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# Exceptions and anomalies: An ERP study on context sensitivity in autism

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ABSTRACT

Several studies have demonstrated that people with ASD and intact language skills still have problems processing linguistic information in context. Given this evidence for reduced sensitivity to linguistic context, the question arises how contextual information is actually processed by people with ASD. In this study, we used event-related brain potentials (ERPs) to examine context sensitivity in high-functioning adults with autistic disorder (HFA) and Asperger syndrome at two levels: at the level of sentence processing and at the level of solving reasoning problems. We found that sentence context as well as reasoning context had an immediate ERP effect in adults with Asperger syndrome, as in matched controls. Both groups showed a typical N400 effect and a late positive component for the sentence conditions, and a sustained negativity for the reasoning conditions. In contrast, the HFA group demonstrated neither an N400 effect nor a sustained negativity. However, the HFA group showed a late positive component which was larger for semantically anomalous sentences than congruent sentences. Because sentence context had a modulating effect in a later phase, semantic integration is perhaps less automatic in HFA, and presumably more elaborate processes are needed to arrive at a sentence interpretation.


## 1. Introduction

Autism spectrum disorders (ASD) are characterized by deficits in social interaction and communication, and by restrictive, stereotyped and repetitive behaviors and narrow interests (DSM-IV, 1994). Both Asperger syndrome and autistic disorder belong to ASD, and are characterized by similar features but differ in early language development (DSM-IV, 1994). One core feature of ASD are deficits in pragmatic language, which include difficulties in understanding non-literal language like irony and metaphors (Dennis, Lazenby, & Lockyer, 2001; Happé, 1993; Martin & McDonald, 2004; Ozonoff & Miller, 1996). A possible account for such deficits is that people with ASD find it difficult to use context when computing meaning.

It has been demonstrated that individuals with autistic disorder or Asperger syndrome who have intact language skills, still have problems processing linguistic information in context (Happé, 1997; Jolliffe & Baron-Cohen, 1999). In a homograph task, they failed to use sentence context to derive the appropriate pronunciation of the homographs, for instance, when they had to pronounce the homograph *tear* in a sentence like "In her dress/eye there was a big tear" (Frith & Snowling, 1983; Happé, 1997; Jolliffe & Baron-Cohen, 1999). They were also found to be less able to use contextual information to make a global inference in a sentence arrangement task, were less likely to choose a bridging inference to make a scenario coherent if they had to select from a list of alternatives, and were less able to use context to interpret ambiguous sentences (Jolliffe & Baron-Cohen, 1999, 2000). These findings indicate that people with ASD have difficulty understanding language in context. Moreover, of the two subgroups, people with autistic disorder had greater difficulty in using contextual information than people with Asperger syndrome (Jolliffe & Baron-Cohen, 1999, 2000). It has been argued that these findings support the weak central coherence account of ASD, which claims that people with ASD have a processing bias for details at the expense of the global picture (Frith, 2003; Happé, 1999; Happé & Frith, 2006). Given this evidence for reduced sensitivity to linguistic context, the question arises how contextual information is actually processed by people with ASD.

In the present work we used event-related brain potentials (ERPs) to examine context sensitivity in high-functioning adults with autistic disorder (HFA) and Asperger syndrome. ERPs have the advantage that they have good temporal resolution, and therefore

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can provide precise information about the time course of cognitive processes. Thus ERPs can give us more insight into when particular information is processed in the brain. We investigated the notion of context sensitivity in autism at two levels: at the level of sentence processing and at the level of solving reasoning problems. Both require one to make use of earlier encountered information in order to interpret the incoming new information, though the last mentioned involves a more elaborate context requiring inference making and reasoning. In the following sections, we will introduce these topics in greater detail.

## 2. Integrating words into context – the N400 effect

In ERP research a component called N400 has been proven to be a good tool to examine the online integration of lexical-semantic information. The N400 is a negative deflection that peaks around 400 ms after the onset of a word and is topologically distributed over central-parietal sites on the scalp. The N400 is elicited by every content word, but its strength varies as a function of the degree of semantic fit between a word and its context. For example, a semantically anomalous word in a sentence like "He spread his warm bread with *socks*" elicits a larger N400 than the congruent word *butter* in "He spread his warm bread with *butter*" (Kutas & Hillyard, 1980). The N400 effect also occurs in sentences that are semantically appropriate but where words conflict with expectancy (Hagoort & Brown, 1994), world knowledge (Hagoort, Hald, Bastiaansen, & Petersson, 2004), or discourse context (Van Berkum, Brown, & Hagoort, 1999; Van Berkum, Brown, Hagoort, & Zwitserlood, 2003). In general, the N400 effect is seen as an index of processes involved in the integration of the meaning of a word into a representation of its preceding context, which could be established by a word (Holcomb, Reder, Misra, & Grainger, 2005; Rugg, 1985), a sentence (Kutas & Hillyard, 1980, 1984), or a larger discourse (Van Berkum, Hagoort, & Brown, 1999; Van Berkum, Zwitserlood, Hagoort, & Brown, 2003). As integration of a word into the context becomes harder because it does not satisfy semantic expectations, the amplitude of the N400 increases (Brown & Hagoort, 1993; Van Berkum, Hagoort, et al., 1999).

Currently, evidence for N400 effects in autism is equivocal. For example, children with ASD failed to show any N400 effect when they had to detect words whose semantic category deviated from others in the same set, e.g., non-animal words in a set of animal words (Dunn & Bates, 2005; Dunn, Vaughan, Kreuzer, & Kurtzberg, 1999). One limitation of these studies is that they failed to match the ASD children and the control children on intelligence and verbal abilities. That is, the absence of an N400 effect might be attributed to impaired verbal abilities or lower intelligence, and not to the autistic condition itself. Other research demonstrated that children with autistic disorder and Asperger syndrome had a similar N400 amplitude as controls for incongruent versus congruent word pairs, though in the children with autistic disorder the N400 effect was delayed (Méndez, Sans, Abril, & Valdizan, 2009; Valdizan et al., 2003). In adults with ASD, Strandburg et al. (1993) also found a clear N400 effect for meaningless word pairs relative to meaningful word pairs (e.g. *square wind*/*vicious dog*). Also at sentence level, an N400-like effect was found when adults with ASD read semantically incongruent sentences while MEGs were recorded, but there were differences in spatial distribution between the ASD group and control group (Braeutigam, Swithenby, & Bailey, 2008).

In the present study, we used highly constraining sentences to investigate the time course of linguistic integration in high-functioning adults with ASD. By 'highly constraining' we mean sentences that strongly drive semantic expectations about the upcoming final word, for instance, "Finally the climbers reached the top of the . . .". It is known that when listening to or reading such a constraining sentence, people very rapidly make specific predictions about the continuation of the sentence as it unfolds. When semantic expectations are violated (". . . tulip"), then an N400 effect occurs relative to the expected word (". . . mountain"). We hypothesized that if high-functioning adults with ASD make less use of sentence context and focus more on the meaning of the individual words, their semantic expectations might be less strong, which should give rise to reduced N400 effects. Because adults with HFA and Asperger syndrome may differ in the way they process linguistic information, we will explore whether these subgroups differ in semantic processing (Jolliffe & Baron-Cohen, 1999, 2000; Méndez et al., 2009; Valdizan et al., 2003).

## 3. Defeasible reasoning – taking exceptions into account

So far we have discussed the integration of words into a sentence context. However, the primary aim of the present work is to examine how high-functioning people with ASD make use of context information when reasoning with conditionals, which involves a more elaborate context. Conditionals are of the form "If *P*, then *Q*". A characteristic feature of everyday conditional inferences is that they allow for exceptions. In other words, conditional inferences are defeasible: they can be revised in the light of new information. Exceptions to conditional inferences are quite common in everyday life. For instance, we expect a lamp to light if we switch it on, but we will withdraw this inference if the lamp turns out to be broken. Because one has to adjust one's conclusions when the context changes, defeasible reasoning seems to require mental flexibility (Pijnacker et al., 2009).

