Neuropsychologia 48 (2010) 2940–2951

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

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

Judith Pijnacker[a,*], Bart Geurts[b], Michiel van Lambalgen[c], Jan Buitelaar[a,d,e], Peter Hagoort[a,f,*]

[a] Donders Institute for Brain, Cognition and Behaviour, Centre for Cognitive Neuroimaging, Radboud University Nijmegen, The Netherlands
[b] Department of Philosophy, Radboud University Nijmegen, The Netherlands
[c] Institute for Logic, Language and Computation, University of Amsterdam, The Netherlands
[d] Department of Psychiatry, Radboud University Nijmegen Medical Centre, The Netherlands
[e] Karakter Child and Adolescent Psychiatry University Centre, Nijmegen, The Netherlands
[f] Max Planck Institute for Psycholinguistics, Nijmegen, The Netherlands

ARTICLE INFO

Article history:
Received 8 July 2009
Received in revised form 29 April 2010
Accepted 4 June 2010
Available online 11 June 2010

Keywords:
Autism
Asperger syndrome
Context
Linguistic processing
Reasoning
ERPs
N400 effect
Late positive component
Sustained negativity

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

* Corresponding authors at: Donders Institute for Brain, Cognition and Behaviour, Centre for Cognitive Neuroimaging, Radboud University Nijmegen, P.O. Box 9101, 6500 HB Nijmegen, The Netherlands. Tel.: +31 24 36 10651; fax: +31 24 36 10652.
E-mail addresses: j.pijnacker@pwo.ru.nl (J. Pijnacker), p.hagoort@donders.ru.nl (P. Hagoort).

0028-3932/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.neuropsychologia.2010.06.003

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