The electrophysiology of semantic processing in individuals with autism spectrum disorder: A meta-analysis

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Abstract

Language deficits vary widely among people with autism spectrum disorder (ASD). However, the semantic processing of autism and its underlying electrophysiological mechanism are still unclear. PubMed, Web of Science, and Embase were searched for event-related potential (ERP) studies on semantic processing in people with ASD published in English before September 1, 2022. Pooled estimates were calculated by fixed-effects or random-effects models according to the heterogeneity. The potential moderator was explored by meta-regression and subgroup analysis. This meta-analysis has been registered on PROSPERO (no. CRD 42021265852). Our study included 14 articles and 18 studies, including 254 ASD patients and 262 controls. Compared to the controls, ASD patients showed a reduced N400 amplitude (Hedges' $g = 0.350$, $P<0.001$) in response to linguistic stimuli instead of non-linguistic stimuli. The N400 amplitude can be affected by verbal intelligence and gender. The reduced overall N400 amplitude in ASD patients under linguistic stimuli suggests a linguistic-specific deficit in semantic processing in individuals of ASD. The decrease of N400 amplitude might be a promising indication of the pool language capacity of ASD.

Introduction

Autism spectrum disorder (ASD) is a group of neurodevelopmental conditions characterized by impairments in social interaction as well as restricted/repetitive behavior and interests\(^1\). Although language impairment is no longer a core symptom of ASD, it is still more extensive than assumed in patients with ASD. In addition, the language proficiency of ASD patients is highly variable, ranging from silent to verbally fluent. Compared to language production, language comprehension deficits may be more severe and may serve as an early sign of ASD\(^2\)\(^3\). Semantic processing, which means understanding and categorizing a stimulus's meaning, plays a vital role in language comprehension\(^4\). Some studies suggested that semantic language ability can provide the foundational language skills to guide social interactions, support social skills development and predict the social skills of ASD adolescents in the later stages\(^5\). Numerous methods have been used to measure the neural processes of semantic processing, like electroencephalography (EEG) and functional magnetic resonance imaging (fMRI). Event-related potential (ERP) is an efficient and sensitive technology for assessing cognitive processing with a high temporal resolution and is well suitable to characterize subtle differences in semantic processing\(^6\). The N400 and the P600 are two ERP components that have been consistently linked to language progress\(^4\).

The N400 component is one of the most studied language ERP components associated with semantic processing and integration. It was first noted as increased negativity in response to semantic violations by Kutas and Hillyard\(^7\). Although it is a negative peaking over the central-posterior electrode sites, it need not be negative in absolute terms\(^8\). The language processing of accessing long-term memory representation (such as words and morphemes) and integrating these representations into current semantics can affect the amplitude of the N400 response\(^9\). The N400 effect refers to a difference ERP created via subtraction of a congruent condition from an incongruent one\(^10\) and reflects the activation of
related semantic networks, leading to facilitated processing of the target or the effect differences to integrate the word into the previous sentential context\textsuperscript{11}. The N400 response is often elicited from two paradigms. The semantic-anomaly paradigm generates a narrative with contextually congruent or incongruent sentence-final words. The amplitude of the N400 is greater for the incongruent condition because integration is difficult in incongruent context\textsuperscript{12}. The semantic-priming paradigm provides a related or unrelated word before a target word and the priming word is considered to be the context for the target word to be integrated\textsuperscript{13}. The decrease in the amplitude of N400 reflects the response to the target word, which is semantically related to the previous word\textsuperscript{14}. Both of the two paradigms reflect the process of semantic integration of the critical word with the working context. In addition, another theory supported that the N400 response reflects facilitated activation of the long-term memory as N400 is sensitive to word frequency\textsuperscript{15}. Generally speaking, high-frequency and early-acquired words result in shorter N400 latency and a smaller N400 amplitude relative to less frequent words as they are easier to access from memory\textsuperscript{16}. Furthermore, N400 is also evoked in response to nonlinguistic material, such as comic and environmental sound\textsuperscript{17}.

