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Semantic integration during metaphor comprehension in Asperger syndrome

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ABSTRACT

Previous research indicates severe disabilities in processing figurative language in people diagnosed on the autism spectrum disorders. However, this aspect of language comprehension in Asperger syndrome (AS) specifically has rarely been the subject of formal study. The present study aimed to examine the possibility that in addition to their pragmatic deficits, the difficulties in the comprehension of metaphors in AS may be explained by deficient linguistic information processing. Specifically, we aimed to examine whether a deficient semantic integration process underlies the difficulties in metaphor comprehension frequently experienced by persons with AS. The semantic integration process of sixteen AS participants and sixteen matched controls was examined using event related potentials (ERPs). N400 amplitude served as an index for degree of effort invested in the semantic integration process of two-word expressions denoting literal, conventional metaphoric, and novel metaphoric meaning, as well as unrelated word pairs. Large N400 amplitudes for both novel and conventional metaphors demonstrated the greater difficulties in metaphor comprehension in the AS participants as compared to controls. Findings suggest that differences in linguistic information processing cause difficulties in metaphor comprehension in AS.

1. Introduction

Asperger syndrome (AS) is one of the autism spectrum disorders (ASD). It is characterized by social impairments, difficulties in communication, and a set of circumscribed interests and/or a rigid adherence to routines. Although there is no significant delay in language or cognitive development in AS (APA, 2000), people with AS often exhibit difficulties in pragmatic and/or semantic aspects of language, as manifested in difficulties to comprehend non-literal language (Gillberg & Gillberg, 1989), such as metaphors, irony and indirect requests. Previous research indicates severe disabilities in processing figurative language in people diagnosed as ASD (e.g. Dennis, Lazenby, & Lockyer, 2001; MacKay & Shaw, 2004). However, relatively few studies examined this aspect of language comprehension in AS specifically, mainly focusing on children and adolescents and not adults. Studying metaphor comprehension in adults with AS can indicate whether developmental difficulties in the comprehension of figurative language persist into adulthood.

Furthermore, research that did address this issue regarded the difficulties as reflecting a language-use dysfunction. For instance, difficulties in metaphor comprehension were regarded as an aspect of the general pragmatic impairment in ASD (e.g., Jolliffe & Baron-Cohen, 1999a, 1999b, 2000; Losh & Capps, 2003). The present study aimed to examine the difficulties in metaphor comprehension in adults with AS from a different perspective – a neurolinguistic perspective. We aimed to examine differences in linguistic information processing pattern in AS persons compared to controls. Specifically, we examined whether a deficient semantic integration process underlies the difficulties in metaphor comprehension frequently experienced by these persons even when the metaphors are presented without larger context. Excluding context thus enabled us to examine the semantic integration process by minimizing the effects of pragmatic abilities.

In addition, the present study aimed to extend the available research on metaphor comprehension in AS by examining the semantic integration process of two types of metaphors – novel and conventional. People typically encounter both types of metaphors in everyday life as novel metaphors are created constantly and some of them become conventional with repeated use. Thus, examining the semantic integration of both types of metaphors should give a more precise picture of metaphor comprehension in AS.

Semantic integration refers to a specific stage in semantic processing that involves detection, elaboration, and refinement of higher order semantic relations (for a thorough description see Jung-Beeman (2005)). Thus, semantic integration follows an initial stage during which semantic representations are accessed. Several studies show that when people perform tasks emphasizing semantic integration, neuroimaging signals can be predominantly right-sided (e.g., St. George, Kutas, Martinez, & Sereno, 1999). For a

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review see Jung-Beeman, 2005). According to Jung-Beeman (2005), the stage of semantic integration most probably relies on coarse semantic coding mechanisms of the right hemisphere (RH). Coarse semantic coding refers to the distinct pattern of sensitivity to distant semantic relations attributed to the RH. The accumulated evidence from neurologically intact, split-brain, and brain-injured participants indicates that when a word is recognized by the RH a broad set of meanings, including distant, unusual, nonsalient, subordinate and figurative meanings becomes available (e.g., Chiarello, 2003; Faust & Lavidor, 2003; Jung-Beeman, 2005). Much research indicates that these semantic processes enable the unique RH involvement in processing metaphorical meanings that are relatively more distant and may require coarse semantic coding (e.g., Anaki, Faust, & Kravetz, 1998; Mashal, Faust, & Hendler, 2005, but see also Coulson & Van Petten, 2007, for contrary evidence indicating that metaphoricity effects are very similar across hemifields). Thus, deficient coarse semantic coding may result in difficulties to integrate two-word metaphorical expressions that could be reflected in the ERP pattern showed by AS as compared to controls.

When people attempt to comprehend a two-word literal expression, the semantic processing begins with the activation of semantic representations of each of the words, and their meaning is accessed. In the following stage, semantic relations between the two words are established, and thus the meaning of the two words may be integrated into a coherent expression. For literal expressions ("pearl necklace"), the integration process is fairly simple, whereas for metaphorical expressions ("misty scarf") this process may be far more taxing (e.g. Arzouan, Goldstein, & Faust, 2007b). The greater effort invested in the integration of metaphors as compared to literal expressions is due to the fact that metaphors are formed through the integration of concepts from distantly-related semantic domains.

Furthermore, according to current theoretical models (e.g., Bowdle & Gentner, 2005), linguistic information processing is not equal for all metaphors. Thus, for example, according to the Career of Metaphor Model (Bowdle & Gentner, 2005), there is a clear differentiation between metaphoric expressions which are familiar, frequent, and prototypic, i.e., conventional metaphors, and new, original metaphoric expressions, such as those appearing in poetry. This model posits that the comprehension of conventional metaphors is much less demanding, in terms of cognitive and linguistic resources, than the comprehension of novel metaphors.

