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Computer Vision Analysis Captures Atypical Attention in Toddlers with Autism

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Abstract

Objective—To demonstrate the capability of computer vision analysis (CVA) to detect atypical orienting and attention behaviors in toddlers with autism spectrum disorder (ASD).

Method—104 toddlers 16-31 months old (Mean=22) participated in this study. Twenty-two of the toddlers had ASD and 82 had typical development or developmental delay. Toddlers watched video stimuli on a tablet while the built-in camera recorded their head movement. CVA measured participants' attention and orienting in response to name calls. Reliability of the CVA algorithm was tested against a human rater. Differences in behavior were analyzed between the ASD group and the comparison group.

Results—Reliability between CVA and human coding for orienting to name was excellent (ICC 0.84, 95%CI 0.67-0.91). Only 8% of toddlers with ASD oriented to name calling on >1 trial, compared to 63% of toddlers in the comparison group (p=0.002). Mean latency to orient was significantly longer for toddlers with ASD (2.02 vs 1.06 sec, p=0.04). Sensitivity for ASD of atypical orienting was 96%, and specificity was 38%. Older toddlers with ASD showed less attention to the videos overall (p=0.03).

Conclusions—Automated coding offers a reliable, quantitative method for detecting atypical social orienting and reduced sustained attention in toddlers with ASD.

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Introduction

Early behavioral risk markers for ASD include deficits in social attention and social orienting. In fact, these characteristics are among the earliest-emerging and most specific markers of risk for autism spectrum disorder (ASD). Studies of children in the first 3 years of life have shown that a failure to orient to name, attend to distress in others, or show interest in other children, distinguish children with ASD from those with typical development and other developmental delays (Dawson et al., 1998, 2004; Werner et al., 2000). These signs of atypical social development have now been incorporated into screening and diagnostic instruments for ASD. Both the Modified Checklist for Autism in Toddlers, Revised with Follow up (M-CHAT-R/F), and the Autism Diagnostic Observation Scale in Toddlers (ADOS-T) use orienting to name as part of their risk assessment; the former is the widely used screening measure for ASD and the latter is the gold standard diagnostic instrument for ASD in toddlers (Lord et al., 2000; Robins et al., 2014). In four observational studies of children ages 1-4 years, the proportion of children who oriented to name on any 1 of 3 opportunities ranged from 82-100% in children without ASD (including those with other developmental delays), and 44-57% in children with ASD, demonstrating the potentially high specificity of atypical orienting to name as a marker of ASD risk (Baranek et al., 2013; Gabrielsen et al., 2015; Nadig AS et al., 2007; Oner et al., 2014).

The ability to distinguish between toddlers with ASD and other delays is important because it is known that early, autism-specific treatment improves cognitive outcomes for children with ASD (Dawson et al., 2010; Landa and Kalb, 2012; Rogers et al., 2012). However, assessment of these behaviors in primary care where children are typically screened for ASD is often not feasible. Currently, assessment of orienting to name relies on expert rating of behavior and is based only provide binary ratings, without characterization of quantitative features, such as speed of orienting. A challenge for the field is to develop objective, quantifiable markers of early risk behaviors that can be feasibly implemented in community settings.

Progress in developing automated measures of social attention has been made with gaze-tracking technology. Gaze-tracking utilizes passive viewing tasks where demands on the child are low and measurement is non-invasive. These tasks allow for quantification of natural tendencies of infants and toddlers to attend to stimuli of interest, revealing their developing abilities to direct and shift their attention. An experimental paradigm often employed is the gap-overlap task, where a child is presented with a central stimulus, and then a competing stimulus that is meant to draw their attention away. Visual disengagement of attention is very fast in typical development: 500 msec in 3-6 month old infants and 320 msec in adults (Hood and Atkinson, 1993). Even in these tasks utilizing rapid attentional shifts, toddlers with ASD shift attention more slowly when compared to age-matched controls (Elsabbagh et al., 2013). Additionally, children with ASD tend to direct their attention toward less socially-salient stimuli as indexed by studies employing gaze-tracking and social attention quantified through blink inhibition (Jones and Klin, 2013; Pierce K et al., 2011; Shultz et al., 2011). These studies raise the possibility that by measuring the speed at which a child disengages from a stimulus of interest in order to orient to their name being called, we may be able to quantify a semi-physiologic measure of atypical social development in young children.

Further evidence from physiologic measures suggests that analysis of the timing of complex movements may be important for creating normative values for social behavior and detecting differences in children with ASD. Studies of facial expression in children with ASD suggest that subtle abnormalities in social behaviors may be detectable. When imitating facial expressions, involuntary movements were found to be slower in children with ASD (Oberman et al., 2009). In a study of orienting to an adult displaying distress, the timing of orienting to distress in toddlers with ASD was atypical, with the ASD group orienting after 3.5 seconds and the comparison group orienting after 1.5 seconds (Dawson et al., 2004). Another study showed that infants who later went on to have ASD were more likely to show head lag on a pull to sit task administered when they were 6 months old, which is a marker of immature motor development (Flanagan et al., 2012). Taken together, these studies suggest that timing is a key element in detecting differences in social attention and complex motor behaviors in children with ASD. However, no study has yet quantified the range of timing of typical orienting to name in toddlers. Furthermore, eliciting toddlers' natural tendency to engage with people could provide more information about their social development and ability to coordinate complex behaviors.

