Linguistic Markers of Autism Spectrum Disorder:

Classification Sensitivity and Specificity of Language Produced During Clinical Evaluations

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Today's Talk

- Why we are interested
- The CAR/LDC ADOS Project
- Four Features and Clinical Correlates within ASD
- Applications

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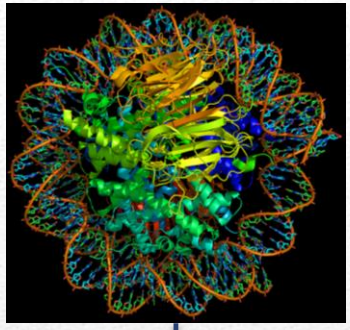
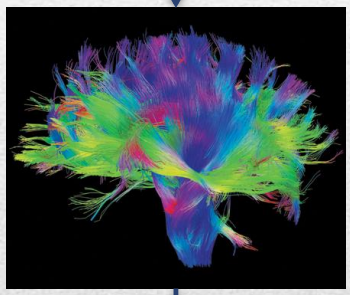
Why we are interested

- Natural language
  - Highly nuanced outward signal of internal brain activity
  - Fundamentally social
- Most children with ASD acquire language; nearly all vocalize
- Can applying HLT and Big Data methods help us reliably identify and understand ASD?





Language in ASD

- Variable vocalization throughout development:
  - Differences evident in infancy
  - Language delay as toddlers/preschoolers
  - Difficulty being understood/trouble understanding humor and sarcasm
  - Conversational quirks (unusual word use, turn-taking, synchrony, accommodation)

- Real-life Effects of pragmatic language problems:
  - Difficulty forming/maintaining friendships
  - Increased risk of being bullied
  - Difficulty with romantic relationships
  - Difficulty maintaining employment

Language in ASD

- Many small variations accumulate to create an odd impression
- It's hard to "put your finger on" what exactly differs, so it's tricky to treat!

Clinical computational linguistics

- Natural language:
  - Nuanced signal (marriage of cognitive and motoric systems)
  - No practice effects
- Can identify and extract features ("linguistic markers")
- Specific linguistic features associated with:
  - Depression
  - Dementia
  - PTSD
  - Schizophrenia
- …Autism

Treatment gains can be measured via the linguistic signal alone!

Prior research

On average, individuals with ASD:

- Produce idiosyncratic or unusual words more often than typically developing peers (Ghaziuddin & Gerstein, 1996; Prud'hommeaux, Roark, Black, & Van Santen, 2011; Rouhizadeh, Prud'Hommeaux, Santen, & Sproat, 2015; Rouhizadeh, Prud'hommeaux, Roark, & van Santen, 2013; Volden & Lord, 1991)
- Repeat words or phrases more often than usual (echolalia; van Santen, Sproat, & Hill, 2013)
- Use filler words "um" and "uh" differently than matched peers (Irvine, Eigsti, & Fein, 2016)
- Wait longer before responding in the course of conversation (Heeman, Lunsford, Selfridge, Black, & Van Santen, 2010)
- Produce speech that differs on pitch variables; these can be used to classify samples as coming from children with ASD or not (Asgari, Bayestehtashk, & Shafran, 2013; Kiss, van Santen, Prud'hommeaux, & Black, 2012; Schuller et al., 2013)

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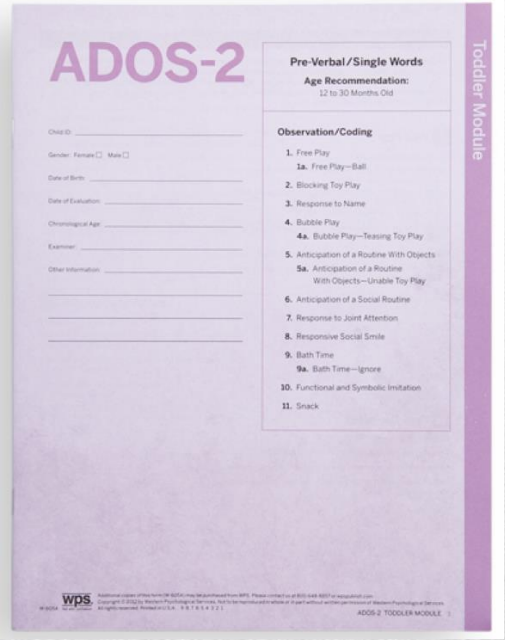
ADOS Project

