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Measuring the relationship between bilingual exposure and social attentional prefeences in autistic children

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Article

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Abstract: Background: Autistic children show reduced attentional preferences to social stimuli early in development, and these differences have consequences on a range of social domains. One factor that could influence development in those processes is bilingualism. Parents and practitioners frequently have unfounded concerns that bilingualism could cause delays in autistic children, yet there is little evidence to dispute this idea. While there are studies focusing on the impact of bilingualism on cognition in autistic children, no research has focused on the relationship between bilingualism and social attention. Aims: This study therefore investigated the impact of bilingual exposure on social attention in autistic (n=33) and neurotypical children (n=42) aged 6-13 years. Rather than a monolingual/bilingual comparison, participants had varying degrees of bilingual exposure, and exposure was treated as a continuous variable. Participants completed an eye-tracking task measuring visual attention to interacting versus non-interacting human figures. Results: Bilingual exposure did not affect dwell time to interacting or non-interacting figures for the neurotypical or autistic groups. However, there was a 3-way interaction between diagnosis, figure type and vocabulary scores on dwell time. Conclusions: Higher vocabulary scores in neurotypical participants was associated with significantly less dwell time to non-interacting stimuli. This is the first study to assess the effects of bilingualism on social attention; here, concerns of bilingualism are not upheld.

Keywords: autism; bilingualism; social attention; language

1. Introduction

Autism and social attention

Autism Spectrum Disorder (hereafter autism) is broadly defined by a set of core diagnostic criteria, including characteristic patterns of social communication and interaction with others (American Psychiatric Association, APA, 2013). Autistic children are often referred for diagnosis because of atypicalities in early developing social communication, including social attention (Nelson, De Haan & Thomas, 2006) and eye-contact (Jarrold et al., 2013). These behaviours are thought to provide the foundation for more complex social cognition, and early divergences from typical development are associated with different social developmental outcomes (Karmiloff-Smith, 2009).

Prioritising social information for attention is a pivotal trait early in development, and the ability to understand the intentions and attitudes of different people in daily life is highly reliant on the capacity to assign visual attention to relevant environmental cues. This ability develops across early life and is thought to enable infants to develop skills for processing more complex social information later in development. Autistic children exhibit reduced attention to social content early in development (Elsabbagh et al., 2013), and this is one of the earliest developmental features that distinguishes children who go on to receive an autism diagnosis from neurotypical children (Zwaigenbaum et al., 2005; Rogers, 2009; Bedford et al., 2012). Studies have shown that autistic infants attend less to faces in naturalistic video tasks (Chawarska et al., 2013; Shic et al., 2014), exhibit fewer gaze behaviours towards faces at 12 months and show a reduced amount of looking to faces across the first two years of life (Gangi et al., 2020). An absence of preferential looking has also been associated with higher levels of social difficulty in 2-year-old autistic children (Webb et al., 2010). Likewise, parent reports suggest reduced looking towards people and faces at 9 months (Feldman et al., 2012). Subtle differences have also been established in gaze following in 13-month infants who went on to receive an autism diagnosis, and this was correlated with socio-communication difficulties at three years of age (Bedford et al., 2012). Early gaze behaviours are seen as foundational to the development of more complex social attentional mechanisms later in childhood, including joint attention and theory of mind (Bedford et al., 2012; Mundy & Newall, 2007) and language development (Young, Merin, Rogers & Ozonoff, 2009).

For autistic people, differences in attention to social content have been shown to persist to some degree across childhood (Nakano et al., 2010; Rice et al., 2012) and into adulthood (Sasson et al., 2007). In studies with older autistic children (aged 9-18 years), eye tracking studies have identified associations between atypical dwell patterns and fixations to social stimuli (Rice et al., 2012; Speer et al., 2007). A meta-analysis of 122 independent studies identified a distinct pattern of gaze atypicalities when selecting socially relevant information from an environment, that persisted across development (Frazier et al., 2017). A second meta-analysis also reported that autistic participants spent significantly less time looking at social stimuli compared to neurotypical participants (Chita-Tegmark, 2016).

Other research has shown that autistic children attended less to faces and social interactions compared to children with specific language impairment and neurotypical children (Hosozawa et al., 2012). Taken together, social attention appears to be reduced for autistic people compared to neurotypical people, and for many this difference is maintained across the lifespan.

There are, however, still questions over what constitutes a social stimulus, and a review of autism research findings suggests that stimulus complexity impacts social attention and autistic versus neurotypical group differences (Risko et al., 2012). Specifically, the largest effects in eye tracking studies measuring facets of social attention are likely to arise from the use of more socially complex stimuli.

One paper using such stimuli examined attentional viewing preferences to 2-dimensional static images of interacting versus non-interacting pairs of human stimuli (Stagg, Linnell & Heaton, 2014). Three groups of participants were compared: neurotypical adolescents and autistic adolescents with or without a language delay in early childhood. When comparing looking times to interacting (socially salient) versus non-interacting stimuli, patterns of saliency only distinguished neurotypical children from autistic children with language delays. Neurotypical and autistic participants without early language delays spent significantly longer looking at interacting stimuli and exhibited comparable viewing patterns. On the other hand, autistic children with language delays spent significantly less time fixating on interacting stimuli. The authors argue that attentional placement was related to individual differences in language development, specifically early language delays. It should be noted that dichotomising language variables into categorical variables, particularly with such small samples (10 and 11 participants for the autistic groups with and without language delay respectively) could have led to less robust findings.

Other studies comparing viewing preferences of interacting versus non-interacting dyads in neurotypical adults have also found that interacting pairs of figures capture attention faster in a visual search paradigm compared to non-interacting figures (Papeo, Stein & Soto-Faraco, 2017), and participants are more likely to attend more to interacting human dyads (Papeo, Goupil & Soto-Faraco, 2019).

