

Event-Related Potentials as Implicit Measures of Vocabulary in Individuals with Autism

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Introduction

Assessments of the cognitive operations responsible for language are typically quantified by measuring overt behaviors such as response time or verbal reports. However, such explicit measures assume an understanding of task goals and an ability to execute the required response. In certain populations, such as non- or minimally-verbal low-functioning individuals with autism (LFAs) in whom such measures might be difficult or impossible to obtain, implicit measures of cognitive abilities that do not require explicit understanding and cooperation are essential.

Event-related potentials (ERPs) can serve as implicit measures of vocabulary knowledge. The amplitude of the N400 ERP component is influenced by the ease of semantic integration and is reduced to stimuli that are semantically congruent (such as matching pairs of pictures and words), which are easier to integrate relative to those that are incongruent (such as mismatching pairs, which are more difficult to integrate; Kutas & Federmeier, 2011). This modulation by congruency, or "N400 effect", is limited to the individual's vocabulary range: no such effect occurs for unknown words, for which prior knowledge cannot help ease integration (Connolly & D'Arcy, 2000).

In recent work, we have shown that ERPs can be used to estimate vocabulary knowledge in normal adults (Ledoux et al., 2015). In a picture-word congruity paradigm, an N400 effect was observed for high-frequency 'known' words but not for low-frequency 'unknown' words, suggesting that the N400 effect can reliably estimate vocabulary knowledge in a population of normal adults.

Although ERPs hold potential for cognitive assessment in the absence of behavioral responses, the utility of these measures in individuals with autism has not been determined. Here we investigate whether ERPs can serve as within-subject measures of vocabulary knowledge in individuals with autism with a range of functioning levels.

Methods

Participants

- 24 participants with autism; mean age 29 years (range 15-66); 23 males; 19 Caucasian, 1 African American, 3 Asian, 1 Hispanic.
- 9 participants were enrolled in adult or educational programs specific to assisting individuals with autism and required direct 24-hour support staff and/or parental supervision.

Neuropsychological Testing

- Receptive language abilities:** Peabody Picture Vocabulary Test, Fourth Edition (PPVT-4; Dunn & Dunn, 2007)
- Verbal and non-verbal intelligence:** Kaufman Brief Intelligence Test, Second Edition (K-BIT-2; Kaufman & Kaufman, 2004)
- Autism symptoms:** Autism Diagnostic Observation Schedule (First Edition (ADOS-1) or Second Edition (ADOS-2), depending on the version current at the time of testing; Lord et al. 2000).
 - For 3 participants there was no appropriate module of the ADOS, as currently no modules address nonverbal adolescents or adults. For these participants, "adapted" modules were performed.
- Some participants were unable to complete behavioral testing due to lack of compliance or inability to understand task instructions

