Hidden Literacy in Minimally Verbal Autistic Individuals Revealed by Eye Gaze

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Abstract

Minimally verbal autistic individuals (mvASD) are often presumed to have severe cognitive and language impairments based on their poor performance on standardized assessments requiring voluntary motor responses, such as pointing. However, emerging evidence suggests that these individuals may possess latent cognitive abilities. Here, we introduce the Cued Looking Paradigm (CLP), a novel eye-tracking method that bypasses motor requirements by capturing involuntary gaze responses to language-based stimuli. In our study, 35 minimally verbal autistic adolescents and adults were presented with spoken or written words, followed by a pair of images (target and foil) as their eye movements were recorded. The majority (83%) of mvASD participants demonstrated hidden receptive language and reading abilities, with eye gaze performance, including time course and spatial displacement, comparable to neurotypical controls. In contrast, the same mvASD individuals averaged only 57% accuracy when asked to point to the target, revealing a significant gap between reporting via pointing and actual lexical-semantic knowledge. Furthermore, pupil dilation analysis during tasks indicated reduced arousal recruitment in mvASD participants, potentially implicating dysregulation of the locus coeruleus-norepinephrine (LC-NE) system associated with the performance gap between pointing and eye-gaze. These findings challenge assumptions of global intellectual limitation while confirming specific lexical-semantic competence among mvASD individuals. Results highlight the need for- and provide alternative- assessments that bypass manual motor responses. The CLP shows promise for revealing cognitive and language abilities, with important implications for both research and education.

Significance Statement

Standard language tests assume that a person can point or speak. Although minimally verbal individuals can point, their accuracy is often variable, and pointing may not reliably reflect their comprehension. Using a simple eye-tracking task that replaces pointing with automatic gaze shifts, we demonstrate that most mvASD participants accurately match spoken or written words to pictures—even though they fail the same task when pointing is required. This finding overturns the long-standing belief that absence of speech equates to absence of understanding and reveals systematic bias in

common assessments. Motor-free tools like the Cued Looking Paradigm, together with broader systematic modifications in assessment and treatment, could transform diagnosis, guide individualized education, and open new research avenues on covert language processing in neurodevelopmental conditions.

Introduction

Minimally verbal autistic individuals (mvASD), estimated about 30% of the autism spectrum (Chakrabarti 2017; Tager-Flusberg and Kasari 2013) have often been grouped together with autistics with cooccurring intellectual disabilities (Pizzano et al. 2024). This categorization is primarily based on their poor performance on conventional assessments (Kasari et al. 2013), such as the PPVT-4 or Raven's Progressive Matrices, which depend on voluntary motor responses (Courchesne et al. 2015). While one explanation attributes this to true deficits in cognition and receptive language (Chen et al. 2024), such an interpretation may overlook the heterogeneity within the mvASD population (Pizzano et al. 2024). This heterogeneity is supported by reports from caregivers and clinicians of clear signs of comprehension of spoken or printed words. Indeed, a lack of spoken language and inconsistent behavior do not necessarily indicate impaired comprehension or cognition (Eagle 2003). Supporting this view, Courchesne et al. (2015) found that two-thirds of mvASD children scored within the typical age-range (>70) on a modified version of the Raven's Colorful Progressive Matrices (RCPM) (Bal et al. 2016; Bello et al. 2008, Pizzano et al 2024), see also (Sykes-Haas & Bonneh, 2025, preprint). These findings suggest that poor performance on standardized tests may not reflect a lack of ability, but rather difficulties in voluntarily demonstrating cognitive skills, leading to floor performance and underestimated competence (Courchesne et al. 2015; Kasari et al. 2013). This pattern is echoed in our recent study (Sykes-Haas & Bonneh, 2025, preprint) in which mvASD children (ages 6–11) frequently *fixated* on the target in a simple visual oddball task but failed to *point* to it, underscoring a striking gap between perceptual capacity and voluntary action.

We propose that for some (or many) mvASD individuals, the primary barrier to communication may be a profound difficulty in executing intentional motor actions. That is, dysregulated action selection may impair the ability to produce appropriate motor behavior—a challenge best conceptualized as an "output problem" (see Cisek, 2007 for a description of the affordance competition hypothesis for action selection). Unlike voluntary pointing, which for many minimally verbal individuals remains an effortful and non-automatized action, eye gaze is a highly overlearned and largely automatic response, making it a particularly suitable window into latent cognitive abilities (Mishra et al. 2013).

Taken together, the aforementioned findings and observations highlight the need for alternative assessment approaches that among others may rely on involuntary, automatized, or physiological responses. Such methods may bypass impaired voluntary

motor control or disrupted affordance competition, and reveal cognitive abilities that remain hidden in tasks requiring voluntary actions, such as pointing (Courchesne et al. 2015; Gernsbacher et al. 2008; DiStefano et al. 2019). To address this need, we introduce the **Cued Looking Paradigm (CLP),** a novel eye-tracking method designed to uncover receptive language and reading skills in individuals with mvASD. Unlike the Looking-While-Listening (LWL) paradigm (Plesa-Skwerer et al. 2016) which may still involve voluntary search behavior, CLP may reduce task load by presenting the auditory or written cue *before and separately from* the image pair. This design may promote automatic gaze responses without engaging conscious decision-making or deliberate motor planning (Mishra et al. 2013). We hypothesize that due to these aforementioned modifications the CLP, will more accurately capture lexical-semantic competence in minimally verbal individuals with autism.

Evidence for Hidden Cognition and Action-Control Deficits in mvASD

Clinical observations suggest that some preverbal toddlers and older children with mvASD demonstrate rapid eye gaze to correct objects when prompted, even when they fail to point (author NSK, personal clinical experience). Some mvASD individuals can independently communicate through typing (Orlievsky and Cukier 2013). Unlike the discredited facilitated communication method (Mostert 2001), these individuals generate meaningful text without physical assistance (Orlievsky and Cukier 2013), and some report difficulties initiating and controlling intentional actions (Bonneh et al. 2008), such as pointing inaccurately despite knowing the correct response (Kedar 2012). Jaswal et al. (2024; 2020) provide indirect support for this dissociation. Eye-tracking during letterboard use showed that mvASD participants fixated on each letter just before touching it, with timing like neurotypical spellers. A follow-up study using a fixed iPad ruled out manual prompting by assistant and found independent letter selection and faster responses for meaningful sentences and common letter pairs, consistent with English orthographic knowledge. These findings suggest lexical–semantic literacy in low-verbal autistic individuals. Additionally, some researchers have linked autism to catatonia, a condition where individuals retain awareness but struggle to initiate actions (Wing and Shah 2006). Across these findings, a common theme emerges: a consistent gap between observed overt behavior and latent cognitive abilities.

Despite this compelling evidence for latent cognitive abilities in mvASD, we do not endorse the notion that minimally verbal autistic individuals are simply typically developing individuals whose intact cognition and perception are merely masked by output barriers. We acknowledge that these individuals face substantial expressive challenges that are not yet fully understood or characterized and could largely vary across individuals. Our position is that certain research approaches or experimental contexts may allow previously unobservable or latent capacities to become evident. The nature and developmental status of these capacities—whether potential, partially or

substantially developed, or contextually hidden—remain open empirical questions rather than theoretical assumptions of intact or typical functioning.

