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Brief report: Temporal distribution of visual attention between the eyes and mouth in young autistic children

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ABSTRACT

Background: Face scanning studies in autistic children report mixed results as to attention allocated to the eyes and mouth regions. While face scanning is a dynamic process, the way autistic children distribute their attention between the eyes and mouth of their interlocutor is usually analyzed by averaging the proportion of time spent looking either on the eyes or the mouth over the whole duration of stimulus presentation.

Method: In this study, instead, we focused on the temporal distribution of visual attention between the eyes and mouth of adult faces in 58 autistic and 61 typically developing (TD) children. Participants' eye movements were recorded as they were freely watching videos of faces of silent and speaking adults. We explored attention to the eyes and mouth with fine-grained analyses of the temporal trajectory of fixations on the two regions using generalized additive mixed effects models.

Results: These analyses revealed that both groups started their observation of speaking faces on the eyes and shifted to the mouth as the actor started speaking. However, TD, but not autistic children then slowly shifted their attention back to the eyes.

Conclusions: Rigorous analyses of how autistic children modulate their visual attention between key social features of the face over time may provide more accurate descriptions of their face scanning abilities.

1. Introduction

Over the past decade, eye-trackers have been increasingly used to observe autistic individuals' processing of social stimuli. Overall, eye-tracking studies have suggested that autistic individuals have diminished social attention marked by a reduced visual attention to social stimuli and atypical scanning of faces in comparison with neurotypical peers (Chita-Tegmark, Arunachalam, Nelson, & Tager-Flusberg, 2015; Guillon, Hadjikhani, Baduel, & Rogé, 2014). One aspect of social attention that may be particularly crucial for autistic children's early development is their visual attention to the eyes and mouth, because attention to the eyes and the (speaking) mouth plays an important role in social and language development (Lewkowicz & Hansen-Tift, 2012; Tenenbaum, Sobel, Sheinkopf, Malle, & Morgan, 2015; Wagner, Luyster, Yim, Tager-Flusberg, & Nelson, 2013).

Most eye-tracking studies investigating visual attention to videos or images of adult faces report comparable amounts of time spent

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focusing on the eyes in autistic and typically developing (TD) children (Åsberg Johnels et al., 2014; Chawarska et al., 2012; Chawarska & Shic, 2009; Falck-Ytter et al., 2010; Irwin & Brancazio, 2014). Jones et al. (2008), however, did report that autistic children gazed less at the eyes, and also more at the mouth, than TD children. This increased interest for the mouth was not replicated in other studies which either found diminished attention (Åsberg Johnels et al., 2014; Chawarska et al., 2012; Chawarska & Shic, 2009; Irwin & Brancazio, 2014) or a comparable amount of attention (Falck-Ytter et al., 2010) to the mouth in comparison to TD children. Shic et al. (2019) suggest that these attentional patterns may be further modulated by other factors such as the presence or absence of speech and direct gaze. These authors' results were that TD children gazed more at the eyes than autistic children when the actors were speaking and gazing directly at them. Unlike autistic children, TD children also favored the mouth over the eyes when speech was present.

Face scanning is essentially a dynamic process, and the eye-tracking studies surveyed in the foregoing generally use videos as stimuli (Åsberg Johnels et al., 2014; Chawarska et al., 2012; Falck-Ytter et al., 2010; Irwin & Brancazio, 2014; Jones et al., 2008; Shic et al., 2019). However, most of the previous findings are based on statistical analyses performed by averaging the proportion of time spent looking either on the eyes or the mouth over the whole duration of the stimulus. This process obfuscates the way in which children distribute their attention between the two zones over the course of stimulus presentation. There have been few attempts at describing temporal dynamics of face scanning in autistic children. Irwin and Brancazio (2014) showed that fixations on the mouth increased from time bin to time bin over the course of stimulus presentation, and much more so for TD than for autistic children. Using growth curve analysis, Del Bianco et al. (2021) showed that both autistic and neurotypical 6- to 30-year-old individuals were very likely to start their stimulus observation on faces. This initial observation was followed by a decline, after which neurotypical individuals were much more likely to redirect their attention to the face than their autistic peers. Both studies suggest that reduced social attention in autism is also marked by different temporal dynamics of face scanning.

