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Receptive Vocabulary Knowledge in Low-Functioning Autism as Assessed by Eye
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14. ABSTRACT We have been testing the hypothesis that relatively implicit measures of cognitive processing (eye movements, pupillary dilation monitoring, and the N400 component of event-related potentials) will prove sensitive to receptive vocabulary knowledge, even in the absence of more traditional behavioral responses. We have sought to first demonstrate the use of these measures in three populations in whom behavioral responses are expected to be reliable: normal adults, normally developing children, and higher-functioning individuals with autism. In all three groups, the implicit measures differentiated known from unknown words: eye movements were faster to a named picture for known words; pupillary dilation from baseline was greater in the unknown condition; and an N400 congruency effect was observed for known (but not unknown) words. Our results also suggest that these measures similarly differentiate known from unknown words in lower-functioning individuals with autism, even in the absence of a behavioral response. These results suggest that these measures may be used as valid measures of comprehension, even in nonverbal, non-responding individuals. We have also begun exploring whether these same measures can be used to track learning in lower-functioning individuals with autism that might accompany exposure to new words in a training paradigm.					
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INTRODUCTION

Approximately 50% of individuals affected by autism fail to develop useful speech, and many of these individuals never learn to communicate in any functional way. An important scientific as well as practical question about such individuals, as well as in those with other diagnoses and a similar inability to express themselves, is whether this lack of expressive ability is necessarily accompanied by an equally severe deficit in knowledge of receptive language. Little rigorous research has been directed at this possibility, both because of the difficulty of working with such low-functioning subjects, and because of the lack of sensitivity of most traditional behavioral methodologies. Recently, however, several experimental methodologies have been developed and refined to the point that they may prove sensitive enough to provide reliable evidence of comprehension, even in the absence of more traditional behavioral responses such as speech and gesturing, and even at the individual subject level. We have been developing the use of three such research methods to attempt to detect receptive vocabulary knowledge – eye movement recording, pupillary dilation monitoring, and event-related brain potentials. We have been testing whether these relatively implicit measures of comprehension actually do reflect single-word comprehension in participants in whom we expect reliable behavioral responses to serve as comparison measures (normal adults, normally developing children, and high-functioning individuals with autism), as well as in low-functioning, nonverbal individuals with autism, for whom overt behavioral responses might be unreliable or even impossible. We have also begun testing whether these methodologies might be used to track learning in this same group of individuals, in whom overt behavioral responses may not accurately reflect the acquisition of new vocabulary knowledge.

BODY

Experiment 1: Validating the use of the eye movement monitoring (EM), pupillary dilation monitoring (PD), and event-related potential (ERP) techniques for the measurement of receptive vocabulary knowledge – normal adults

Our first experiment was designed to validate the use of the three implicit methodologies for the detection of receptive vocabulary knowledge in normal adults, a participant population in whom overt behavioral responses would be expected to be reliable (and thus capable of serving as a measure of comparison). Participants were asked to engage in two separate tasks using the same set of 160 words and pictures. Eighty of the words were very high frequency and were expected to be very familiar to all of the adults; these included words such as *airplane* and *camera*. The remaining 80 words were low frequency, relatively unfamiliar words that were not expected to be known by many of the participants (as confirmed by prior pre-testing). Examples of words in this set included *agouti* and *cainito*. All words were concrete and highly imageable. High-resolution, color digital pictures were selected to represent each word. In the *forced-choice recognition task*, participants were asked to use the mouse to select one of four pictures presented simultaneously on a computer screen after hearing one of the objects named. We simultaneously collected eye movement and pupillary dilation data, using an ASL Model 504 eye-tracking system. In the *congruity task*, a picture was presented on the computer screen, accompanied by the auditory presentation of a single word, which either matched (congruous condition) or did not match (incongruous condition) the pictured item. Participants were asked to push a button to indicate whether the auditory word and the picture matched. Simultaneously, ERPs were recorded using Electrical Geodesics Inc.'s 256-channel Hydrocel Geodesic Sensor Nets. Finally, normal adult participants were asked to participate in a word familiarity posttest, in which they were asked to rate their familiarity with the 160 words used in the experiment, on a scale from 1 (very unfamiliar) to 9 (extremely familiar), with an additional option of 0 (no familiarity whatsoever).