The difference in effort/ease of linguistic information processing required during the comprehension of novel metaphors, as opposed to conventional metaphors, has also been supported by recent behavioral (Faust & Mashal, 2007; Mashal & Faust, 2008), imaging (Mashal, Faust, Hendler, & Jung-Beeman, 2007; Mashal et al. 2005), ERP (Arzouan, Goldstein, & Faust, 2007a, 2007b) and TMS (Pobric, Mashal, Faust, & Lavidor, 2008) studies. The findings emphasize the importance of examining both types of metaphors, as was done in the present study.

A study by Arzouan et al. (2007b) utilized the ERP technique to track the stages of semantic processing of literal and metaphoric two-word expressions, both conventional and novel in the intact brain. ERPs are electrophysiological recordings characterized by high temporal resolution that can be analyzed in order to define the brain's activity during semantic processing of metaphors (e.g., Arzouan et al., 2007a). ERPs are especially useful for the study of language comprehension because a negative component peaking at approximately 400 ms after stimulus-onset (the N400) has been shown to vary systematically with the processing of semantic information. The N400 component can be thought of as a general index of the ease or difficulty of retrieving stored conceptual knowledge associated with a word (Kutas & Federmeier, 2000), the difficulty in semantic integration of words within sentences (for review see Kutas, Federmeier, Coulson, King, & Mmuente, 2000), and the degree of the anticipation of a word considering the word preceding it (Bentin, McCarty, & Wood, 1985).

In Arzouan et al.'s (2007b) study, participants read two-word expressions of four types: literal, conventional metaphors, novel metaphors, as well as unrelated word pairs, and were asked to perform a semantic judgment task in which they decided whether each word pair conveyed a meaningful expression. The findings showed that the N400 amplitude to the second word of the pair varied as a function of expression type in a graded manner increasing from literal to conventional metaphors, to novel metaphors and to unrelated word pairs. The authors suggest that greater N400 amplitudes for novel metaphors reflect the relatively more taxing effort to semantically integrate the distantly related two words into a meaningful expression.

Following Arzouan et al. (2007a, 2007b), in the present study we compared the pattern of semantic integration of conventional metaphors, novel metaphors and literal expressions in persons with AS as compared to a control group. The main goal was to examine the patterns of information processing in the brain of persons with AS and controls during metaphor comprehension *regardless* of context. Therefore, the linguistic stimuli consisted of two-word expressions, instead of the commonly used sentences. The relatively "impoverished" stimuli presented to the participants enabled us to focus on neurolinguistic processes, i.e., semantic integration, by minimizing the effects of pragmatic abilities.

Previous studies examining semantic processing in ASD have consistently found a different N400 pattern as compared to controls. Most of these studies tested the ability of ASD participants to integrate words with preceding contexts (semantic categories or sentences), and indicate a failure to set up a selective expectancy for target words (Dunn, Vaughan, Kreuzer, & Kurtzberg, 1999). For example, a study conducted by Ring, Sharma, Wheelwright, and Barrett (2007) compared the N400 to congruous and incongruous sentences in AS participants and controls. Results showed that while the seven controls appropriately demonstrated N400 potentials only to semantically incongruent stimuli, the seven participants with AS inappropriately demonstrated N400 potentials to congruent stimuli. The authors concluded that AS participants did not use the context within sentences to predict the final word of the sentence.

Similarly, Braeutigam, Swithenby, and Bailey (2008) used the MEG methodology to record neural responses in 11 adults with ASD (AS and high-functioning autism) while reading meaningful sentences and sentences ending with a semantically incongruous word. They found strong neuronal responses to semantic incongruity within the N400 interval in both subject groups. Similar to Ring et al's (2007) findings, these results also indicate that ASD participants have relatively weak expectancy with respect to the final word of the sentence. However, Braeutigam et al. (2008) found a difference between the groups in terms of the degree of lateralization of activity, indicating a RH dominance in the ASD group. The authors suggest that ASD participants attempt an anomalous contextual integration, with an emphasis on the spectrum of possible meanings of the final word, a process leading to RH processing dominance. Their findings may indicate unusual strategies for resolving semantic ambiguity in autism.

Strandburg et al. (1993) observed an ERP correlate of impaired idiom processing in adults with high-functioning autism. Subjects completed an idiom recognition task involving literal, idiomatic and nonsense phrases. Autistic subjects were impaired only with regard to the identification of idiomatic statements and showed greatly reduced N400 amplitude to idioms. The authors hypothesize that the reduced N400 to idioms in autistic persons, as compared to a clear and larger N400 in normal participants, "reflects less associative elaboration, less elicitation of alternative meanings, and hence less depth of processing of idioms by autistics" (p. 429).

In summary, the few ERP studies that examined semantic processing in AS focused mainly on sentence context integration and suggest different processes of semantic access and integration in persons with AS as compared to controls. The only ERP study that specifically examined the comprehension of figurative language in ASD focused on the comprehension of idioms which are frequently used metaphoric expressions that are equivalent to conventional metaphors (Strandburg et al., 1993). The present study aimed to extend the research on metaphor comprehension in AS by looking at the processing of two different types of metaphors, conventional and novel metaphors. Both types of metaphors are frequently used in everyday conversation, and thus an inability to discern their correct meaning may have an impact on the success of social encounters (Weylman, Brownell, Roman, & Gardner, 1989). Distinguishing between the two types of metaphors is important because, as described above, the comprehension of these two types of metaphoric expressions may require different degrees of information processing effort.