In this brief report, we aim at comparing temporal distribution of visual attention between the eyes and the mouth of silent and speaking adults between autistic and TD 3- to 5-year-olds. Face scanning patterns are investigated dynamically by modelling the temporal distribution of attention to the eyes and mouth over time, using generalized additive mixed effects models.

2. Methods

2.1. Participants

Fifty-eight autistic children (47 boys, 11 girls) aged from three to five were recruited and matched on chronological age to a group of 61 TD children (36 boys, 25 girls). Inclusion criteria for autistic children were to have received a clinical diagnosis of autism spectrum disorder and to be exposed to French at home or at school. Autistic children (n = 2) who scored below cut-offs for autism spectrum disorder (ASD) on the *Autism Diagnostic Observation Schedule-Second Edition* (ADOS-2; Lord et al., 2012) were not excluded from the study because they had previously received a clinical diagnosis from a multi-disciplinary team. Inclusion criteria for the TD group were to be exposed to French at home or at school and to have no known neurodevelopmental disorder or history of intellectual and language delay. All TD children scored within the typical range on verbal IQ, as measured by the French version of the *Peabody Picture Vocabulary Test-Revised* (PPVT-R; Dunn & Dunn, 2007), and nonverbal IQ, as measured by the *Leiter International Performance Scale-Third Edition* (Leiter-3; Roid, Pomplun, & Martin, 2009); they also all scored below cut-offs for autistic spectrum on the ADOS-2. In an effort to extend our understanding of social attention in autism to non- or minimally verbal preschoolers, we did not try to match the groups on measures of intelligence. This recruitment strategy led to a highly heterogeneous (but representative) group of autistic children, as can be inferred from the variability (or lack of data) in measures of nonverbal and verbal IQs as well as expressive vocabulary (see Table 1). Autistic children's raw expressive vocabulary was measured as total number of spoken words reported by

Table 1
Participants' characteristics.

	Autism		TD	
	N*	Mean (sd) range	N	Mean (sd) range
Chronological Age (months)	58	56.34 (9.99) 39–71	61	54.54 (9.82) 36–71
ADOS-2 Comparison score	60	6.98 (1.84) 2–10	61	1.18 (0.46) 1–3
Nonverbal IQ	43	86.9 (17.22) 47–115	61	103.93 (9.7) 70–129
Verbal IQ	29	77 (16.93) 56–130	61	103.3 (19.37) 70–149
Raw expressive vocabulary T1	47	165.6 (192.62) 0–577	/	/
Raw expressive vocabulary T2	41	210.29 (211.6) 0–623	/	/
Socio-economic status	55	9.23 (2.46) 5.5–16.5	59	11.59 (3.14) 3–18

*Due to missing data for some participants, sample size varies from one measure to another. Nonverbal IQ is measured by Leiter-3 and verbal IQ by PPVT-R, and expressive vocabulary by number of spoken words on the MB-CDI.

parents on the MacArthur Bates Communicative Development Inventories (MB-CDI; Fenson et al., 2007) at the time of the study (T1) and one year after (T2).

2.2. Material

We created 30 five-second-long stimuli consisting of videos of the face of a man or a woman looking straight at the camera. In half of the videos, the person remained silent for the whole duration of the stimulus and in the other half, the person uttered a short sentence. Example: *un rat garde du fromage dans son nid* (a rat keeps some cheese in its nest).

Thirty trials were presented to each participant for a total duration of approximately 3 min. In each trial, the stimulus video was preceded by an attention-getter in the shape of a star accompanied by a short jingle. Trials were pseudo-randomized across participants in such a way that maximum three stimuli of the same condition (speaking vs. silent face) appeared in a row. Fig. 1 shows the time course of one trial.

2.3. Procedure

Ethical approval was received for the study from the Erasme-ULB Ethics Committee in accordance with the Declaration of Helsinki (approval code: P2018/499/B406201837514). Participants' parents signed a written consent for their child to be enrolled in this study after being informed of their rights and all aspects of the experimental design.