The combination of reduced attention to social stimuli and slower motor movements could amplify differences in social development in toddlers with ASD. Computer vision analysis (CVA) offers a promising tool for detecting and automatically analyzing attentional and motor behavior in toddlers in response to a social stimuli (Hashemi et al., 2014). The current study aimed to detect atypical attention behaviors and evaluate whether CVA could reliably measure the consistency and latency of orienting to name in toddlers with ASD versus a comparison group of toddlers without ASD. We developed a novel assessment delivered on a tablet (iPad) wherein toddlers watched videos that were designed to capture their attention and tested their ability to sustain attention to the videos as well as to disengage from the videos to orient when their name was called. We assessed the automatically computed frequency and timing of these orienting behaviors in children with and without ASD. We also measured the reliability of observations recorded from the camera embedded in the tablet and detected via CVA in comparison to human coding of orienting behavior. Then, we examined whether CVA could detect group differences between toddlers with and without ASD in engagement with stimuli and orienting to name.

Methods

Participants and Recruitment

Participants were 104 toddlers between 16–31 months of age, 22 who had autism spectrum disorder (ASD) and a comparison group of toddlers (N=82) of similar age for whom concerns for ASD had not been raised based on autism screening and parent/clinician report. Participants were recruited from primary care pediatrics clinics either directly by a research assistant or via referral from their physician, as well as by community advertisement. For pediatric clinic recruitment, a research assistant approached participants at their 18- or 24-month well child visit, when all children in the clinic are screened for ASD with the

Modified Checklist for Toddlers-Revised with Follow-up Questions (M-CHAT-R/F; Robins et al., 2014). Toddlers with known vision or hearing deficits were excluded. Toddlers were also excluded if they did not hear any English at home or if parents/guardians did not speak and read English sufficiently for informed consent. All parents/legal guardians of participants gave written, informed consent, and the study protocol was approved by the Duke University School of Medicine Institutional Review Board.

Screening and Diagnostic Assessments

The majority of children recruited into the study had already received screening with a digital version of the M-CHAT-R/F as part of a quality improvement study ongoing in the clinic (Campbell et al., 2017). Participants from community recruitment received ASD screening with the digital M-CHAT-R/F prior to the tablet assessment. As part of their participation in the study, children who failed the M-CHAT-R/F or for whom parents/legal guardians or their physicians had concerns about possible ASD, underwent diagnostic and cognitive testing with a licensed psychologist or trained research-reliable examiner overseen by a licensed psychologist. Testing consisted of Autism Diagnostic Observation Scale – Toddler Module (ADOS-T) and Mullen Scales of Early Learning (MSEL), (Gotham et al., 2007; Mullen, 1995). Children who received a diagnosis of ASD based on the ADOS-T and clinician assessment were referred to early intervention services.

Procedures and Stimuli

During the tablet assessment, the participant sat on a caregiver's lap while watching a set of videos on a tablet. The tablet was placed on a stand approximately 3 feet away from the child to prevent them from touching the screen. The stimuli consisted of a series of brief developmentally-appropriate videos designed to engage the child's attention. The videos consisted of cascading bubbles, a mechanical bunny, and animal puppets interacting with each other. Examples of the stimuli and experimental setup are presented in Figure 1 and further described in a previous publication of the CVA algorithm (Hashemi et al., 2015). The entire series of videos lasted 5 minutes. During three of the videos, “Call Name” appeared in small text in the corner of the screen to prompt the examiner to call the child's name. The examiner, standing behind the child, called the child's name loudly. If the child was already looking at the examiner or parent when the prompt appeared, the examiner waited until the child was looking at the video to call the name. If the child turned to look at parent or examiner after the name call, the examiner silently smiled and waved. Later, the experimenter watched the recording and marked the exact frame in which the name call occurred. In order to allow the child to naturally direct their own attention, parents were instructed to refrain from speaking to the child or pointing to direct the child's attention and were asked to respond minimally with “mmhm” if the child tried to communicate with them. Parents were also asked to attempt to keep the child seated in their lap, but to allow the child to get off their lap if they became too distressed to stay seated. Researchers stopped the task for 1 comparison subject due to crying. Researchers restarted the task for three participants with ASD due to difficulty remaining in view of the tablet's camera for more than half of the first video stimulus.

Computer Vision Analysis

The frontal camera in the tablet recorded video throughout the experiment at 1280×720 resolution and 30 frames per second. The CVA algorithm automatically detected and tracked 49 facial landmarks on the child's face, allowing for detection of head, mouth, and eye position (see Figure 1) (De la Torre et al., 2015). Head positions relative to the camera were estimated by computing the optimal rotation parameters between the detected landmarks and a 3D canonical face model (Fischler and Bolles, 1981). A “not visible” tag was assigned to frames where the face was not detected or the face exhibited drastic yaw (greater than 45 degrees from center). All other frames were assigned a “visible” tag.

The examiner was positioned behind the child to press the child to turn his/her head to make eye contact in response to the name call. To encode head turning automatically, we tracked change in yaw of the head position before and after each segment of consecutive “not visible” tags. Ideally, when the child turned his/her head to orient to name the magnitude of the yaw pose with respect to time exhibited a smooth bell-shaped curve with a flat plateau in the center, indicating when the child had turned their head to orient. However, in practice in such an unconstrained setting, the yaw curve often had many perturbations and non-smooth slope changes due to factors including differences in head turning velocity and noisy landmark measurements. To overcome these factors, we analyzed the yaw at half-second windows before and after each segment of “not visible” tags. For each segment, our algorithm only marked a head turn if both half-second windows exhibited maximum yaw of at least 30 degrees (Figure 2). These rules helped distinguish between true head turning and obstructed detection of the face due to the child looking around the room or covering the face. Also, these yaw values were chosen because our head position algorithm required both eyes to be visible on the face and also to reflect what human coders would consider clear head turning in previous validation testing (Hashemi et al., 2015).