In a previous behavioral study, we found that high-functioning adults with ASD were good at conditional reasoning, but were less sensitive to exceptions that prevent a conclusion from being drawn, compared to matched controls (Pijnacker et al., 2009). We suggested that it is exception-handling that is the difficult part of defeasible reasoning for people with ASD. Exception-handling requires that we ignore possible exceptions as long as there is no evidence thereof. That is, we apply a so-called closed-world assumption with regard to exceptions. For instance, in "If I switch the lamp on *and nothing abnormal is the case*, then it will light", we assume that there is indeed nothing abnormal the case as long as we have no evidence for exceptions (Pijnacker et al., 2009; for a detailed description, see Stenning & Van Lambalgen, 2005, 2008). However, if an exception becomes salient – e.g. a broken lamp, then the original closed-world assumption cannot be maintained anymore. This may prevent people from drawing the conclusion that the lamp will light. The important thing is that one must disregard all possible exceptions as long as there is no evidence thereof (i.e. apply the closed-world assumption), but adjust the closed-world assumption when the context changes. Given the evidence of impaired exception-handling in ASD, the question arises how defeasible inferences are processed by people with ASD.

In this study we employed a paradigm that we previously used to explore the electrophysiological signature of defeasible reasoning in a group of college students (Pijnacker, Geurts, Van Lambalgen, Buitelaar, & Hagoort, in press), and which is a modified version of the suppression task (Byrne, 1989, 1991). Participants were visually presented with modus ponens inferences. Modus ponens is a simple argument form, which has two premises. The first premise is the conditional *If P*, *then Q*, which states that *P* implies *Q*. The second premise asserts the first part of the conditional (*P*). From these two premises we can logically conclude that the consequent of the conditional (*Q*) must be true (for examples, see Table 2).

Inferences were preceded either by a congruent context or a disabling context. The disabling context contained a possible exception with regard to the conditional, and was introduced to elicit suppression of modus ponens. Thus it was the context that was decisive for whether a conclusion was drawn or not. However, one may argue that there could be some alternative scenario that overrules the disabling context, e.g. that Lisa bought new lenses or received a refractive surgery, which causes the conclusion still to hold in the presence of a disabling context. However, it is precisely closed-world reasoning that comes into play here: as long as there is no information about alternatives or exceptions, one can assume that all such things are not the case. It has been shown by Stenning and Van Lambalgen (2008) that people indeed apply the closed-world assumption when reasoning with conditionals.

It is important to note that in the original suppression task (Byrne, 1989, 1991; but also see Pijnacker et al., 2009) possible exceptions were presented in the form of a conditional. In order to enable good time-locking to critical words, we had to modify the original task in such a way that the presentation of exceptions became more explicit. As we will see later, this may have had an effect on participants' performance.

In a group of college students ($n = 18$) we found that an electrophysiological brain response occurred just within 250 ms when a conclusion could be withdrawn because of a possible exception (Pijnacker et al., in press). We observed a widely distributed sustained negativity from about 250 ms until the end of the epoch at the final word of the conclusion in the disabling context relative to the congruent context. The observed negativity differed from that of semantic anomaly at least in its morphology and temporal profile. However, we could not conclude that the effect was qualitatively different from a N400 effect, because it had an N400-like central scalp distribution. We suggested that the observed negativity could reflect additional processing because a default inference must be revised to incorporate an exception. Alternatively, it could be associated with more complex, inference-driven interpretive processes (Pijnacker et al., in press).

In the present study, we applied the above described ERP paradigm to people with ASD and matched controls, following up on the earlier behavioral findings that high-functioning adults with ASD are less sensitive to exceptions when reasoning with conditionals (Pijnacker et al., 2009). We explored how high-functioning people with autistic disorder (HFA) and adults with Asperger syndrome make use of context information when reasoning with conditionals compared to matched controls.

To summarize, we will investigate the notion of context sensitivity in high-functioning autism at two levels: at the level of sentence processing and at the level of solving reasoning problems. Both require one to make use of earlier encountered information in order to interpret the incoming new information. However, in the sentence conditions – the N400 paradigm – there is a local violation of meaning: a word occurs that does not semantically fit into the preceding context. In contrast, in the reasoning conditions the words themselves do not involve a semantic violation, but it is the propositional content that may clash with the prior context. Our primary aim is to investigate how people with autism deal with context during reasoning, but by including a standard N400 paradigm we can explore whether there is a specific difficulty with using context in reasoning, or a more general difficulty with the processing of contextual information.

## 4. Methods

### 4.1. Participants

Twenty high-functioning adults with ASD participated in this study, of whom 18 were included in the final analysis (11 males). Two participants with ASD were excluded due to low signal quality. The ASD group consisted of two subgroups based on DSM-IV criteria: a group of participants with Asperger syndrome ($n = 12$) and a group of high-functioning participants with autistic disorder ($n = 6$, henceforth HFA).

Most ASD participants were recruited from the Department Psychiatry Radboud Medical Centre Nijmegen, which is specialized in diagnosing (high-functioning) adults with ASD. We did not include participants with IQs below 100, because of the demanding task. The diagnoses of autistic disorder and Asperger syndrome were established through expert clinical evaluation based on the DSM-IV criteria for these disorders (DSM-IV, 1994). Clinical diagnosis was supplemented with the Autism Diagnostic Interview – Revised (ADI-R), which is a structured developmental diagnostic interview with parents or caregivers, and is based on behavior of the participant at the age of 4–5 years (Lord, Rutter, & Le Couteur, 1994). Two participants did not meet the onset cut-off, and two participants scored below the cut-off on one of the other scales. This could be attributed to the fact that their parents could not recall the relevant developmental information. For four participants no parents or caretakers were available, and hence the ADI-R could not be administered. In all these cases, the clinical diagnosis of autism was beyond doubt, meaning that they satisfied the full DSM-IV criteria for autistic disorder or Asperger syndrome, established by thorough clinical assessment by experts. People with a PDD-NOS diagnosis were excluded as well as those with severe comorbid axis-I conditions like major depressive disorder, anxiety disorders, or ADHD.

**Table 1**
Description of the matching variables age, verbal intelligence (VIQ), performance intelligence (PIQ) and full scale intelligence (FIQ) for the control group and ASD subgroups. *M* = mean, *SD* = standard deviation. There were no significant differences between the matching variables (all $p > .10$).

| | Control ($n = 18$) | | Asperger ($n = 12$) | | HFA ($n = 6$) | |
|---|---|---|---|---|---|---|
| | *M* (*SD*) | Range | *M* (*SD*) | Range | *M* (*SD*) | Range |
| Age | 26 (6) | 18–41 | 28 (6) | 20–42 | 31 (7) | 24–40 |
| VIQ | 118 (8) | 105–135 | 123 (13) | 100–142 | 116 (10) | 103–128 |
| PIQ | 122 (10) | 104–138 | 116 (11) | 101–130 | 120 (15) | 104–144 |
| FIQ | 121 (7) | 108–139 | 122 (12) | 101–140 | 119 (10) | 109–134 |

Data of the ASD subgroups were compared to data of 18 matched controls (11 males). For inclusion, control participants were screened to exclude those with psychiatric, neurological or developmental disorders. There were no significant differences between the groups with respect to age and intelligence scales (verbal, performance and full scale intelligence) as assessed by the Wechsler Intelligence Scales (see Table 1, $p > .10$ for all variables). All participants were right-handed native speakers of Dutch, and had normal or corrected-to-normal vision. All participants signed an informed consent form, and received reimbursement for participation. The study was approved by the local medical ethics committee.

### 4.2. Materials

The sentence conditions consisted of 80 Dutch sentences that ended with a word that was either semantically incongruent (40 items) or congruent (40 items) with the preceding sentence context, like, "Finally the climbers reached the top of the *tulip*/*mountain*". Materials were taken from a previous study by Van den Brink, Brown, and Hagoort (2001). Final words were matched for number of letters and frequency. Mean cloze probability[1] of the sentences was 94% (range 80–100%). Two different stimulus lists were created to counterbalance congruency so that no participant saw the same item more than once. Each stimulus list was presented to an equal number of participants in the control group as well as in the ASD group.