The main hypothesis was that differences in linguistic information processing will be reflected in a different N400 amplitudes grading pattern for the different pair types in persons with AS as compared to controls. For the control group, we predicted that the N400 amplitude will vary as a function of expression type in a graded manner increasing from literal to conventional metaphors, to novel metaphors and to unrelated word pairs. These predictions were based on previous findings (e.g., Arzouan et al., 2007b; Coulson & Van Petten, 2002; Geiger & Ward, 1999; Pynte, Besson, Robichon, & Poli, 1996).

For the AS participants, we predicted that the N400 amplitude will vary as a function of expression type in a graded manner increasing from literal to conventional metaphors, to unrelated word pairs and novel metaphors for which the N400 amplitude will be the largest or, alternatively, not different from that of the unrelated word pairs. Following, we will explain the reasons for these predictions. First, conventional metaphors are expected to be more effortful to integrate than literal word pairs. This is consistent with Strandburg's (1993) predictions, as well as with the reported difficulties in metaphor comprehension in persons with AS, alongside to their ability to discern literal meanings. Second, the prediction of a large N400 amplitude for novel metaphors is based on the notion that novel metaphors are more difficult to process than conventional metaphors (Bowdle & Gentner, 2005; Faust & Mashal, 2007). We predicted that AS participants will show one of two information processing patterns when introduced with novel metaphors. They were expected to either have difficulties to semantically integrate the novel metaphor, and thus perceive it as unrelated. This was expected to result in N400 amplitudes similar to those obtained for unrelated word pairs. The other possibility was that AS participants will differentiate between novel metaphors and unrelated meaningless word pairs. This differentiation was expected to foster further efforts to semantically integrate novel metaphoric pairs (and not unrelated pairs) in order to extract their meaning. This further effort would be reflected in larger N400 amplitudes for novel metaphors as compared to unrelated word pairs. It was predicted that if AS participants carry out the task using a different set of neural generators, this would be reflected in different spatial distributions of the ERP components. Most importantly, we expected that AS persons' known difficulties in metaphor comprehension will be reflected in larger N400 amplitudes specifically for metaphors – both novel and conventional. In addition, based on previous studies suggesting RH dysfunction in AS (McKelvey, Lambert, Mottron, & Shevell, 1995), N400 laterality was expected to differ between the two groups.

In respect to behavioral results, it was predicted that reaction times in both groups will vary as a function of expression type. Based on previous studies on both healthy adults (Faust & Mashal, 2007) and adults with AS (Gold & Faust, submitted), processing of literal word pairs and conventional metaphors was expected to result in shorter reaction times as compared to novel metaphors and unrelated word pairs. However, based on studies indicating atypical motor preparation (Rinehart et al., 2006) in AS and on a behavioral study conducted in our lab (Gold & Faust, 2010), overall reaction times were expected to be longer in the AS group.

Based on the findings of our behavioral study (Gold & Faust, 2010), it was predicted that AS participants will show a similar pattern of errors across word pairs as controls. Thus, it was expected that in both groups, attempts to comprehend novel metaphors and unrelated word pairs will result in higher error rates as compared to literal word pairs and conventional metaphors. However, overall error rates in the AS group were expected to be higher as compared to controls.

2. Method

2.1. Participants

A total of 33 participants were included in this experiment. Seventeen (14 men, 3 women) comprised the Asperger syndrome (AS) group and 16 (12 men, 4 women) comprised the control group. One participant from the AS group had difficulties completing the experimental session and was excluded from analysis. The final AS and control groups did not differ in sex distribution, $\chi^2(1) = .183$, $p > .05$. The groups did not differ in age (for AS: $M = 21.9$, $SD = 3.0$, age ranged from 17.83 to 30.1 vs. control: $M = 23.1$ $SD = 3.07$), age ranged from 18.08 to 31.5, $t(30) = 1.0$, NS), or verbal IQ (for AS: $M = 105.8$,$SD = 15.1$, scores ranged from 87 to 134 vs. controls: $M = 106.8$, $SD = 12.6$, scores ranged from 90 to 128), $t(30) = 0.2$, NS).

All participants were native Hebrew speakers who completed at least twelve years of formal education. All were right handed with a laterality quotient of at least +90 on the Edinburgh Inventory (Oldfield, 1971), and had normal or corrected to normal vision. Diagnosis of the participants with AS was carried out by a single psychiatrist with extensive experience in this area following DSM-IV criteria (American Psychiatric Association, 1994), who also ensured no comorbidites. All AS participants were outpatients and were recruited through the Israeli Asperger Association ($n = 10$) and from a protected homes project for persons with ASD ($n = 6$). Participants were not on medication during the period of testing. In addition, those who suffered from co-morbid mental illness or reading disabilities were excluded. To confirm diagnosis, all AS participants completed the autism-spectrum quotient (AQ) (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001). All participants scored above 26 (scores ranged from 26 to 40, $M = 31.7$, $SD = 3.73$). This score fits with two recent studies that have suggested that a score of 26 is a more sensitive cut off point for the AQ (Kurita, Koyama, & Osada, 2005; Woodbury-Smith, Robinson, & Baron-Cohen, 2005), and also fits the cut off point distinguishing the general Israeli population and Israeli persons diagnosed on the autism spectrum disorders (Golan, Gold, & Fridenzon, 2009). In addition, according to parental report, all participants had no significant language delay. All participants signed an informed consent form prior to the research session. The AS participants were paid for their participation, and the control group participants received course credit.