During this third year, we have improved the sophistication of our data analysis techniques even further. With the hiring of a new post-doctoral associate, we were able to develop methods to apply principal components analysis (PCA) and independent components analysis (ICA) to our EEG data. These analysis techniques allow for the identification of eye blink, eye movement, and other artifacts in the data, and (importantly) allow the removal of these artifacts from the EEG without the loss of the entire data set for that particular trial (as had often been the result under our previous techniques). That is, once the activity associated with these artifacts (and with other non-cognitive activity) is identified, it is mathematically isolated and removed, with the electrical activity specific to the cognitive event of interest remaining intact. These techniques thus allow the retention of a much larger proportion of the data from most participants, and this is especially true for those participants who have difficulty performing the experiment without creating a lot of artifacts, such as children or individuals with autism. We believe, then, that these techniques will greatly improve our ability to analyze larger numbers of clean, artifact-free trials from all participant groups.

This has proven true in the normal adult data analysis. Re-analyzing our data using these techniques, we have found that we were able to include in our final analysis the data from seven additional participants whose data had previously been ruled un-useable due to the loss of a large number of trials due to artifacts. We have thus revised our manuscript draft to include the

analyses over this larger group of participants. For this group, the main findings that we had previously reported hold true: eye movements to the picture that matched the auditory word were faster for known than for unknown words. End-of-trial fixations were also on the named picture more frequently for known words. Pupillary dilation from baseline was greater in the unknown condition (evidencing the greater engagement of cognitive resources when the word is unknown). Additionally, an N400 congruency effect was observed in the event-related potentials for known words, but not for unknown words. Thus, all three implicit measures (EM, PD, and ERPs) were able to distinguish the processing of known from unknown words in this participant population.

During this third year, we have also developed a model that allows us to predict the knowledge ratings provided by the normal adults based on the results from the implicit measures. We used the results from the eye tracking, pupillary dilation, and ERPs jointly to create a regression model that predicts participants' explicit word knowledge ratings. The predicted knowledge ratings from the model were then used to re-code words as "known" or "unknown." In this way, we are using the implicit measures to provide us with information about which words are truly likely to be known or unknown to a given individual participant, and re-coding all of the stimulus items specifically based on that information, for each participant individually. Once we had done that, we then looked at the ERP effects under the individualized coding scheme. Stronger differences were observed on the N400 component; specifically, the N400 to the congruent picture-word pairs that were known to the participant showed a larger reduction in amplitude relative to those that were known but incongruent. The amplitude of the N400 to words that were unknown were intermediate to the two known conditions, and did not differ by congruency (as would be expected for words about which participants truly have no knowledge). In this way, the regression model allows us use the data itself to determine which words are most likely to be known or unknown to each participant individually, and in a way that does not rely on overt behavioral responses. This model will thus be especially useful when analyzing the data from the typically developing children and the autism participants, in whom there is expected to be greater variability in knowledge about the vocabulary words, and in whom behavioral responses are not always the best indicator of that knowledge.

Experiment 2: Validating the use of the EM, PD, and ERP techniques for the measurement of receptive vocabulary knowledge – normally developing children

Our second experiment was designed to validate the use of the three implicit methodologies for the detection of receptive vocabulary knowledge in normally developing children (ages 5 – 17), another participant population in whom overt behavioral responses would be expected to be reliable (and thus capable of serving as a measure of comparison). The child participants were tested on the Peabody Picture Vocabulary Test (PPVT; [1]), the Kaufman Brief Intelligence Test (KBIT; [4]) and the Autism Spectrum Screening Questionnaire (ASSQ; [2]), the latter of which was used to ensure that none of the normally developing children exhibited excessive behaviors associated with autism. All of the children were asked to complete the forced-choice recognition task and the congruity task described above. Older children (those old enough to understand and properly perform the task; generally those ages 10 and above) were also asked to complete the familiarity post-test described above.

During this third year, we completed testing of the typically developing children participants by testing an additional 14 participants, among whom we were able to obtain good,

“useable” data from six. Our preliminary analyses on the data of these 20 children continue to demonstrate that the results for the child participants are very similar to those observed for the normal adults. Behaviorally, children were faster and more accurate at both the forced-choice task and the congruity task for known words than for unknown words. Eye movements to the picture that matched the auditory word were faster for known than for unknown words. End-of-trial fixations were also on the named picture more frequently for known words. Pupillary dilation from baseline was greater in the unknown condition. Additionally, an N400 congruency effect was observed in the event-related potentials for known words, but not for unknown words. Thus, all three implicit measures (EM, PD, and ERPs) were able to distinguish the processing of known from unknown words for the normally developing children that we have tested.