For the reasoning conditions, we created 80 reasoning problems in Dutch. All reasoning problems had the inference form of modus ponens (*If P then Q*; *P*, *therefore Q*). Because the ERP technique requires many trials per condition, we could not include other inference forms (i.e. modus tollens, denial of the antecedent, and affirmation of de consequent). We chose to use modus ponens, because this inference form is the most simple and straightforward conditional inference. It is endorsed by most adults, and moreover, children as young as the age of five can make modus ponens inferences with a variety of materials (e.g. familiar, abstract, counterfactual). In contrast, the valid inference modus tollens is much less often endorsed than modus ponens (Evans, Newstead, & Byrne, 1993)

Reasoning problems were preceded by a congruent context or a disabling context (Table 2). The disabling context contained a possible exception or precondition with regard to the conditional. Congruent contexts and disabling contexts were kept as similar as possible with regard to syntactic structure and sentence length. There were no significant differences in sentence length between the congruent and disabling contexts ($p > .10$). Final words of the sentences were never longer than 12 letters to avoid eye movements and average final word length was 6.7 letters.

In addition to the 80 experimental reasoning problems, 80 filler reasoning problems were used, which included 40 modus ponens inferences with an incongruent conclusion, 20 affirmations of the consequent inferences (AC) with a congruent conclusion and 20 with an incongruent conclusion (see Table 3 for examples). All fillers were preceded by a congruent context. Fillers were included to reduce the pre-

[1] Cloze probability is determined by measuring the probability that a particular word is given on a sentence completion task. The higher the cloze probability, the more a particular word is expected.

**Table 2**
Two examples of the experimental conditions. MP = modus ponens.

| Condition | Sentence type | Example |
|---|---|---|
| MP-disabling | Disabling context | Lisa probably lost a contact lens. |
| | Premise 1 | If Lisa is going to play hockey, then she will wear contact lenses. |
| | Premise 2 | Lisa is going to play hockey. |
| | Conclusion | Lisa will wear contact lenses. |
| MP-disabling | Disabling context | Lately Stefan usually parks his Mercedes in the garage. |
| | Premise 1 | If it is raining, then the Mercedes will become wet. |
| | Premise 2 | It is raining. |
| | Conclusion | The Mercedes will become wet. |
| MP-congruent | Congruent context | Lisa has recently bought contact lenses. |
| | Premise 1 | If Lisa is going to play hockey, then she will wear contact lenses. |
| | Premise 2 | Lisa is going to play hockey. |
| | Conclusion | Lisa will wear contact lenses. |
| MP-congruent | Congruent context | Stefan bought a Mercedes from his savings a few weeks ago. |
| | Premise 1 | If it is raining, then the Mercedes will become wet. |
| | Premise 2 | It is raining. |
| | Conclusion | The Mercedes will become wet. |

**Table 3**
Fillers. MP = modus ponens, AC = affirmation of the consequent.

| Fillers | Sentence type | Example |
|---|---|---|
| MP-incongruent | Congruent context | Mark lives on a farm far away from the town. |
| | Premise 1 | If Mark is going to the town, then he will go by scooter. |
| | Premise 2 | Mark is going to the town. |
| | Incongruent conclusion | Mark will go by bike. |
| AC-congruent | Congruent context | Golf is becoming a popular sport. |
| | Premise 1 | If Luc is going to play golf, then he will wear a hat. |
| | Premise 2 | Luc will wear a hat. |
| | Congruent conclusion | Luc is going to play golf. |
| AC-incongruent | Congruent context | Miriam likes water sports. |
| | Premise 1 | If Miriam is going to the lake, then she will go rowing. |
| | Premise 2 | Miriam will go rowing. |
| | Incongruent conclusion | Miriam is going to the forest. |

dictability of the materials and to balance for response types (i.e. to evoke 'maybe' and 'no' responses). In total, each participant read 160 reasoning problems: 40 reasoning problems in a disabling context, 40 reasoning problems in a congruent context, and 80 fillers. As in the sentence conditions, the two versions of the reasoning problems were counterbalanced across two lists. Thus no participant saw the same reasoning problem more than once. Each list was presented to an equal number of participants in the control group as well as in the ASD group.

### 4.3. Procedure

The reasoning conditions were presented first, followed by the sentence conditions. Participants received written instructions about the reasoning conditions, in which they were instructed that they had to decide whether a conclusion followed from short stories. They were instructed to read all sentences carefully and to respond by pressing one of the buttons 'yes', 'no', or 'maybe' on a button box. Participants were instructed to sit quietly in a comfortable position and not to blink during the word-by-word presentation of the sentences. Stimuli were presented in a white font against a black background, using Presentation 10.2 software.

The reasoning materials were partly presented in whole sentences and partly word-by-word when good time-locking was critical. The trial sequence was as follows (see Fig. 1). Each trial started with a 3000 ms fixation cross (+) on the screen. Then the context sentence was presented for a duration of 2000 ms plus an additional 250 ms times the number of words. After the context sentence, the first part of the conditional ("If. . ., then") appeared for 2000 ms plus an additional 250 ms times the number of words. Subsequent sentences were presented word-by-word. Each word was displayed for 300 ms, followed by a blank screen for another 300 ms, after which the next word appeared. The conclusion was preceded by three hedges (###) to indicate that the conclusion was following. After the final word of the conclusion, there was a 1000 ms blank screen before the response options MAYBE–YES–NO appeared on the screen for 4000 ms. There were blank screens between sentences. Reasoning problems were presented in blocks of ten trials. After each block there was an optional break. The session started with a practice block of ten reasoning problems to familiarize the participant with the procedure.

After the reasoning conditions, the sentence conditions were presented in serial visual presentation (300 ms + 300 ms interstimulus interval, and a 3000 ms fixation cross between sentences for blinks). Participants were instructed to read for comprehension only, and to minimize eye blinks during the word-by-word presentation. No additional task demands were imposed. There were five blocks of sentences with optional breaks in between. The whole EEG session lasted approximately 75 min without breaks.

### 4.4. EEG recording

The EEG was recorded from 29 electrode sites across the scalp using an Easycap with Ag/AgCl-electrodes. Recordings were referenced to the left mastoid. Three additional electrodes were placed to monitor eye movements. Vertical EOG was recorded by placing an electrode below the right eye, and FP1 was used for above the eye. Horizontal EOG was recorded via a right-to-left canthal montage. All EEG and EOG channels were amplified using BrainAmp DC amplifiers. A band-pass filter was applied from 0.016 to 125 Hz. The EEG and EOG signals were recorded and digitized using Brain Vision Recorder software with a sampling frequency of 500 Hz. Impedances were kept below 10 kΩ for EOG and below 5 kΩ for all other electrodes.

### 4.5. Data analysis

For the analysis of the behavioral responses of the reasoning conditions, percentages of accepted items ('yes' responses) per condition were calculated. Because of the non-normal distribution of the response data, nonparametric Kruskal–Wallis tests (exact, two-sided) were used to examine whether responses were different across groups per context.

Prior to analyzing, EEG data were preprocessed using Brain Vision Analyzer software. EEG data were re-referenced to the mean of the two mastoids, and corrected for eye movement artifacts using an algorithm described by Gratton, Coles, and Donchin (1983). Data were filtered off-line with a 30 Hz low-pass filter. Data were segmented from 150 ms before to 1000 ms after the critical words (final word in

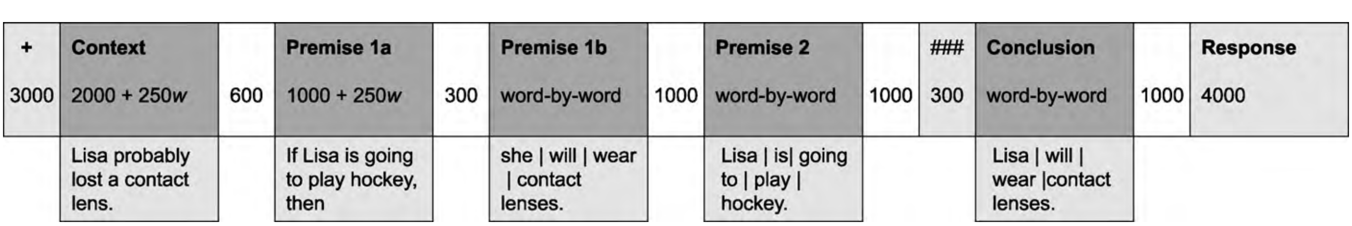


**Fig. 1.** Setup of how stimuli were presented. Times are in milliseconds, *w* stands for word length per sentence, white boxes represent blank screens. Premise 1b, premise 2 and the conclusion were presented word-by-word for 300 ms + 300 ms interstimulus interval (ISI) per word.

the sentence conditions, and final words of premise 1, premise 2, and conclusion in reasoning conditions). Baseline correction used the 150 ms interval preceding the onset of the critical word. Trials containing artifacts (9%) were rejected. For the reasoning conditions the mean number of accepted trials was $M = 36.9$ ($SD = 3.5$, range 25–40), and for the N400 conditions the mean number of accepted trials was $M = 35.4$ ($SD = 4.7$, range 23–40). Rejected trials were equally distributed across conditions and groups ($p > .10$). For each participant, average waveforms were computed across all remaining trials per condition.