Limitations of ERP and LWL Approaches

Several studies have used ERP methods to explore receptive language in mvASD without requiring active responses. Most focus on the N400 component, which signals mismatches between spoken words and visual stimuli (Cantiani et al. 2016; Coderre et al. 2019; DiStefano et al. 2019). However, results have been mixed; only one study found significant semantic processing in a group of 20 mvASD children (DiStefano et al. 2019). Group-level findings suggest some sensitivity to lexical processing, but individual variability and task constraints remain limiting. Eye-tracking offers a noninvasive, behavior-independent alternative for assessing cognition like in the aforementioned LWL paradigm (Fernald and Zangl 2008). However, Plesa-Skwerer et al. (2016) did not find eye-gaze performance more informative than pointing. We suggest that these findings may reflect task complexity of the LWL rather than true ability and that the novel CLP overcomes these experimental challenges.

The current study

In the present study, 35 minimally verbal autistic adolescents and adults completed two CLP conditions (spoken-word and written-word trials). In matched conditions with identical cues and response stimuli, participants were also asked to respond by pointing to laminated cards, simulating standard educational assessments (e.g., PPVT-4). This design allowed us to directly compare gaze-based and manual responses within the same individuals. Strikingly, the CLP revealed lexical-semantic knowledge that was not evident from pointing responses, suggesting that gaze-based methods provide a more accurate estimate of cognitive abilities in mvASD.

Methods

Participants

Participant characteristics are summarized in Table 1. The study was approved by the Bar-Ilan University Ethics Committee, and written informed consent was obtained from all adult participants or their legal guardians. Five mvASD participants were excluded during eye-tracking quality control, leaving 30 mvASD and 30 TD individuals in the final analysis.

Characteristic	**mvASD (n = 35)**	**TD (n = 30)**
Age (years)	19.5 ± 4.2 (15–30)	19.8 ± 4.0 (15–29)
Sex (F / M)	9 / 26	10 / 20
Primary language	Hebrew (100%)	Hebrew (100%)
Functional spoken words	< 30 (caregiver report)	Typical
SCQ total score	24.7 ± 6.1	
Diagnosis basis	DSM-IV/5 certificate	
Recruitment source	Clinics & special-ed schools	Community adverts
Key exclusions	Epilepsy; able to read aloud	Neurologic/psychiatric history

Table 1. Participant characteristics

Thirty-five adolescents and young adults with autism spectrum disorder (mvASD; aged 15–30 years; mean age 19.5) and a comparable group of 30 age-matched typically developing (TD) adolescents and young adults participated in the study. All mvASD participants had an official diagnosis based on DSM-IV or DSM-5 criteria (State of Israel regulations). According to parent and/or teacher reports, they had little to no functional language, using fewer than 30 words for communication. mvASD participants were recruited by word of mouth through clinics and special-education schools and all came from Hebrew-speaking homes. The Social Communication Questionnaire (SCQ) was completed by a caregiver (teacher or parent) to support the ASD diagnosis. Limited verbal communication was verified in a brief (15-min) interaction by the experimenter (author KE, a special-education teacher). Exclusion criteria for the mvASD group included any form of epilepsy and the ability to read aloud from text (even if minimally verbal and with speech not used for communication).

Stimuli and Procedures

Cued-Looking Paradigm (CLP). We adapted the seminal Looking-While-Listening (LWL) paradigm (Fernald and Zangl 2008), modifying it to present the cue word first and to use shorter stimulus durations. This adaptation allows testing of both text reading and speech comprehension. We refer to this as the "cued-looking" paradigm because the word—whether written or spoken—acts as a pre-cue or prime. The paradigm is illustrated in Figure 1.

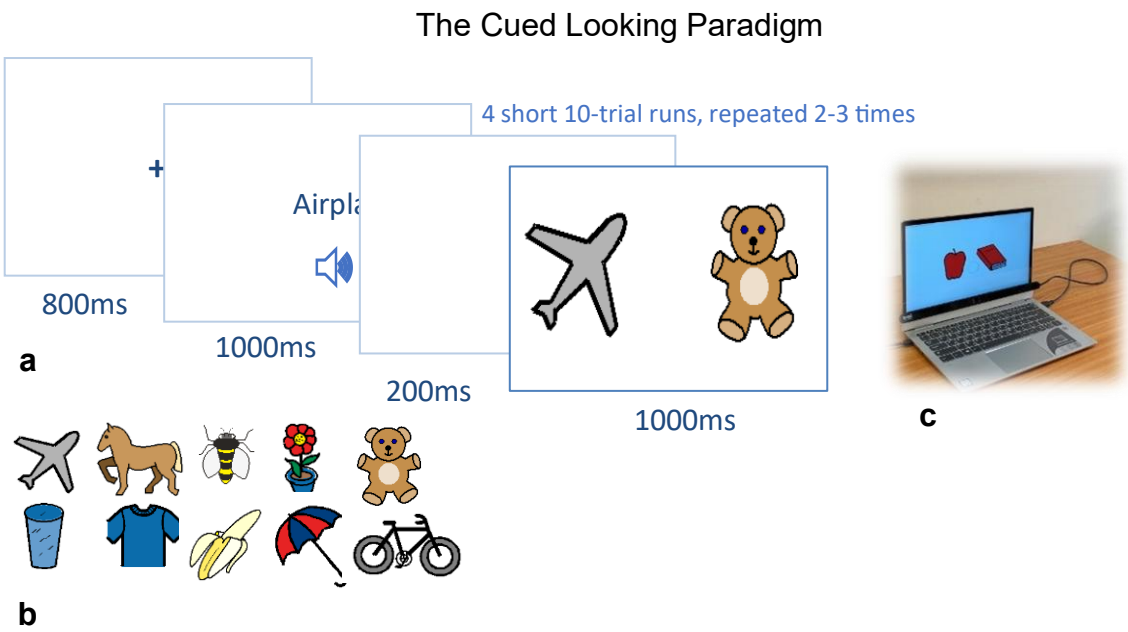

Figure 1. The Cued Looking Paradigm (CLP). (a) Trial sequence. Each trial begins with central fixation, followed by a cue (spoken or written word), a brief blank interval, and then two side-by-side pictures, target and foil. Display durations are indicated in the schematic. Participants are instructed to look at the named (spoken or written) item; gaze typically shifts automatically to the matching image. (b) Examples of the simple object drawings used as stimuli.

Stimuli: Color drawings of simple objects (examples in Figure 1b) were presented on a white background with luminance of ~150 cd/m². Images appeared ~4 dva (degrees of visual angle) from fixation on the horizontal meridian (based on an average viewing distance of 54 cm) and typically subtended ~4° in diameter. Their mean luminance was ~70 cd/m² (SD 25 cd/m² for the inner parts), and the average RMS contrast across images was 0.472 (SD = 0.114), computed from pixel-wise relative luminance. In total, 28 images were used, taken from an educational image set (Widgit Symbols, The Center for Educational Technology, Tel Aviv, Israel). Text cues were presented in black Hebrew font (~1 dva high and ~3–5 dva wide). Spoken words were pre-recorded by a female colleague from the lab and played through the computer's speaker at ~67 dB SPL with a duration of ~1 s (SD = 0.04 s).