So far, there are considerable variabilities in N400 response among individuals with ASD. A few studies have concluded that individuals with ASD exhibit a reduction or disappearance of the N400 effect, suggesting that the neuron's response to language processing is disturbed\textsuperscript{5,18}. Meanwhile, in some studies, the N400 effect is typical, with more significant negativity elicited by the incongruent stimulation in ASD\textsuperscript{19–21}. By comparing the N400 component between individuals of ASD and controls, some studies found that ASD patients showed a larger or smaller N400 response compared to the normal controls\textsuperscript{22}. In addition, N400 could not only be elicited by the paradigms with verbal stimuli, but also by the paradigms represented with the nonverbal stimuli such as visual narratives and environmentally sound. Some studies suggested that individuals with ASD experience deficits in the semantic processing of language but the semantic processing of non-verbal stimuli is intact\textsuperscript{23,24}. While some literature showed a potential benefit of using verbal material but a medium difficulty for visual long-term memory in ASD group\textsuperscript{25}.

P600, a positive deflection in centro-parietal is assumed to be a family of the late positive components (LPC). This component is another language-related ERPs and was first characterized in the context of syntactic processing\textsuperscript{26}. Recent studies suggested that P600 might reflect more general conflict monitoring mechanisms and semantic reinterpretation rather than purely syntactic processes\textsuperscript{27}. Previous studies have not yet determined whether ASD individuals present abnormal P600 under semantic or syntactic violation conditions.

The inconsistent results can attribute to the heterogeneity from individual differences, modalities, and paradigms among the studies. For participants involved in the studies, the difference in age (children/adolescents or adults), diagnosis (autism or Asperger syndrome), and cognitive ability might contribute to the discrepancy. For modalities, in some of the studies, the N400 effect was elicited in a unimodal task such as visual or auditory tasks. While the other studies recorded the task with the cross-modal paradigms given the high multisensory nature of our language cues.
So far, a systematic understanding of the language-related ERPs of N400 and P600 in ASD is lack. To assess whether there is an atypical ERP response in autistic individuals and the factors which may affect these components of language processing, we conducted this meta-analysis, which is a well-established approach in summarizing results with heterogeneity. The goals of this study were 1) to investigate whether there is a significant difference in the difference wave in the N400 and P600 time windows between ASD patients and controls; 2) to investigate whether the damage of semantic processing is language-specific; 3) to explore the potential moderator that may affect the effect size of the N400 or P600 amplitudes.

Methods

This review was registered a priori (PROSPERO no. CRD 42021265852) and followed guidance for conducting and reporting systematic reviews from the Cochrane handbook and the PRISMA NMA checklist assessed by the editorial team of PRISMA.

Search Protocol

The articles were searched before September 1 2022 in PubMed, Web of science, and Embase. The search terms we used were MeSH phrases and text words related to autism spectrum disorder ("Autistic disorder" or "Asperger Syndrome" or "Autistic Spectrum Disorder" or "Disorder, Autistic Spectrum"), semantics ("semantic" or "language" or "linguistics") and Event Related Potential ("N400" or "P600" or "Potential, Event-Related" or "Potential, Event Related"). The combination of search terms was listed in Supplementary material 1.

Selection Criteria

Publications were only included in the analysis if: (1) Full text was available and published in English; (2) the study included both ASD participants and normal controls; (3) ERP technique was used to measure N400 and P600 components; (4) the incongruent condition minus the congruent condition or the unrelated condition minus the related condition was used to represent the different wave. (5) the time windows of N400 and P600 were 200-600ms and 600-1000ms respectively.