All analyses were conducted on the mean amplitudes of ERPs evoked by the critical words over two latency windows based on the N400 literature: a 250–500 ms latency window (N400 effect), and a 600–900 ms latency window (late positive component). For good comparison, we used the same latency windows for the analysis of the reasoning conditions. The effects were evaluated in repeated measures ANOVAs with the factors Context (congruent, incongruent/disabling), Quadrant (left anterior, right anterior, left posterior, right anterior), and Group (control, Asperger, HFA). Electrodes were assigned to quadrants as follows: left anterior (F3, F7, FC1, FC5, C3), right anterior (F4, F8, FC2, FC6, C4), left posterior (CP1, CP5, P3, P7, O1), and right posterior (CP2, CP6, P4, P8, O2). Interactions with the factor Quadrant were followed up by single quadrant analyses. Separate ANOVAs were conducted for the midline electrodes (Fz, FCz, Cz, Pz). Because our primary interest was in whether the effect of Context differed by group, planned follow-up analyses entailed separate ANOVAs per group to test for a Context effect. For all analyses, we applied a Huynh-Feldt correction for violations of sphericity when necessary (Huynh & Feldt, 1976). In these cases, the corrected $p$-values with the original degrees of freedom will be reported.

## 5. Results

First, we will discuss the group results of the sentence conditions. To gain more insight into the variation within the groups, we will also present the individual participant data. Next, we will discuss the results of the reasoning conditions, for both the group data and the individual participant data.

### 5.1. Sentence conditions

Fig. 2 displays the grand average waveforms of the sentence conditions containing semantically congruent and incongruent final words. Visual inspection of these waveforms shows a N1–P2 complex for each group, which is characteristic for visual stimuli. Furthermore, the control group and the Asperger group demonstrate a negative shift for the incongruent condition relative to the congruent condition, which appears to be absent in the HFA group. Finally, a late positive component for the incongruent condition compared to the congruent condition is apparent in all groups.

Statistical analysis in the 250–500 ms latency window demonstrated a main effect of Context ($F(1,33) = 15.5$, $p < .001$), a Context

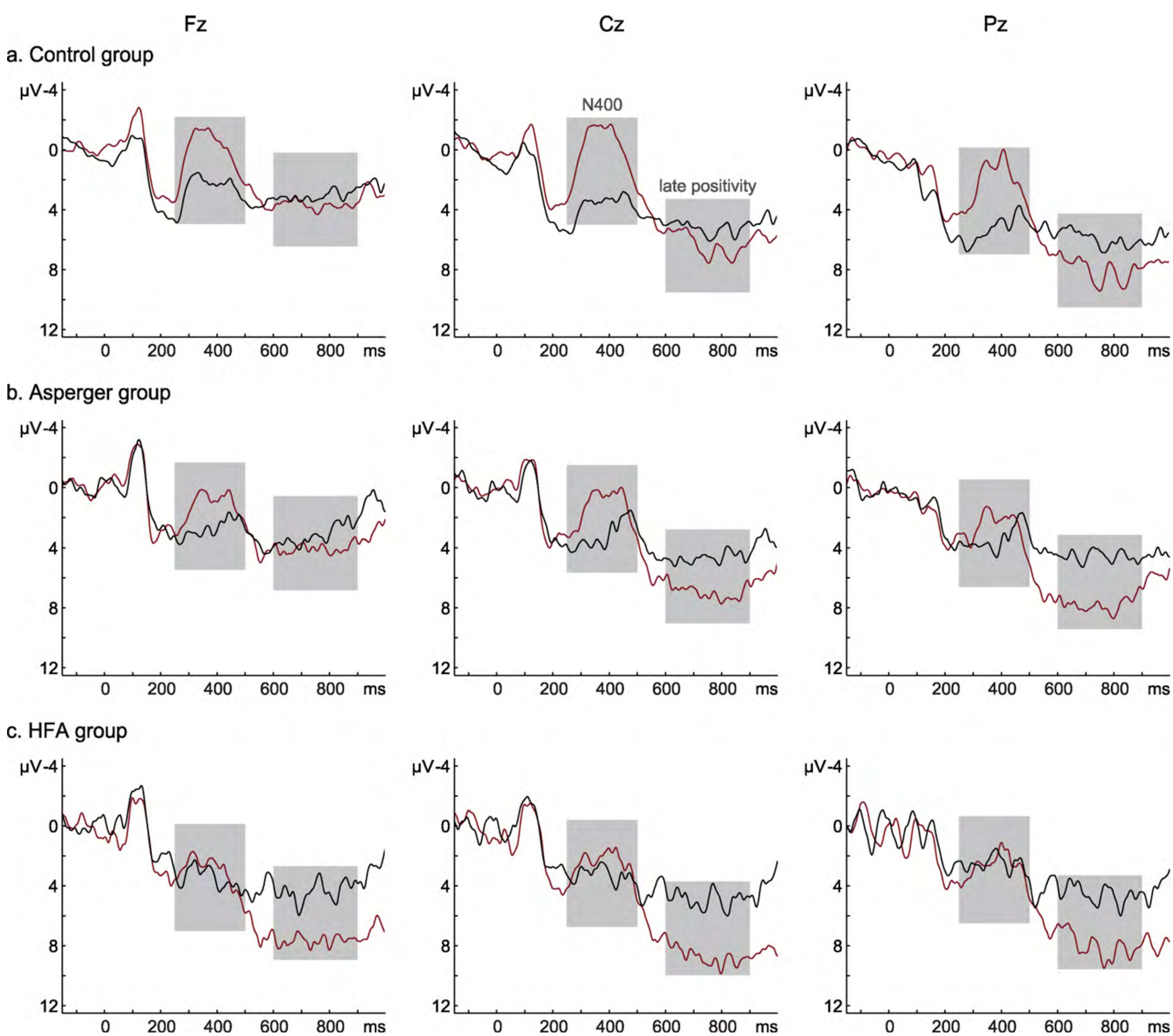


**Fig. 2.** Grand average ERPs (Fz, Cz and Pz) of the congruent and incongruent linguistic condition time-locked to the onset of the sentence-final word. The grey boxes display the latency windows in which the effects were evaluated. Black line = congruent condition, red line = incongruent condition. Negative values are plotted upward. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.)

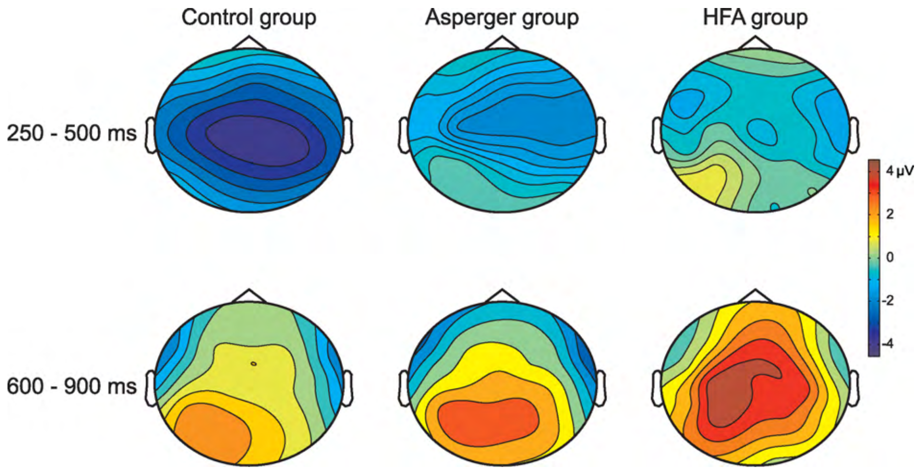


**Fig. 3.** The topographical distributions of the mean amplitude difference between the ERPs evoked by the incongruent linguistic condition relative to the congruent linguistic condition time-locked to the sentence-final word, in the latency windows 250–500 and 600–900 ms.

by Quadrant interaction ($F(3,99) = 6.46$, $p = .001$), and a Context by Group interaction ($F(2,33) = 3.91$, $p = .030$). The midline analysis also revealed a main effect of Context ($F(1,33) = 12.9$, $p = .001$), and a marginal Context by Group interaction ($F(2,33) = 3.19$, $p = .054$).