2.2. Stimuli

The stimulus pool consisted of 240 word pairs, all in Hebrew (see Appendix A for examples). The two words formed four types of semantic relations: literal (*soft blanket*), conventional metaphoric (*juicy gossip*), novel-metaphoric taken from poetry (*wilting hope*), or unrelated (*sink dispute*). Because of Hebrew grammar, the order of words in the translated examples was actually reversed. All primes were nouns, targets were either nouns or adjectives, and both prime and target words consisted of two to six letters. Word length and grammatical category were counterbalanced across the four types of word pairs. Thus, each condition contained equal numbers of 2, 3, 4, 5 and 6 letter primes and targets, and an equal number of nouns and adjectives.

Stimuli were also balanced between conditions according to word frequency, concreteness, grammatical category, and syntactic structure. Several pretests were performed to determine the type of semantic relationship between the two words in each pair, concreteness and word frequency.

The aim of the first pretest was to determine the type of each two-word expression (metaphoric, literal or unrelated). In order to do so, 40 judges who did not participate in the experiment, were presented with a list of two-word expressions and asked to decide whether each expression is literally plausible, metaphorically plausible or not plausible. Expressions that were rated by at least 80% of the judges as either metaphorically/literally plausible or not plausible were selected as expressions with either a metaphoric or a literal meaning or as unrelated word pairs, respectively.

In order to distinguish between unfamiliar novel metaphors and conventional metaphors, another group of 35 judges, who also did not participate in the experiment, was presented with a list of only the plausible metaphoric expressions from the first pretest. Subjects were asked to rate the degree of familiarity of each metaphoric expression on a five-point familiarity scale ranging from one (highly non familiar) to five (highly familiar). Metaphoric expressions scoring less than 2.4 on the familiarity scale were selected for the study as novel metaphors (rating average 1.53, $SD = .23$), whereas those scoring above 3.6 on this scale were selected as conventional metaphors (rating average 4.45, $SD = .44$). The degree of familiarity of these two types of metaphors was significantly different, $t(118) = 45.72$, $p < .001$.

In another pretest, 23 additional judges were presented with the list of all primes and targets and were asked to rate the level of concreteness on a scale ranging from one (highly abstract) to five (highly concrete). Words with an average of less than three (on the 1–5 scale) were considered as abstract words whereas words with an average of more than three were considered concrete words. For the prime words 70%, 75%, 71.66% and 76.66% of the words were judged as concrete for the novel metaphors ($M = 3.9$, $SD = .57$), conventional metaphors (M = 4.2, $SD = .52$), literal (M = 4.1, $SD = .56$), and unrelated (M = 4.2, $SD = .54$) conditions, respectively. For the target words 65%, 68.33%, 63.33% and 65%, of the words were judged as abstract for the novel metaphors ($M = 2.1$, $SD = .42$), conventional metaphors ($M = 2.3$, $SD = .39$), literal ($M = 2.2$, $SD = .37$) and unrelated ($M = 2.1$, $SD = .44$) conditions, respectively. There were no significant differences in levels of concreteness between the four pair types.

Since in Hebrew there is no extensive database for word frequency, the fourth pretest tested subjective word frequency. Forty-five additional judges, who did not participate in the former pretests and not in the experiment, were presented with the list of all the words and asked to rate their degree of frequency on a five point frequency scale ranging from one (highly non frequent) to five (highly frequent). The average rates on the frequency scale for the target words were 3.57, 3.59, 3.65 and 3.62, for the novel metaphors, conventional metaphors, literal, and unrelated, respectively. The average rates on the frequency scale for the priming words were 3.74, 3.60, 3.68 and 3.72 for the novel metaphors, conventional metaphors, literal, and unrelated, respectively. No significant difference was found for the target and the priming words between the four conditions ($F < 1$).

The final stimulus pool consisted of 60 novel metaphoric expressions, 60 conventional metaphoric expressions, 60 literal expressions and 60 unrelated word pairs. The balancing process described above was crucial, because each of these parameters affects the process of semantic integration (e.g. Kroll & Merves, 1986; Marslen-Wilson, 1990).

2.3. Procedure

Following Arzouan et al. (2007b), the word pairs were presented in a random order, one word at a time, on the center of a computer screen using white letters and black background. Stimuli on each trial were presented in the following time sequence: fixation cross (200 ms), first word (200 ms), fixation cross (200 ms), and second word (200 ms). Participants were instructed to "judge whether the presented two-word expression conveys a meaning (be it literal or metaphoric) or does not convey a meaning as a pair", and press a corresponding key. The key designation was counterbalanced between participants in each group. The session began with a practice list, consisting of 20 word pairs not used in the experimental list.

2.4. EEG recording

EEG was recorded continuously using a 64-channel geodesic net (Electrical Geodesics Inc.). Impedance was kept below 40 kΩ. All channels were preprocessed on-line by means of 0.1 Hz high-pass and 100 Hz low-pass filtering and digitized at a rate of 250 Hz. Further processing, filtering, artifact screening, and eye-movements correction was performed off-line. EEG records were segmented 100 ms pre-stimulus to 1100 ms post-stimulus.

2.5. Data analysis

ERP waveforms were calculated by averaging artifact-free, correct trials for each condition for each participant. ERPs were derived by averaging correctly classified trials on each condition for each participant. Mean amplitude at the time-windows of interest were analyzed with ANOVA with group as a between-subject measure and condition and electrode site as repeated measures. Geisser–Greenhouse correction was applied to the within-subjects variables and the reported *p*-values reflect the corrected values.