The eye-tracking task was displayed on a 1920 × 1080 computer screen using Tobii Studio. Eye movements were recorded at 60 Hz using a Tobii Pro X2–60 remote eye-tracker located just below the screen. Participants were seated approximately 60 cm away from the screen to ensure optimal measures. No specific instruction was given. Participants were simply encouraged to look at the screen as if they were watching a cartoon. Before starting the eye-tracking task, participants completed a child-friendly standard five-point calibration procedure.

The task reported in this paper was part of a larger project on early linguistic development in ASD. This project was composed of four sessions including tasks unrelated to the topic of this paper. The present eye-tracking task took part during the first session along with another eye-tracking task and a parent-child free play. ADOS-2, Leiter-3 and PPVT-R were administered at the second, third and fourth session, respectively, along with other eye-tracking tasks not relevant to this paper. Testing took place at the lab, at the children's school or at home. Participants were individually tested (sometimes in the presence of a parent) by the first author or the lab neuropsychologist.

2.4. Analytical plan

Eye-tracking data was extracted from Tobii Studio using the Data Export function. For each participant, horizontal and vertical coordinates of the averaged left and right eye gaze point on the screen (in pixels) were exported every 16.67 ms. Especially in sensitive populations like young children (autistic or not), eye-tracking data can be subject to a loss in precision and accuracy. To correct for calibration errors, we applied an offline correction method used in Clin et al. (2020). In addition, each eye gaze point was classified as corresponding to a fixation vs other event using the *identification by two-means clustering* (I2MC) algorithm, a fixation detection algorithm developed by Hessels and colleagues (2017). The algorithm was built specifically to be used on data of infants or young children which may contain a wide range of noise level and relatively large periods of data loss. We implemented the I2MC algorithm in MATLAB R2023a (The MathWorks Inc, 2023) on the horizontal and vertical coordinates of the averaged left and right eye gaze point, with a 100 ms period value for interpolation of missing data, a 200 ms window moving in steps of 20 ms for the two-means clustering procedure (no downsampling), 0.7° and 40 ms separation values for merging fixation candidates, and a 40 ms cut-off for exclusion of short fixation candidates. Only eye gaze points corresponding to a fixation event were included in subsequent analyses (i.e., eye gaze points corresponding to non-fixation events were discarded). Subsequently, we defined two Regions of Interest (ROIs) and

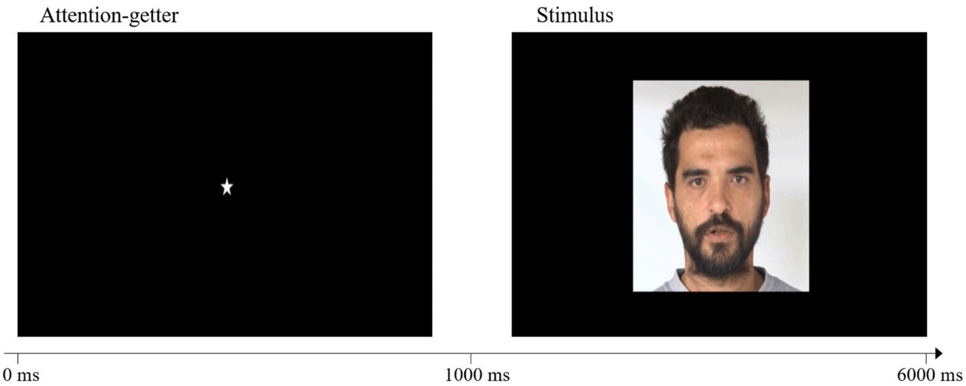

Fig. 1. Eye-tracking task. Time course of one trial.

coded whether the corrected eye gaze points belonging to fixation events were located (fixation=1) or not (fixation=0) in one of the ROIs. Proportions of eye gaze points on each ROI were then aggregated over 100 ms intervals. One rectangle delimited the Eye region including the two eyes and the space between the eyes. (It should be noted that the location of the star-shaped attention getter displayed before stimulus presentation overlaps with the eye region ROI's location on the screen). Another rectangle delimited the Mouth region. Only trials with a minimum 50% of valid eye gaze samples were included in subsequent analyses. However, there were no differences in results between analyses on the 50%-valid-sample dataset reported here, and two more liberal datasets, one with a minimum of 25% of valid samples and one with no excluded samples. Analyses of overall attention to the screen are reported in Suppl. material.