Separate analyses per group in the 250–500 ms latency window demonstrated a main effect of Context for both the control group[2] ($F(1,17) = 26.0$, $p < .001$) and the Asperger group ($F(1,11) = 5.07$, $p = 0.046$). Moreover, the Asperger group showed a Context by Quadrant interaction ($F(3,33) = 4.91$, $p = .014$). Single quadrant analyses indicated that in the Asperger group there was a main effect of Context in the right anterior region ($F(1,11) = 9.86$, $p = .009$), and a trend for the left anterior region ($F(1,11) = 4.81$, $p = 0.051$) and the midline region ($F(1,11) = 4.19$, $p = 0.065$). The HFA group did not show a significant main effect of Context ($F(1,5) = 1.26$, $p > .10$), but there was a marginal Context by Quadrant interaction ($F(3,15) = 3.15$, $p = 0.056$). However, the analyses for the separate quadrants and midline failed to show any significant effects for Context (all $p > .09$).

The next latency window in which the effects were tested was from 600 to 900 ms. For this latency window, the repeated measures ANOVA showed a main effect of Context ($F(1,33) = 28.0$, $p < .001$), indicating that the incongruent condition is more positive than the congruent condition, and a Context by Quadrant interaction ($F(3,99) = 14.2$, $p < .001$), but no Context by Group interaction ($F(2,33) = 1.81$, $p = .18$). The midline analysis also showed a main effect of Context ($F(1,33) = 28.0$, $p < .001$), but no Context by Group interaction ($F(2,33) = 2.12$, $p = .14$).

Planned follow-up analyses confirmed that there is indeed a late positive component present in each group (control: $F(1,17) = 4.55$, $p = .048$; Asperger: $F(1,11) = 12.1$, $p = .005$; HFA: $F(1,5) = 37.9$, $p = .002$). In addition, in the control group and Asperger group a Context by Quadrant interaction was observed (control: $F(3,51) = 9.16$, $p < .001$; Asperger: $F(3,33) = 13.0$, $p < .001$). Single quadrant analyses revealed that in both the control group and Asperger group, there was a main effect of Context in left and right posterior regions (control: $F(1,17) = 18.2$, $p = .001$, $F(1,17) = 6.38$, $p = .022$; Asperger: $F(1,11) = 36.7$, $p < .001$, $F(1,11) = 15.5$, $p = .002$), and the midline region (control: $F(1,17) = 4.56$, $p = .048$; Asperger: $F(1,11) = 10.0$, $p = .009$). The topographical distributions for the Context effects per group can be seen in Fig. 3.

Figs. 4 and 5 display the N400 effect and the late positive component for the sentence conditions per individual participant per group. As can be seen in Fig. 4, the majority of the control and Asperger participants demonstrated an N400 effect for the incongruent condition relative to the congruent condition, but with some variation in individual effect sizes. In the HFA group, the N400 effect appears to be reduced or absent. In contrast, all HFA participants demonstrated a large late positive component for the incongruent condition compared to the congruent condition, like most control and Asperger participants (Fig. 5).

### 5.2. Reasoning conditions

The groups did not differ significantly on the percentage of accepted inferences in the congruent condition ($H(2) = 1.28$, $p > .10$), as well as in the disabling condition ($H(2) = 4.20$, $p > .10$), although the HFA group seems to show more accepted inferences in the disabling condition than the Asperger group and control group (see Fig. 6). Separate comparisons between the subgroups for the disabling condition yielded no significant effects (HFA–control: $U = 32.5$, $p = .16$; HFA–Asperger: $U = 16.0$, $p = .062$).

Fig. 7 displays the grand average waveforms of the congruent and disabling condition time-locked to the onset of the final word of the conclusion. Visual inspection of the waveforms shows for each group an N1–P2 complex. Moreover, visual inspection reveals a large negative shift for the disabling condition relative to the congruent condition in the control group and the Asperger group, which appears to be reduced in the HFA group.

Statistical analysis confirmed that in the latency window from 250 to 500 ms, the disabling condition was significantly more negative than the congruent condition ($F(1,33) = 14.6$, $p = .001$). The midline analysis also confirmed an effect of Context ($F(1,33) = 16.5$, $p < .001$). There were no Context by Group interactions ($F(2,33) = 1.18$, $p = .32$, $F(2,33) = .90$, $p = .42$). Planned follow-up analyses per group revealed that both the control group and the Asperger group demonstrated a main effect of Context (control: $F(1,17) = 15.8$, $p = .001$; Asperger: $F(1,11) = 7.96$, $p = .017$). In contrast, the HFA group failed to show any effect of Context ($F(1,5) = 1.10$, $p > .10$).

[2] As can be seen in Fig. 2, there are early differences in the N1–P2 complex in the control group. Statistical comparison revealed that there is indeed an early significant negative effect in the 0–200 ms latency window, indicating that the incongruent condition is more negative than the congruent condition. This early effect was neither present in the ASD groups nor in the previous college students' data. Because the N400 effect in controls could possibly be a consequence of this early difference, we checked whether the N400 effect was still present in controls if we took into account the unexplained early difference in the 0–200 ms latency window by subtracting the mean amplitude in that latency window from each data point. It turned out that the N400 effect in controls remained significant when corrected for the early effect ($F(1,17) = 19.0$, $p < .001$).

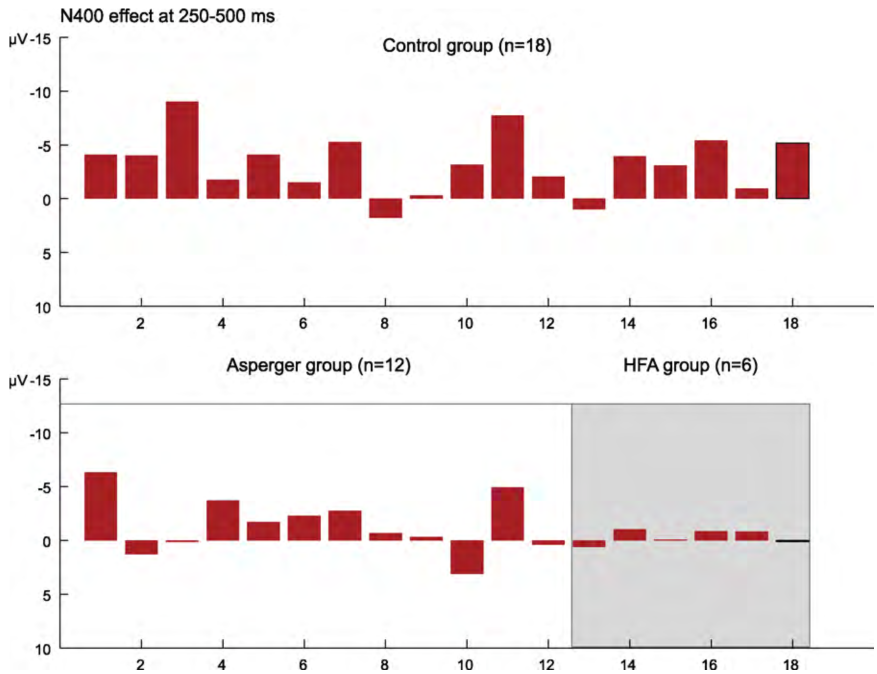


**Fig. 4.** Mean amplitude of the N400 effect (incongruent condition minus congruent condition in latency window 250–500 ms averaged over FCz, Cz, and Pz) for each individual participant. Negative values are plotted upward.