We have begun to re-analyze the children’s data using the PCA/ICA techniques described above for the normal adults, with the hope that we will be able to retain more trials from the participants and thus strengthen our results. We have also begun to apply the regression model described above for the normal adults to the data of the typically developing children, to re-classify individual stimuli as “known” or “unknown” for each child individually, based on the results from the three implicit measures.

Experiment 3: Validating the use of the EM, PD, and ERP techniques for the measurement of receptive vocabulary knowledge – high-functioning individuals with autism

Our third experiment was designed to validate the use of the three implicit methodologies for the detection of receptive vocabulary knowledge in high-functioning individuals with autism, another participant population in whom overt behavioral responses would be expected to be reliable (and thus capable of serving as a measure of comparison), but which also offers a more closely-matched comparison group to the low-functioning individuals with autism. Participants were administered the Kaufman Brief Intelligence Test (KBIT; [4]), the Autism Diagnostic Observation Schedule (ADOS; [5]), and the Autism Diagnostic Interview – Revised (ADI-R; [6]) to confirm diagnosis and to determine level of functioning/verbal ability.

An additional 7 participants with autism were recruited for participation. Of these, 5 were determined to be higher-functioning. These participants were asked to complete the forced-choice recognition task and the congruity task described above. Of the 5 higher-functioning individuals with autism recruited, 2 participants supplied a complete set of “useable” data from the three implicit measures, in addition to the 8 participants that had completed testing at the time of last year’s report, for a total of 10 high-functioning individuals.

Among this group, our results continue to show similarities to those observed for normal adults and for typically developing children. The individuals in this group were able to make reliable behavioral responses. Behaviorally, they were faster and more accurate at both the forced-choice task and the congruity task for known words than for unknown words. Eye movements to the picture that matched the auditory word were faster for known than for unknown words. End-of-trial fixations were also on the named picture more frequently for known words. Pupillary dilation from baseline was greater in the unknown condition. Additionally, an N400 congruency effect was observed in the event-related potentials for known words, but not for unknown words. Thus, all three implicit measures (EM, PD, and ERPs) were able to distinguish the processing of known from unknown words for the high-functioning individuals with autism that we have tested.

As for the typically developing children, we have begun to re-analyze these participants' data using the PCA/ICA techniques described above for the normal adults, with the hope that we will be able to retain more trials from the participants and thus strengthen our results. We have also begun to apply the regression model described above for the normal adults to the data of the high-functioning individuals with autism, to re-classify individual stimuli as “known” or “unknown” for each child individually, based on the results from the three implicit measures.

We experienced some lulls in autism recruitment this year, despite having implemented continued and renewed efforts at outreach with this group. We established new relationships with community autism outreach groups in our area, which allowed us to send our recruitment materials to new individuals. We also attempted to reach new participants by participating in local autism fairs. Despite this, we found it difficult to find new high-functioning individuals to participate in our study. We suspect that for this group in particular, participation in experiments might be less appealing. There are many reasons why this may be true; for instance, higher-functioning individuals may be intrinsically less motivated to help in the process of discovering potential deficits in autism and in developing intervention strategies because they see less need for these strategies for themselves, as they are often able to function quite well in school or work settings. Alternatively, higher-functioning individuals may be too busy to participate in research because they attend more mainstream schools or are involved in afterschool activities, making it difficult for them to find the necessary time for testing. We have tried to identify such reasons and have made attempts to circumvent them in our recruitment efforts; nonetheless, the fact remains that we need more participants from this group to complete our experimental design.

Experiment 4: Extending the use of the EM, PD, and ERP techniques for the assessment of receptive vocabulary knowledge to low-functioning individuals with autism

Our fourth experiment was designed to extend the use of the three implicit methodologies for the detection of receptive vocabulary knowledge to a population in whom behavioral responses are generally less reliable (or absent altogether) – low-functioning, low- or non-verbal individuals with autism. Participants were administered the Kaufman Brief Intelligence Test (KBIT; [4]), the Autism Diagnostic Observation Schedule (ADOS; [5]), and the Autism Diagnostic Interview – Revised (ADI-R; [6]) to confirm diagnosis and to determine level of functioning/verbal ability. Of the 24 participants recruited, seven are currently scheduled for initial screening, or are currently at some stage in the initial screening process.