3. Results

3.1. Behavioral results

For the purpose of this analysis we calculated for each participant mean reaction times for correct trials only, and error rates for each pair type. Table 1 presents RTs and error rates in the various conditions.

A 2 (group: AS/control) $\times$ 4 (pair type: novel/conventional/literal/unrelated) ANOVA for repeated measures on reaction times and error rates revealed a significant effect of group only for RTs, $F(1, 30) = 5.41$, $p < .05$, such that reaction times were longer for the AS group ($M = 790.44$, $SD = 344.18$) as compared to the control group ($M = 619.85$, $SD = 269.69$). However, the pair type effect was significant for both RTs $F(3, 90) = 23.52$, $p < .001$) and error rates $F(3, 90) = 29.32$, $p < .001$). For RTs, Bonferroni's post hoc analyses ($Ps < .05$) indicated that RTs were shorter for both the literal pairs ($M = 542.72$, $SD = 153.89$) and conventional metaphors ($M = 573.23$, $SD = 218.6$) as compared to the unrelated pairs ($M = 910.91$, $SD = 386.54$) and novel metaphors ($M = 793.74$, $SD = 331.21$). The difference between RTs for unrelated and novel metaphors, and the difference between literal word pairs and

Table 1
Mean (and *SDs*) of reaction times for correct responses and for error rates for the four pair types in AS and control groups.

Pair type	Asperger syndrome		Controls	
	Reaction times (ms) Mean (*SD*)	Error rates (%) Mean (*SD*)	Reaction times (ms) Mean (*SD*)	Error rates (%) Mean (*SD*)
Novel metaphors	857.72 (368.04)	37.60 (18.70)	729.76 (256.78)	36.04 (25.23)
Conventional metaphors	672.54 (224.14)	9.87 (9.30)	473.91 (156.92)	5.62 (11.08)
Literal	613.07 (145.56)	9.87 (9.30)	472.36 (124.99)	3.54 (4.55)
Unrelated	1018.44 (426.59)	24.04 (16.85)	803.4 (306.58)	15.52 (15.61)

conventional metaphors were not significant. For error rates, Bonferroni's post hoc analyses (*P*s < .05) indicated that error rates were significantly higher for the novel metaphors ($M = 36.82$, $SD = 21.86$) and unrelated word pairs ($M = 19.79$, $SD = 16.58$) than for conventional metaphors ($M = 7.75$, $SD = 10.29$), and literal word pairs ($M = 6.09$, $SD = 6.34$). The difference in error rates between novel metaphors and unrelated word pairs was also found to be significant. The group by pair type interaction was not significant for either RTs or error rates.

3.2. Event related potentials

Fig. 1 shows the grand average waveforms elicited by novel metaphors and literal word pairs over the central electrodes for the AS group and controls. The waveforms in the present study were qualitatively similar for AS participants and controls and were characterized (Fig. 2) by a sizeable N400 component peaking around 400 ms post-stimulus, as well as *N*1 (~100 ms), *P*2 (~200 ms), and a later positive component (600–1000 ms). Analysis focused on the N400 component. There was no significant difference in N400-peak latency between the AS and control groups thus the analyses are focused on amplitude only. Analysis for both groups included mean amplitude measurements of the 380–430 ms time window from the appearance of the target word, thus capturing most of the activity of the N400 component. Eight electrodes which best captured the N400 activity were selected for the analysis (electrodes number 5, 9, 18, 29, 42, 43, 55 and 58, marked in Fig. 3) measuring frontal, central, centroparietal and parietal areas on the scalp, on both the left and right side.

Mixed ANOVA with three repeated variables: 4(electrode Site: anterior/posterior/central/centroparietal) × 2(electrode laterality: left/right) × 4(pair type: novel/conventional/literal/unrelated) and one between variable (group: AS/control) revealed no significant main effect of group, $F(1, 30) = 2.06$, $p > .05$.

The pair type effect was significant, $F(3, 90) = 8.08$, $p < .001$. The N400 increased in a graded manner from the literal word pairs for which the N400 was most positive ($M = .644$, $SD = .139$), followed by conventional metaphors ($M = .555$, $SD = .125$), novel metaphors ($M = .250$, $SD = .135$), and the most negative N400 for the unrelated word pairs ($M = .167$, $SD = .144$). Bonferroni's post hoc analyses

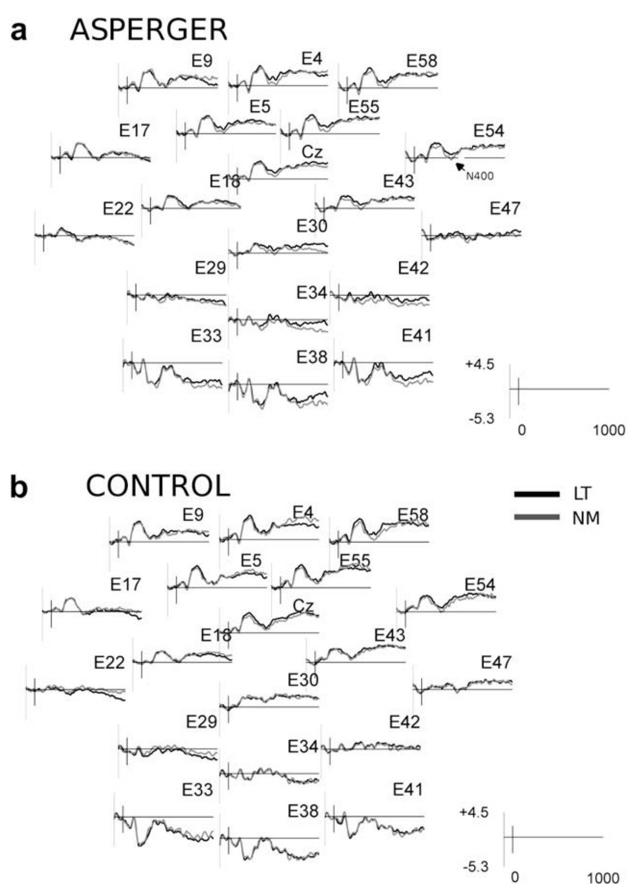

Fig. 1. Grand average ERPs for literal (black lines) and novel metaphor (grey lines) conditions on the central electrodes of the Asperger syndrome group (a) and the control group (b).