In the next latency window from 600 to 900 ms, the repeated measures ANOVA yielded a main effect of Context ($F(1,33) = 14.2$, $p = .001$), and a Context by Quadrant interaction ($F(3,99) = 11.3$, $p < .001$), but no Context by Group interaction ($F(2,33) = 1.60$, $p = .22$). The midline analysis also showed a main effect of Context ($F(1,33) = 11.5$, $p = .002$) and no Context by Group interaction ($F(2,33) = 1.43$, $p = .26$). Planned follow-up analyses per group revealed a main effect of Context for the control group ($F(1,17) = 18.0$, $p = .001$) and the Asperger group($F(1,11) = 7.86$, $p = .017$), and a Context by Quadrant interaction in both groups (control: $F(3,51) = 6.62$, $p = .004$; Asperger: $F(3,33) = 5.73$, $p = .10$). A main effect of Context was found for every separate quadrant and for the midline region in both groups (all $p < .05$). In contrast, the HFA group did not demonstrate a main effect of Context ($F(1,5) < 1$, $p > .10$), but there was a significant Context by Quadrant interaction ($F(3,15) = 5.12$, $p = 0.012$). However, the analyses for the separate quadrants and midline failed to show any significant effects for Context (all $p > .10$). The topographical distributions for the Context effects per group can be seen in Fig. 8.

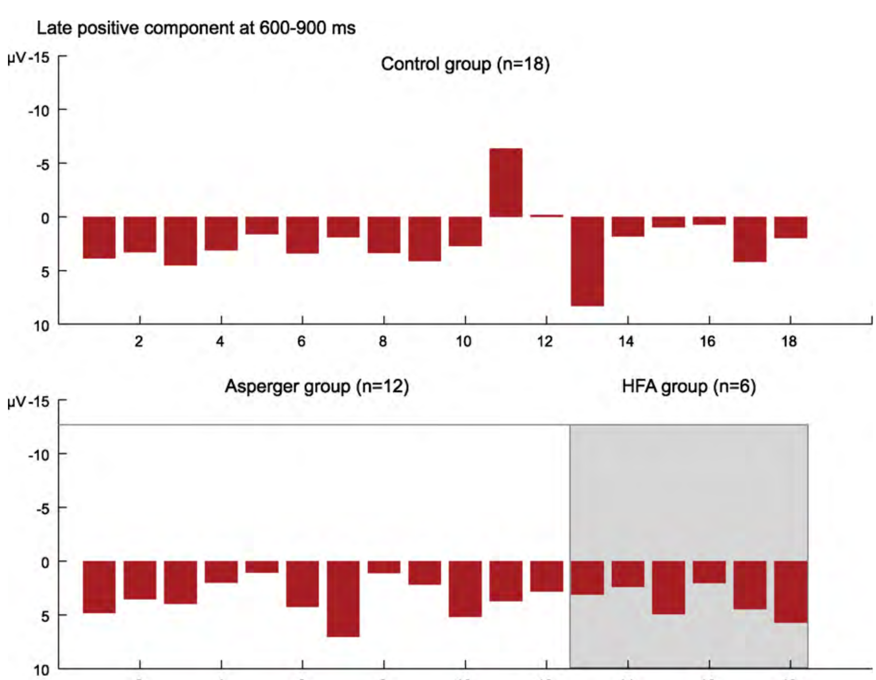


**Fig. 5.** Mean amplitude of the late positive component (incongruent condition minus congruent condition in latency window 250–500 ms averaged over Pz and P3) for each individual participant. Negative values are plotted upward.

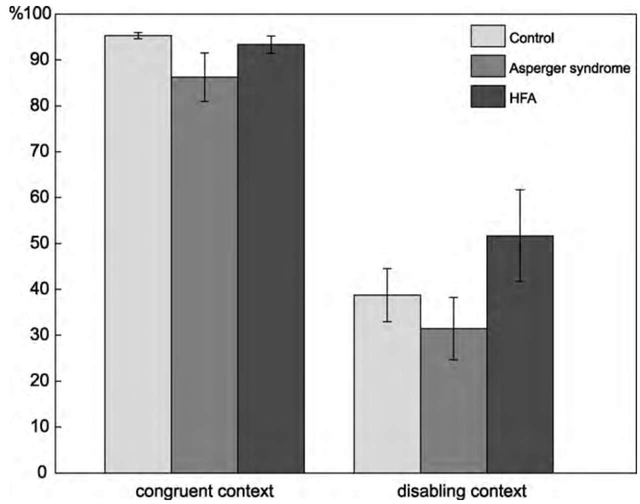


**Fig. 6.** Percentage of accepted inferences ('yes' responses) for the congruent context and the disabling context. Error bars represent 1 S.E. of the means.

Consistent with previous college students' data, ERPs time-locked to the onset of the final word of the first premise and the second premise did not demonstrate any significant effects of Context in both latency windows (all $p > .10$).

Figs. 9 and 10 display the negative shift for the reasoning conditions per individual participant per group. As is evident from Figs. 9 and 10, the majority of the control participants and the Asperger participants showed a negative shift for the disabling condition compared to the congruent condition, though with some variation in individual effect sizes. In the HFA group only two out of six participants showed a clear negative shift.

In order to determine to what extent the size of the negative shift in the reasoning conditions was related to the behavioral responses, we computed Pearson correlations between the sustained negativity (mean amplitude difference averaged over FCz, Cz and Pz in the 250–900 ms latency window as the effect is sustained over this whole latency window) and percentage of accepted inferences in the disabling condition for the control group and ASD group separately. It turned out that there were no significant correlations between the sustained negativity and the percentage of accepted