Bilingualism and autism

Bilingualism is a widespread phenomenon, with estimates suggesting that more than half of the world's population are bilingual (Grosjean, 2021, 2010). Bilingualism can be defined as exposure to two or more languages, and the manifestation of this is highly heterogeneous. As such, the term "bilingualism" covers a range of proficiently levels, ages of acquisition, and language use in daily life (Marian, 2018).

Despite the lack of evidence to date for negative effects of bilingualism in autistic people (Uljarević et al., 2016), parents of autistic children remain concerned that bilingualism could be detrimental to developmental outcomes and exacerbate language delays

(Hampton et al., 2017). Similarly, research has shown that parents are frequently advised by clinicians to maintain a monolingual environment to avoid confusion or delays across cognitive, language and social development (Kay-Raining Bird et al., 2012; Yu et al., 2013), despite the lack of evidence. It is clear that a more rigorous evidence base is needed for parents and clinicians to make informed decisions about a child's linguistic and cultural environment.

Bilingualism and social cognition

Despite the volume of research demonstrating group differences between autistic and neurotypical participants in terms of social attentional patterns, the mechanisms driving individual differences in social attention are still not well understood (Elsabbagh & Johnson, 2016). One factor that could theoretically influence attentional preferences is an enriched language environment. The impact of early multi-language exposure extends across multiple facets of social cognition and is associated with a range of potential benefits in neurotypical social development, including increased gesture use (Nicoladis, Pika & Marentette, 2009), development of pragmatic language skills (Siegal et al., 2010) and enhanced performance across theory of mind tasks (Schroeder et al., 2018; Kovács, 2012; Goetz, 2003). One explanatory framework for understanding the potential relationship between bilingualism and social cognition relates to the practice of tailoring language to the linguistic knowledge of one's interlocutor; specifically, that children living in a bilingual environment will encounter more opportunities to confront conflicting mental representations, providing additional opportunities for exercising perspective taking skills, which could then enhance bilingual children's understanding the mental states of others (Kovaćs, 2009; Kovács, 2012; Rubio-Fernández & Glucksberg, 2012).

However, this theory doesn't account for why bilingual advantages are also found in pre-verbal infants. Infants who have experience of dual-language exposure also demonstrate bilingual advantages (Kovaćs & Mehler, 2009; D'Souza et al., 2020). Although to date this has only been tested in relation to executive function skills, both studies demonstrated positive effects of bilingual exposure, suggesting that immersion in a bilingual environment through exposure alone can shape cognitive development. D'Souza et al. (2020) propose that bilingual infants explore their environments more than monolingual children and prioritise new stimuli over the consolidation of familiar information.

At the least, this research raises the question of whether the influence of bilingual exposure requires verbal practice, but we can also ask how this could relate to theory of mind and the overall social development of autistic, bilingually exposed children? We might posit that growing-up in a multi-lingual environment would promote attention to social content by making language and underlying mental states more salient. Although this idea has not yet been established quantitively, it has been considered in qualitative studies looking to understand the perspectives of parents of autistic bilingual children (Howard, Gibson & Katsos, 2021; Hampton, Rabagliati, Sorace & Fletcher-Watson, 2016). Both studies found that some parents of autistic bilingual children perceived there to be a cognitive advantage regarding bilingualism and that being bilingual positively influenced their child's perspective taking abilities and facilitated opportunities for social interaction.

Alternatively, if we assume the position of D'Souza et al. (2020), bilingualism might promote greater exploration, including of social stimuli. This in turn could provide more opportunities to rehearse more complex social behaviours such as understanding intentions. In the autism literature, there is currently little evidence about how bilingualism interacts with social cognition. The research that does exist suggests that bilingualism is unlikely to be detrimental to development (Uljarević et al., 2016). The literature on social cognition specifically has either identified no differences between bilingual and monolingual autistic children across a range of social skills (Valicenti-McDermott et al., 2019), or positive effects of bilingualism. For example, Valicenti-McDermott et al. (2013) reported increased gesture use and imaginative play in autistic bilingual children, and a longitudinal study of social and language outcomes reporting increased gesture use for bilingual autistic children when compared to monolinguals (Zhou et al., 2019). The effects of bilingualism on social cognition (specifically theory of mind) in autistic children have also reported higher scores in bilingual children (Peristeri et al., 2021; Andreou et al., 2020). However, there is currently no research to date that addresses the impact of bilingualism on foundational building blocks of social cognition in autism – namely, social attention.

Aims and hypotheses:

The aim of this study was to investigate whether bilingual exposure moderates' social attention preferences in autistic and neurotypical children. The ability to understand the intentions and attitudes of different people in daily life is highly reliant on the capacity to assign visual attention to relevant environmental cues. Therefore, we implemented an eye tracking paradigm used in Stagg et al. (2014) as a measure of social attentional processes in autistic and neurotypical children. We assessed whether children's patterns of visual attention to interacting stimuli versus non-interacting stimuli were influenced by bilingual exposure, and how this interacted with autism diagnostic status and vocabulary. This study provides the first opportunity to explore whether bilingual exposure might lead to increases in social attention.

Based on the findings of Stagg et al. (2014) and general assumptions from the social attention literature, we hypothesised that there would be no diagnostic group (autistic vs neurotypical) differences in dwell-time to back-to-back (non-interacting) figures, but there *would* be a diagnostic group (autistic vs neurotypical) difference in dwell-time to face-to-face (interacting) figures – i.e., neurotypical children would spend more time looking to face-to-face figures than autistic children.

We also explored whether there would be an interaction effect between group (autistic vs neurotypical) and bilingual exposure on dwell-time to face-to-face stimuli. Specifically, we asked whether autistic vs neurotypical group differences would be reduced when bilingual exposure was high.