Procedure: Experiments were run on a 13.3-inch Windows laptop with an FHD display at 60 Hz using the PSY experimental tool developed by author YSB, as in our previous studies (e.g., Bonneh et al. 2016). While observers fixated a central cross, a spoken or written cue was presented for 1 s, followed by a 200 ms blank screen and then a 1 s presentation of two side-by-side images (target and foil), one of which (the target)

matched the cue (Figure 1a). Participants were instructed to look at the named object. Each experiment comprised four runs of 10 trials lasting 40–50 s each, repeated 2–3 times (~100 trials per experiment). To sustain attention, a transparent "bubble" dynamically displayed real-time gaze position (a Tobii tracker feature). The experimenter (author KE) sat behind the participant, mostly invisible, to monitor tracking quality. If tracking was interrupted, the run was repeated after a short or long break.

Pointing Paradigm. We conducted additional pointing experiments using the same vocabulary and images presented on printed cards. In the written cue condition each standard A4 card (~21 × 30 cm) displayed a text word and two images. Cards were shown until participants responded, and performance was recorded manually. Participants viewed the cards from ~50 cm. The text spanned ~5 × 1 cm, and each image measured 9 × 9 cm. A total of 40 cards were used, each presented once. The experiment was repeated with spoken words, in which the experimenter asked the participants to "Show me the object" referring to the target word. This format simulated conditions commonly encountered in educational settings and paper-based assessments used to evaluate cognitive abilities in individuals with severe autism.

Eye-tracking and Data Analysis

Eye tracking: Participants' eye movements were recorded with a Tobii 4C eye tracker sampling at 90 Hz, which we found to be reliable and robust for head-free tracking. Accuracy was verified in preliminary experiments with controls, yielding a typical fixation SD of ~0.5 dva in the current setup. This precision is also evident in the main results, including effects of pupil-size changes of <1%. Before each session, the tracker was calibrated using Tobii's fast four-point calibration. Some mvASD participants required several attempts. In a few cases, calibration failed; for these participants we used calibration data from another participant with a similar profile (see below for how calibration inaccuracy was handled).

Preprocessing:

Because participants viewed the stimuli with unrestricted head movements (see Procedure), actual viewing distance varied across trials and participants. For each trial we estimated viewing distance as the mean eye-to-screen distance from –0.4 to 0 s relative to tracking onset, excluding >2 SD outliers. Average participant distances ranged from 42–74 cm (one control outlier at a higher distance). Group means were similar (controls 56.5 cm; mvASD 54.1 cm; $p = 0.28$). To standardize gaze data across participants for group-level averaging, eye positions were converted from screen pixels to degrees of visual angle using a fixed reference distance of 54 cm. Data were preprocessed to detect and remove periods without tracking and blinks (including preceding vertical displacements) with a 50 ms margin, following our previous studies (Bonneh et al. 2016). Epochs were extracted from –2 s to +3 s relative to picture onset

(Figure 1a). Participants with fewer than 20 valid epochs (epochs containing >50% valid samples) were excluded, leaving 30 mvASD participants. Additional epochs were rejected if fixation during the reading period (–1.2 to –0.2 s before image presentation) was inaccurate (Figure 1a). To mitigate calibration inaccuracy, we computed each participant's baseline fixation during the reading period (averaged across runs) and marked as invalid any epoch whose displacement from baseline exceeded a threshold. A 4 dva threshold was used for testing individual significance, and a stricter 2 dva threshold for performance analyses (rejecting more trials but improving accuracy). Outliers exceeding 2 SD from the mean were removed from all computed averages.

Gaze laterality and performance: Two primary measures were derived from the CLP: (1) Gaze Laterality (Figures 2a,b) and (2) Eye-gaze Performance (Figure 2c). *Gaze laterality* was computed by averaging horizontal gaze traces of valid epochs sorted by target side (left or right), rejecting >2 SD outliers at each time point, and baseline-correcting (subtracting the mean gaze position from –2 to –0.2 s before image presentation). This analysis was used to visualize and quantify the time course of lateralized gaze, which then defined the time window for the performance measure. *Eye-gaze performance* (percent correct) was computed by averaging the horizontal gaze position per trial in the 0.25–1.5 s window after image onset (again removing >2 SD outliers and baseline-correcting using the –2 to 0 s period, termed "Hav"). A trial was scored as correct when the sign of Hav matched the side of the target. Invalid trials (deviant fixation during reading; 2 dva threshold) were excluded. For each participant, we assessed above-chance laterality by testing the difference between Hav values for left- versus right-sided targets using one-tailed t-tests and Wilcoxon rank-sum tests with FDR correction (Benjamini and Hochberg 1995) across participants, excluding trials with deviant fixation (4 dva threshold). Group comparisons used two-tailed t-tests, and we additionally computed effect sizes (Cohen's d).