Measures of Orienting to Name

Reported and observed orienting to name were compared across three different measures: the M-CHAT-R, the ADOS-T, and the experimental task (see Table 2). For this analysis, orienting to name within 2 seconds on any of 3 prompts was criteria for valid orienting on the experimental task. For parent report of orienting, question 10 on the M-CHAT-R was used. For expert clinician rating, item B07 on the ADOS-T was used. This item is a structured observation of orienting to name. A score of 0 or 1 indicates that the child oriented within 4 calls by the examiner or 2 calls by the parent; a score of 2 or 3 indicates that the child never oriented to their name.

Statistical Analysis

Demographic characteristics of participants in the two diagnostic groups were compared with t-tests and chi-squared analysis. Task engagement was quantified based on time looking at the videos or at the people in the room. This measure was derived by combining the time the child was either facing the screen or turning their head towards the parent or examiner, and removing time that the child was blinking, covering eyes, closing eyes, looking down, or looking around the room. Proportion of time engaged was calculated for each child by taking the ratio of time engaged in each stimulus to the total recorded time. Proportion of time engaged was compared between groups with a linear model with the main effects of group and interaction of age and group as predictors. Inter-rater reliability between the computer and human raters for timing of orienting to name was quantified with the consistency, average, two-way intra-class coefficient (ICC), with ICC above 0.75 considered excellent agreement (Hallgren, 2012). Orienting to name was first defined as turning to look at the examiner or parent within 5 seconds after the name call. This limit was chosen based on Baranek's Sensory Processing Assessment task in which children are given 4-5 seconds to orient to name (Baranek, 1999). In post-hoc analysis, the time limit was reduced to 2 seconds, as described in the results section. Proportion of participants turning to name and consistency of orienting across the three name prompts were compared between the ASD and comparison groups with chi-squared tests. To investigate group differences in the latency to orient to name, time-to-event analysis was used with the time the child initiated head movement toward the examiner as the event and right-censoring at 5 seconds. Cox proportional hazards models were created with all three name calls for each child linked as repeated measures and with age as a co-variate (Wei et al., 1989). Hazards ratios were tested against the null hypothesis of equal hazards between groups with the log-rank test. Kaplan-Meier curves of the cumulative events were constructed to visualize proportion of events in each group over time. All analyses were conducted in R Version 3.3.2 (R Core Team, 2014). using the packages psych, survival, dplyr, datatable, ggplot2, tidyr, and survminer (Revelle, 2014; Therneau, 2015; Wickham and Francois, 2015; Dowle et al., 2014; Wickham, 2009, 2016; Kassambara and Kosinski, 2016). Statistical significance was set at the alpha=0.05 level. All results describing group differences are from the CVA analysis data.

Results

Participant characteristics

One hundred and seven participants enrolled in the study and data were analyzed from a final group of 104 participants. Data from one participant in the comparison group were excluded due to crying during the experiment and inability to finish the task. Data from two additional participants in the comparison group were excluded due to incomplete transfer of data. Twenty-two of the 104 toddlers were diagnosed with ASD (Table 1). Of these, 4 scored in the low-risk range on the M-CHAT-R/F (but were tested due to parent or clinician concern for ASD) and 18 scored in the medium or high-risk range. One toddler in the comparison group failed the M-CHAT-R/F, but did not qualify for a diagnosis of ASD based on the ADOS-T. Eight participants in the comparison group had a diagnosis of language delay or developmental delay of clinical significance sufficient to qualify for speech or developmental therapy. Participants in the comparison group had a mean age of 21.91 months (SD=3.78) and those in the ASD group had a mean age of 26.19 months (SD=4.07; see Table 1). Due to the small but significant difference in age, age was included as a covariate in group comparisons. There were no group differences in race (p=0.56). Parents of participants with ASD reported, on average, 1 more hour of screen time per day than comparison participants (p=0.02).

Engagement

Validation of the detection of engagement using CVA when compared to human raters has been shown in previous work (Hashemi et al., 2015). Toddlers in the comparison group were engaged in the task 89% of the time on average (SD=9), compared to 76% (SD=19) for the toddlers with ASD. There was a significant interaction between diagnostic group and age, with the ASD group showing significantly lower amount of time engaged in the task than the comparison group at older ages (p=0.03; Figure 3).

Orienting to Name

Reliability—Videotapes were coded by trained research assistants who were unaware of the diagnosis of the child. Coders noted each instance of orienting (head turns) when the child's name was called. Reliability was excellent between CVA and human coding of head turns (ICC 0.84, 95% CI 0.67-0.91).

Group comparisons—In the comparison group, 49 of 82 toddlers oriented at least once during the 3 trials (60%, 95% CI 48-70%), whereas10 of 22 toddlers with ASD oriented to name at least once (55%, 95% CI 33-75%). This did not constitute a statistically significant difference between proportions of participants from each group orienting to name at least once. In analysis of consistency, however, of the 49 comparison participants who oriented to name, 31 (63%) oriented to multiple name calls, whereas of the 12 ASD participants who oriented to name, only 1 (8%) oriented multiple times (p=0.002; Figure 4A, table 3). In analysis of latency to orient in non-ASD participants who did orient to name, mean latency between name call and initiation of head movement was 1.06 seconds (SD=0.72). For ASD participants, mean latency was almost twice as long, 2.02 seconds (SD=1.43), indicating a significantly longer latency to orient in toddlers with ASD (0.96 sec difference, 95% CI 0.05-1.89, p=0.04). Hazards ratio for orienting to name showed higher odds of responding for the comparison group relative to the ASD group (2.26, 95% CI 1.29-2.17) and no effect of age or an age by group interaction (p=0.5). Log-rank test confirmed a statistically significant group difference in cumulative events (p=0.003; Figure 4B). In post-hoc analysis, of toddlers in the comparison group who oriented to name, 94% oriented within 2 seconds of the name call prompt.