Of the additional 7 participants with autism recruited this year (see above for Experiment 3), 2 were determined to be low-functioning. All were minimally verbal to nonverbal. Stimuli for the low-functioning group were drawn from the larger pool of 160 words and pictures, but were individualized for each participant based on parental/caregiver report of items that were expected to be known receptively by the child. Parents/caregivers were asked to complete the MacArthur-Bates Communicative Development Inventory – Words and Gestures ([3]), plus a similar experiment-specific inventory that covered those words from our set of 160 that were not included on the MacArthur-Bates. These measures thus provided information about what words were likely to be known (and unknown) receptively by the child. The number of stimuli tested were determined for each individual to maximize signal-to-noise ratio while minimizing experiment length. For some individuals, for whom the pool of known words was small, repetition of items within a testing session, or the repeated testing across multiple testing sessions, was necessary to adequately assess their receptive knowledge.

In addition to the assessments provided by the ADOS and the ADI-R, each low-functioning participant received a series of behavioral assessments designed to evaluate his/her ability to successfully participate in our language testing. We assessed potential participants on things such as their ability to sit still for extended periods of time; their ability to look at the computer screen; their ability to tolerate the eye tracking and ERP equipment; and their likelihood to exhibit adverse behaviors (such as hitting, biting, or other aggressive behaviors). Based on these assessments, an individual determination was made as to the appropriateness of participation and the need for further individualized training to acclimate the participant to the eye-tracking and ERP equipment and experiment procedures. Such training was then conducted as needed over a period of days or weeks, sometimes in our testing space, and often at the participant's home.

After training, participants completed the same forced-choice and congruity tasks as described for Experiments 1-3. However, they were not required to make any overt behavioral response (using the mouse or pressing a button). (Some low-functioning individuals with autism are very familiar with computer programs of the type used in our experiments, and would like to engage in some kind of task during the experiment. For these participants, we allow them to make responses as they wish. However, importantly, the successful analysis of the implicit measure data in this experiment does not depend upon the behavioral completion of these tasks.)

Of the 2 lower-functioning individuals with autism recruited, 1 participants supplied a complete set of "useable" data from the three implicit measures. Reasons for data exclusion were similar to those described above for the other groups. Additionally, even with acclimation training, low-functioning participants have a much harder time engaging in the tasks for extended periods of time, and therefore all of the eye-tracking and ERP artifacts for this group are very pronounced. The behavior of individuals in this population is quite variable, so that on some days, they are unwilling to participate at all. Also, participant attrition is a problem, given the large time commitment required of the participants and their families for successful acclimation training and testing.

When combined with our data from the first two years, we are now able to report results from five low-functioning individuals with autism. To date, there is a fair amount of individual variability amongst the results of the low-functioning individuals with autism, but the results for most trials for the five participants show great similarities to the results from our other participant groups: eye movements were faster and more accurate for known words than for unknown words. For four of the five participants, changes in pupillary dilation were greater to unknown than to known words. Finally, each of the five LFA participants showed evidence of an N400 congruency effect, with a larger amplitude in the N400 time range in the incongruent condition relative to the congruent condition, but only for the words that were expected (based on parental report) to be known by the individuals.

As for the other groups, we have begun to re-analyze these data using the PCA/ICA techniques described above for the normal adults, with the hope that we will be able to retain more trials from the participants and thus strengthen our results. We have also begun to apply the regression model described above for the normal adults to the data of the lower-functioning individuals, to re-classify individual stimuli as "known" or "unknown" for each child individually, based on the results from the three implicit measures. This will be especially important in this group, as these individuals cannot provide very accurate information about what they know about words themselves. Relying on parental report is not necessarily accurate either, as it is certainly possible (in fact, from our results, expected) that these individuals know more

about words than they can demonstrate, and so parents may not have a complete sense of what their children do and do not know.

Experiment 5: Using the EM, PD, and ERP techniques to study new word learning in low-functioning individuals with autism

Our fifth experiment was designed to examine changes in EM, PD, and ERP measures in nonverbal, low-functioning individuals with autism that accompany repetitive exposure to new words during a learning period.

During year two, we completed pilot testing to explore different teaching methods and stimulus sets for this phase of our experiment. In year three, we enrolled our first participant for actual testing in Experiment 5. The participant that we enrolled, DL, was a 22-year-old functionally nonverbal male with autism who had successfully completed Experiment 4, and with whom we have worked extensively in the past five years. This individual was generally quite tolerant of the eye tracking and ERP equipment, and thus seemed well suited to further and repeated testing in Experiment 5. Over a period of six months, we worked with him and his family to select appropriate stimuli for the training study, and to optimize our proposed training procedure.

Unfortunately, at about the time that we were hoping to begin the actual word training with DL, his parents decided that they would have to temporarily withdraw him from the study. DL has recently transitioned from a school setting to an adult activity center, and this change has resulted in an increase in obsessive-compulsive behaviors (which were previously present, but have since become worse) and other anxiety-related behaviors. His parents worried that the word training sessions and the post-training testing would be adding too much novelty to his already altered world, and requested that we postpone the testing for at least six months.