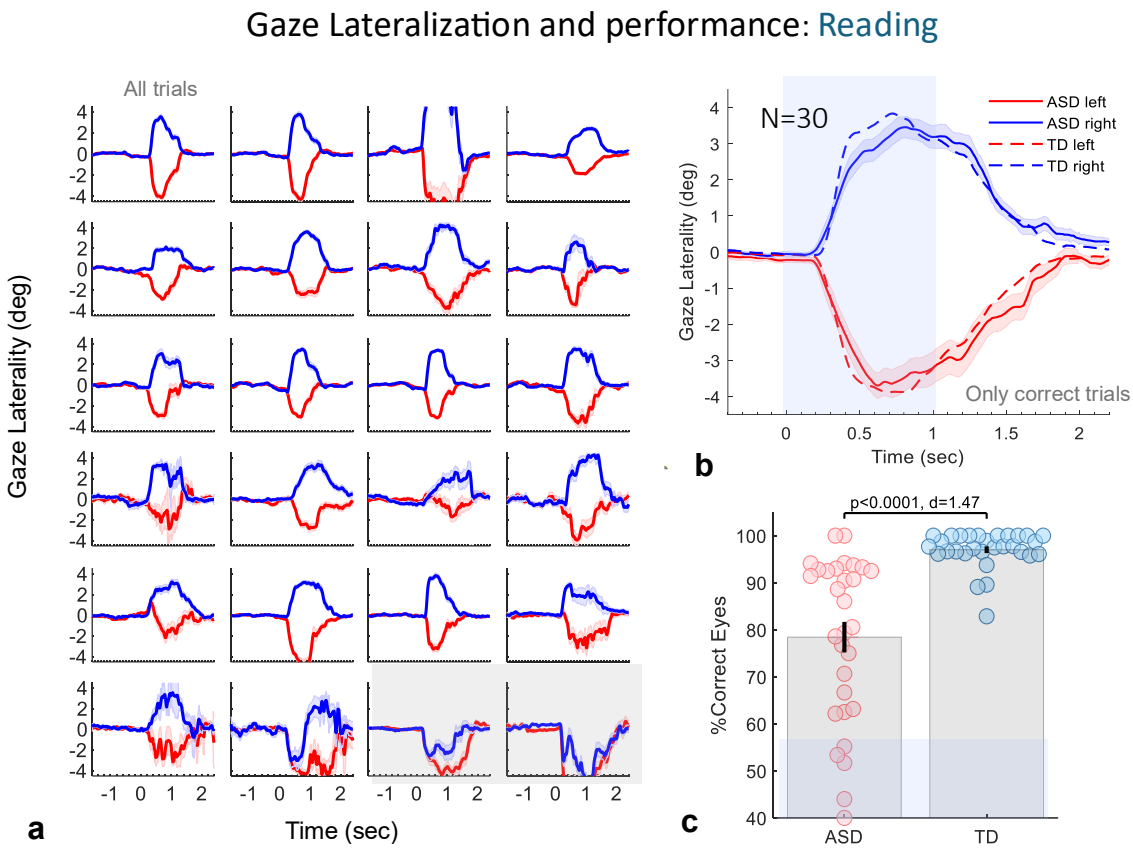

Figure 2. Gaze lateralization in the reading CLP. (a) Horizontal eye position over time for 24 of 30 mvASD participants. Traces are sorted by target side (right: positive values in blue; left: negative in red). All but two participants show clear lateralization toward the correct picture; the two examples in gray panels (bottom right) show no significant lateralization. (b) Group-average gaze traces for all mvASD participants and for all typically developing (TD) controls (dashed lines), including only correct trials. Error sleeves denote 1SE across mvASD participants. Movement toward the correct picture begins ~250 ms after image onset and follows a similar time course in both groups. (c) Eye-gaze performance (percent-correct lateralization) for the mvASD and TD groups shown as a bee-swarm plot. Each dot represents one participant, with group means ±1 SE overlaid. Significance (Wilcoxon rank-sum test) and Cohen's d are shown, and insignificant performance is indicated by shaded symbols.

Pupil analysis: Pupil dilation was analyzed by first averaging left-eye pupil traces from valid epochs (good fixation; see above) with correct lateralization, rejecting outliers (>2 SD from the mean) at each time point and converting the values to a percentage relative to baseline (the epoch's average pupil size during the last 1 s before image presentation). This procedure was used for visualization and for determining the region for peak detection. We then computed the maxima and minima of the pupil traces, as well as the mean percentage change from baseline (1 s pre-image period) in the 0.5–1 s window after image presentation.

Head movement: We analyzed the head movement around the time of presentation of the images to assess its impact on performance. We used the distance from the monitor time course provided by the tracker to compute its absolute derivative (abs(diff(dist)) in matlab) and computed its average in the time 0 to 0.2s post picture presentation, before the eyes started to move.

Perseveration analysis: We quantified motor perseveration using two metrics computed from the sequence of responses in the pointing and eye-gaze tasks. The first and simplest measure was *side bias*, defined as the absolute deviation from equal left/right responses:
Side Bias $= \left| \frac{n_{\text{left}} - n_{\text{right}}}{n_{\text{trials}}} \right|$. This captures the extent to which a participant preferentially pointed to one side across trials. In addition, we computed an *incongruent repetition index*, designed to reflect motor perseveration in the face of task demands. Specifically, we measured how often a participant repeated the same response (left or right) despite a change in the correct side from the previous trial. The metric was calculated as the proportion of trials where the response repeated but the correct side had changed:

$$\text{Incongruent Repetition Rate} = \frac{\text{\# trials where response repeated and correct side changed}}{\text{\# trials where correct side changed}}.$$

A high value indicates a tendency to perseverate in response despite shifting task contingencies. To assess whether incongruent repetition rates exceeded chance expectations, we generated null distributions by simulating 1000 random response sequences per subject, matched in length and trial structure to the observed data. Each subject's observed incongruent repetition index was compared to this distribution to compute a Z-score and empirical one-tailed p-value.

Results

Gaze lateralization and performance in reading

Figure 2 presents the results of the Cued Looking Paradigm (CLP) for the reading condition. As described in Figure 1 and the Methods, gaze laterality was analyzed by sorting horizontal eye-position traces by target side (left vs. right) and normalizing to the pre-stimulus baseline. Trials with poor fixation during the reading period (>2 dva from center) were excluded on a per-participant basis (on average 45% rejected for mvASD and 15% for TD).

Individual examples are shown in Figure 2a. Of the mvASD participants, 22 clearly shifted their gaze toward the correct image, whereas two examples (bottom right) show no lateralization. To identify mvASD participants with statistically significant lateralization, we compared horizontal gaze for left- and right-target trials using one-tailed t-tests and Wilcoxon rank-sum tests with FDR correction across participants (see Methods). Twenty-four mvASD participants (80%) showed significant performance ($p < 0.05$), 17 of them at $p < 0.001$. For computing individual performance we applied a stricter fixation criterion (>4 dva), rejecting on average 35% of mvASD trials and 15% of TD trials.

Figure 2b shows group-average gaze traces for left and right targets in both groups, including only trials with correct lateralization and good fixation. The mvASD and TD groups showed highly similar time courses and spatial displacements. Latency of the first saccade (0.1–0.4 s window) did not differ significantly between groups (276 ms vs. 279 ms for mvASD and TD, respectively). Likewise, maximal gaze laterality in the 0.25–1.5 s was comparable (4.47 dva vs. 4.36 dva) with no significant difference. Figure 2c shows the individual performance and group averages for the reading CLP experiment. The groups clearly differed, with average of 78% vs 97% for mvASD and TD respectively. When excluding the 5 mvASD participants with insignificant performance, the group average was 84.3%. Interestingly, there was a sub-group of 13 mvASD participants who did above 90% correct, although this was mostly below the TD performance average of 97%.

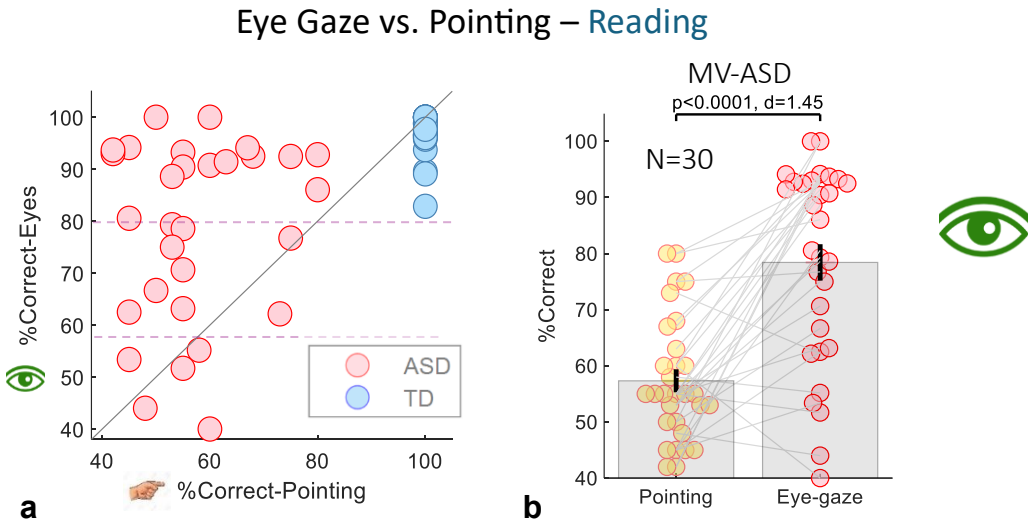

Figure 3. Eye-gaze versus pointing performance. (a,b) Eye-gaze and pointing performance in the reading experiment shown in two formats. (a) Scatter plot of pointing accuracy (x-axis) versus eye-gaze accuracy (y-axis), one dot per participant (red: mvASD; blue: TD controls). Most mvASD participants lie above the diagonal, indicating better performance with eye-gaze than with pointing. The blue dashed line marks the border between participants at chance level (five mvASD participants) and those performing significantly above chance. Thirteen mvASD participants scored above 90% correct. (b) Within-subject comparison of eye-gaze and pointing accuracy for reading. Lines connect data from the same participant; paired t-test p-values and Cohen's d values are reported.