2. Materials and Methods

2.1. Study design

The paper describes a two-group experimental study, exploring the influence of bilingual exposure (see below for definition) on social attention (dwell-time, using a free viewing eye-tracking paradigm), and the differences between autistic and neurotypical children.

2.1.1. Participants

Seventy-five children (42 neurotypical, 33 autistic) aged 6-12 years contributed data to the study from an original sample of 86. Children were excluded from the original sample if they were unable to complete the eye-tracking task, or if the quality of the eye-tracking data recorded did not reach the set threshold as described in the analysis methods below. A total of four neurotypical children (4.65%) and nine autistic children (10.4%) did not reach the quality threshold for data analysis. All participants were recruited from Scotland and England, utilising links with speech and language services, schools, charities, practitioner networks, community groups, and using social media. Neurotypical participants were recruited primarily through social media and school networks. In addition to our research-specific webpage, we also commissioned an animated recruitment video for parents. See Table 1 for participant demographics.

Autistic participants had a pre-existing clinical diagnosis of autism. Additionally, these children were screened using the Autism Diagnostic Observation Schedule (2nd edition) (Lord, et al., 2012) and as an additional measure of autistic traits, all parents completed the Social Communication Questionnaire–Lifetime (SCQ-L) (see "measures" for more information). A total of 29 children completed an ADOS, with three children unable to participate as they had very recently completed an ADOS, or due to practical constraints at home visitations. Out of the 29 children who could participate, one child received an ADOS algorithm score one point below the likelihood threshold for a diagnosis of autism. However, the participant (and indeed all participants in the autistic group) scored above the typical range of 15 on the SCQ-L screening threshold, indicating high levels of autistic traits (Rutter, Bailey & Lord, 2003). Taking into consideration the SCQ score and pre-existing clinical diagnosis of this participant, their data was included in subsequent analyses.

Parents of children in the neurotypical group also completed the SCQ-L. The only inclusion criterion applied was that children scored within the "typical" range (0-15, indicating low levels of autistic traits). All neurotypical children scored below an 8, indicating that the two participant groups could be distinguished by pre-existing clinical diagnosis and by parent-rated autistic traits. Neurotypical children were screened at recruitment by asking parents about other developmental conditions. No known conditions were identified in the group.

All participating families had the potential to raise their child bilingually: all families had access to English language in the community and at school, and at least one parent in each family was sufficiently fluent to engage with the English-language recruitment materials and parent-report measures. All parents in this study were fluent in English. In addition, one or both parents were fluent in at least one additional language. Participating children had varied experience of familial bilingual exposure. This ranged from minimal exposure to or use of a second language, including families who did not report any substantive bilingual exposure, to families using two languages in the home concurrently. See *Measures* below for information regarding how this was quantified.

2.1.2. Measures

Autistic participants:

The Autism Diagnostic Observation Schedule, 2nd edition *(ADOS-2;* Lord, et al., 2012) is a semi-structured, standardized assessment tool used to measure social and communication behaviours relevant to a diagnosis of autism. Participants are administered activities from one of the four modules. The selection of an appropriate module is based on developmental and language levels.

All participants:

The SCQ-Lifetime (Rutter Bailey & Lord, 2003) is a parent-administered questionnaire that can be used as an initial screening measure for autism. The 'Lifetime' form takes the entire developmental history into account. Scores over 15 are indicative of higher-than-average levels of autistic traits.

Bilingual exposure

The Bilingual Experience Calculator (BiLEC; Unsworth, 2013) is a parent-administered questionnaire used to measure bilingual experience. Language exposure was measured by the number of hours their first (L1) and second (L2) languages were used both within the home, (including after school, at weekends, and during the holidays) and outside of the home (including during the school day, and with friends). These scores always sum to 100%. This measure has been used in previous analyses on a different set of task data, with some of the same participants (see Montgomery et al., 2021). We derived a measure of bilingual exposure from the ratio between these two input percentages. This was calculated by multiplying the lowest of the two input percentages by two (number of languages) which provided a bilingual exposure score that could range from zero (i.e., Input from L1 was 0% and Input from L2 was 100%, therefore, a bilingual exposure of zero) to 100 (i.e., input from L1 and L2 was 50% each, giving rise to the maximum possible bilingual exposure). To further describe this metric, a participant exposed to 20% L1 and 80% L2 would have a bilingual exposure score of 40, while a participant exposed to 30% L1 and 70% L2 would have a bilingual exposure score of 60. The more balanced inputs from the two languages are, the higher the bilingual exposure score. In the current study, all participants had some degree of bilingual exposure, and scores ranges between 8% and 92%.

Eye tracking paradigm:

Stimuli used in this study were the same as those used in Stagg et al. (2014) (see Figure 1). In each trial, participants passively viewed a white background with images of two pairs of human figures (originally photographs, transformed using Photoshop to produce colour, cartoon-like figures). The pairs were in one of two configurations: face-to-face or back-to-back. There were two pairs of figures visible in each trial – one pair of each configuration. These pairs appeared in diagonally opposite quadrants on screen (i.e., top left and bottom right, or top right and bottom left). Face-to-face and back-to-back pairs did not consistently appear in the same quadrant. In each trial, two pairs of stimuli were selected as opposed to four (one per quadrant). In part this was because the task in its current form had already been validated in previous research. Second, we did not want to provide participants with multiple social and non-social stimuli pairings on the screen at once with the relatively short viewing time per trial (3 seconds), but rather the choice to view one scene at a time, either a social or non-social pairing.

The Wechsler Abbreviated Scales of intelligence, second edition (WASI-II; Wechsler, 2011) assesses cognitive ability. Only the vocabulary (31 items) and matrix reasoning (30 items) subtests were used, which were sufficient to calculate a partial IQ score and were used as an estimate of general cognitive ability. IQ limits were not stated within the inclusion criteria in order to permit a representative autistic sample. However, IQ was included as a covariate in subsequent analyses.