Stimuli

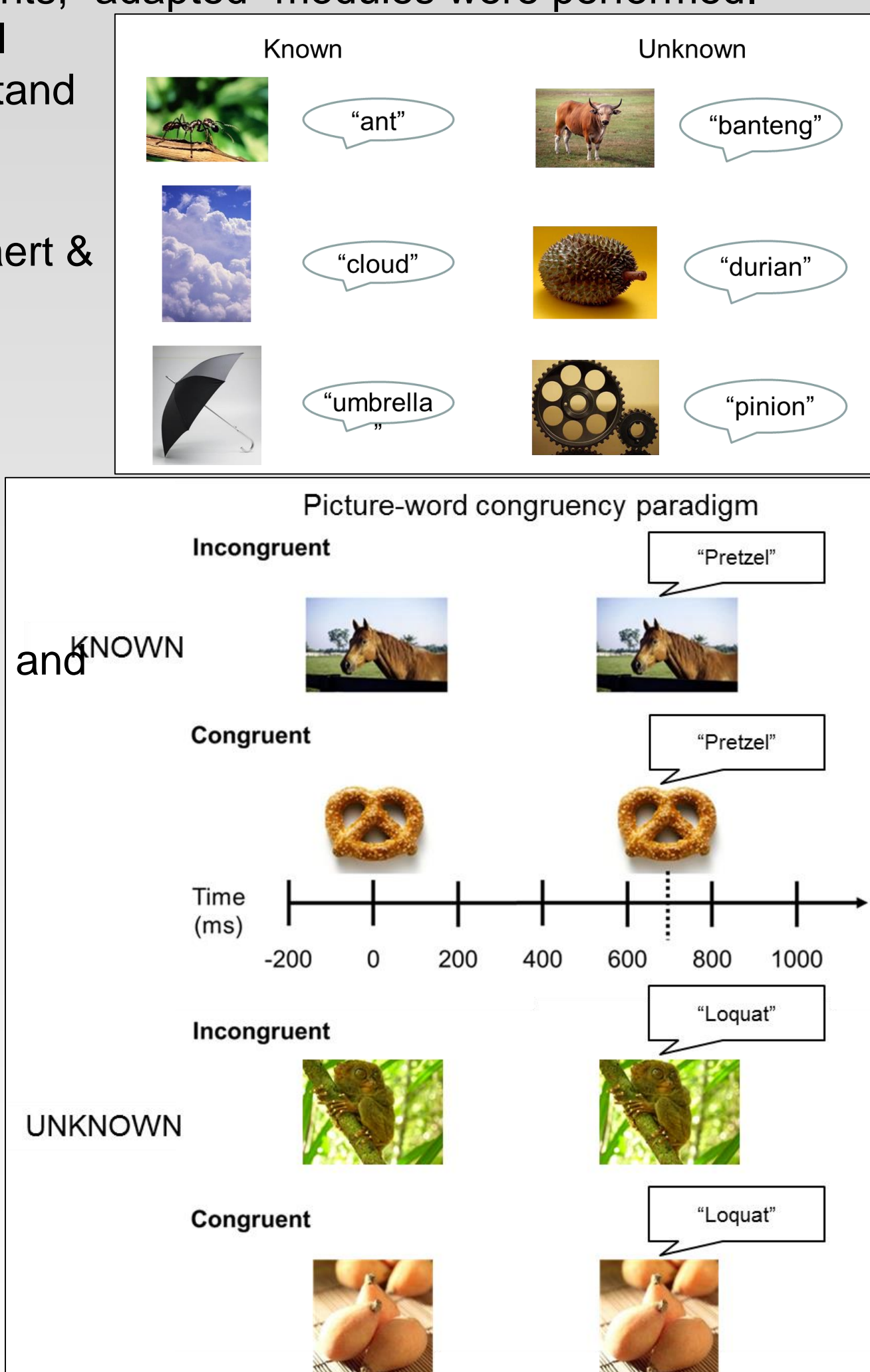
- 80 high-frequency words (average SubtlexUS (Brysbaert & New, 2009) log10 frequency rating = 3.14, SD = 0.6). Because of their high frequency, these words were expected to be 'known' to participants
- 80 low-frequency words (average SubtlexUS log10 frequency rating = 0.85, SD = 0.5). Because of their low frequency, these words were expected to be 'unknown' to participants
- Corresponding high-resolution color photographs and auditory recordings