- Process and analyze recorded language samples from Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2012)
  - Conversation and play-based assessment of autism symptoms
  - Recorded for reliability and clinical supervision, coded on a scale, then filed away
- 600+ at CAR alone, thousands more across the U.S. and in Europe; never compiled
- Associated with rich metadata that includes family history, social, cognitive, and behavioral phenotype, genes, and neuroimaging



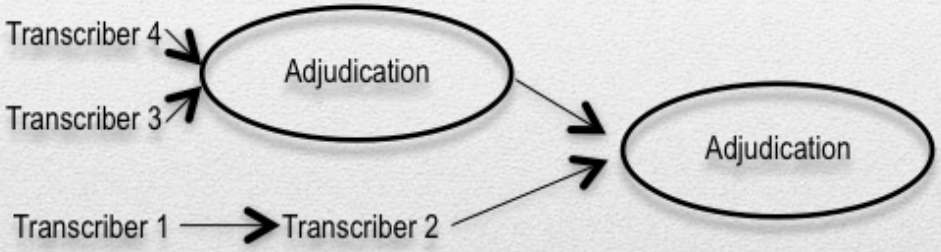
ADOS Project

Goals of pilot effort:

- Assess feasibility
- Identify and extract linguistic features
- Machine learning classification
- Correlate features with clinical phenotype

Transcription

- Time aligned, verbatim, orthographic transcripts (~20 minutes of conversation)
- New transcription specification developed by LDC resembles those used for conversational speech
- 4 transcribers and 2 adjudicators from LDC and CAR produced a “gold standard” transcript for analysis and for evaluation/training of future transcriptionists



- Simple comparison of word level identity between CAR’s adjudicated transcripts and LDC’s transcripts: 93.22% overlap on average, before a third adjudication resolved differences between the two
- Transcripts force-aligned to audio

Participants

- N=100
- Mean age=10-11 years
- Primarily male
- 65 ASD, 18 TD, 17 Non-ASD mixed clinical
- Average full scale IQ, verbal IQ, nonverbal IQ

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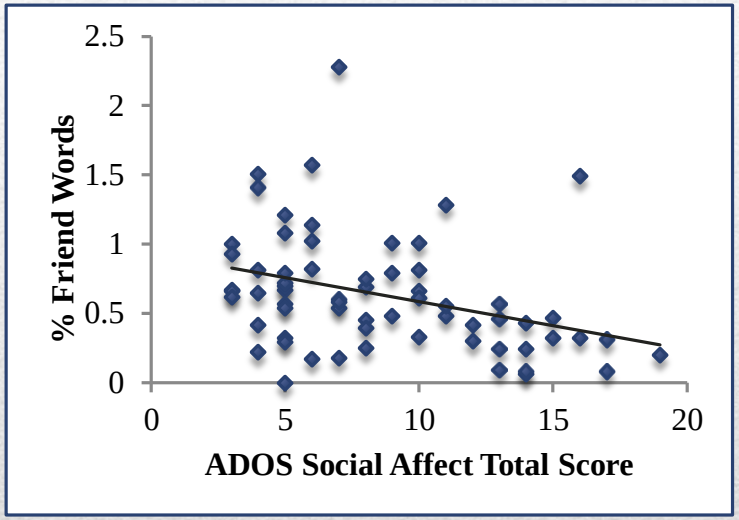
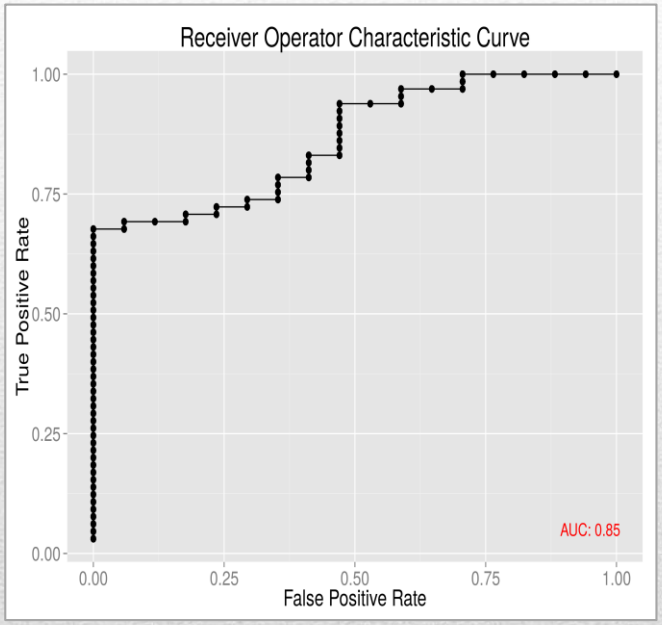
Word Choice