Vocabulary

To assess whether social attentional preferences were associated with measures of receptive language, participants completed *The British Picture Vocabulary Scale, Third Edition (BPVS-III*; Dunn, Dunn & Styles, 2009). The assessment measures receptive vocabulary abilities, and participants are instructed to match a word spoken by the examiner to one of four pictures using non-verbal responses. Correct responses are combined with the overall number of errors to provide a total score. All assessments were conducted in English. All children were living in the UK by the time they were 18 months of age and attended English speaking schools. All parents of participants were fluent in English. Only monolingual norms were available for the BPVS vocabulary scores. Groups were matched on age, gender, and bilingual exposure. See Table 1 for Demographics for autistic and neurotypical participants.

Values in bold indicate significant differences between groups at the 0.05 threshold. Comparisons were calculated using independent sample t tests for Age, WASI-II, BPVS-III and SCQ scores. Fisher's Exact Test scores were calculated to compare Gender scores. Age and bilingual exposure were not normally distributed; therefore, Mann-Whitney U tests were computed as a non-parametric alternative.

Table 1. Descriptive statistics (Mean (Standard Deviation)) for demographics.

	Autistic (n=33)	**SD**	**Range**	**Neurotypical (n=42)**	**SD**	**Range**	**Comparisons**
Age	8.86	2.49	6.10-12.4	7.89	1.77	6.11-12.1	U = 724, p = .071
Gender	Female =15, Male = 18			Female = 16 Male = 26			p = 0.634
IQ – WASI-II	89.57	23.88	72-134	105.67	12.53	78-136	3.951 (73), p = <**.001**
BPVS-III	90.58	35.23	70-121	101.87	11.32	75-122	2.281 (73), p = .085

SCQ	21.55	3.97	16-27	2.79	2.22	0-5	*26.319(74)*, *p* = <**.001**
Bilingual Exposure (%)	57.71	27.75	8-92	56.83	23.63	10-92	*U* = 873, *p* = .347

2.1.3. Apparatus and Procedure

General procedure

Ethical approval was obtained from the [BLINDED FOR REVIEW]. In order to send parent questionnaires out prior to home visits, written informed consent was first recorded electronically prior to visits. Consent forms were then signed again physically at each visit. Children were also asked to provide verbal assent prior to participation. The data collection methods reported here were part of a larger experimental task battery. Participants completed all assessments over one appointment. All but two families were visited at home by the researchers, and two families visited the research centre to participate in assessments. Where possible, children were assessed following the same timeline protocol: all autistic participants first completed the ADOS. All children were then assessed on the BPVS-III and WASI-II, followed by a break and the eye tracking battery. Parents had received the demographics and SCQ questionnaire packs by post two weeks prior to the visit. Questionnaire packs were collected at the visit by the researcher or sent by post to the research centre within two weeks of the visit.

Eye tracking procedure

Looking behaviour was recorded using a portable SMI REDn eye-tracker. The eye tracker has an infrared light source and was mounted to a 15-inch laptop screen, with a display comprising 1920 x 1080 pixels. Stimuli were presented using SMI Experiment Centre software. Children were seated approximately 60cm from the screen and chairs were adjusted to support optimal tracking of the participants eyes. The eye tracking task was preceded by a five-point calibration phase and a further 5-point validation phase. The experimental task was initiated when at least four points were correctly calibrated. If the participant did not pass the validation phase, the validation procedure was automatically initiated again. Eye position data were collected at 60hz.

Participants were told that they would be viewing images of people and that they could look wherever they wanted on the screen. Each stimulus was presented for 3 seconds. This presentation time was shorter than the original task (Stagg et al., 2014) to account for the longer task battery that children were participating in (see Davis, Montgomery, Rabagliati, Sorace & Fletcher-Watson, 2022). Attention grabbers (in the form of colourful pictures on black backgrounds with sound effects) were presented in between blocks to maintain attention to the screen. There was a total of 60 trials, with each stimulus appearing twice. However, at the second presentation, the stimulus content was arranged into different quadrants of the screen than the first time, so no two stimuli were identical. The procedure took five minutes to run in total.

2.2. Analysis Methods

Preregistered report

We submitted a pre-registered analysis plan in February 2020 (https://osf.io/ymzbn), far in advance of analysis of the dataset. Subsequently, we realised that that pre-registration did not incorporate statistical best practices, and so we deviated from it to conduct a more rigorous analysis. Specifically, we now use a linear mixed model as opposed to a three-way mixed ANOVA, and do not conduct any analyses where the continuous bilingual exposure measure was going to be split into high and low binary groups.

Dichotomising these variables risks losing statistical power, underestimating variability between groups and conceals potential non-linearity (Altman & Royston, 2006). There are also advantages to adopting a continuous approach to measuring bilingualism as opposed to bilingual versus monolingual groups. It has been argued that a continuous variable of bilingualism accounts for more abilities and experiences, is more representative of bilinguals in real world settings (e.g., de Bruin, 2019; Marian & Hayakawa, 2020), and could allow for more individual variation (Kremin & Byers-Heinlein, 2021).

The decision to use a continuous measure of bilingualism was also due to practical implications. For families with the potential to raise their children bilingually, there is no option for 0% bilingual exposure. For instance, if a native Spanish speaker brings up a child in an English environment with an English-speaking partner, the child will hear Spanish at least some percentage of the time (e.g., speaking Spanish with friends and family), even if Spanish is never spoken directly to the child. We argue that a continuous measure of bilingualism is the only relevant data that could inform clinical practice for these children.