Procedure

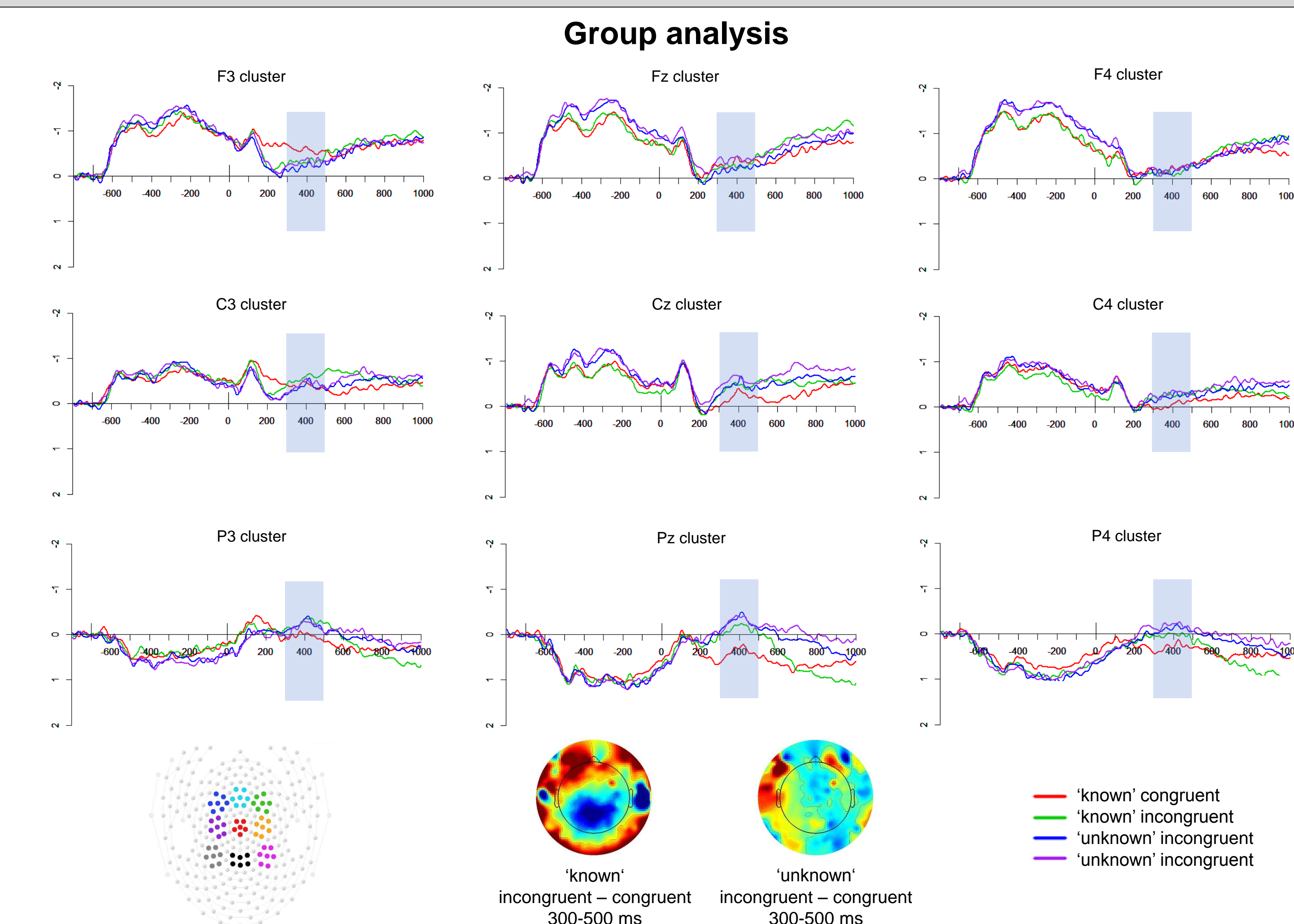
- Picture-word congruency paradigm:** each picture presented twice, once with congruent and once with incongruent word pairing

EEG Data Acquisition and Preprocessing

- EEG recorded at 250 Hz using an Electrical Geodesics Inc. GES 300 EEG System with 256-channel Hydrocel Geodesic Sensor Nets and NetStation version 4.3
- Bandpass filter 0.1-30Hz. Motion and eye movement artifacts corrected using ICA decomposition
- Electrodes grouped into 9 clusters for analyses