Comparisons to parent and clinician ratings of orienting

In general, a lack of consistency was observed between orienting in the experimental task of this study, parent reports of orienting to name on the M-CHAT-R/F, and orienting to the ADOS-T prompt within subjects (Table 2). The experimental task agreed with parent report on the M-CHAT-R/F for 59% of ASD participants and with clinician observation on the ADOS-T for 38% of ASD participants. The greatest proportion of ASD children failing the orienting to name task was seen on the tablet task, although this was not statistically significantly different (68%, vs 45% on M-CHAT/R-F and 43% on ADOS-T, p>0.025 (Bonferroni correction for multiple comparisons)). Sensitivity for ASD for orienting to name consistently (on 2 or 3 out of 3 trials) and within typical latency (within 2 seconds) on the experimental task was 96%, and specificity was 38% (Table 3). Of the 8 subjects with a reported developmental delay but no concern for ASD, 1 failed to orient to name on the experimental task. Notably, two of the ASD participants who passed all three measures of orienting to name also received a false negative overall passing score on the M-CHAT-R/F.

Discussion

There is a great need for feasible, scalable methods for reliably measuring autism risk behaviors in community settings, such as primary care where children are screened for ASD. Results indicated that significant differences in task engagement as well as the consistency and latency of orienting to name can be reliably detected between toddlers with and without ASD using an assessment tool that is delivered and recorded on a tablet and relies on measures that are automatically captured with computer vision analysis. Although typically-developing and developmentally-delayed toddlers remained engaged with the task across the age range, older toddlers with ASD were less able to maintain attentional engagement. These findings are consistent with previous studies using eye-gaze tracking that found that toddlers with ASD show less sustained attention to dynamic stimuli (Chawarska et al., 2016). Other studies have found that toddlers with ASD spend less time engaged with socially relevant stimuli and have functional differences in social attentional networks of the brain (Elison et al., 2012; Jones et al., 2017; Pierce K et al., 2011).

Our analysis revealed a lack of consistency of orienting in ASD, replicating past findings in toddlers with ASD and adding a new element of timing, which has not been previously studied in detail. This study demonstrated that in typical development, orienting to name is very rapid, with a lag of only about one second, and orienting in toddlers with ASD lags behind by an additional second. With the ability to automatically detect timing of complex movement, we open the door for further studies of infant development that would have previously been time-intensive and inaccurate. CVA measures of timing employs rapid and objective detection of head position. Such detection of head position for the measurement of complex social behaviors has not been previously utilized, and could aid studies of young children which benefit from non-invasive measures and technology which automatically analyzes behavior rather than relying on human coding. Automatic characterization utilizing CVA of subtle atypical characteristics of behaviors may allow for the development of improved screening tools for ASD, as the earliest detectable deviations from typical behavior may not be a complete lack of a developmental milestone, but rather a subtle deficit in the quality of the behavior. We found that using timing of social behavior, specificity of the task was higher than expected from previous studies, and similar to the ratings of parents and trained clinicians. Therefore, we suggest that automatic analysis of social behavior could aid in screening and diagnostic measures.

The finding of delayed orienting in toddlers with ASD by approximately 1 second is a large difference in the sampling rate of the experiment (30 frames/second) and in the realm of signal processing and motor control. We hypothesize that this lag may relate to inefficient signaling pathways and/or lack of differentiation between social and non-social stimuli in the ASD brain (Harris et al., 1999; Solso et al., 2016). In fact, in other studies of toddlers with ASD, deficits in visual disengagement are apparent only in tasks with short inter-stimulus intervals, as pointed out in a review of gap-overlap tasks (Sacrey et al., 2014). This implies that the neural systems controlling rapid attentional shifts may be slower to respond in ASD. In measuring timing of head turn, we may be amplifying a motor coordination difference in toddlers with ASD by demanding the ASD child to initiate a head movement, and also demonstrating the lack of salience of a social cue to the attentional system in toddlers with ASD. This quantification of timing of orienting to name, at scales not detectable by the naked human eye, is a novel finding in the developmental literature and should be further studied and correlated with functional brain measures such as EEG or functional MRI.

The current results need to be considered in light of the following limitations. First, in order for this task to be successfully incorporated into screening or diagnostic measures, it will need to be developed further. Past studies found that, in this age group 82-100% of typically developing and developmentally delayed toddlers orient to name within 3 trials (Baranek et al., 2013). In this task, only 60% of children in the comparison group oriented to name, suggesting that the task needs to be refined to better elicit the target behavior. Most presses for orienting to name involve a child looking at a semi-interesting toy rather than a video, and this may be the reason our comparison group showed reduced orienting compared to previous studies. Further development of this task would benefit from further testing in controls with a less engaging video stimulus. However, sensitivity of delayed orienting for distinguishing ASD was high, suggesting a novel way to increase the psychometric properties of a classically specific but not sensitive task, which merits further investigation. Second, in the children with ASD who participated in this study, we showed a lack of agreement at an individual level between measures of orienting on the M-CHAT-R/F and ADOS-T, suggesting a need for a low-cost and objective measure of the quality of orienting, as introduced here. There is a need for development of a task that combines multiple measures of behavior before it can be applied in a clinical setting. This includes the potential combination of multiple sources, from questionnaires as the M-CHAT-R/F to low-cost automatic stimuli and behavioral encoding.