Data parsing and area of interest (AOI) selection

Raw eye-tracking data were parsed using SMI BeGaze software to generate fixation data. To ensure high quality data, trials were removed if there was a tracking ratio of less than 40% (reflecting poor data quality; 1.96% of trials were removed for this reason). Trials where the sum of all fixations was <500ms were excluded as they were not considered a sufficient quantity of data to represent the results of multiple, purposeful eye movements to AOI within a single trial (Gillespie-Smith et al., 2016). A total of 0.83% of trials were removed for this reason.

We selected two variables of interest:

1. Fixation count, defined as the number of fixations per trial, averaged across all trials, was used to assess gaze control between participants. See table 3 for more information.
2. Total dwell time was defined as the cumulative duration of all fixations within each trial, for each AOI (face-to-face and back-to-back figures). This was also averaged across trials, for each AOI separately.

As per Stagg et al. (2014), we defined four areas of interest (AOIs). The first two AOIs were of identical size and covered the whole figures: one covering the face-to-face figures, the second covering the back-to-back figures (see figure 1). The other two AOIs were created for a head-only analysis, one covering the face-to-face head and shoulders, the second covering the back-to-back head and shoulders. All AOIs were identified using a rectangular selection tool. Example images and AOIs from trials presented to participants are displayed in Figure 1. Table 2 shows the average dwell times for each AOI per diagnostic group:

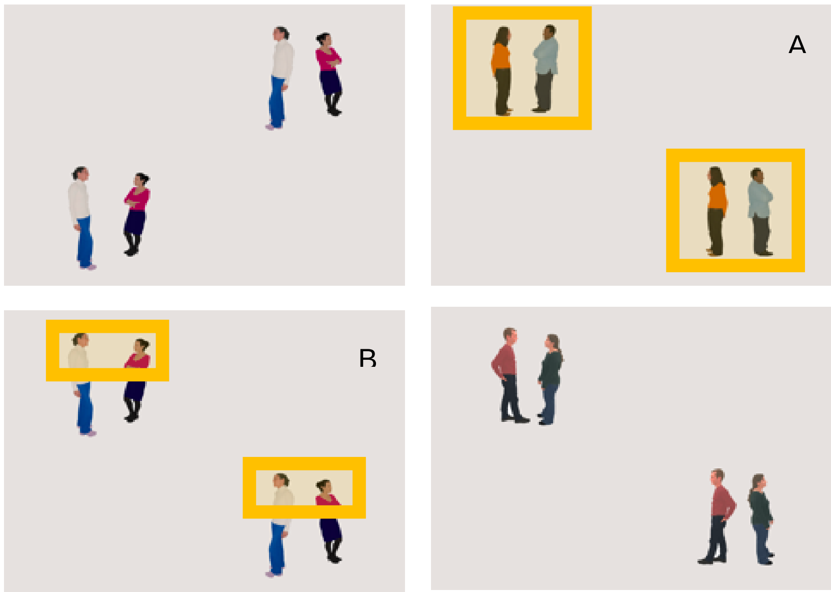


Figure 1. Example of the stimuli presented with example AOIs by a yellow outline. Box A shows an example of generated whole figure interacting and non-interacting AOIs in a single trial. Box B shows an example of the head-only interacting and non-interacting AOIs in a single trial.

Table 2. Details of dwell time data in milliseconds (ms) for the two groups Scores show the mean, with standard deviation in brackets.

		Autistic	**Neurotypical**
Whole figure	Interacting (ms)	1026.39 (339.56)	1174.42 (427.24)
Whole figure	Non-interacting (ms)	967.49 (295.58)	1049.26 (371.44)
Head-only	Interacting (ms)	638.63(319.33)	750.73(393.55)
Head-only	Non-interacting (ms)	572.97(216.10)	633.90(275.09

Analyses were conducted using SPSS version 25 and R Studio. Mixed models were fit using the lme4 package (Version 3.3.1; Bates, Maechler, Bolker, & Walker, 2015). For all analyses, a standard *p* value threshold of 0.05 was used to determine statistical significance. However, we used a Bonferroni adjustment to correct for testing multiple simple main effects. Raw scores for each independent variable were standardised to have a mean of zero and a standard deviation of one to ensure that all variables were analysed on the same scale.

Independent sample *t*-tests were applied to check data for mean group differences in total dwell time and number of fixations that could indicate abnormalities in gaze control. Underlying assumptions were validated for all subsequent analyses. Data for both the whole figure and head only AOIs data violated normality assumptions and homogeneity of variance, and was log transformed and rechecked to pass assumptions. We classified outliers as above 2.5 SD, but these data points were retained if the data were still normally distributed. None of the data points had overt leverage values. For correlations between mean event duration and language and social cognition scores, first order Spearman's correlations were used as not all variables were normally distributed (Shapiro-Wilk's test ($p < .05$).

We used linear mixed effects models for all hypothesis testing, specifically to explore the relationship between bilingual exposure, diagnostic status, and dwell time to face-to-face and back-to back-stimuli. We also assessed the impact of English vocabulary scores on dwell time. Separate models were run for whole figure AOIs and head only AOIs. Replicating the analysis from the original study using the eye tracking paradigm, (Stagg et al., 2014), the same analyses were run on head only AOIs to assess whether there would be differences specific to the head regions of the interacting versus non-interacting figures.

Marginal R squared were calculated as a measure of model fit for fixed effects, and conditional R squared was used where appropriate for fixed and random effects. Rather than using a statistical selection procedure for model fit, we selected the criteria for the model based on theoretical hypotheses. The first mixed effects model therefore included AOI type (interacting or non-interacting), diagnostic group, bilingual exposure, a two-way interaction term of bilingual exposure and diagnosis, AOI type and diagnosis, and a three-way interaction term of bilingual exposure, AOI type and diagnostic group, with the inclusion of by-participant random intercepts.