Data Extraction

Two reviewers (D-F.Y. and X-Y. Y.) independently extracted and checked the data. Any disagreement was resolved through discussion until a consensus was reached with the third reviewer (Z-J. L.). We extracted data from selected studies regarding the number of participants, mean age, diagnosis, verbal IQ, non-verbal IQ, full-scale IQ, receptive language ability, stimulus characteristics, Autism Quotient scores (AQ) as well as mean and standard deviation or F-value of effect sizes in each group. Five effect sizes were computed to examine the pattern of semantic processing including N400 amplitude, N400 different wave
(the difference in the N400 amplitude between congruent and incongruent conditions), N400 amplitudes for congruent conditions, N400 amplitudes for incongruent conditions, and P600 amplitude. A total of 14 articles were retained for the current meta-analysis. Among these, one study contained participants with two different age group and three studies had two different N400 time windows, each experiment was taken as an independent study, making a total of 17 datasets for meta-analysis.

**Data Synthesis**

We divided N400 data into two categories according to the "stimulus characteristics": linguistic and non-linguistic stimulus. Furthermore, paradigms of the semantic process were classified into three categories: semantic violation, semantic priming, and word frequency. The "N400 effect" and the "P600 effect" were defined as the amplitude difference between related and unrelated conditions or congruent and incongruent conditions. The statistical analysis was performed by Comprehensive Meta-Analysis 2.0.

**Statistical analysis**

Hedges' g and 95% confidence interval (CI) were calculated as the effect size by the mean amplitude differences between the patient and control groups, divided by the pooled SD. When means and SDs were unavailable, the effect size was computed from F value or mean change scores with t or P value within groups. Cochran's Q and $I^2$ tests examined the heterogeneity between studies, which helps to evaluate the consistency across studies $^{28}$. Data were analyzed using a random-effects model (if $I^2 \geq 50\%$) or a fixed-effects model (if $I^2 < 50\%$). The subgroup analysis categories were age group, diagnosis, paradigm, modality, verbal level of the stimulus, and electrode site. The age group was classified into two groups: children/adolescents and adults. The diagnosis was based on the patients' language ability and classified into Asperger syndrome and autism. As the N400 response can be elicited by the response to several kinds of paradigms, we divided the paradigms into three groups: semantic priming, semantic violation, and word frequency. Since the presentation of the linguistic stimulus might impact semantic processing, we classified the modalities as the auditory stimulus, visual stimulus, and audiovisual stimulus. Furthermore, the verbal level of the stimulus was classified into two groups: lexical level and sentence level. Given that the N400 component was measured over central and parietal electrodes, the electrode site was divided as Cz and Pz. In addition, the meta-regression was performed with gender, verbal IQ, performance/non-verbal IQ, full-scale IQ, receptive language proficiency, Autism Quotient scores, and trials of each condition.

A funnel plot was conducted to detect whether the included studies had publication bias visually when the pool studies reached 10. A more symmetrical funnel shape indicates less bias between studies. To quantify the extent of asymmetry of the plot, we also applied the Egger test to check the publication bias $^{29}$.

**Results**
A total of 157 primary literature related to search protocol were discovered: 42 from PubMed, 81 from Web of Science and 34 from Embase. After selecting titles and abstracts, the full texts of 30 were considered potentially relevant. In the end, 14 articles were included in the meta-analysis after excluding 16 articles for the following reason: data no available, no case-control study, and no semantically related condition. The flowchart of study selection and inclusion is shown in Fig. 1.

The characteristics of the included studies are listed in Table 1. All of the studies were conducted between 2005 and 2022. In total, this meta-analysis pooled results from 254 participants of ASD and 262 neurotypical controls, in which half of the subjects were children and adolescents and half were adults. Most of the studies included in the meta-analysis enrolled high-function autism. Two studies recruited Asperger syndrome. In one study, minimally verbal children with ASD were recruited. As to the stimulus, some were presented as verbal materials, and others were presented as visual materials. According to the “stimulus characteristics”, these articles were divided into two categories (linguistic and non-linguistic stimuli).