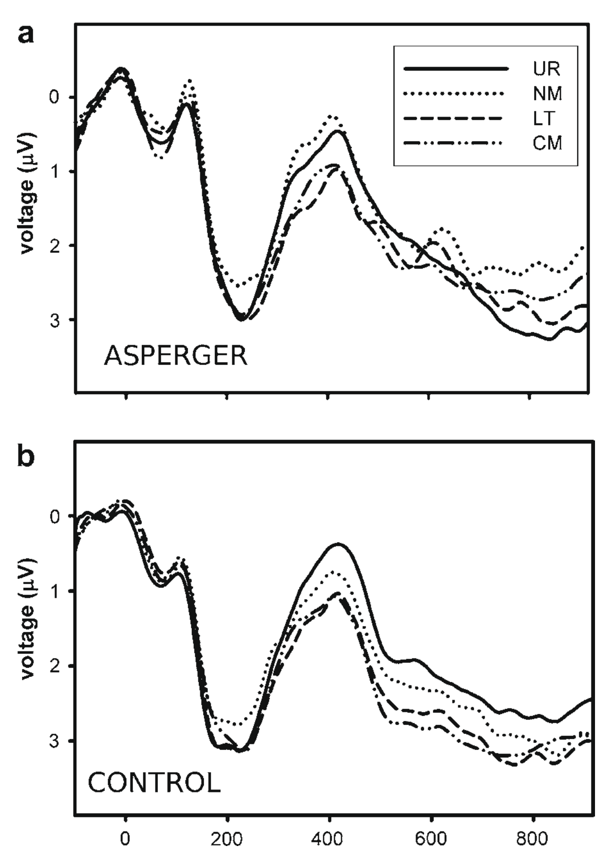

Fig. 2. Grand average ERP waveforms for target words of each expression on the Cz electrode in the Asperger syndrome group (a) and the control group (b). Negative voltage is plotted upwards.

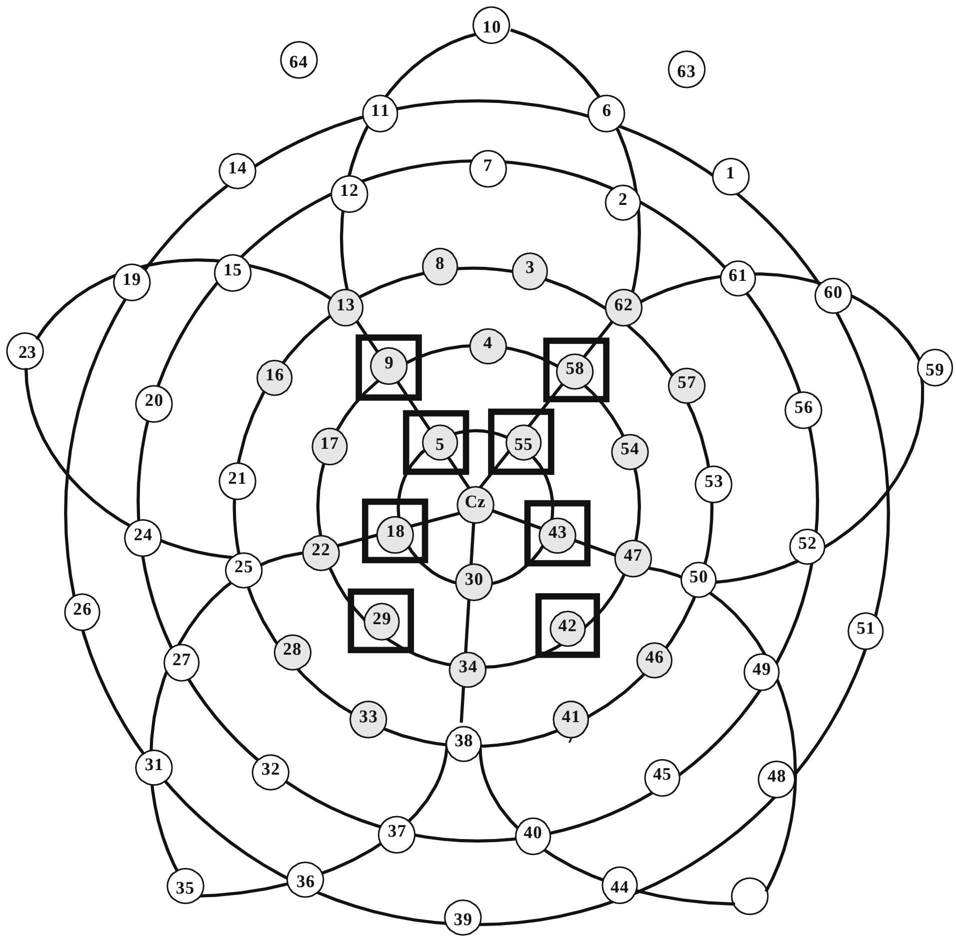

Fig. 3. Electrode sites selected for statistical analysis (in squares).