All statistical analyses were conducted in R (R Core Development Team, 2019). Generalized additive mixed effects models (GAMM) were used to analyze non-linear time effects using the *mgcv* package (Wood, 2017). Group (ASD vs. TD), Stimulus type (Silence vs. Speech) and Time (in 100-ms time bins) were used as independent variables.

2.5. Results

Tables summarizing the effects of all generalized additive models can be found in Suppl. materials.

In order to investigate group differences between fixation trajectories on both ROIs (Eyes and Mouth), we fitted a GAMM separately for each Region and Stimulus type. We used a Group parametric term, Time and Time by Group fixed smooth terms, and Time by participant and by item random smooths. Starting with the eye region, in the Silence condition, there was a significant Group effect, but no effect of Time, showing that autistic children fixated less the eye region of silent faces. By contrast, in the Speech condition, there was a significant effect of Group and Time x Group interaction on fixations on the eye region. Fig. 2A displays mean fixations on the eye region over time along with fitted curves for the Speech condition. Both groups started their visual observation by fixating the eyes, although autistic children allocated less fixations overall to the eye region than their TD peers. In both groups, fixations on the eyes dropped at around 1 s, when the actor started speaking (which likely reflects a shift towards the mouth). Children in the TD group, however, rapidly shifted back to the eyes, but no such rapid shifting back to the eyes was observed in autistic children.

For the mouth region, however, in both Stimulus type conditions (Speech and Silence), the analysis revealed no effect of Group and no Time x Group interaction (all $p > .05$). Overall, both groups allocated as much attention to the mouth region in both conditions.

To further explore dynamic patterns of fixations on the mouth between conditions, we fitted another GAMM for the mouth region across both groups (as the group effect did not reach significance in the previous model); we used a Stimulus type parametric term, Time and Time by Stimulus type fixed smooth terms, and Time by participant and by item random smooths. Fig. 2B displays mean fixations on the mouth region over time, across groups, along with fitted curves by Stimulus type conditions. In the speech condition, all children rapidly increased their fixations on the mouth when the actor started speaking. This phenomenon mirrors the decrease in

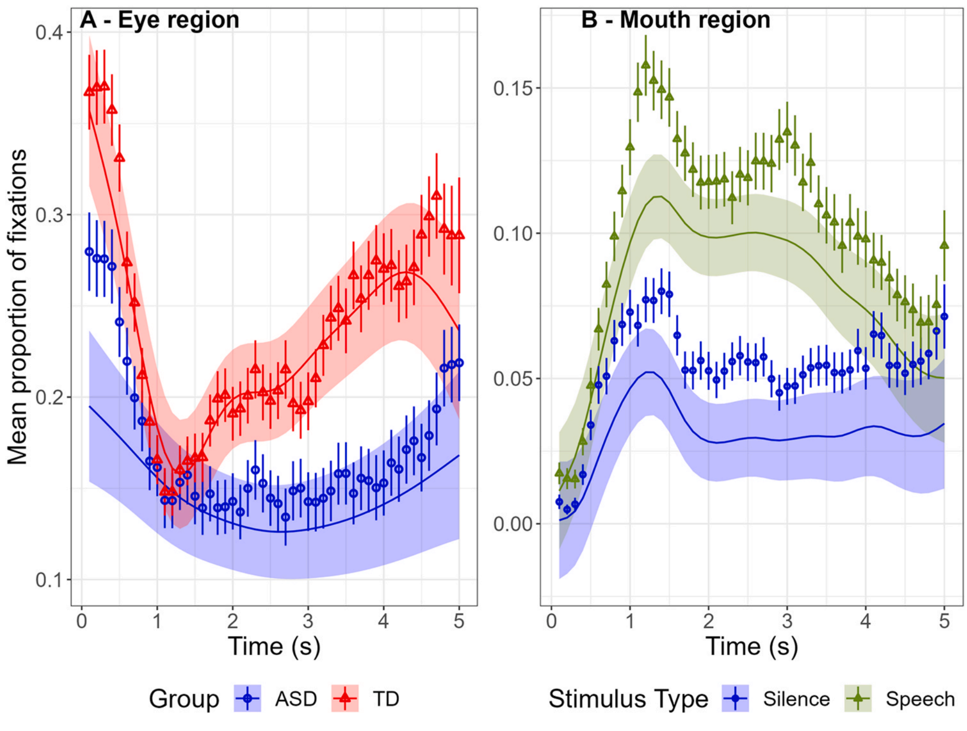

Fig. 2. Mean proportion of fixations over time and fitted curves for (**A**) Eye region, Speech condition, between groups; and (**B**) Mouth region, both groups collapsed, between Stimulus types.

fixations to the eyes in both groups in Fig. 2A.