Eye-gaze vs pointing in reading

In a separate experiment, all mvASD participants were tested on the same stimuli presented on laminated cards for pointing—each card containing the text word and two pictures (see Methods). The eye-gaze compared to pointing performance in the reading experiment are shown in Figures 3a,b. In striking contrast to their gaze-based reading, most mvASD participants who showed significant reading with their eyes performed at or near chance when pointing. This pattern is evident in Figure 3a, where most scatter-plot symbols lie above the diagonal (better performance with eyes than with pointing). Group-average performance is shown in Figure 3b, revealing a very low pointing performance (58%) and a highly significant difference between the two testing modes (t-test, $p < 0.0001$, Cohen's $d = 1.45$). This effect was even stronger in the subgroup that scored above 80% with gaze: their average performance was 92% with the eyes versus 58% with pointing.

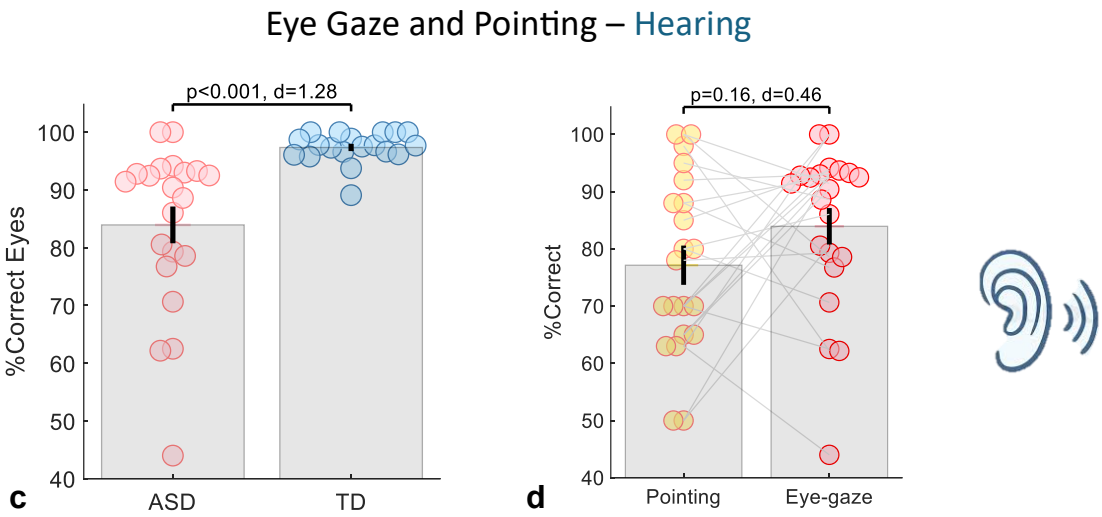

Figure 3. Eye-gaze versus pointing performance. (c, d) Results for the hearing experiment. (c) Percent-correct eye-gaze lateralization, with each dot representing one participant and group means ±1 SE overlaid. (d) Within-subject comparison of eye-gaze and pointing accuracy for hearing, analogous to (b). Most mvASD participants performed well above chance with their eyes but poorly with pointing in the reading condition (five at chance; 13 above 90% correct).

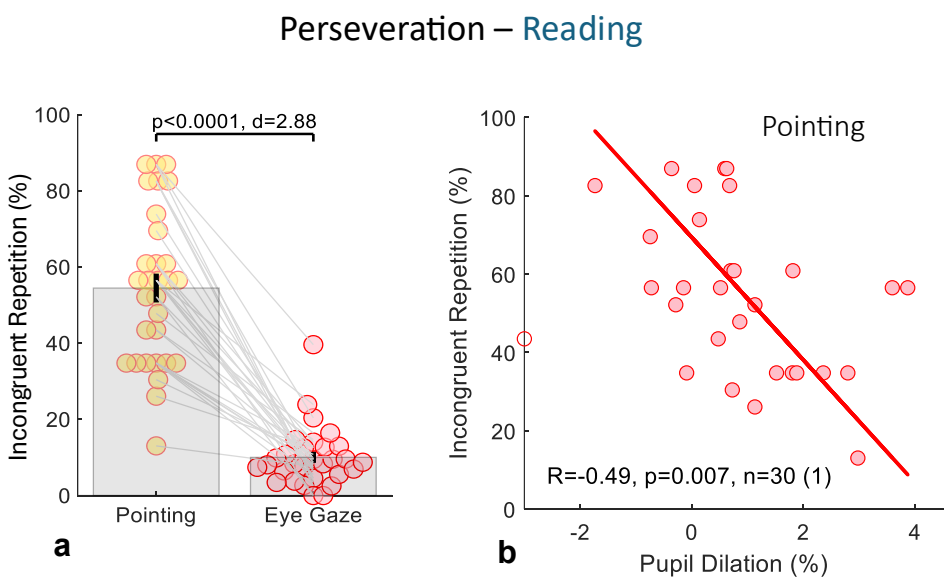

Figure 4. Perseveration in pointing responses (reading CLP). (a) Bee-swarm plot comparing perseveration rates—defined as responding to the same side when the target switches sides—between pointing and eye-gaze. The upper bar indicates t-test p-value and Cohen's d. Pointing shows markedly higher perseveration than eye-gaze. (b) Correlation between pupil dilation during correct reading trials and pointing perseveration in the same participants. Greater pupil dilation is associated with less perseveration (R = 0.49, p = 0.007; outlier shown with open symbol).

Eye-gaze performance for listening

In a second experiment, the text word was replaced with a spoken word (see Methods). Results are shown in Figure 3c,d. Twenty-two of the 30 mvASD participants completed this experiment, which was administered after the reading condition and thus may have been affected by fatigue. Gaze performance in this experiment was slightly higher than in the reading condition, with the mvASD group averaging ~84% (Figure 3c). Importantly, there was no significant difference between pointing and eye-gaze in the listening experiment (Figure 3d).

The two perseveration metrics revealed a clear dissociation between pointing and eye-gaze responses. For side bias, pointing responses showed significantly higher perseveration than gaze ($p < 0.005$, paired *t*-tests on both raw and z-normalized scores). The incongruent repetition index (IRI), a more behaviorally specific measure (Figure 4a), yielded the largest difference between modalities ($p < 0.0001$, $d = 2.28$), with similar results for the z-normalized scores ($p < 0.0001$, $d = 3.48$). Furthermore, the IRI showed a significant negative correlation with pupil dilation in the eye-gaze task ($r = –0.49$, $p < 0.007$), indicating that greater response perseveration in pointing was associated with reduced phasic arousal recruitment during gaze responses. While the side bias measure produced some extreme values (e.g., z-scores > 8) in pointing responses, the incongruent repetition index provided a more balanced and interpretable distribution across participants and best captured the failure to adjust motor output in response to task-relevant changes.