(2) The second mixed effects model assessed the effect of vocabulary scores to assess whether any differences in dwell time were related to language abilities. Therefore, this model included AOI type (head-to-head or back-to-back), diagnostic group, BPVS vocabulary scores, a two-way interaction term of BPVS scores and diagnosis, AOI type and diagnosis, and a three-way interaction term of BPVS scores, AOI type and diagnostic group, with the inclusion of by-participant random intercepts

3. Results

Abnormalities in gaze control

There were no significant differences between the two groups in mean number of fixations (p = .353) or mean duration of fixations (p = .659). This suggests there was comparable levels of ocular control when viewing the stimuli. Table 3 provides mean group descriptive statistics, including the average dwell time to each area of interest (AOI).

Table 3. Details of eye movement data for the two groups including the duration and number of fixations, and dwell time to whole figure and head-only stimuli (compared using independent samples t-tests). Scores show the mean and deviation in brackets.

		Autistic	**Neurotypical**	**Comparisons**
Whole stimulus	Mean duration of fixations (ms)	350.881 (96.28)	361.53 (107.29)	2.223(73), p = .659
	Mean overall number of fixations	145.00 (48.01)	156.86 (58.62)	3.263(73), p = .353

3.1. Whole figure analysis

Model 1 assessed the impact of AOI type (interacting versus non-interacting whole figures), bilingual exposure and diagnosis as individual factors, and included interaction effects of AOI type and bilingual exposure, and AOI type, diagnosis, and bilingual exposure. Two factors that were significantly predictive of dwell time. First, AOI type, p = .024; all participants, regardless of diagnostic status spent significantly more dwell time on interacting versus non-interacting figures. Second, diagnosis, p =.042; Across all types of stimuli, there was a difference between the autistic and non-autistic participants. Bilingual exposure was not predictive of dwell time, either individually or as part of higher order interactions. See table 3 for full statistics. Figure 2 shows the non-significant interaction

Table 3. Fixed and random effects as a summary of the linear mixed model with bilingual exposure for the whole figure AOIs. The conditional R^2 accounts for the variance explained by the whole model, while the marginal R^2 accounts for the fixed effects only.

		Log transformed dwell time		
Predictors	*Estimates*	*CI*	*p*	*df*
(Intercept)	998.16	940.68 – 1055.64	**<0.001**	3844
AOI type (Interacting vs non-interacting)	57.88	7.73 – 108.03	**0.024**	3844
Diagnosis [Neurotypical]	59.34	2.28 – 116.41	**0.042**	3844
Bilingual Exposure	-14.99	-72.59 – 42.61	0.610	3844
Diagnosis [Neurotypical] * AOI Type [Interacting]	16.71	-33.17– 66.59	0.511	3844
AOI Type [Interacting] * Bilingual Exposure	-11.12	-61.39 – 39.16	0.665	3844
Diagnosis * Bilingual Exposure	-2.66	-59.40 – 54.08	0.927	3844
AOI type [Interacting] * Diagnosis * Bilingual Exposure	-22.70	-72.41 – 27.01	0371	3844
Random Effects				
σ^2	391092.62			
τ_{00}	55536.89			
ICC	0.20			
N	75			
Observations	3854			
Marginal R^2 / Conditional R^2	0.017- 0.210			

Model 2 assessed the impact of vocabulary scores, AOI type (interacting versus non-interacting) and diagnosis as individual factors and included interaction effects of AOI type and vocabulary scores, and AOI type, diagnosis, and vocabulary scores. The interaction between AOI type and vocabulary scores was significant, as was AOI type, diagnosis, and vocabulary scores. Looking to figure 2, higher vocabulary scores were correlated with shorter looking times to non-interacting figures, and longer looking to interacting figures. Table 4 shows all fixed and random effects from the model.

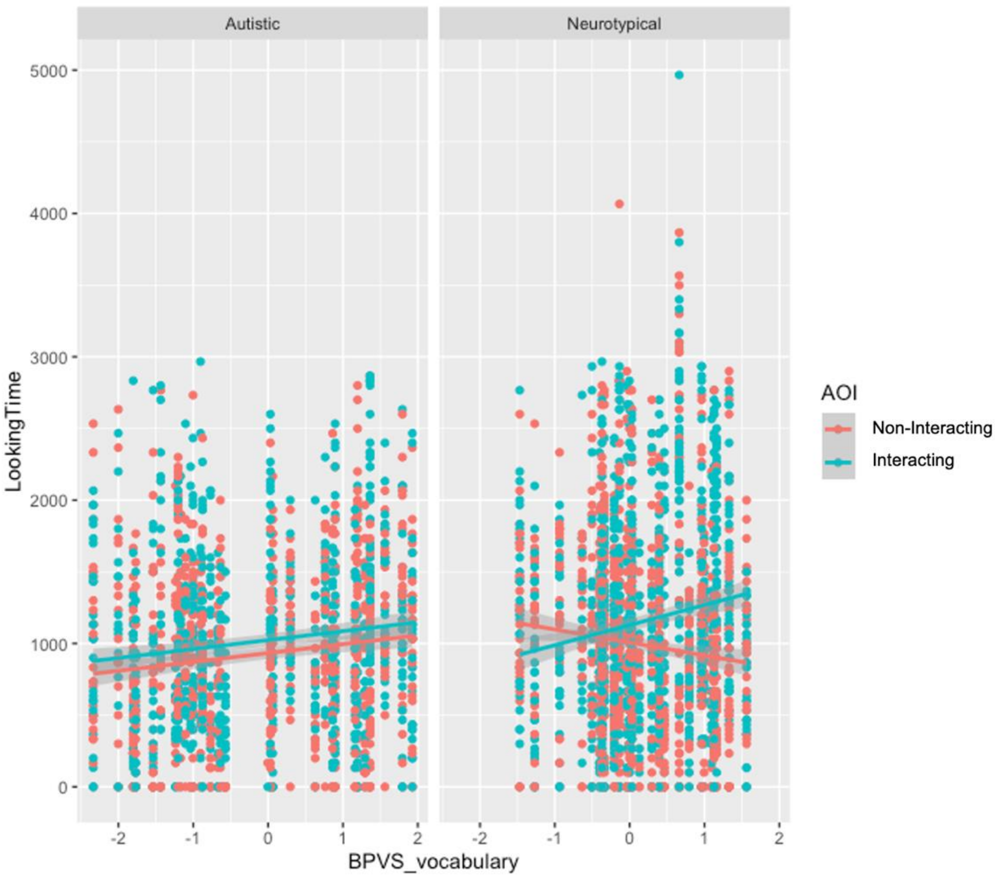
Table 4. Fixed and random effects as a summary of the linear mixed model with vocabulary scores for the whole figure AOIs. The conditional R^2 accounts for the variance explained by the whole model, while the marginal R^2 accounts for the fixed effects only