3. Discussion

In this study, we explored autistic children's early visual social attention by integrating analyses of the distribution of their fixations between the eyes and mouth over time.

Overall, autistic children spent less time looking at the eyes and an equal amount of time looking at the mouth of the actors in comparison to their TD peers. Both groups also increased their fixations on the mouth of speaking vs silent faces. These results are inconsistent with reports that autistic children do not modulate their attention to the mouth when speech is present or absent, but attend to the eyes in the same way as TD peers (Chawarska et al., 2012; Shic et al., 2019), or with reports that autistic and TD children pay as much attention to the eyes as to the mouth (including in live interactions) (Falck-Ytter et al., 2015).

A finer-grained analysis of the temporal trajectory of fixations on the eyes and mouth revealed an interesting difference between groups. In the speech condition, both groups started their visual observation of faces on the eyes. However, fixations on the eyes dropped when the actor started speaking and this event was contingent with an increase of fixations on the mouth. Fixations on the mouth then decreased in both groups as the actor continued speaking. The difference between the two groups arose next, when TD children then rapidly shifted their visual attention back to the eyes. No such rapid and steep shift back of visual attention to the eyes was observed in the autistic group. This group difference in gaze trajectories over time on speaking faces is unlikely to be caused by potentially slower eye movements in autistic children, as no group difference emerged for the timing of gaze shift towards the speaking mouth at the beginning of the trials. One plausible explanation of the differential temporal gaze course is that autistic children do consider the eyes as a salient facial feature and, therefore, attend to it at the beginning of their observation. Their attention (and of their TD peers) is then caught by the speaking and moving mouth for a little while. However, autistic children may be less sensitive to the social value of the eyes than TD children, as they do not feel the need to shift back to the eye region. That being said, we cannot rule out that autistic children's initial relative interest for the eyes is simply due to them fixating the attention getter a few ms before. In that case, results would suggest that autistic children show an overall disinterest for the eyes, but do attend to the mouth when it starts speaking. However, in comparison to TD children, they are then less likely to (re)orient towards the eyes. Recent studies of social attention in children with ADHD (Frick et al., 2023) and social anxiety (Kleberg et al., 2021) showed that children in the clinical groups were as likely as TD comparison groups to reorient their attention to the eyes after being prompted to attend to the mouth. Given the significant phenotypical overlap between autism, ADHD and social anxiety, our results may suggest that being disinterested or feeling aversion for the eyes is a characteristic that is very specific to autism.

3.1. Implications and limitations

Using dynamic temporal analyses, instead of averaging fixations per trial, we highlighted important differences in the way autistic and TD children distribute their fixations between the eyes and mouth of speaking vs silent faces over time. Superficial comparisons of mean proportions of fixations on the two regions might not always suffice to uncover such subtle group differences in the visual scanning of faces. Given the current state of knowledge regarding overall amounts of attention that autistic children spend scanning the eyes and mouth, we believe the field would benefit greatly from systematically integrating fine-grained analyses of temporal distributions between regions of interests on the face, as this approach is more likely to provide accurate insights into what happens as children dynamically scan faces.

Despite being highly informative, the reported results should be interpreted in the scope of at least one limitation that is inherent in all research that seeks to include young non- and minimally verbal autistic children. Our sample of autistic children was not matched in either verbal or nonverbal IQs to the comparison group of TD children. IQ tests are notoriously difficult to administer to this population (Courchesne et al., 2019; Tager-Flusberg et al., 2017) which is illustrated by the amount of missing data on those two measures in the autistic group.

Declaration of Competing Interest

The authors declare no conflict of interest.

Data availability

Data will be made available on request.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.rasd.2023.102292.

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