Perseveration measures

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Pupil dilation and gaze performance

Pupil dilation in response to the pictures may reflect both changes in luminance and the recruitment of arousal needed to make a decision and shift gaze. We analyzed pupil-size changes for the two groups in the reading experiment, with results shown in Figure 5. First, we compared the time course of pupil change (percentage relative to the pre-onset baseline; see Methods) in both experiments. As shown in Figure 5a, the TD group exhibited much stronger dilation, peaking around 0.5 s after picture presentation. We quantified dilation per trial by computing the maximum in the 0.5–1 s window after stimulus onset; individual and group averages (including only correct trials; see Methods) are shown in Figure 5b. The TD group showed markedly larger dilation than the mvASD group (5.5% vs. 1.3%, $p < 0.0005$). This difference in dilation could not have been due to differences in exposure to the images since in this analysis only correct trials were taken into account, and the average gaze lateralization for correct trials was very similar between groups (Figure 2b). Figure 5c shows the correlation between pupil dilation and eye-gaze performance (correct trials only). A significant positive relationship emerged between the change from baseline (in %) and eye-gaze performance.

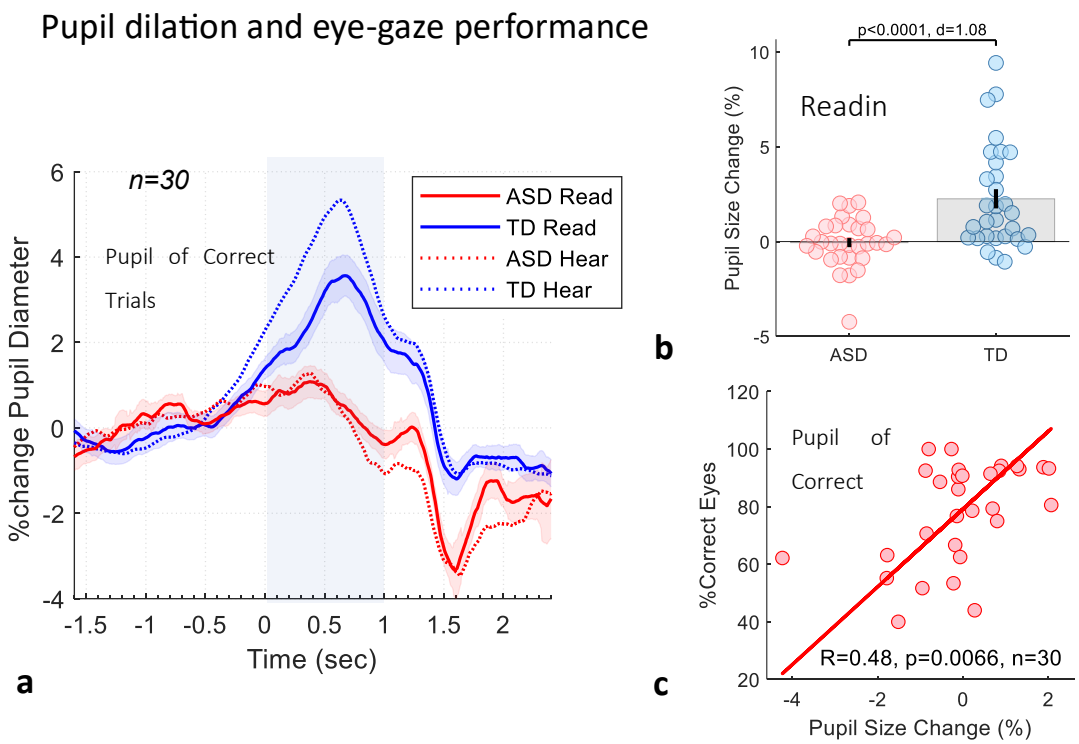

Figure 5. Pupil size change at picture onset in the CLP. (a) Time course of pupil size change (percentage relative to the pre-onset baseline) averaged across participants. Solid lines: reading; dotted lines: hearing. Shaded areas show ±1 SE. (b) Mean pupil change 0–1 s post-onset for correct trials in reading, plotted as group means ±1 SE with individual data points overlaid. mvASD participants show markedly reduced dilation compared with TD controls (n = 30 each). (c) Correlation between pupil size change from (b) and eye-gaze performance for each mvASD participant.

Discussion

Revealing Hidden Abilities via Eye Gaze: Summary of Findings

The Cued Looking Paradigm (CLP), which presents spoken/written words *prior* to visual stimuli measuring eye-gaze laterality, offers, to our knowledge the first systematic direct evidence of hidden reading and receptive language skills in individuals with mvASD, challenging assumptions of severe cognitive and language impairments and extending recent reports of strengths in communication and cognition found in some individuals (Pizzano et al. 2024). A clear dissociation between gaze-based performance and traditional pointing responses suggests that standard assessment methods may significantly underestimate cognitive abilities in this population.

Gaze–Pointing Dissociation and the Role of Automaticity

Most mvASD adolescents and adults showed a clear reading effect during the CLP, similar to neurotypical (NT) controls. This was evident in their consistent lateral gaze toward target image. In the written-word condition, mvASD participants demonstrated similar reaction times and saccade amplitudes to NT participants. Similar results were found in the spoken-word condition. However, many of the same individuals performed at or near chance when asked to point to the correct image on laminated cards. This striking dissociation could reflect the fact that, unlike eye gaze—a highly overlearned and largely automatic response (Mishra et al. 2013) —pointing remains an effortful, non-automatized skill for many minimally verbal individuals, making it a challenge in testing situations. Similar gaze–pointing dissociations have been observed by our group in other tasks, including a simple visual oddball paradigm with older children (Sykes-Haas & Bonneh, 2025, preprint) supporting the view that these effects generalize beyond the present CLP and are not task-specific artifacts.

CLP Paradigm Strengths vs. Prior Work

Our findings differ substantially from earlier studies that used eye tracking to assess receptive language in mvASD. For example, Plesa-Skwerer et al. (2016) reported only ~60% accuracy in the Looking-While-Listening (LWL) paradigm, with better performance when participants pointed (72%). In our CLP, by contrast (Figure 3), mvASD participants achieved 87% accuracy in the spoken-word condition and 79% in the written-word condition, while performing worse when pointing (58% in reading). CLP results also diverge from ERP studies, which often detect group-level effects but show limited reliability at the individual level (DiStefano et al. 2019). In CLP data, robust gaze-based effects were evident for most participants, indicating the paradigm provides a more sensitive and individually valid measure of hidden language ability. We propose the structure of the CLP is central to its effectiveness. Unlike traditional paradigms like LWL, which present auditory and visual information simultaneously, the CLP presents the spoken or written cue before the test images. This sequencing allows the cue to act as a prime, reducing visual competition and facilitating rapid, automatic orienting to the target.