(Ps < .05) indicated that the N400 measured for literal and conventional word pairs was significantly more positive than for the unrelated word pairs. N400 for novel metaphors was significantly more negative than literal word pairs.

More interestingly, the pair type by group interaction was significant $F(3, 90) = p < .05$, and is plotted in Fig. 4. Although there was a significant effect of pair type in both the AS ($F(3, 45) = 5.46$, $p < .05$) and control groups ($F(3, 45) = 5.8$, $p < .05$), the pattern of N400 elicited for the four pair types was different between the two groups. For the AS group, literal word pairs elicited least negative N400 ($M = .565$, $SD = .743$), followed by conventional metaphors ($M = .266$, $SD = .620$), unrelated word pairs ($M = .160$, $SD = .867$), and novel metaphors for which the N400 was most negative ($M = -.041$, $SD = .664$). Bonferroni's post hoc analyses (Ps < .05) indicated that there was a significant difference only between the literal and novel metaphors. In contrast, for the control group, N400 for conventional metaphors was least negative ($M = .844$, $SD = .782$), followed by literal word pairs ($M = .723$, $SD = .827$), novel metaphors ($M = .542$, $SD = .853$), and unrelated word pairs (M = .174, $SD = .752$). Bonferroni's post hoc analyses (Ps < .05) indicated that there was a significant difference only between the conventional metaphors and the unrelated word pairs.

Paired sampled t-tests were conducted on N400 amplitudes to further investigate the difference between AS and controls for each pair type. This analysis revealed a significant difference between the groups in N400 amplitude only for novel metaphors $t(254) = -3.13$, $p = .002$) and for conventional metaphors $t(254) = -3.43$, $p = .001$), such that N400 amplitudes were more negative in the AS group as compared to controls for both types of metaphors.

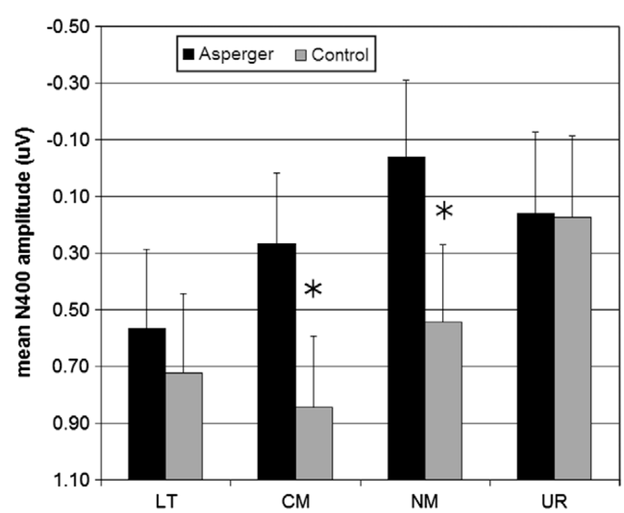

Fig. 4. Mean N400 amplitude for literal (LT), conventional metaphors (CM), novel metaphors (NM), and unrelated word pairs (UR) for the Asperger syndrome participants and controls.

The electrode site effect was significant, $F(3, 90) = 12.39$, $p < .001$. Bonferroni's post hoc analyses (Ps < .05) indicated that N400 amplitude measured in parietal electrodes was significantly more negative ($M = -0.300$, $SD = 0.197$) than in frontal ($M = 0.752$, $SD = 0.172$), central ($M = 0.819$, $SD = 0.157$) and centroparietal ($M = 0.345$, $SD = 0.158$) electrodes. In addition the difference in

N400 amplitude was significant between central and centroparietal electrodes. However, the group by electrode site interaction was not significant. The electrode laterality effect approached significance, $F(1, 30) = 3.61$, $p = .07$.

The electrode laterality by pair type interaction was also significant, $F(3, 90)$,$p < .01$. post hoc analyses revealed no significant effect for pair type in the left electrodes, whereas for the right electrodes there was a significant effect for pair type, $F(3, 93) = 9.72$, $p < .01$. The N400 varied gradually from literal word pairs for which the N400 was least negative ($M = .914$, $SD = .961$), followed by conventional metaphors ($M = .835$, $SD = 1.08$), novel metaphors ($M = .22$, $SD = 1.041$), and unrelated word pairs ($M = .213$, $SD = 1.031$). Bonferroni's post hoc analyses (Ps < .05) revealed that N400 for novel and unrelated word pairs were significantly higher than for literal and conventional word pairs. However, electrode laterality did not interact significantly with group.

Finally, an analysis was conducted to further examine differential N400 amplitudes to novel metaphoric word pairs that were judged as meaningful as opposed to those judged as meaningless. In this analysis we compared the N400 elicited by novel metaphoric pairs that were judged as meaningless (i.e. error trials, NME) to that of novel metaphoric pairs judged as meaningful (NM) and unrelated (UR) pairs judged as meaningless (i.e. correct trials). A 2 (group: AS/controls) $\times$ 3 (type: NM/NME/UR) ANOVA for repeated measures on N400 amplitudes revealed no significant effect for type. However, the group *x* type interaction was significant, $F(2, 28) = 7.1$, $p < 0.01$. post hoc analyses indicated no significant difference between N400 amplitudes elicited by the different types in the AS group, whereas for controls the N400 elicited by unrelated word pairs was the most negative ($M = .173$, $SD = .387$), followed by that elicited for novel metaphors judged as meaningless ($M = .221$, $SD = .365$), followed by correctly classified novel metaphors for which N400 amplitudes were least negative ($M = .597$, $SD = .198$).