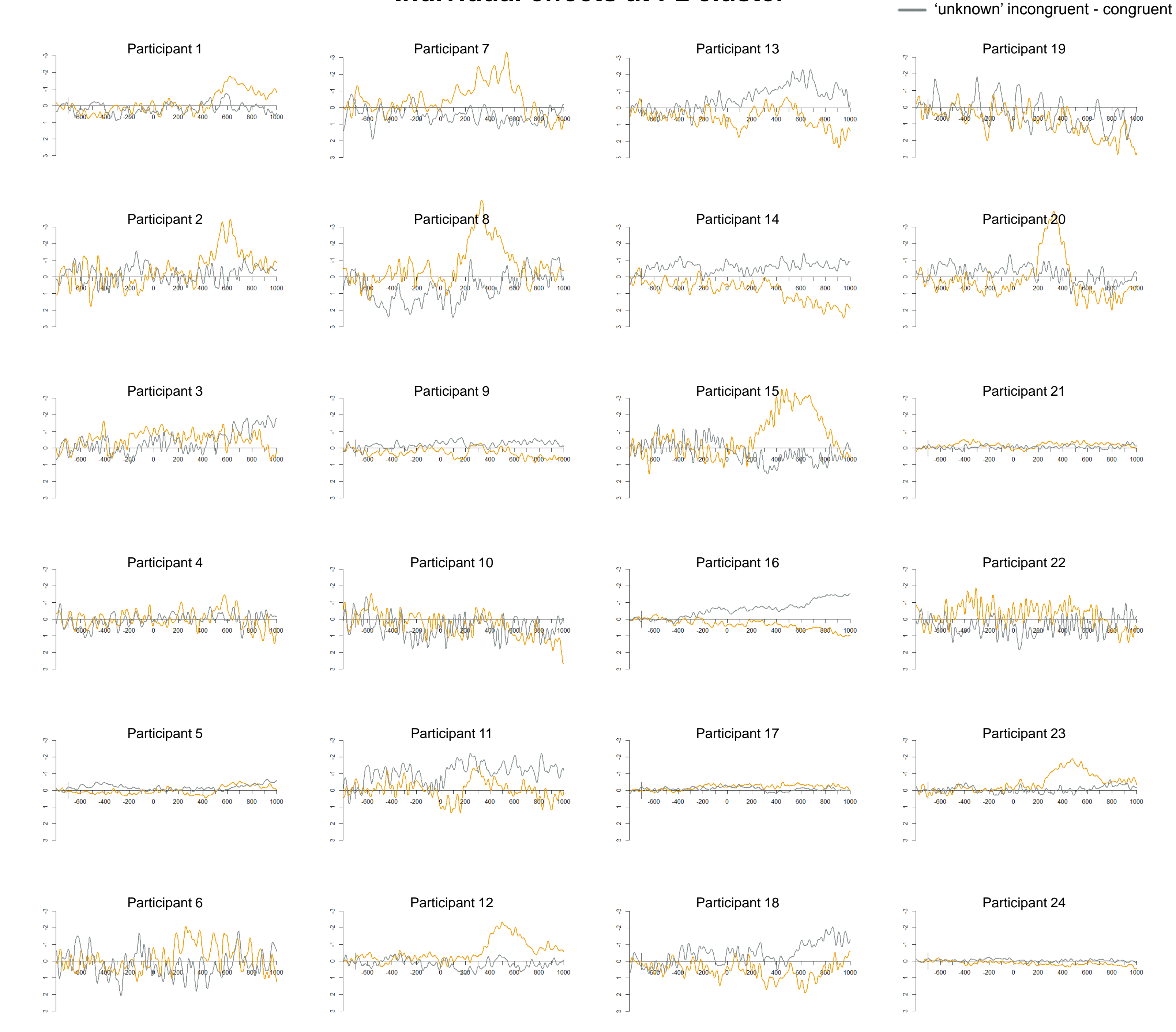


Results

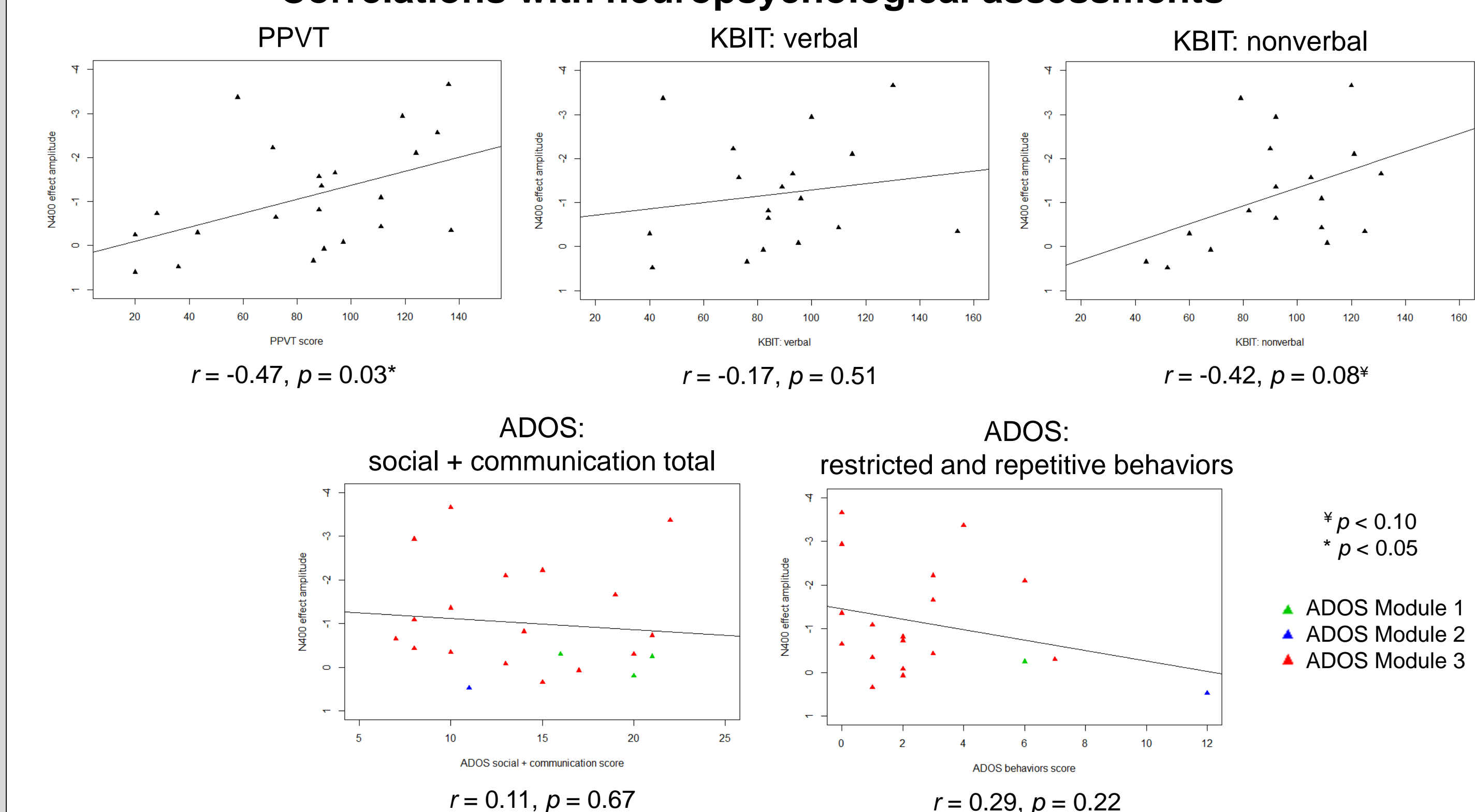


- A 2 (knowledge: known/unknown) x 2 (congruency: congruent/incongruent) x 3 (site: frontal/central/parietal) x 3 (laterality: left/midline/right) repeated-measures ANOVA was run on the average amplitude from 300-500 ms (blue shaded areas).
- A significant four-way interaction ($F(4,92) = 2.58, p < 0.05$) arose from trends towards significant interactions of knowledge and congruency at left parietal (P3 cluster; $F(1,23) = 3.35, p = 0.08$) and midline parietal (Pz cluster; $F(1,23) = 3.56, p = 0.07$) sites.
- At both P3 and Pz clusters an N400 effect occurred in known conditions ($p < 0.05$) but not unknown conditions (all p 's > 0.64).