In addition, the CLP presents information sequentially and unimodally—one stimulus type at a time—thereby reducing the cognitive demands of integrating input across sensory channels that are often atypical in ASD (Brandwein et al. 2013). This likely lowers task load and helps individuals with suspected LC–NE dysregulation sustain engagement (London 2018) consistent with evidence for atypical arousal regulation in mvASD (see below). The CLP's temporal structure is also analogous to "gap" trials in oculomotor research, where removing a central fixation before target onset shortens saccadic latency by reducing competition between stimuli (Elsabbagh et al. 2013; Keehn et al. 2021). In contrast, LWL and similar paradigms resemble "overlap" trials, in which simultaneous stimulus presentation increases competition and slows orienting—a challenge that may be particularly pronounced in autism.

Taken together, these design features—sequential presentation, reduced competition, and unimodal presentation—may explain why the CLP elicits clearer and more consistent results than prior methods. The remaining question is *why* mvASD participants succeed with gaze but struggle with deliberate motor responses, an issue addressed below.

Pupil Dilation and LC-NE Dysregulation

To explore a potential mechanism accounting for the gap between comprehension and expression in mvASD, we examined pupil dilation (PD) during CLP trials. PD is considered an indirect index of activity in the locus coeruleus–norepinephrine (LC-NE) system, which plays a key role in attention and the initiation of voluntary behavior (London 2018). Compared to neurotypical controls, mvASD participants showed reduced pupil dilation, especially those with lower gaze-based performance (Figure 5b). This was also reflected in a significant correlation between pupil size and eye-gaze task accuracy (Figure 5c), and in an inverse correlation with pointing perseveration (Figure 4b).

These findings suggest that reduced transient activation of the LC-NE system may impair the recruitment of arousal needed for deliberate actions like pointing. In contrast, more automatic behaviors such as gaze shifts may remain accessible, offering a powerful alternative for assessing hidden cognitive abilities. The CLP's continuous, computerized presentation with fixed, predictable timing likely further reduces the transient recruitment of arousal required by clinician-led pointing tasks, which demand re-engagement and adjustments to variable timing, voice, and card placement before each trial.

Dysregulated Action Selection as a Mechanism for Hidden Cognition

The convergence of pupil dilation, perseveration, and head-movement findings points to a dysregulation of the neural systems that govern action selection. Within the *affordance-competition* framework (Cisek 2007), multiple potential actions—such as gaze shifts or pointing movements—compete for execution based on sensory evidence. In minimally verbal autism, this competition may be imbalanced: voluntary, goal-

directed actions like pointing fail to be initiated or stabilized, whereas highly automatized actions such as gaze shifts remain accessible. Reduced phasic activation of the locus coeruleus–norepinephrine (LC-NE) system, reflected in diminished pupil dilation, may weaken the transient arousal signal needed to resolve this competition in favor of the intended action. The CLP design effectively bypasses this bottleneck by minimizing competing motor and sensory demands, allowing latent skills to manifest through largely automatic eye movements rather than effortful motor output.

Limitations

Our findings should be interpreted in light of several limitations. The vocabulary tested consisted of simple, concrete nouns typically acquired in early childhood, and we did not examine sentence comprehension, grammar, or phonological decoding. Thus, our results do not imply high-level language or general cognitive competence. Sample bias is also a concern: many participants were recruited through networks of parents who believe their children have unrecognized abilities, although we also observed similar patterns among 7 participants from a special-education setting. The examiner (KE) was not blinded to study aims; while unintentional cueing is unlikely given the rapid timing of eye movements, and the mostly out-of-view position of the examiner, future studies should consider blinded examiners for eye-gaze and pointing conditions. Sessions were lengthy (40–90 minutes) and required a skilled professional to interpret subtle behaviors and maintain cooperation, which may limit scalability. Finally, participants pointed to laminated cards rather than a touchscreen. Pointing is often inconsistently acquired and not automatized in mvASD (Courchesne et al. 2015; Gernsbacher et al. 2008), and previous touchscreen studies have likewise not shown good pointing performance on similar tasks . We therefore expect that the core dissociation between pointing and gaze would persist if our pointing tasks were assessed on a touch screen.

Implications and Future Directions

Our findings indicate that some minimally verbal individuals with autism possess lexical–semantic abilities that remain hidden in traditional assessments. By removing the need for intentional motor responses, the Cued Looking Paradigm (CLP) offers a new way to access these abilities. Future research could extend CLP to more complex tasks—such as simple sentence comprehension (Huettig et al. 2022), verb and action-word processing, and phonological awareness (e.g., presenting spoken nonwords paired with visually similar written forms) to determine to what extent minimally verbal individuals rely on whole-word recognition versus phoneme–grapheme decoding, a distinction relevant to hyperlexia and atypical reading development (Ostrolenk et al. 2017). Beyond language, CLP may also be adapted to nonverbal cognition such as categorization, memory, or visual reasoning. Furthermore, early identification of hyperlexic abilities could help tailor instruction for young minimally verbal children who can already recognize written words.

References

Bal, Vanessa H., Cristan Farmer, and Audrey Thurm. 2017. "Describing Function in ASD: Using the DSM-5 and Other Methods to Improve Precision." *Journal of Autism and Developmental Disorders* 47 (9): 2938–41. https://doi.org/10.1007/s10803-017-3204-3.

Bello, Katrina D, Nahal Goharpey, Sheila G Crewther, and David P Crewther. 2008. "A Puzzle Form of a Non-Verbal Intelligence Test Gives Significantly Higher Performance Measures in Children with Severe Intellectual Disability." *BMC Pediatrics* 8 (1): 30. https://doi.org/10.1186/1471-2431-8-30.

Benjamini, Yoav, and Yosef Hochberg. 1995. "Controlling the False Discovery Rate : A Practical and Powerful Approach to Multiple Testing." *Journal of the Royal Statistical Society . Series B (Methodological)* 57 (1): 289–300.

Bonneh, Yoram S., Yael Adini, and Uri Polat. 2016. "Contrast Sensitivity Revealed by Spontaneous Eyeblinks: Evidence for a Common Mechanism of Oculomotor Inhibition." *Journal of Vision* 16 (7). https://doi.org/10.1167/16.7.1.

Bonneh, Y.S., D. Sagi, A. Gorea, N. Soroker, J. Treger, and M. Pavlovskaya. 2008. "When They See, They See It Almost Right: Normal Subjective Experience of Detected Stimuli in Spatial Neglect." *Neuroscience Letters* 446 (1): 51–55. https://doi.org/10.1016/j.neulet.2008.09.031.

Brandwein, A. B., J. J. Foxe, J. S. Butler, et al. 2013. "The Development of Multisensory Integration in High-Functioning Autism: High-Density Electrical Mapping and Psychophysical Measures Reveal Impairments in the Processing of Audiovisual Inputs." *Cerebral Cortex* 23 (6): 1329–41. https://doi.org/10.1093/cercor/bhs109.

Cantiani, Chiara, Naseem A. Choudhury, Yan H. Yu, Valerie L. Shafer, Richard G. Schwartz, and April A. Benasich. 2016. "From Sensory Perception to Lexical-Semantic Processing: An ERP Study in Non-Verbal Children with Autism." *PLoS ONE* 11 (8): 1–31. https://doi.org/10.1371/journal.pone.0161637.

Chakrabarti, Bhismadev. 2017. "Commentary: Critical Considerations for Studying Low-Functioning Autism." *Journal of Child Psychology and Psychiatry and Allied Disciplines* 58 (4): 436–38. https://doi.org/10.1111/jcpp.12720.