Among the linguistic stimuli, some were presented in a sentence and elicited through the semantic violence paradigm; the other were presented in words and elicited by the semantic priming paradigm or in-category and out-of-category words paradigm.

**ERP component elicited by Linguistic stimulus**

A total of 14 articles and 18 studies were included for applying the linguistic stimuli. Five effect sizes were computed to examine the N400 and P600 responses under the linguistic stimulus, including N400 amplitude, N400 different wave, N400 amplitude for congruent condition, N400 amplitude for incongruent condition, and P600 amplitude.

**The N400 amplitudes difference between ASD and controls**

Thirteen articles and seventeen studies compared N400 amplitude differences elicited by linguistic stimuli between ASD and controls. The sample size in the ASD and control groups were 218 and 237, respectively. All of the studies were homogenous, and the fixed effect model was used for analysis ($I^2 = 0.00\%, Q = 12.614$). The analysis revealed a significantly reduced overall N400 response to linguistic stimuli in the autistic group than the control group (Hedges’ $g = 0.350$, 95% CI ranged from 0.187 to 0.498, $P < 0.001$, Fig. 2a). Further analysis with potential moderators was evaluated.

The subgroup analysis was conducted as we assumed that the age, paradigm, diagnosis, level of verbal stimuli, modality, and electrode location might affect the N400 amplitude. The synthetic results of N400 amplitude were homogeneous in different ages, diagnoses, modalities, language levels, and paradigms. However, no significant effect size was found in the subgroup of Asperger syndrome, in-versus out-of-category words paradigm and Pz electrode site (Table 2), suggesting that the difference of N400 amplitude was not significant for the in-versus out of category words paradigm, Asperger’s syndrome and Pz electrode site between individuals of ASD and controls.
<table>
<thead>
<tr>
<th>Moderators</th>
<th>subgroup</th>
<th>N</th>
<th>Point estimate</th>
<th>Z-value</th>
<th>P-value</th>
<th>Q-value</th>
<th>$\bar{\rho}$(%)</th>
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<td></td>
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<td>17</td>
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<td>0.955</td>
<td>25.581</td>
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Abbreviation: N number of studies, Q test of heterogeneity, $P$ $P$-value, ASD Autism spectrum disorder, AS Asperger syndrome

* $P<0.05$, ** $P<0.01$
<table>
<thead>
<tr>
<th>Moderators</th>
<th>subgroup</th>
<th>N</th>
<th>Point estimate</th>
<th>Z-value</th>
<th>P-value</th>
<th>Q-value</th>
<th>I²(%)</th>
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<td>0.826</td>
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</table>

Abbreviation: N number of studies, Q test of heterogeneity, P P value, ASD Autism spectrum disorder, AS Asperger syndrome

*P<0.05, **P<0.01

According to the meta-regression analysis, gender might be a potential moderator (Z = 2.254, P = 0.024). The result suggested that as the proportion of males in ASD increased, the N400 amplitude showed a trend of decrease. However, age is not a potential moderator with no significant effect size (Z=-1.358, P = 0.174). Given the fact that the cognitive function in ASD patients, especially the language capacity, was highly heterogeneous and was generally lower than neurotypical controls, we considered “verbal IQ”, “non-verbal IQ”, “full-scale IQ”, and “receptive language” as potential moderators. The result showed significant heterogeneity in “verbal IQ” (Z=-2.024, P = 0.043), which indicated that verbal IQ can significantly affect the N400 amplitude between individuals of ASD and controls. However, the influence of “non-verbal IQ” and “receptive language ability” on N400 amplitude was not significant(P<0.05). In addition, we considered that the trials for each condition and autistic traits measured by AQ might be the potential moderators. The results revealed that no significant influence was found (P<0.05, Table 3). The funnel is symmetrical, indicating that publication bias was not captured among the smaller and larger studies (Fig. 3). The P-value of the Egger test was 0.064, which confirmed that the results did not suffer from publication bias.
### Table 3
Results of meta-regressions