The challenge with current observational and parent-report measures used for screening and diagnosis is the labor-intensive and subjective rating of behaviors. Current methods of behavior analysis in diagnostic testing require expert training of clinicians and hand-coding of behaviors, which is expensive and time-consuming. Automatic coding allows for analysis of behaviors that rapidly and objectively characterize subtle deficits. Additionally, the time scale of this analysis showed differences in how ASD toddlers maintain and direct attention that are beyond the level of human perception. Fine characterization of movement also allowed us to define the range of timing of typical orienting to name, which has never before been described. With the aid of technology, in particular with ubiquitous cameras in tablets and mobile phones, this approach could be scaled for wider use, for example to perform a large study of the development of orienting to name in infants, or to increase access to diagnosis in remote areas. With further development and validation, analysis of complex social behaviors could potentially aid in screening and symptom monitoring methods for toddlers with ASD. Next steps will be to continue to optimize the stimuli for eliciting autism risk behavior, improve CVA analytic algorithms, and evaluate these tools on smart phones which would allow for wider dissemination.

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References

Baranek, GT. Sensory Processing Assessment for Young Children (SPA). University of North Carolina; Chapel Hill: 1999.

Baranek GT, Watson LR, Boyd BA, et al. 2013; Hyporesponsiveness to Social and Nonsocial Sensory Stimuli in Children with Autism, Children with Developmental Delays, and Typically Developing Children. Development and psychopathology. 25(2):307–320. DOI: 10.1017/S0954579412001071 [PubMed: 23627946]

Campbell K, Carpenter KLH, Espinosa S, et al. 2017; Use of a Digital Modified Checklist for Autism in Toddlers – Revised with Follow-up to Improve Quality of Screening for Autism. The Journal of Pediatrics. 183:133–139.e1. DOI: 10.1016/j.jpeds.2017.01.021 [PubMed: 28161199]

Dawson G, Meltzoff AN, Osterling J, et al. 1998; Children with Autism Fail to Orient to Naturally Occurring Social Stimuli. Journal of Autism and Developmental Disorders. 28(6):479–485. DOI: 10.1023/A:1026043926488 [PubMed: 9932234]

Dawson G, Toth K, Abbott R, et al. 2004; Early Social Attention Impairments in Autism: Social Orienting, Joint Attention, and Attention to Distress. Developmental Psychology. 40(2):271–283. DOI: 10.1037/0012-1649.40.2.271 [PubMed: 14979766]

Dawson G, Rogers S, Munson J, et al. 2010; Randomized, Controlled Trial of an Intervention for Toddlers With Autism: The Early Start Denver Model. PEDIATRICS. 125(1):e17–e23. DOI: 10.1542/peds.2009-0958 [PubMed: 19948568]

De la Torre, F, Chu, WS, Xiong, X. , et al. Automatic Face and Gesture Recognition (FG), 2015 11th IEEE International Conference and Workshops on. Vol. 2015. IEEE; 2015. Intraface; 1–8. Available at: http://ieeexplore.ieee.org/abstract/document/7163082/ [accessed 13 April 2017]

Dowle, M; Short, T; Lianoglou, S; , et al. data.table: Extension of data.frame. R package version 1.9.4. 2014. Available at: http://CRAN.R-project.org/package=data.table

Elison JT, Sasson NJ, Turner-Brown LM, et al. 2012; Age trends in visual exploration of social and nonsocial information in children with autism. Research in Autism Spectrum Disorders. 6(2):842–851. DOI: 10.1016/j.rasd.2011.11.005 [PubMed: 22639682]

Elsabbagh M, Fernandes J, Jane Webb S, et al. 2013; Disengagement of Visual Attention in Infancy is Associated with Emerging Autism in Toddlerhood. Biological Psychiatry. 74(3):189–194. DOI: 10.1016/j.biopsych.2012.11.030 [PubMed: 23374640]

Fischler MA, Bolles RC. 1981; Random Sample Consensus: A Paradigm for Model Fitting with Applications to Image Analysis and Automated Cartography. Commun ACM. 24(6):381–395. DOI: 10.1145/358669.358692

Flanagan JE, Landa R, Bhat A, et al. 2012; Head lag in infants at risk for autism: a preliminary study. AJOT: American Journal of Occupational Therapy. 66(5):577–+. [PubMed: 22917124]

Gabrielsen TP, Farley M, Speer L, et al. 2015; Identifying autism in a brief observation. Pediatrics. 135(2):e330–338. DOI: 10.1542/peds.2014-1428 [PubMed: 25583913]

Gotham K, Risi S, Pickles A, et al. 2007; The Autism Diagnostic Observation Schedule: Revised Algorithms for Improved Diagnostic Validity. Journal of Autism and Developmental Disorders. 37(4):613–627. DOI: 10.1007/s10803-006-0280-1 [PubMed: 17180459]

Hallgren KA. 2012; Computing Inter-Rater Reliability for Observational Data: An Overview and Tutorial. Tutorials in quantitative methods for psychology. 8(1):23–34. [PubMed: 22833776]

Harris NS, Courchesne E, Townsend J, et al. 1999; Neuroanatomic contributions to slowed orienting of attention in children with autism. Cognitive Brain Research. 8(1):61–71. [PubMed: 10216274]

Hashemi J, Tepper M, Vallin Spina T, et al. 2014; Computer Vision Tools for Low-Cost and Noninvasive Measurement of Autism-Related Behaviors in Infants. Autism Research and Treatment. 2014:e935686.doi: 10.1155/2014/935686

Hashemi J, Campbell K, Carpenter K, et al. 2015; A scalable app for measuring autism risk behaviors in young children: A technical validity and feasibility study. EAI Endorsed Transactions on Scalable Information Systems. 16(10)doi: 10.4108/eai.14-10-2015.2261939

Hood BM, Atkinson J. 1993; Disengaging visual attention in the infant and adult. Infant Behavior and Development. 16(4):405–422.