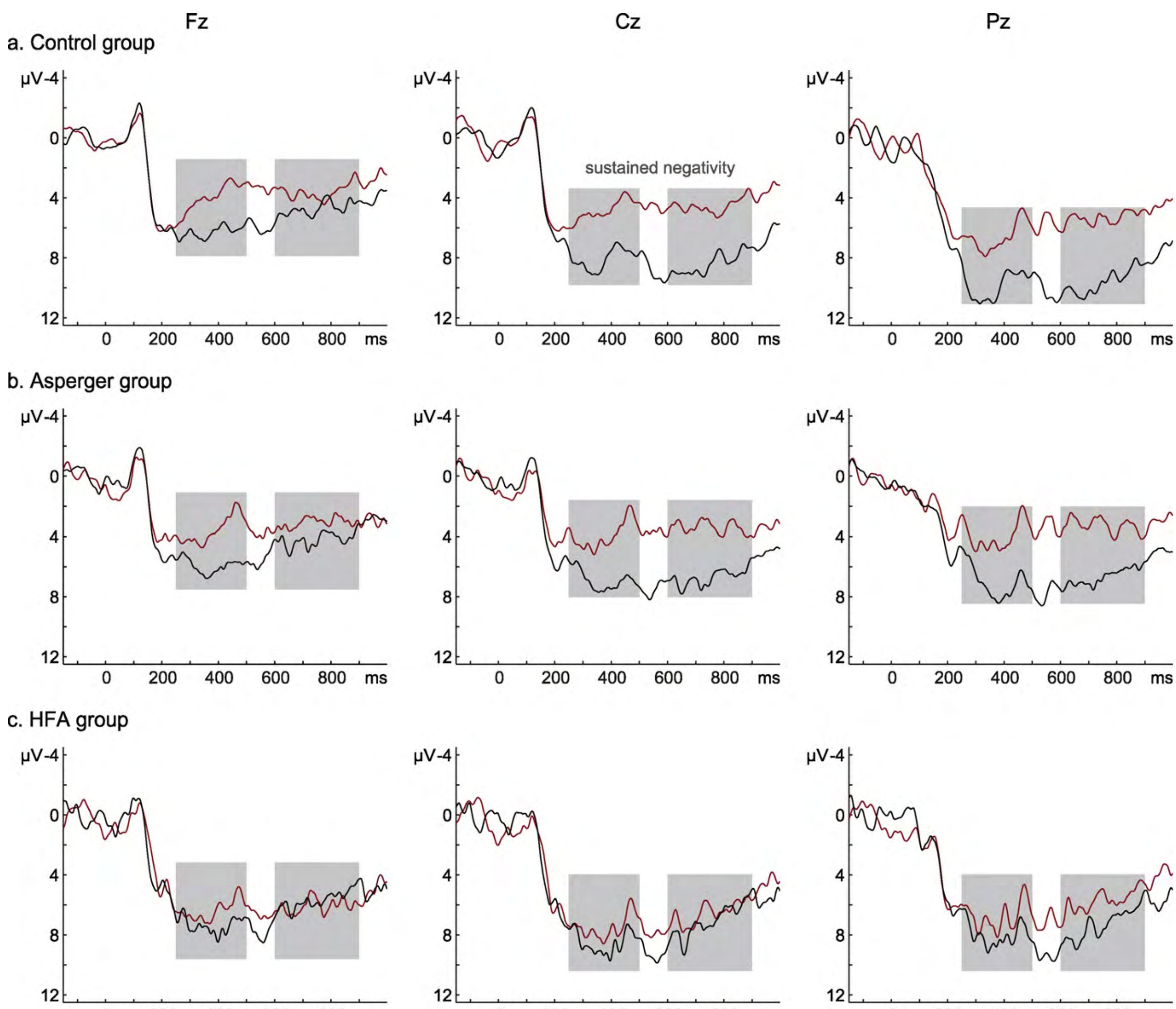


**Fig. 7.** Grand average ERPs (Fz, Cz and Pz) of the congruent and disabling reasoning condition time-locked to the onset of the final word of the conclusion. The grey boxes display the latency windows in which the effects were evaluated. Black line = congruent condition, red line = disabling condition. Negative values are plotted upward. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.)

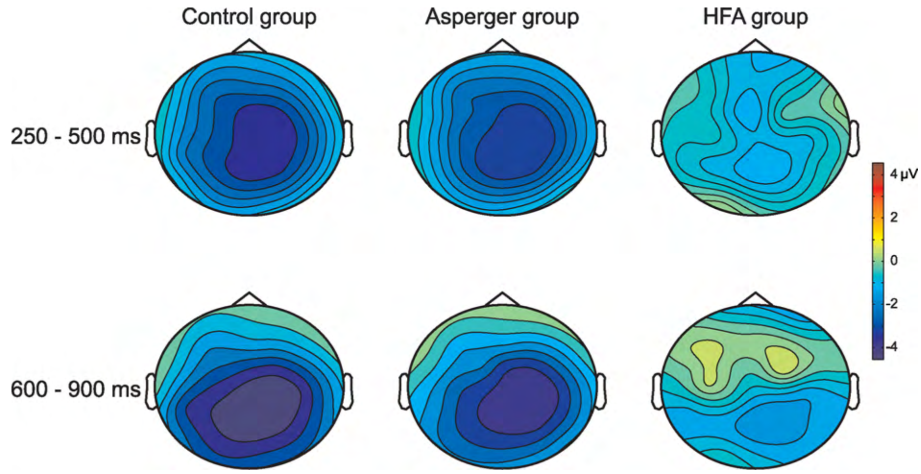


**Fig. 8.** The topographical distributions of the mean amplitude difference between the ERPs evoked by the disabling reasoning condition relative to the congruent reasoning condition time-locked to the onset of the final word of the conclusion, in the latency windows 250–500 and 600–900 ms.

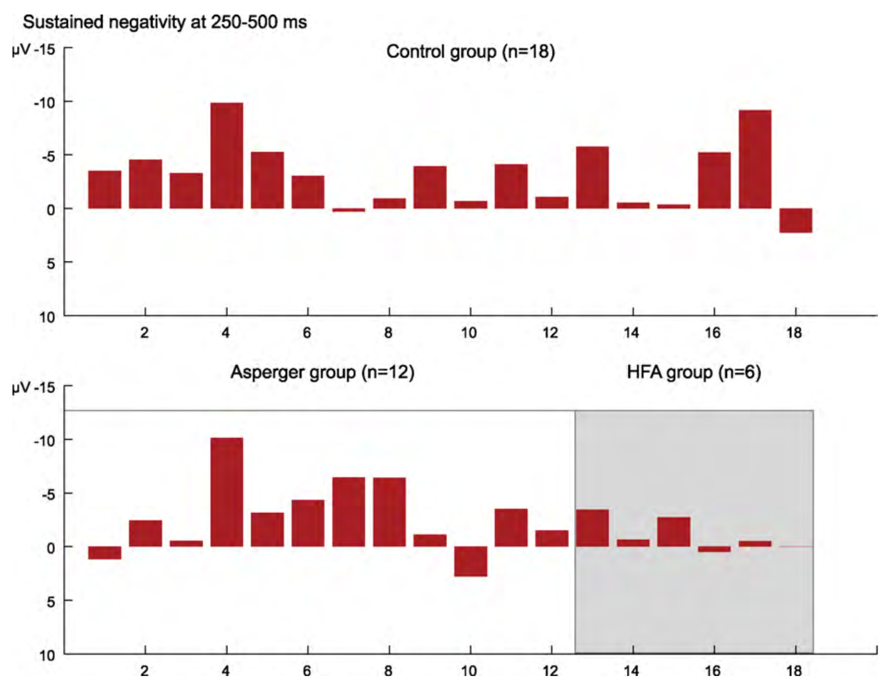


**Fig. 9.** Mean amplitude of the sustained negativity (disabling condition minus congruent condition in latency window 250–500 ms averaged over FCz, Cz and Pz) for each individual participant. Negative values are plotted upward.

inferences in the disabling condition for both groups ($p > .10$), which is consistent with previous college students' results.

Moreover, to investigate whether the two manipulations may rely on the same cognitive resources, we looked whether the size of the N400 effect (mean amplitude difference averaged over FCz, Cz and Pz in the 250–500 ms latency window) and the late positive component (mean amplitude difference averaged over FCz, Cz and Pz in the 600–900 ms latency window) in the sentence manipulation was related to the size of the sustained negativity (mean amplitude difference averaged over FCz, Cz and Pz in the 250–900 ms latency window) in the reasoning manipulation. Pearson correlations revealed no significant correlation between the N400 effect and the sustained negativity for the control group ($p > .10$), but a weak trend for the ASD group ($p = .066$, $r = .44$). There were no significant correlations between the late positive component and the sustained negativity (both $p > .10$). Finally, Pearson correlations between verbal intelligence and the ERP effects of both manipulations revealed no significant effects (all $p \geq .10$).

## 6. Discussion

In the present study we explored the online processing of context information – sentence context as well as reasoning context – in autism spectrum disorders (ASD), following up on behavioral research indicating that people with ASD fail to process linguistic information in context (Frith & Snowling, 1983; Happé, 1997; Jolliffe & Baron-Cohen, 1999). One aim was to investigate whether high-functioning adults with autistic disorder (HFA) and Asperger syndrome make use of sentence context to build up semantic predictions about the continuation of the sentence. For this purpose, ERPs were recorded while participants read sentences that had a semantically congruent or an anomalous ending.

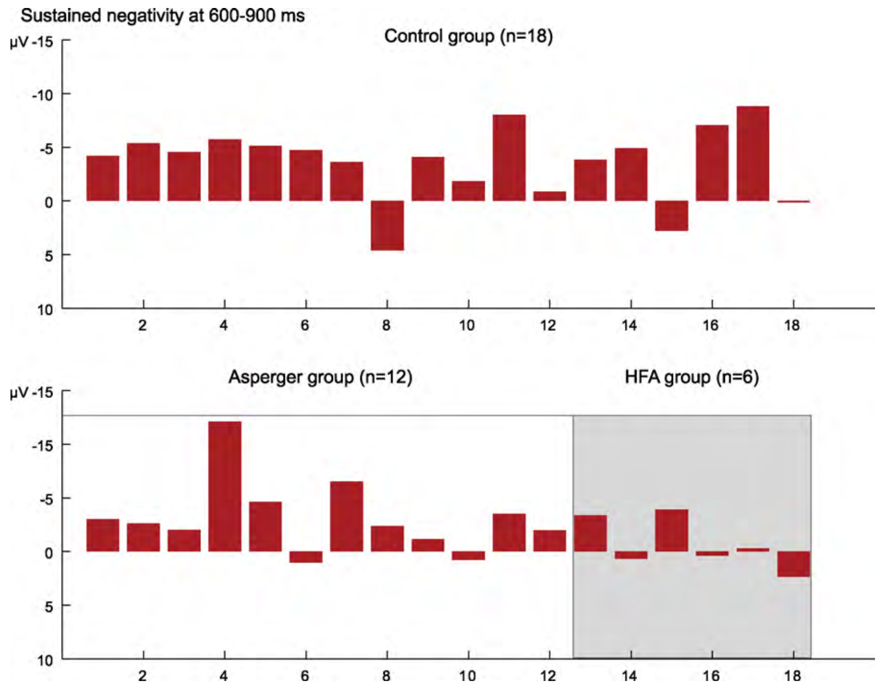


**Fig. 10.** Mean amplitude of the sustained negativity (disabling condition minus congruent condition in latency window 600–900 ms averaged over FCz, Cz and Pz) for each individual participant. Negative values are plotted upward.