		Log transformed dwell time		
Predictors	*Estimates*	*CI*	*p*	*df*
(Intercept)	1002.66	945.33 – 1059.99	**<0.001**	3844
AOI type (Interacting vs non-interacting)	48.62	-0.62 – 97.87	0.053	3844
Diagnosis [Neurotypical]	51.90	-5.00 – 108.80	0.074	3844
BPVS vocabulary scores	38.90	-23.22 – 101.03	0.220	3844
Diagnosis [Neurotypical] * AOI Type [Interacting]	7.63	-41.35– 56.62	0.760	3844
AOI Type [Interacting] * BPVS vocabulary scores	56.47	3.17 – 109.78	**0.038**	3844
Diagnosis * BPVS vocabulary scores	-20.60	-82.74 – 41.54	0.516	3844
AOI type [Interacting] * Diagnosis * BPVS vocabulary scores	-56.27	2.96 – 109.59	**0.039**	3844
Random Effects				
σ^2	391131.41			
τ_{00}	52917.78			
ICC	0.19			
N	75			
Observations	3854			
Marginal R^2 / Conditional R^2	0.027- 0.209			

Figure 3 shows the significant three-way interaction from model 2. For the neurotypical children, there is a significant trend of decreasing dwell time to non-interacting figures and increasing dwell time to interacting figures as vocabulary scores increase. The autistic group shows a non-significant trend of increasing dwell time to figures overall as vocabulary scores increase, regardless of AOI type.

Model 2 assessed the impact of vocabulary scores, AOI type (interacting versus non-interacting) and diagnosis as individual factors and included interaction effects of AOI type and vocabulary scores, and AOI type, diagnosis, and vocabulary scores.

Figure 3. Significant three-way interaction effect from the linear mixed model using whole figure AOIs with raw data points included. Z-scores were used for BPVS scores, and looking times are in milliseconds (ms).



3.2. Analysis of head region

Model 1 assessed the impact of AOI type (interacting versus non-interacting whole figures), bilingual exposure and diagnosis as individual factors, and included interaction effects of AOI type and bilingual exposure, and AOI type, diagnosis, and bilingual exposure. There were no significant factors in this model.

Model 2 assessed the impact of vocabulary scores, AOI type (interacting versus non-interacting) and diagnosis as individual factors and included interaction effects of AOI type and vocabulary scores, and AOI type, diagnosis, and vocabulary scores. Although the factors were not statistically significant, the trends were the same as the whole figure analysis. Lack of significant effects are likely to be reflected by lower power and fewer trials due to smaller AOIs.

4. Discussion

This study investigated the impact of bilingual exposure on social attentional preferences to interacting and non-interacting stimuli in autistic and neurotypical children. To our knowledge, this is the first study to focus on the interplay of social attention and bilingualism in autistic children.

Prior findings using the same task compared autistic children with and without historical language delay (Stagg et al., 2014). Regardless of configuration, patterns of visual attention only distinguished autistic children who had delays in early language onset; this group spent less time looking at human figures overall, and less time looking at interacting stimuli. In the current study, we focused on the effect of bilingual exposure rather than language delay. Based on previous findings in the social attention literature we hypothesised that the neurotypical group would spend more time looking to interacting figures compared to the autistic group. We explored whether bilingual exposure affected social gaze preferences, whether this interacted with group and AOI type, and whether there was an effect of language in the form of current vocabulary levels.

We found that in younger children than those studied by Stagg et al. (2014), social attentional preferences were influenced by vocabulary scores for neurotypical children; as vocabulary scores increased, neurotypical participants spent significantly less time looking to non-interacting figures. There was no significant effect of vocabulary on social attentional preferences in the autistic group, and no significant effect of bilingual exposure in autistic or neurotypical groups. Increased dwell time relating to higher vocabulary scores was not a measure of task compliance, but of attentiveness to the AOIs.

There was no significant group difference in dwell time to interacting stimuli, and the amount of time autistic participants spent looking at interacting versus non-interacting stimuli was not statistically different. While the head only analysis was not statistically significant, the model suggest the same results as the whole figure analysis. Non-significance was likely due to the smaller AOIs and subsequently fewer datapoints. We discuss potential reasons for the findings below.

Bilingual exposure

Importantly, bilingual exposure was not found to impact social attentional preferences in either the neurotypical or autistic group. This has implications for the pervasive (and scientifically unsupported) view among many clinicians and parents that a bilingual environment could be detrimental for development in autism by causing cognitive delays (Kay-Raining Bird et al., 2012; Yu, 2013; Hampton et al., 2017). The current study does not provide evidence for this view; bilingual exposure did not delay social attention in autism, there being no differential effects when compared with the neurotypical group.