- Which words did participants use most frequently?
- 20 most "ASD-like" words:
  - *{nsv}, know, he, a, now, no, uh, well, is, actually, mhm, w-, years, eh, right, first, year, once, saw, was*
  - {nsv} stands for "non-speech vocalization", meaning sounds that with no lexical counterpart, such as imitative or expressive noise
  - "uh" appears in this list, as does "w-", a stuttering-like disfluency.
- 20 least "ASD-like" words:
  - *like, um, and, hundred, so, basketball, something, dishes, go, york, or, if, them, {laugh}, wrong, be, pay, when, friends*.
  - "um" appears, as does the word "friends, and laughter
- Decreased use of "friend" words correlates with increased social impairment in ASD, as rated by clinicians, Pearson's r = -.35, p = .03.



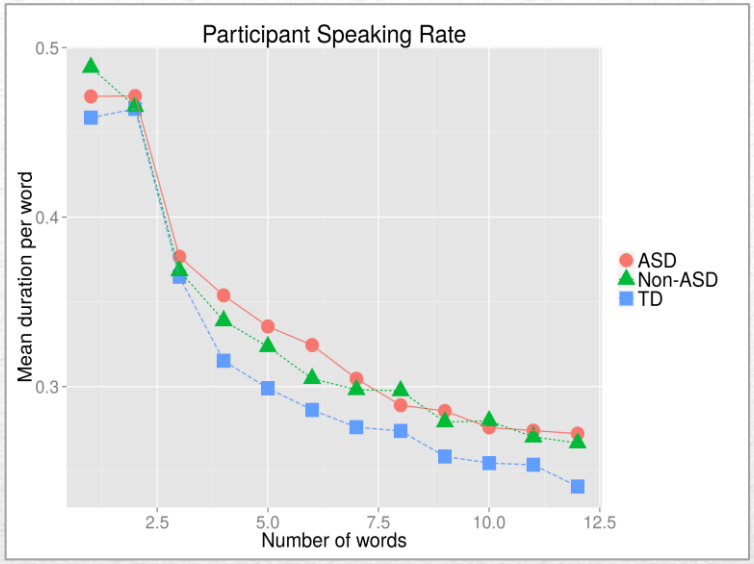
Classification: Word Choice

- Word choice correctly classified 68% of ASD participants and 100% of typical participants
- Naïve Bayes, leave-one-out cross validation and weighted log-odds-ratios calculated using the "informative Dirichlet prior" algorithm (Monroe et al., 2008)
- Receiver Operating Characteristic (ROC) analysis revealed good sensitivity and specificity; AUC=85%

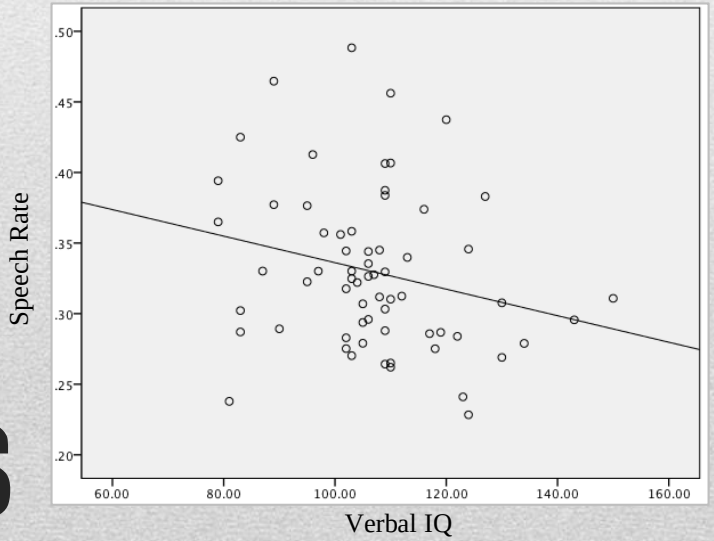


Rate Differences

- Mean word duration as a function of phrase length
- TD participants spoke the fastest (overall mean word duration of 376 ms, CI 369-382, calculated from 6891 phrases)
- Followed by the non-ASD mixed clinical group (mean=395 ms; CI 388-401, calculated from 6640 phrases)
- Followed by the ASD group with the slowest speaking rate (mean=402 ms; CI: 398-405, calculated from 24276 phrases)
- Faster speech associated with higher verbal IQ in ASD
  - Spearman's rho = -.26, p = .04