The results indicated that sentence context had an immediate ERP effect in adults with Asperger syndrome and matched controls. Both groups showed typical larger N400 amplitudes for words that were semantically anomalous in the prior sentence context than words that were semantically congruent, although the N400 effect in the Asperger group was more pronounced over the right hemisphere than in the control group. In contrast, in the HFA group sentence context did not appear to modulate the ERP brain response immediately, as an N400 effect was absent. However, the HFA group showed a late positive component which was larger for semantically anomalous sentences than congruent sentences, like in the control and the Asperger group.

Late positive components have been observed more often in N400 paradigms (Coulson & Van Petten, 2002; Holcomb, 1988; Juottonen, Revonsuo, & Lang, 1996; Salmon & Pratt, 2002; Severens & Hartsuiker, 2009; Van de Meerendonk, Kolk, Vissers, & Chwilla, 2010), but have not consistently found across studies (e.g. Hagoort et al., 2004; Kutas & Hillyard, 1980, 1984; Van Berkum, Hagoort, et al., 1999). There is a lack of consensus about the functional interpretation of this late positive component, but it seems to have a different role than the N400 effect (Juottonen et al., 1996; Salmon & Pratt, 2002). Several accounts allude to processes related to semantic memory, e.g. extensive retrieval of information from semantic memory in the course of arriving at an interpretation (Coulson & Van Petten, 2002), extended retrieval from semantic memory and updating the contents of working memory with the retrieved information (Van Petten, Kutas, Kluender, Mitchiner, & McIsaac, 1991), an attention-demanding process after more automatic semantic memory processes (Juottonen et al., 1996), or active search in semantic memory due to violations of expectations (Schwartz, Kutas, Butters, Paulsen, & Salmon, 1996). Others have suggested that the late positive component might be indicative of a delayed and more elaborate interpretive process (Nieuwland & Van Berkum, 2005), or post-lexical processes (Holcomb, 1988). Finally, the late positive component has been argued to be an index of a monitoring process that triggers reanalysis when integration fails (Severens & Hartsuiker, 2009; Van de Meerendonk et al., 2010).

The question that arises is why the HFA group demonstrated a late positive component but not the typical N400 effect in response to semantic anomalies. Since participants always mentioned the anomalous sentences when they were debriefed, it is unlikely that they did not notice the semantic anomalies. It is therefore more plausible that in HFA semantic anomalies were not detected immediately, as reflected by the reduced N400 effect, and that a delayed and more extended process was used to arrive at a sentence interpretation, as indexed by the late positive component. In contrast, the Asperger group and control group were immediately sensitive to sentence context, as reflected by the N400 effect to anomalous words, followed by a late positive component suggesting an effortful attempt to make sense of the anomalous sentence. Remarkably, the pattern we found in HFA does not seem to be specific to autism. For instance, Ditman and Kuperberg (2007) found no N400 effect in people with schizophrenia but did find a late positive component for causally unrelated discourse scenarios relative to causally related ones. Moreover, older people showed a reduced N400 effect for semantic anomalies but a similar late positive component as young people (Günter, Jackson, & Mulder, 1992).

Another, and more primary, aim of the present work was to examine how high-functioning adults with HFA and Asperger syndrome make use of context information when reasoning with conditionals. For that purpose, ERPs were recorded while participants read conditional reasoning problems, which were preceded by a congruent context or a disabling context that contained a possible exception that could prevent people from drawing the conclusion. In comparison with the sentence manipulation where a word did not semantically fit into the prior context, the words in the reasoning manipulation fitted well into the preceding context, but it was the propositional content that did not match with the preceding context.

In contrast to our previous behavioral findings, both the Asperger group and the HFA group suppressed the conclusion at the same rate as the control group when a possible exception was provided (Pijnacker et al., 2009). Due to ERP constraints, exceptions had to be presented more explicitly in the current study than in the previous one, and we believe that this may have facilitated the reasoning process. This explanation is supported by research indicating that people with ASD have trouble processing implicit information (Begeer, Terwogt, Lunenburg, & Stegge, 2009; Dennis et al., 2001). Our data suggest that when exceptions are sufficiently explicit, high-functioning adults with ASD cease to have difficulties taking exceptions into account when reasoning with conditionals. For clinical practice and treatment, this finding underlines that it may be important to be more explicit than usual when communicating with people with ASD.

While there were no observable performance differences, the neural processing of defeasible inferences appears to be different in high-functioning adults with autistic disorder (HFA). Whereas the Asperger group showed a similar brain response as the control group for the disabling condition relative to the congruent condition, context had no differential ERP effect in the HFA group. When the conclusion did not fit with the preceding context, both the Asperger group and the control group demonstrated a sustained negativity that started just within 250 ms after the onset of the final word of the conclusion. This finding suggests that defeasible reasoning is an immediate process. As mentioned in the introduction, the sustained negativity may either reflect additional processing because a default inference must be revised to incorporate the possible exception, or more complex, inference-driven interpretive processes (Pijnacker et al., in press). Our ERP results suggest that context had no immediate effect in the HFA group, in contrast to the Asperger group and the control group. However, by the time HFA participants were required to make a response, contextual information had been taken into account, as there was a normal pattern of behavioral responses. This suggests that the participants with HFA made use of context information, but in a less automatic and more effortful way than is the case in controls.

One should note that there was no relationship between the size of the N400 effect and the size of the sustained negativity in the control group, but in the ASD group there was a weak trend that the size of the individual's ERP effects correlated across the two manipulations. This finding suggests that the two manipulations may be relying on overlapping cognitive resources, at least in ASD, and hence that they may be dependent.

One limitation of the current study is that the group sizes were relatively small in particular for the HFA group. We took effort including a homogeneous ASD group of adults without intellectual disabilities, without severe co-morbodity, and sufficient capacity to perform the task. This resulted in small sample sizes, and in consequence reduced the statistical power of our effects. We should therefore be tentative in interpreting the absence of the sustained negativity and the N400 effect in adults with HFA, which could be possibly due to a lack of statistical power. Nonetheless, the individual data revealed that the patterns were consistent across participants in all groups. Testing with larger samples will be needed to confirm our results. Moreover, for a more complete understanding it is necessary to investigate how younger or lower-functioning groups with ASD process semantic anomalies and exceptions.

A final comment is in order concerning the different patterns we found for adults with HFA and Asperger syndrome. Until now, it is still a matter of debate whether Asperger syndrome is a variant of HFA, or is a distinct disorder (Frith, 2004; Macintosh & Dissanayake, 2004; Matson & Wilkins, 2007). Although the present findings cannot offer decisive evidence in favor of one position or the other, they make it clear that collapsing data across the whole ASD group may obscure important differences between HFA and Asperger syndrome.

In conclusion, the most striking finding in this study was that context – sentence context as well as reasoning context – had an immediate ERP effect in adults with Asperger syndrome, as in matched controls, while the HFA group failed to demonstrate an immediate ERP effect, though at the behavioral level they showed a normal response pattern. Because sentence context had a modulating effect in a later phase, semantic integration is perhaps less automatic in HFA, and presumably more elaborate processes are needed to arrive at a sentence interpretation. Both the sentence conditions and the reasoning conditions suggest that participants with HFA made use of context information, but in a less automatic and more effortful way.

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