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Point estimate</th>
<th>Lower limit</th>
<th>Upper limit</th>
<th>z-value</th>
<th>P-value</th>
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<td><strong>N400 amplitude for linguistic stimuli</strong></td>
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<td></td>
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<tr>
<td>Receptive language</td>
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<td>0.342</td>
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<td>1.534</td>
<td>0.558</td>
<td>0.576</td>
</tr>
</tbody>
</table>

Abbreviation: N number of studies, VIQ = Verbal IQ, PIQ Performance/Nonverbal IQ, FIQ Full-scale IQ

*P<0.05, **P<0.01

### N400 effect difference between ASD and Controls
Among the articles, nine studies included a different wave of N400 between congruent and incongruent conditions. The fixed effect model was selected as acceptable heterogeneity ($I^2 = 0.000\%$, $Q = 1.751$). After summarizing the outcome of N400 different waves, the synthetic results of N400 different waves revealed a marginally significant difference between the two groups (Hedges' $g = 0.194$, 95% CI ranged from $-0.23$ to $0.412$, $P=0.08$) (Fig. 2b). The subgroup analysis of the electrode site and diagnosis revealed that neither would affect the heterogeneity, although the difference of N400 effect was more pronounced at the central electrode (Table 2).

### Amplitudes of N400 for incongruent and congruent condition
Five studies compared the N400 amplitude for congruent/related conditions between ASD and control groups\textsuperscript{45–49}. The synthetic result revealed that the N400 amplitude for congruent condition between the two groups was insignificant and the studies in the pool were heterogeneous (Hedges’ $g=0.017$, 95% CI ranged from $-0.632$ to $0.597$, $P=0.955$, $I^2=80.454\%$, $Q=25.581$) (Fig. 2c). In addition, five studies included the N400 amplitude for the incongruent/unrelated conditions. The effect size was insignificant, with an increased difference between the two groups observed at the parietal electrode. The studies in the pool were homogenous (Hedges’ $g=0.079$, 95% CI ranged from $-0.182$ to $0.340$, $P=0.552$, $I^2=0.000\%$, $Q=2.922$) (Fig. 2d). The subgroup analysis of the electrode site indicated a more negative N400 amplitude for the incongruent and congruent conditions at the parietal site, although the effect size was insignificant (Table 2).

**P600 amplitude difference between ASD and Controls**

We included 7 articles and 8 studies in the meta-analysis that reported P600 amplitudes differences between ASD and the control group\textsuperscript{43,44,48,51–54}. The heterogeneity was moderate for the P600 amplitude difference to speech sound stimulation and the fixed effect model was applied for analysis ($Q=12.516$, $P^2=44.073$). Among the 8 studies, only 2 studies revealed a late positive potential\textsuperscript{37,40} and most studies reported a sustained negativity. The effect size was significant, indicating greater negativity in the control group compared to the ASD group (Hedges’ $g=0.289$, 95% CI ranged from 0.059 to 0.518, $P=0.014$, Fig. 4). As indicated by meta-regression, age and cognitive ability were not potential moderators for the effect size ($P>0.05$, Table 3).

**ERP component elicited by non-linguistic stimulus**

A total of 5 article and 7 studies were included for applying the non-linguistic stimuli such as music, pictures, and comics\textsuperscript{44,50,52–54}. Two effect sizes were computed to examine the N400 and P600 responses for non-linguistic stimulus: N400 amplitude and P600 amplitude.

**N400 amplitude difference between ASD and Controls**

A total of 5 articles and 7 studies were included in this analysis\textsuperscript{32,33,38–40}. The available evidence was not enough to show a statistically significant difference between ASD and the control group in amplitudes of the N400 elicited by the non-linguistic stimuli (Hedges’ $g=0.025$, 95% CI ranged from $-0.217$ to $0.268$, $P=0.837$, Fig. 5). The studies in the pool were homogenous ($I^2=23.510\%$, $Q=7.844$).