In the meantime, we have begun working with another low-functioning individual with autism, a 24-year-old male who we refer to by the letters AI. AI was previously nonverbal, but through his participation in an intensive, home-based educational program, he began to speak at age 15; in the time since, he has acquired a spoken vocabulary of approximately 150 words, and a receptive vocabulary that is estimated to be at approximately 500 words. AI continues to participate in the educational program, and it is within this setting that we have begun to prepare to implement the word training phase of our study. AI participates in an art class that he really enjoys, so his program director has suggested that we embed word training within the context of the art class. AI will receive directed exposure to new color terms (such as *teal* and *mauve*) during his art lessons, and we will track his learning of these color terms using our implicit measures. We expect to collect post-training measures by the end of the summer.

KEY RESEARCH ACCOMPLISHMENTS

- Implementation of state-of-the-art data analytic techniques (independent components analysis and principal components analysis)
- Re-analysis of all normal adult data using new analysis techniques; identification of additional adult participants whose data can be included in final analysis
- Development of regression model that allows the use of the implicit measures to classify stimuli as “known” or “unknown” (instead of relying on *a priori* classification which might not hold true for any given individual); application of this model to the normal adult data; abstract presenting model submitted for presentation at the Annual Meeting of the Psychonomic Society, 2013
- Draft of manuscript describing normal adult data with new analysis procedures and including regression model
- Completion of child recruitment/testing; re-analysis of child data using PCA/ICA techniques; draft of manuscript describing typically developing child data; initial application of regression model to child data
- Recruitment and testing of 5 new high-functioning individuals with autism, of whom 2 provided good data; analysis of all high-functioning data
- Recruitment, training, and testing of 2 new low-functioning individuals with autism, of whom 1 provided good data; analysis of all low-functioning data using best practices
- Implementation of word training procedures with 2 low-functioning individuals with autism (of which 1 had to withdraw from the study); pre-testing measures completed, and word training of color names underway

REPORTABLE OUTCOMES

Coderre, E., Bosley, L., Chernenok, M., Gordon, B., & Ledoux, K. (2013). *Modeling Implicit Measures of Receptive Vocabulary Knowledge in Normal Adults*. Abstract submitted for presentation at the Annual Meeting of the Psychonomic Society.

Ledoux, K., Coderre, E., Bosley, L.V., Chernenok, M., Gangopadhyay, I., & Gordon, B. (In preparation). The use of eye movements, pupillary dilation, and event-related potentials to assess receptive vocabulary knowledge in individuals with autism.

CONCLUSION

In all three populations capable of reliable behavioral responses (normal adults, normally developing children, and high-functioning children with autism), our results indicate that the implicit techniques provide valid measures of receptive knowledge. All three measures (eye movement monitoring, pupillary dilation monitoring, and ERPs) appear capable of differentiating known from unknown words, as compared to the criterion of behavioral responses. Specifically, eye movements were faster to, and eyes fixated longer on, the matching picture in the forced-choice task for known words relative to unknown words; pupillary dilation was greater from baseline for unknown words, relative to known words; and the N400 congruency effect was observed for known words, but not for unknown words. Thus, these data support the validity of these techniques and our experimental design. Additionally, in normal adults, we have been able to use these implicit measures themselves to make predictions about which words are likely to be “known” and “unknown” to each individual participant; that is, the measures themselves can be used to help us classify words as being known to a given individual. This is a very important development, as the application of this technique in populations who cannot tell us or otherwise behaviorally indicate to us which words they do and don’t know will provide perhaps the best indicator of covert knowledge.

Our testing of low-functioning participants with autism also suggests that these implicit techniques provide valid measures of receptive knowledge even in the absence of behavioral responses. All three measures appear capable of differentiating known from unknown words within this group, in that the results for low-functioning individuals with autism were remarkably similar to those observed for normal adults, normally-developing children, and high-functioning individuals with autism.

The demonstration of receptive abilities in nonverbal individuals would lay a foundation upon which we might better understand their baseline abilities for communication and for comprehension. Knowing that an individual can understand language even when he or she does not speak might support the development of more intensive speech and language therapies, using a broader range of modalities, to capitalize on that individual’s functional preferences or strengths. We believe that our results provide an initial demonstration of such abilities in a group in which such knowledge has traditionally been difficult to assess, and which has been severely under-represented in the studies of cognitive processing and abilities.

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