Jones EJH, Dawson G, Kelly J, et al. 2017; Parent-delivered early intervention in infants at risk for ASD: Effects on electrophysiological and habituation measures of social attention. Autism Research: Official Journal of the International Society for Autism Research. doi: 10.1002/aur.1754

Jones W, Klin A. 2013; Attention to Eyes is Present But in Decline in 2–6 Month-Olds Later Diagnosed with Autism. Nature. 504(7480):427–431. DOI: 10.1038/nature12715 [PubMed: 24196715]

Kassambara, A; Kosinski, M. survminer: Drawing Survival Curves using 'ggplot2'. 2016. Available at: https://CRAN.R-project.org/package=survminer

Landa RJ, Kalb LG. 2012; Long-term Outcomes of Toddlers With Autism Spectrum Disorders Exposed to Short-term Intervention. Pediatrics. 130(Supplement 2):S186–S190. DOI: 10.1542/peds.2012-0900Q [PubMed: 23118250]

Lord C, Risi S, Lambrecht L, et al. 2000; The autism diagnostic observation schedule-generic: a standard measure of social and communication deficits associated with the spectrum of autism. Journal of Autism and Developmental Disorders. 30(3):205–223. [PubMed: 11055457]

Mullen, E. Mullen scales of early learning (AGS ed). Circle Pines, MN: American Guidance Service Inc; 1995.

Nadig AS, Ozonoff S, Young GS, et al. 2007; A prospective study of response to name in infants at risk for autism. Archives of Pediatrics & Adolescent Medicine. 161(4):378–383. DOI: 10.1001/archpedi.161.4.378 [PubMed: 17404135]

Oberman LM, Winkielman P, Ramachandran VS. 2009; Slow echo: facial EMG evidence for the delay of spontaneous, but not voluntary, emotional mimicry in children with autism spectrum disorders. Developmental Science. 12(4):510–520. DOI: 10.1111/j.1467-7687.2008.00796.x [PubMed: 19635079]

Oner P, Oner O, Munir K. 2014; Three-item Direct Observation Screen (TIDOS) for autism spectrum disorder. Autism. 18(6):733–742. DOI: 10.1177/1362361313487028 [PubMed: 24126869]

Pierce K, Conant D, Hazin R, et al. 2011; Preference for geometric patterns early in life as a risk factor for autism. Archives of General Psychiatry. 68(1):101–109. DOI: 10.1001/archgenpsychiatry.2010.113 [PubMed: 20819977]

R Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing; Vienna, Austria: 2014. Available at: http://www.R-project.org/

Revelle, W. psych: Procedures for Personality and Psychological Research. Northwestern University; Evanston, Illinois, USA: 2014. Available at: http://CRAN.R-project.org/package=psych [accessed 4 January 2008]

Robins DL, Casagrande K, Barton M, et al. 2014; Validation of the Modified Checklist for Autism in Toddlers, Revised With Follow-up (M-CHAT-R/F). PEDIATRICS. 133(1):37–45. DOI: 10.1542/peds.2013-1813 [PubMed: 24366990]

Rogers SJ, Estes A, Lord C, et al. 2012; Effects of a Brief Early Start Denver Model (ESDM)–Based Parent Intervention on Toddlers at Risk for Autism Spectrum Disorders: A Randomized Controlled Trial. Journal of the American Academy of Child & Adolescent Psychiatry. 51(10):1052–1065. DOI: 10.1016/j.jaac.2012.08.003 [PubMed: 23021480]

Sacrey LAR, Armstrong VL, Bryson SE, et al. 2014; Impairments to visual disengagement in autism spectrum disorder: A review of experimental studies from infancy to adulthood. Neuroscience & Biobehavioral Reviews. 47:559–577. DOI: 10.1016/j.neubiorev.2014.10.011 [PubMed: 25454358]

Shultz S, Klin A, Jones W. 2011; Inhibition of eye blinking reveals subjective perceptions of stimulus salience. Proceedings of the National Academy of Sciences of the United States of America. 108(52):21270–21275. DOI: 10.1073/pnas.1109304108 [PubMed: 22160686]

Solso S, Xu R, Proudfoot J, et al. 2016; Diffusion Tensor Imaging Provides Evidence of Possible Axonal Overconnectivity in Frontal Lobes in Autism Spectrum Disorder Toddlers. Biological Psychiatry. 79(8):676–684. DOI: 10.1016/j.biopsych.2015.06.029 [PubMed: 26300272]

Therneau, T. A Package for Survival Analysis in S_ version 2.38. 2015. Available at: https://CRAN.R-project.org/package=survival>

Wei LJ, Lin DY, Weissfeld L. 1989; Regression Analysis of Multivariate Incomplete Failure Time Data by Modeling Marginal Distribution. Journal of the American Statistical Association. 84:1065–1073.

Werner E, Dawson G, Osterling J, et al. 2000; Brief report: Recognition of autism spectrum disorder before one year of age: a retrospective study based on home videotapes. Journal of Autism and Developmental Disorders. 30(2):157–162. [PubMed: 10832780]

Wickham, H. ggplot2: elegant graphics for data analysis. Springer; New York: 2009. Available at: http://had.co.nz/ggplot2/book

Wickham, H. tidyr: Easily Tidy Data with ‘spread()’ and ‘gather()’ Functions. 2016. Available at: https://CRAN.R-project.org/package=tidyr

Wickham, H; Francois, R. dplyr: A Grammar of Data Manipulation. R package version 0.4.1. 2015. Available at: http://CRAN.R-project.org/package=dplyr