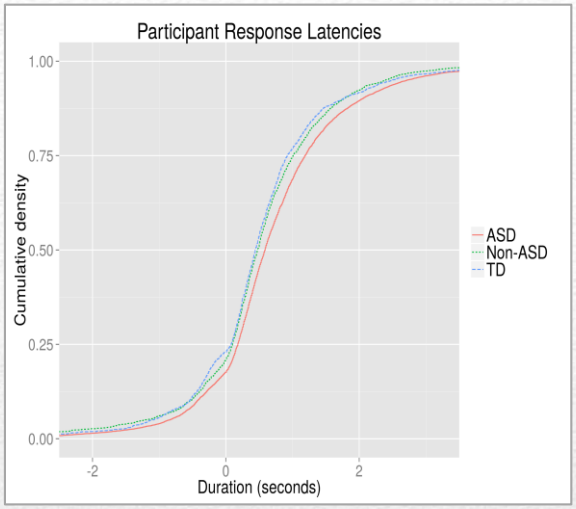


Verbal IQ and Speech Rate in ASD

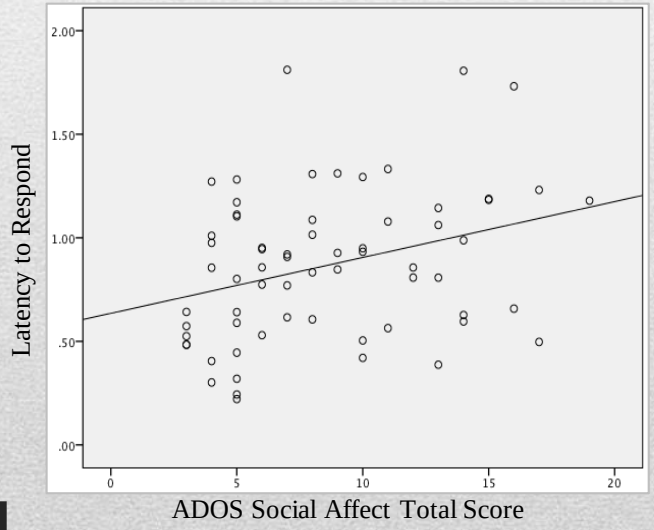


Differences in Latency to Respond

- Gap between speaker turns
- Too short = interrupting or speaking over a conversational partner
- Too long (awkward silences) interrupt smooth social exchanges
- ASD slower than TD
- Longer latency to respond associated with more social impairment (ADOS social affect score)
  - Spearman's rho = .33, p = .007