**P600 amplitude difference between ASD and Controls**

In a meta-analysis of 4 studies that reported P600 amplitude difference under non-linguistic materials, the heterogeneity between studies was significant, and the random effect model was used for analysis ($Q=11.207$, $P^2=73.231$)\textsuperscript{32,33,39,40}. The pooled result showed that no significant difference between the ASD patients and controls was found (Hedges’ $g=-0.099$, 95% CI ranged from $-0.732$ to $0.533$, $P=0.271$, Fig. 6)\textsuperscript{44,52–54}.
**Discussion**

This is the first meta-analysis examining semantic processing in individuals with ASD from the ERPs perspective and providing a comprehensive overview of current knowledge about language-related ERPs in individuals of ASD. The meta-analysis pooled the results of 18 studies and showed that the ASD group tends to display a reduced overall N400 amplitude and N400 effect compared to neurotypical controls. Besides, the reduced N400 amplitude is limited to linguistic materials and no statistically significant effect size was observed for non-linguistic stimuli, indicating a language-specific deficit of semantic processing in ASD individuals.

N400 is a well-studied ERP component of semantic processing. Our meta-analysis revealed an overall reduced N400 amplitude in the ASD group compared to the controls, which suggests abnormal semantic processing in individuals with ASD. According to the assumption of weak central coherence theory, individuals of ASD only focus on fine-grained detail and have difficulty integrating information within the linguistic context. Studies of fMRI, intracranial, and neuropsychological have revealed that the posterior temporal cortex, anterior temporal cortex, and inferior frontal cortex play a role in the semantic processing of linguistic. The evidence from fMRI studies in ASD also showed that the ASD group had less frontal mechanisms control of semantic knowledge in the temporal cortex.

The N400 effect is the difference in amplitude between a congruent and incongruent stimulus. Previous studies have shown that the N400 effect is sensitive to differences between the individual with different comprehensive skills. In our meta-analysis, a reduced N400 effect was found in ASD patients, which suggests a deficit of semantic processing. Although no significant effect size was found in incongruous or congruous conditions, the ASD group showed a subtle reduced N400 in the incongruous conditions and enhanced negativity in the congruous condition. This trend could be the result of a reduced N400 effect in the ASD group. Attenuated N400 in incongruent condition indicates a decreased activation of the incongruent context, and the enhanced N400 in congruent condition reflects the difficulty in using context to generate expectancies.

In addition, there is a contentious debate on whether the impairment of semantic integration is language-specific or a global impairment. The synthesized result of our meta-analysis suggested a language-specific deficit, which can also be supported by the fMRI study indicating that individuals of ASD rely more on visual processing in the occipital cortex than verbal processing in the temporal cortex. Some researchers speculated that pictorial access is superior to verbal access for semantic information in ASD. As the fundamental role of perception processing in language development, perception deficits are closely related to language ability. The ERP study of speech-specific perception deficits in ASD also supported the result of the meta-analysis.

Furthermore, the results of meta-regression showed that the effect size of N400 amplitude might be affected by the verbal IQ, reflecting that the difference in N400 amplitude between the two groups is negatively related to language capacity. A similar finding was also observed in subgroup analysis. For
patients with Asperger syndrome, a part of family of ASD that preserved cognitive and verbal facilities, the difference was insignificant. The result is consistent with the literature reported previously that N400 had a solid relationship to vocabulary learning in children and sentence comprehension in adults. Furthermore, gender may be another potential moderator affecting the N400 amplitude. The result may be explained by the fact that better linguistic abilities more often present in females than in males. The difference of N400 response was observed in semantic anomalies and semantic priming paradigms, which suggests the difficulty in integrating semantic context and facilitating lexical access. However, the inverted-out-of-category words task showed no significant difference between the two groups, which means that the lexical frequency effect is less sensitive in distinguishing ASD from the TD group.