Individual effects at Pz cluster



Correlations with neuropsychological assessments



- Each subject's average N400 amplitude was calculated by finding the peak negative amplitude of the known condition difference wave at the Pz cluster, then averaging over a window 50 ms before and after the peak.
- Pairwise Pearson correlations between N400 effect magnitude and behavioral scores showed significant correlations between the N400 magnitude and PPVT scores, with a trend between N400 magnitude and nonverbal KBIT scores.

Discussion

In the group analysis, "known" words elicited an N400 effect over centro-parietal scalp, whereas there was no such effect for "unknown" words. These findings replicate the results observed in normal adults by Ledoux et al. (2015) and demonstrate that ERPs can serve as within-subject measures of vocabulary knowledge in individuals with autism across a range of functioning levels.

Correlational analyses showed a significant correlation between PPVT scores and N400 effects, such that participants with better vocabulary abilities (larger PPVT scores) showed larger N400 responses. This correlation replicates previous findings in the literature (D'Arcy et al., 2003) and suggests that the N400 response is accurately capturing vocabulary knowledge without reliance on behavioral measures.

The individual data demonstrate significant heterogeneity among the participants. While some had large N400 responses in "known" words, others showed little difference between congruent and incongruent stimuli in either "known" or "unknown" words. This variability suggests that the N400 may be better suited as an implicit estimate of vocabulary knowledge in individuals with autism who show larger effects. Factors such as the ability to tolerate the EEG net and the number of sessions required to obtain enough clean data should also be considered.

Conclusions

Overall, the N400 distinguished between "known" and "unknown" vocabulary in individuals with autism and correlated with receptive language abilities, although there was significant individual variation. Despite the heterogeneity inherent in autism, ERPs can serve as implicit measures of vocabulary in this population, and hold especially strong potential for language assessment in low-functioning individuals.

References

Brysbaert, M., & New, B. (2009). Moving beyond Kucera and Francis: A critical evaluation of current word frequency norms and the introduction of a new and improved word frequency measure for American English. *Behavior Research Methods*, 41(4), 977-990.

Connolly, J.F., & D'Arcy, R.C.N. (2000). Innovations in neuropsychological assessment using event-related brain potentials. *International Journal of Psychophysiology*, 37, 31-47.

D'Arcy, R. C. N., Marchand, Y., Eskes, G. a, Harrison, E. R., Phillips, S. J., Major, A., & Connolly, J. F. (2003). Electrophysiological assessment of language function following stroke. *Clinical Neurophysiology*, 114(4), 662-672.

Dunn, L., & Dunn, D. (2007). *Peabody Picture Vocabulary Tests (4th edition)*. Circle Pines, MN: American Guidance Service.

Kaufman, A., & Kaufman, N. (2004). *Kaufman Brief Intelligence Test (2nd edition)*. Circle Pines, MN: American Guidance Service.

Kuipers, J.R., & Thierry, G. (2011). N400 amplitude reduction correlates with an increase in pupil size. *Frontiers in Human Neuroscience*, 5, 61.

Kutas, M. & Federmeier, K.D. (2011). Thirty years and counting: Finding meaning in the N400 component of the event-related brain potential (ERP). *Annual Review of Psychology*, 62, 621-647.

Ledoux, K., Coderre, E.L., Bosley, L., Buz, E., Gangopadhyay, I., & Gordon, B. (2015). The concurrent use of three implicit measures (eye movements, pupillometry, and event-related potentials) to assess receptive vocabulary knowledge in normal adults. *Behavior Research Methods*. doi:10.3758/s13428-015-0571-6

Lord, C., Risi, S., Lambrecht, L., Cook, E. H., Leventhal, B. L., DiLavore, P. C., Pickles, A., & Rutter, M. (2000). The Autism Diagnostic Observation Schedule—Generic: A standard measure of social and communication deficits associated with the spectrum of autism. *Journal of Autism and Developmental Disorders*, 30(3), 205-223.

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