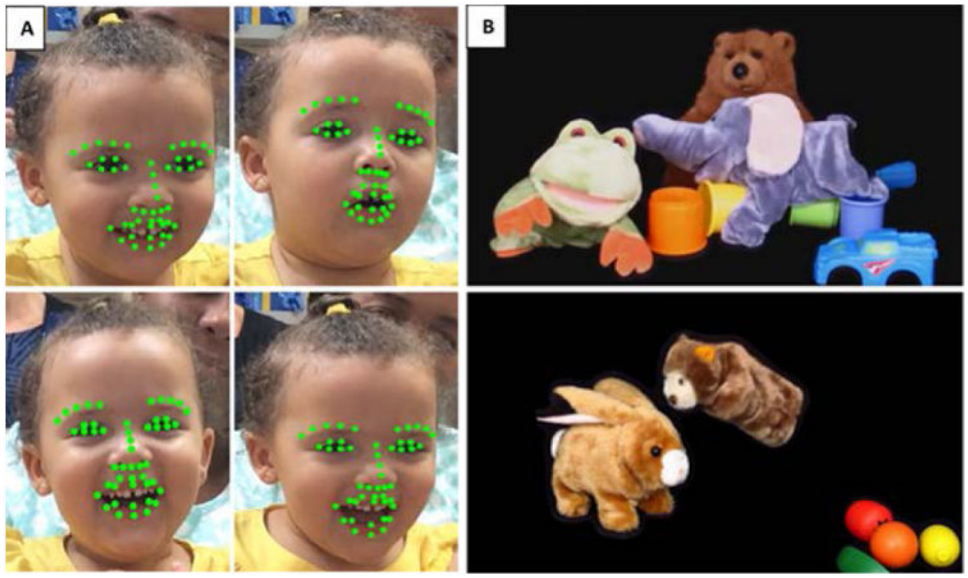

Figure 1.
Experimental setup and facial landmark detection: A) participant sitting on caregiver's lap with experimenter standing behind. A subset of the detected facial landmarks are shown demonstrating detection of face position (green dots). B) Example frames from video stimuli.

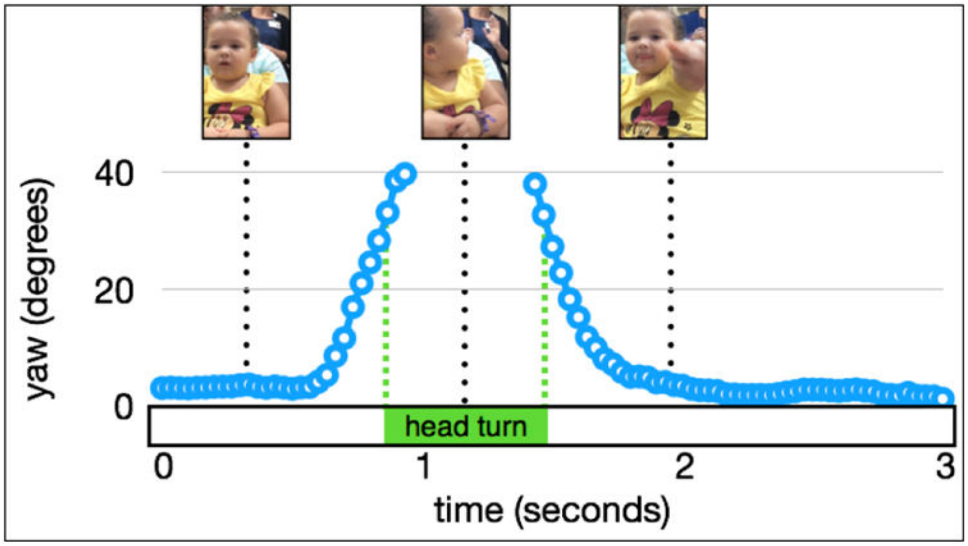

Figure 2.
Example of detecting a head turn after a name call (time=0). From estimated yaw position (shown in blue circles), we detect instances when the head left the frame from a head turn (shown in green squares). Screenshots from the recorded video are displayed above.

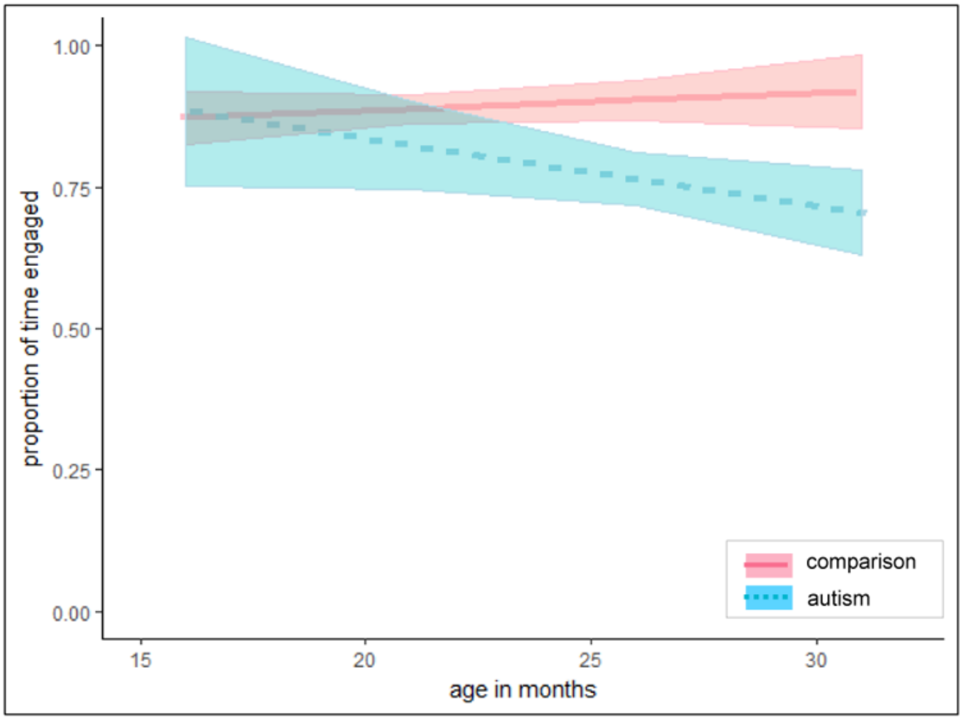

Figure 3.
Predicted means (lines) and 95% confidence intervals (shaded areas) for proportion of time engaged in the task from models covarying for the age by group interaction (p=0.03). The autism group (blue dashed line) showed less time attending at older ages than the comparison group (pink solid line).