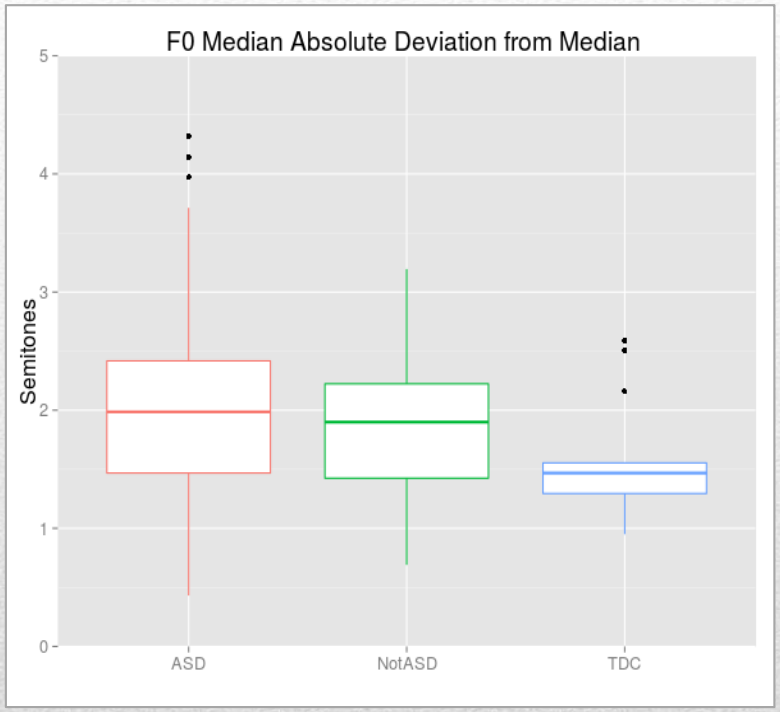


Latency to Respond and ADOS Score



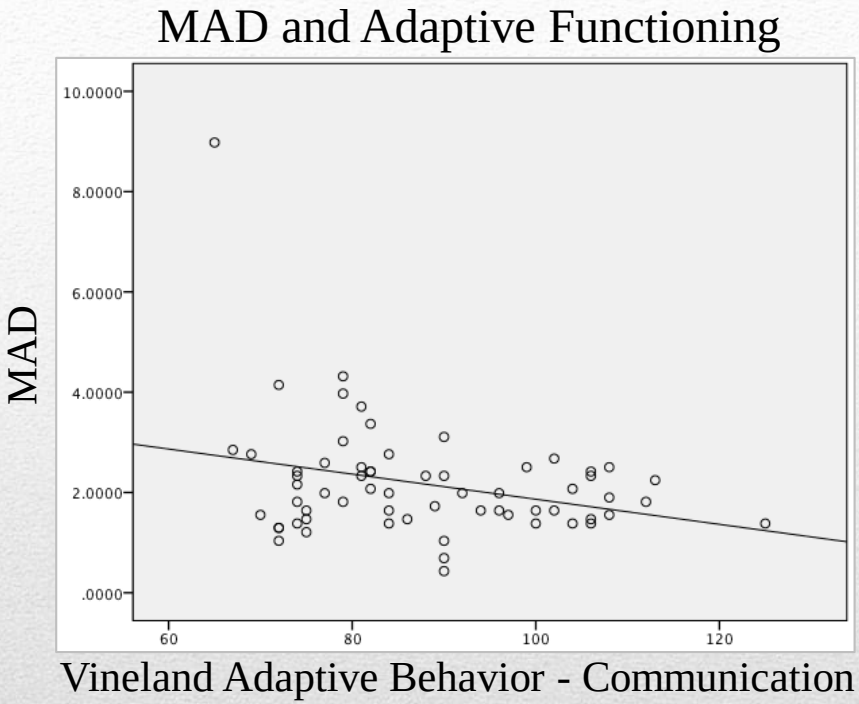
Fundamental Frequency

- Median absolute deviation from the median (MAD)
  - Outlierrobust measure of dispersion in F0 distribution
  - Calculated in semitones relative to speaker's 5th percentile
- MAD values are both higher and more variable within the ASD and non-ASD mixed clinical group than the TD group
  - ASD: median: 1.99, IQR: 0.95
  - Non-ASD: median: 1.95, IQR: 0.80
  - TD: median: 1.47, IQR: 0.26



FO and Clinical Phenotype in ASD

- MAD associated positively with clinician ratings of social impairment, Pearson's r = .27, p = .03
- …and negatively with parent reported adaptive functioning in the communication domain, Pearson's r = -.29, p = .02



Discussion

- ASD and TDC differ on a variety of linguistic features
- Features correlate with clinician ratings of social impairment, as well as with parent report of adaptive functioning
- Emerging collaborations include more ADOS recordings associated with phenotypic data, neuroimaging, and genetics from heterogeneous samples (including mixed clinical and more females with ASD)

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- **Support clinical decision-making and improve access**
  - Low-cost, remote screening
  - Direct behavioral observation: record in clinics, integrate into EHR
  - Inform identification efforts and assist in differential diagnosis

- **Identify behavioral markers of underlying (treatable) pathobiology**
  - Profiles of individual strengths and weaknesses → link to biology = personalized treatment planning and improved outcomes
  - Granular assessment of response to intervention – dense sampling

- **Give participants and families more information about themselves**
  - Online feedback
  - Monitor growth trajectories

Acknowledgements

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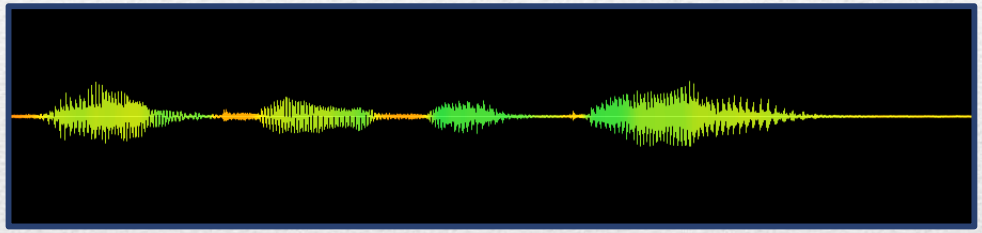
AUTISM SCIENCE FOUNDATION

CAR Center for Autism Research

NIH National Institutes of Health



Questions?