The P600 is a positive deflection of compositional semantic integration processes. The P600 effect can be observed in responses to syntactic violations, semantic incongruency, and pragmatic anomalies. Some studies reported that P600 has not been specifically related to the language process but is more likely to reflect the general monitoring process and modulated with instructions. According to our meta-analysis from limited literature, contrary to Pijnacker et al., the controls showed significantly greater negativity than the ASD group elicited by linguistic stimuli. One possible reason is that the effect of P600 overlapped by the sustained anterior negativity. Previous findings reported that the sustained anterior negativity could be explained by the increased demands on working memory load but the decreased monitoring of violations. Therefore, the presence of negativity masked the expected P600 effect of plausibility. In addition, language capacity did not affect the P600 component according to the meta-regression. These results indicated that P600 might not be a stable index of semantic processing in ASD, even though a significant difference was detected between the two groups. Further research is needed to explore the potential role of P600 in ASD. In the contrary, the attenuated amplitude of N400 might be a relatively reliable estimate of poor semantic ability in ASD. However, it would be premature to conclude that N400 amplitude can be a marker for ASD with language impairment, as a marker must have both high sensitivity and specificity.

Our meta-analysis contains some limitations. First, only a few studies recruited minimally verbal ASD participants. The characteristic of N400 waveform in individuals of ASD with low IQ should be further explored. Second, the number of studies was relatively limited. Some researches were excluded from this study because the N400 response was not elicited. Third, given that the amplitude response of N400 was most susceptible to manipulation and the latency was generally stable, only a limited number of studies reported the N400 latency. Therefore, our meta-analysis only incorporated the N400 amplitude index and did not include the latency indicators. Last but not least, as much of the literature reported previously, the ASD group shows atypical lateralization patterns of ERPs to speech stimuli. The relationship between cerebral lateralization and language-related ERPs should be considered in future studies.

Conclusion
This meta-analysis indicates overall patterns of a reduced N400 amplitude and difference wave in people with ASD compared to the controls under linguistic stimuli. The N400 amplitude is modulated by verbal intelligence and gender. In conclusion, our findings suggest a language-specific semantic processing deficiency in ASD patients from the neurocognitive aspect. The decrease of N400 amplitude might be a promising indication of pool language capacity in ASD.

Declarations

Author Contributions Statement

D.F.Y. (First Author): Conceptualization, Writing-Original Draft
X.Y.Y.: Data Curation, Writing-Review and Editing
L.J.Y: Validation, Writing-Review and Editing.
Z.J.L. (Corresponding Author): Conceptualization, Funding Acquisition, Supervision, Writing-Review and Editing.

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Availability of Data and Materials State

All data generated or analyzed during this study are included in this published article [and its supplementary information files].

Competing Interests

The authors declare that they have no conflict of interest.

References


**Table**

Table 1 is available in the Supplementary Files section.

**Figures**
Figure 1

Flowchart of the study’s inclusion and exclusion criteria.
Figure 2

(a) Forest plot of N400 amplitude for linguistic stimuli between ASD and controls. (b) Forest plot of N400 effect for linguistic stimuli between ASD and controls. (c) Forest plot of N400 amplitude for linguistic stimuli in the congruent condition. (d) Forest plot of N400 amplitude for linguistic stimuli in the incongruent condition.
Figure 3

Funnel plot for publication bias of N400 amplitude for linguistic stimuli between ASD and controls.

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Figure 4

Forest plot of P600 amplitude for linguistic stimuli between ASD and controls.
Figure 5

Forest plot of N400 amplitude for non-linguistic stimuli between ASD and controls.

Figure 6

Forest plot of P600 amplitude for non-linguistic stimuli between ASD and controls.
Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table1.docx
- Supplementaryfile1.docx
- Supplementaryfile2.docx
- Supplementaryfile3.docx