However, the data here also did not lend support to the idea that bilingualism could promote social attention behaviours in autistic or neurotypical children. As a null finding, this can be interpreted in a number of ways. The findings could be taken as further evidence against the broader claim that bilingualism enhances social cognition, given that position has been subjected to some scrutiny (Shroeder, 2018; Paap et al., 2016; de Bruin et al., 2015). While a null finding such as this cannot be conclusive as evidence against a claim, we stress that its existence in the literature is important to counteract publication bias.

Alternatively, this null finding could help to better-specify the mechanisms underlying potential bilingual advantages in social cognition. For instance, it is argued that repeated opportunities to tailor one's linguistic knowledge to that of a conversational partner could exercise executive capacities specific to enhancing perspective taking skills, for example (Kovács, 2009; Kovács, 2012; Rubio-Fernández & Glucksberg, 2012). If this were the case, it could be that bilingualism would not influence traits of social "interest" as measured in the current study, but rather executive capacities would in turn enhance perspective taking skills. However, recent work has failed to find evidence in favour of this view (see Peristeri et al., 2021)

Finally, a lack of effect could be related to the bilingual measures used and it is possible that greater statistical power was required to identify an effect of bilingual exposure given the variability between participants. There is ongoing debate as to the "best" measure of bilingualism, and the extent to which variability in an individual's bilingual experience explains the inconsistencies between findings in the bilingualism and cognition literature. Studies frequently use different aspects of bilingualism such as proficiency, age of acquisition or distance between languages, and these measures do not always generalise across studies (Paap, 2014). As a result, some have argued that taking an individualised, systematic approach to measuring bilingualism would be optimal in the future (Luk, 2014).

Effects of vocabulary

Overall, the current finding suggests that autistic children do not have the same relationship between language and social attention as neurotypical children.

This is consistent with the work of Norbury et al., (2009), who found that autistic adolescents exhibited differential gaze patterns to neurotypical children (looking less to the eye regions of faces), and that better language skills were not associated with longer looking times to social AOIs in autistic participants. The authors argued that integrating information from a number of different social cues could be more important in supporting communication in autistic children, compared to neurotypical children, who may rely more heavily on single social cues. Other research has also suggested that verbally able autistic children may rely on differential social cues than other autistic children (Rice et al., 2012).

Our research findings somewhat contrast those of Stagg et al. (2014), who found group differences in dwell time; specifically, that autistic children with historic language delays showed reduced attention to socially salient stimuli. In this study, greater language skills in neurotypical children were associated with more typical viewing patterns to social stimuli here. This was not the case for autistic children in this age range.

What could explain these discrepancies? One way to interpret this finding is that language skills are more important for social interaction, but the effect is either smaller or delayed in autistic children. It could be that autistic children are trying to interpret social cues from the non-interacting figures, or that autistic children are not making the distinction between socially salient and non-social stimuli.

There are also methodological differences between studies. Stagg et al. (2014) focused on the comparison of children with and without early language delays. We did not have information about the potential of early language delays in our autistic sample, but it is clear that current vocabulary levels also have an effect on gaze behaviours in autistic and neurotypical children. Second, the current study recruited 33-42 participants per group and treated language and bilingualism as continuous variables, both of which provide stronger power to test for effects. Conversely, Stagg et al. (2014) used smaller samples of participants and dichotomized their language competence variable. Taken together, these reductions in power would suggest that the estimates in the current study would be more robust.

Limitations

The results of this study are constrained to understanding the impact of bilingual exposure on social attentional preferences and cannot necessarily be generalised to other facets of bilingualism. We focused on exposure to capture the experiences of a range of autistic children that is more representative of the autistic population overall. Given that other factors such as language switching and expressive language competence are hypothesised to impact cognitive abilities, (Kroll & Bialystok, 2013) we cannot rule out the idea that different facets of bilingual experience would impact on our data in ways not captured here. Additionally, all participants in the current study were exposed to two languages, and these findings may not be representative of the experiences of children who are exposed to more than two languages. Further research would benefit from the inclusion and comparison of children from bilingual, multilingual families and monolingual families. It would also be beneficial to focus future research on the moderating effects of language delay, for example, on the relationship between bilingual exposure and social attention.

Future work should also consider the influence of bilingualism on children with multiple diagnoses. For example, given the high rates of comorbidity between autism and ADHD (e.g., Tureck et al., 2013), it would be interesting to understand the effects of bilingualism in children who are autistic and have an ADHD diagnosis.

Furthermore, there are questions as to what constitutes a social valid stimulus (Risko et al., 2012) and it is possible that using different stimuli, such as live video interactions, could produce different results. For example, research suggests that autistic children spent longer attending to cartoon-life stimuli (Van der Geest et al., 2002), therefore, it is possible that this lack of group difference could also reflect the stimuli used in this research. Extensions of this research using different types of stimuli and different types of bilingual experience would be beneficial to determine the generalisability of the results presented here.

5. Conclusions

The current study did not find effects of bilingual exposure in a social attention eye tracking paradigm, in autistic or neurotypical children. We found an interaction of vocabulary scores, group and AOI type; this was driven by the neurotypical group looking less to the non-interacting stimuli with increasing vocabulary.

However, in the current study, concerns that bilingualism could be detrimental to developmental for autistic children are not upheld. The results add to a growing evidence base that bilingual exposure does not negatively impact on autistic children when compared to neurotypical children and extends this argument for the first time to fundamental social attentional preferences. Beyond any theoretical significance, these findings are highly relevant for clinicians and parents, who are making decisions about a child's linguistic and cultural environment. Providing evidence-based guidelines that bilingualism is not likely to be harmful for development can help to alleviate some of the unfounded concerns that stakeholders frequently face.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.
Conflicts of Interest: The authors declare no conflict of interest.

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