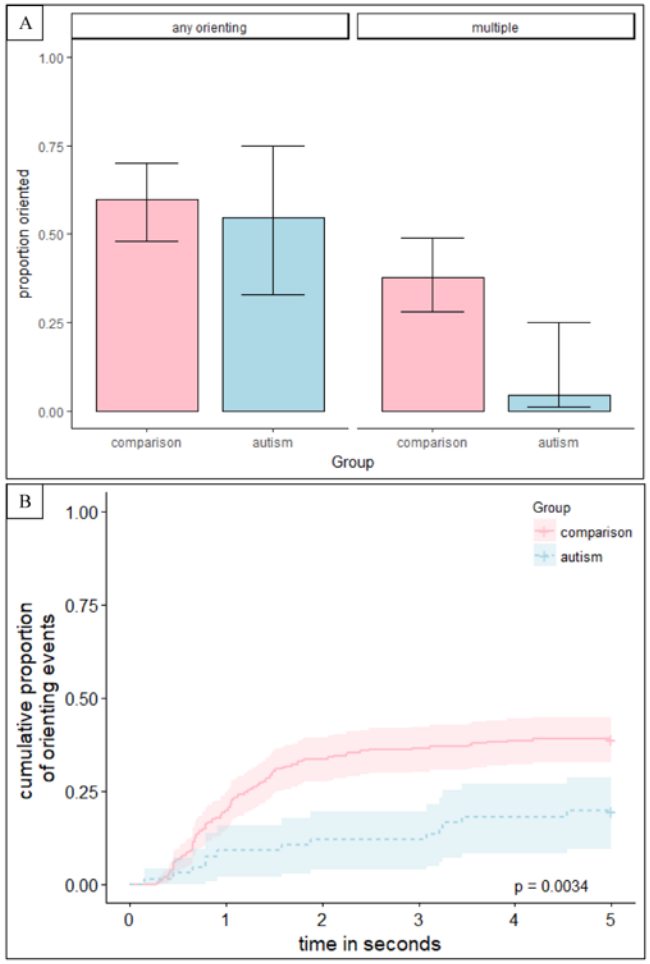

Figure 4.

Orienting to Name: (A) Proportion of participants orienting to name in comparison group (pink) vs autism group (blue) on any of the name calls (left panel) vs multiple (2 or 3 times, right panel, p=0.002), with error bars showing 95% CI (confidence intervals) of proportions. (B) Kaplan-Meier plots of cumulative events over time with 95% CI (shading) for each group showing slower orienting in the autism group (blue dashed line).

Table 1

Subject Characteristics. Reported as means (standard deviations) or number (proportion).

	Comparison N=82	Autism N=22	P-value
Males	48 (59%)	17 (77%)	0.09
developmental delay	8	-	
Age in months	21.91 (3.78)	26.19 (4.07)	<0.001
Race			0.56
Caucasian	48 (59%)	10 (45%)	
African American	11 (13%)	3 (14%)	
Asian	5 (6%)	1 (5%)	
Multiracial or Other	18 (22%)	8 (36%)	
Screen Time in hours	1.15 (0.96)	2.18 (1.58)	0.02
ELC on MSEL	-	63.58 (25.95)	
ADOS-T Total	-	18.81 (4.20)	

ADOS-T=Autism Diagnostic Observation Schedule-Toddler; ELC=Early Learning Composite; MSEL=Mullen Scales of Early learning.

Table 2

Comparison of orienting to name for participants with autism on 3 measures.

Participant	Experiment Orients	M-CHAT-R Orients	ADOS-T Orients (B07 score)	M-CHAT-R Score (Follow up Score)	ADOS-T Total
1	no	no	yes (1)	7 (6)	14
2	no	no	yes (1)	15	24
3	no	no	no (3)	13	21
4	yes	yes	yes (0)	2	22
5	no	yes	yes (1)	4 (2)	19
6	no	no	no (2)	8	22
7	no	no	yes (0)	11	22
8	no	no	no (2)	14	23
9	no	no	no (2)	16	20
10	yes	no	no (2)	13	22
11	yes	no	no (2)	11	19
12	no	yes	NA[a]	6	NA[a]
13	no	yes	yes (1)	7 (2)	23
14	no	no	yes (1)	5 (2)	19
15	yes	yes	no (2)	12	13
16	no	yes	no (2)	4 (0)	22
17	no	yes	yes (0)	8	13
18	yes	yes	yes (1)	5 (3)	17
19	yes	yes	no (2)	6 (4)	20
20	yes	yes	yes (0)	2	11
21	no	yes	yes (0)	2	10
22	no	yes	yes (0)	7 (5)	19
% failing	68%	45%	43%	82%	100%

Shaded cells indicate failing the task.

[a] - Participant 12 had an ADOS-T report in the chart but without item scores.

M-CHAT-R=Modified Checklist for Autism in Toddlers, Revised; ADOS-T=Autism Diagnostic Observation Schedule-Toddler; B07=Item B07 on the ADOS-T.

Table 3

Number of children in each group orienting to name inconsistently (less than twice) vs consistently (twice or more) in each group.

Group	Oriented less than twice	Oriented twice or more	Total
Autism	21	1	22
Comparison	51	31	82
Total	72	32	104