Chen, Yanru, Brynn Siles, and Helen Tager-Flusberg. 2024. "Receptive Language and Receptive-expressive Discrepancy in Minimally Verbal Autistic Children and Adolescents." *Autism Research* 17 (2): 381–94. https://doi.org/10.1002/aur.3079.

Cisek, Paul. 2007. "Cortical Mechanisms of Action Selection: The Affordance Competition Hypothesis." *Philosophical Transactions of the Royal Society B: Biological Sciences* 362 (1485): 1585–99. https://doi.org/10.1098/rstb.2007.2054.

Coderre, Emily L., Mariya Chernenok, Jessica O'Grady, Laura Bosley, Barry Gordon, and Kerry Ledoux. 2019. "Implicit Measures of Receptive Vocabulary Knowledge in Individuals with Level 3 Autism." *Cognitive and Behavioral Neurology* 32 (2): 95–119. https://doi.org/10.1097/WNN.0000000000000194.

Courchesne, Valérie, Andrée Anne S. Meilleur, Marie Pier Poulin-Lord, Michelle Dawson, and Isabelle Soulières. 2015. "Autistic Children at Risk of Being Underestimated: School-Based Pilot Study of a Strength-Informed Assessment." *Molecular Autism* 6 (1): 4–13. https://doi.org/10.1186/s13229-015-0006-3.

DiStefano, Charlotte, Damla Senturk, and Shafali Spurling Jeste. 2019. "ERP Evidence of Semantic Processing in Children with ASD." *Developmental Cognitive Neuroscience* 36 (June 2018): 100640. https://doi.org/10.1016/j.dcn.2019.100640.

Eagle, Rita S. 2002. "Accessing and Assessing Intelligence in Individuals with Lower Functioning Autism." Unpublished manuscript.

Elsabbagh, Mayada, Janice Fernandes, Sara Jane Webb, Geraldine Dawson, Tony Charman, and Mark H. Johnson. 2013. "Disengagement of Visual Attention in Infancy Is Associated with Emerging Autism in Toddlerhood." *Biological Psychiatry* 74 (3): 189–94. https://doi.org/10.1016/j.biopsych.2012.11.030.

Fernald, A, and R Zangl. 2008. "Looking While Listening: Using Eye Movements to Monitor Spoken Language." *Developmental Psycholinguistics*, no. January: 97–135.

Gernsbacher, Morton Ann, Eve A. Sauer, Heather M. Geye, Emily K. Schweigert, and H. Hill Goldsmith. 2008. "Infant and Toddler Oral- and Manual-motor Skills Predict Later Speech Fluency in Autism." *Journal of Child Psychology and Psychiatry* 49 (1): 43–50. https://doi.org/10.1111/j.1469-7610.2007.01820.x.

Hannah S. Sykes-Haas, Yoram S. Bonneh. 2025. "Minimally Verbal Children with Autism May 'See the Point, but Do Not (Always) Point to What They See.'" Preprint, BioRxiv. https://doi.org///doi.org/10.1101/2025.06.26.661808.

Huettig, Falk, Jenny Audring, and Ray Jackendoff. 2022. "A Parallel Architecture Perspective on Pre-Activation and Prediction in Language Processing." *Cognition* 224 (July): 105050. https://doi.org/10.1016/j.cognition.2022.105050.

Jaswal, Vikram K, Andrew J Lampi, and Kayden M Stockwell. 2024. "Literacy in Nonspeaking Autistic People." *Autism* 28 (10): 2503–14. https://doi.org/10.1177/13623613241230709.

Jaswal, Vikram K., Allison Wayne, and Hudson Golino. 2020. "Eye-Tracking Reveals Agency in Assisted Autistic Communication." *Scientific Reports* 10 (1): 7882. https://doi.org/10.1038/s41598-020-64553-9.

Kasari, Connie, Nancy Brady, Catherine Lord, and Helen Tager-Flusberg. 2013. "Assessing the Minimally Verbal School-Aged Child with Autism Spectrum Disorder." *Autism Research* 6 (6): 479–93. https://doi.org/10.1002/aur.1334.

Kedar, Ido. 2012. *Ido in Autismland: Climbing Out of Autism's Silent Prison*. https://www.amazon.com/Ido-Autismland-Climbing-Autisms-Silent/dp/0988324709.

Keehn, Brandon, Girija Kadlaskar, Sophia Bergmann, Rebecca McNally Keehn, and Alexander Francis. 2021. "Attentional Disengagement and the Locus Coeruleus – Norepinephrine System in Children With Autism Spectrum Disorder." *Frontiers in Integrative Neuroscience* 15 (August). https://doi.org/10.3389/fnint.2021.716447.

London, Eric B. 2018. "Neuromodulation and a Reconceptualization of Autism Spectrum Disorders: Using the Locus Coeruleus Functioning as an Exemplar." *Frontiers in Neurology* 9 (December): 1–16. https://doi.org/10.3389/fneur.2018.01120.

Mishra, Ramesh K., Christian N.L. Olivers, and Falk Huettig. 2013. "Spoken Language and the Decision to Move the Eyes: To What Extent Are Language-Mediated Eye Movements Automatic?" *Progress in Brain Research* 202: 135–49. https://doi.org/10.1016/B978-0-444-62604-2.00008-3.

Mostert, Mark P. 2001. "Facilitated Communication since 1995: A Review of Published Studies." *Journal of Autism and Developmental Disorders* 31 (3): 287–313. https://doi.org/10.1023/A:1010795219886.

Orlievsky, Daniel, and Sebastián Cukier. 2013. "Language, Writing, and Activity Disorder in the Autistic Spectrum." *Frontiers in Integrative Neuroscience* 7 (May): 1–3. https://doi.org/10.3389/fnint.2013.00042.

Ostrolenk, Alexia, Baudouin Forgeot d'Arc, Patricia Jelenic, Fabienne Samson, and Laurent Mottron. 2017. "Hyperlexia: Systematic Review, Neurocognitive Modelling, and Outcome." *Neuroscience and Biobehavioral Reviews* 79 (May): 134–49. https://doi.org/10.1016/j.neubiorev.2017.04.029.

Pizzano, Maria, Stephanie Shire, Wendy Shih, et al. 2024. "Profiles of Minimally Verbal Autistic Children: Illuminating the Neglected End of the Spectrum." *Autism Research* 17 (6): 1218–29. https://doi.org/10.1002/aur.3151.

Plesa-Skwerer, Daniela, Samantha E. Jordan, Briana H. Brukilacchio, and Helen Tager-Flusberg. 2016. "Comparing Methods for Assessing Receptive Language Skills in Minimally Verbal Children and Adolescents with Autism Spectrum Disorders." *Autism* 20 (5): 591–604. https://doi.org/10.1177/1362361315600146.

Tager-Flusberg, Helen, and Connie Kasari. 2013. "Minimally Verbal School-Aged Children with Autism Spectrum Disorder: The Neglected End of the Spectrum." *Autism Research* 6 (6): 468–78. https://doi.org/10.1002/aur.1329.

Wing, Lorna, and Amitta Shah. 2006. “A Systematic Examination of Catatonia-like Clinical Pictures in Autism Spectrum Disorders.” *International Review of Neurobiology* 72 (05): 21–39. https://doi.org/10.1016/S0074-7742(05)72002-X.