 11*(7), 280–289.

Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language, 68*(3), 255–278.

Bavin, E. L., Kidd, E., Prendergast, L. A., & Baker, E. K. (2016). Young autistic children use lexical and referential information during on-line sentence processing. *Frontiers in Psychology, 7*, 171.

Boersma, P., & Weenink, D. (2002). *Praat 4.0: a system for doing phonetics with the computer [Computer software]*. Amsterdam: Universiteit van Amsterdam.

Bottema-Beutel, K., Kapp, S. K., Lester, J. N., Sasson, N. J., & Hand, B. N. (2021). Avoiding ableist language: Suggestions for autism researchers. *Autism in Adulthood, 3*(1), 18–29.

Brock, J., Norbury, C. F., Einav, S., & Nation, K. (2008). Do individuals with autism process words in context? Evidence from language-mediated eye-movements. *Cognition, 108*, 896–904.

Brooks, M. E., Kristensen, K., van Benthem, K. J., Magnusson, A., Berg, C. W., Nielsen, A., … Bolker, B. (2017). glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. *The R Journal, 9*(2), 378–400.

Cannon, J., O'Brien, A. M., Bungert, L., & Sinha, P. (2021). Prediction in autism spectrum disorder: A systematic review of empirical evidence. *Autism Research, 14*(4), 604–630.

Clark, A. (2013). Whatever next? Predictive brains, situated agents, and the future of cognitive science. *Behavioral and Brain Sciences, 36*(3), 181–204.

[7] The difference in results between groups is unlikely to reflect a *simple* motivational difference between groups. Considerable research on language-mediated eye gaze suggests that spoken language can guide visual orienting without volitional control. Language-mediated eye movements tend to be fast, unconscious, and largely overlearned and as such fit most of the criteria of an automatic process (see Mishra et al., 2013 for extensive discussion). Listening to the spoken sentences in the current study should have induced this semi-automatic behavior also in autistic children.

[8] How prediction and attentional engagement may be related is a fascinating question. Some interesting proposals have been made. An important part of most predictive coding models for example is precision weighting which provides estimates of the reliability of the signal. If reliability is high, the deviance from the predicted signal is amplified and given priority for further processing. If reliability is low, the deviance from the predicted signal is down-weighted. Errors need to be weighted by their reliability, predictive coding researchers argue, in order to distinguish relevant prediction error from irrelevant prediction error, so-called residue error. Residue error is inevitable it is argued because of an inherently noisy and variable environment. Prediction error and precision weighting hence are the two sides of the same coin. Attention has been postulated to be the key process that implements precision weighting. Both visual and auditory attention are obvious candidate processes for precision weighting, as they by definition selectively process information.

Fernald, A., Perfors, A., & Marchman, V. A. (2006). Picking up speed in understanding: Speech processing efficiency and vocabulary growth across the 2nd year. *Developmental Psychology, 42*(1), 98–116.

Fernald, A., Pinto, J. P., Swingley, D., Weinberg, A., & McRoberts, G. W. (1998). Rapid gains in speed of verbal processing by infants in the 2nd year. *Psychological Science, 9*(3), 228–231.

Frank, M. C., Bergelson, E., Bergmann, C., Cristia, A., Floccia, C., Gervain, J., & Yurovsky, D. (2017). A collaborative approach to infant research: Promoting reproducibility, best practices, and theory-building. *Infancy, 22*(4), 421–435.

Frith, U., & Happé, F. (2005). Autism spectrum disorder. *Current Biology, 15*(19), R786–R790.

Goswami, U. (2015). Sensory theories of developmental dyslexia: Three challenges for research. *Nature Reviews Neuroscience, 16*(1), 43–54.

Huettig, F., Lachmann, T., Reis, A., & Petersson, K. M. (2018). Distinguishing cause from effect – Many deficits associated with developmental dyslexia may be a consequence of reduced and suboptimal reading experience. *Language, Cognition and Neuroscience, 33*(3), 333–350.

Huettig, F., Rommers, J., & Meyer, A. S. (2011). Using the visual world paradigm to study language processing: A review and critical evaluation. *Acta Psychologica, 137*(2), 151–171.

Lam, M. K. T., & Rao, N. (1993). Developing a Chinese version of the Psychoeducational Profile (CPEP) to assess autistic children in Hong Kong. *Journal of Autism and Developmental Disorders, 23*(2), 273–279.

Lord, C., Elsabbagh, M., Baird, G., & Veenstra-Vanderweele, J. (2018). Autism spectrum disorder. *The Lancet, 392*(10146), 508–520.

Mani, N., & Huettig, F. (2012). Prediction during language processing is a piece of cake—But only for skilled producers. *Journal of Experimental Psychology: Human Perception and Performance, 38*(4), 843–847.

Mani, N., & Plunkett, K. (2010). In the infant's mind's ear: Evidence for implicit naming in 18-month-olds. *Psychological Science, 21*(7), 908–913.

Mishra, R. K., Olivers, C. N., & Huettig, F. (2013). Spoken language and the decision to move the eyes: To what extent are language-mediated eye movements automatic? *Progress in Brain Research, 202*, 135–149.

Pickering, M. J., & Gambi, C. (2018). Predicting while comprehending language: A theory and review. *Psychological Bulletin, 144*(10), 1002–1044.

Prescott, K. E., Mathée-Scott, J., Reuter, T., Edwards, J., Saffran, J., & Ellis Weismer, S. (2022). Predictive language processing in young autistic children. *Autism Research, 15*(5), 892–903.

Sinha, P., Kjelgaard, M. M., Gandhi, T. K., Tsourides, K., Cardinaux, A. L., Pantazis, D., … Held, R. M. (2014). Autism as a disorder of prediction. *Proceedings of the National Academy of Sciences, 111*(42), 15220–15225.

Venker, C. E., Edwards, J., Saffran, J. R., & Ellis Weismer, S. (2019). Thinking ahead: Incremental language processing is associated with receptive language abilities in preschoolers with autism spectrum disorder. *Journal of Autism and Developmental Disorders, 49*(3), 1011–1023.

Venker, et al. (2013). Individual differences in the real-time comprehension of autistic children. *Autism Research, 6*, 417–432.

Voeten, C. C. (2023). *buildmer: Stepwise elimination and term reordering for mixed-effects regression. R package version 2.9*.

Zhou, P., Zhan, L., & Ma, H. (2019). Predictive language processing in preschool children with autism spectrum disorder: An eye-tracking study. *Journal of Psycholinguistic Research, 48*(2), 431–452.