4. Discussion

As expected, the findings indicate a different pattern of information processing between the two groups. Although the two groups did not differ in their N400 evoked by literal or unrelated pairs, AS participants showed significantly larger N400s elicited by metaphoric expressions, especially by novel metaphors.

The present findings for the control group may support and complement previous studies on metaphor processing in the intact brain. Thus, they provide additional insight into the process of metaphor comprehension by focusing on a specific stage in processing, i.e., semantic integration that was examined using a high temporal resolution technique. In general, similar to previous ERP studies of metaphor comprehension (e,g, Arzouan et al., 2007b), this study supports the notion that the N400 component is a sensitive measure of the ease or difficulty of semantic information processing involved in metaphor comprehension, yielding a distinct grading pattern for different types of linguistic stimuli.

Alongside the contribution to our understanding of metaphor comprehension in the intact brain, the present study focused on this process in AS persons who are known to experience difficulties in metaphor comprehension. Interestingly, when comparing the N400 amplitudes for each pair type between the two groups, differences were found only for metaphoric expressions – both novel and conventional. Thus, results suggest that it is the metaphoricity that seems to pose difficulties on the semantic integration process in AS.

This specific difference between AS and controls in semantic integration for metaphors is consistent with previous findings indicating AS persons' difficulties to comprehend both conventional metaphors (e.g., Strandburg et al., 1993) and novel metaphors (Gunter, Ghaziuddin, & Ellis, 2002). In addition, these findings support the previously documented relatively intact ability to process literal language in AS (e.g. Attwood, 1998). One of the interesting findings of this experiment is the major difficulty of AS participants to integrate the two seemingly unrelated words forming novel metaphoric expressions. This is reflected by the large N400 amplitude for those novel metaphors that were correctly judged as meaningful in this group. Moreover, when comparing N400 amplitudes for correctly classified novel metaphors and unrelated word pairs, no significant difference was found for the AS group, suggesting that for these persons, the meaning integration process for novel metaphoric expressions is as effortful as that for unrelated, meaningless, word pairs. In contrast, in the control group, N400 amplitudes for correctly classified novel metaphors were significantly smaller than those for unrelated word pairs, while *incorrectly* classified novel metaphors (i.e. in cases which novel metaphors were judged as unrelated because their meaning could not be derived) elicited intermediate N400 amplitudes.

Novel metaphors share common features with unrelated word pairs: both are unfamiliar and both involve distant semantic relationships. However, processing meaningful linguistic expressions, such as novel metaphors, can lead to the integration of the meanings of two words into a coherent and meaningful expression, beyond the search for semantic relations that occurs for unrelated word pairs. By contrast, processing unrelated words pairs involves searching for a connection which is not followed by the successful integration of meanings across the two words and may thus be more effortful. In the control group, the reduced effort invested in creating the connection between the two words forming the novel metaphors seems to be reflected in the significantly smaller N400 amplitude for correctly classified novel metaphors as compared to the larger N400 amplitude for unrelated word pairs. In addition, in the control group, the integration effort increased when confronting a difficult-to-integrate novel metaphor, as reflected by the similarly large N400 amplitudes for *incorrectly* classified novel metaphors and unrelated word pairs.

However, this is not the case for the AS group. For these persons, novel metaphoric expressions seem to pose great difficulties, similar to the semantic integration difficulties experienced when they attempt to comprehend meaningless, unrelated word pairs. Moreover, for the AS group, the integration effort seems to be similar across all unfamiliar conditions, i.e., for both correctly and incorrectly classified novel metaphors as well as for the unrelated word pairs. Thus, for the AS participants, the process of comprehending novel metaphors seems to be as taxing as processing unrelated, meaningless word pairs, even when the novel metaphoric expression is clearly identified as meaningful by persons not diagnosed with AS.

It is important to note, however, that although the present results support different information processing in AS participants and controls, they do not imply different neural generators in the two groups while engaging in metaphor comprehension. In both groups, N400 amplitudes were larger at parietal-centro/parietal electrode sites, in line with the scalp distribution usually found for N400 (Kutas & Federmeier, 2000). Similarly, in both groups, the pair type effect was significant in right lateralized electrodes, and N400 amplitudes significantly differed in the different electrode sites. Thus, these results do not support theories of RH dysfunction in AS (e.g., McKelvey et al., 1995). In addition, since the N400 grading pattern in right lateralized electrodes was observed for *all* pair types, the present results do not provide support to the coarse coding model (Jung-Beeman, 2005), which suggests a unique RH involvement in processing metaphorical meanings.

The major difficulties experienced by the AS participants in the integration of novel metaphoric meanings seem to be consistent with results reported in a study by Just, Cherkassky, Keller, and Minshew (2004). In their study, brain activation of a group of high-functioning autistic participants was measured using fMRI during sentence comprehension. Their results suggest that compared to control participants, high-functioning autistic individuals engage less in the integrative aspects of sentence processing. They propose that their results support the under-connectivity theory (Just et al., 2004), predicting that any facet of psychological function that is dependent on the coordination or integration of brain regions is susceptible to disruption in autism.

Although the present experiment did not examine sentence level integration, the task employed did nonetheless require the semantic integration of the meanings of two words comprising a linguistic expression. Considering previous findings indicating that novel metaphor comprehension relies on the recruitment of language areas from both LH and RH (Arzouan, Goldstein, and Faust, 2007b; Mashal et al., 2007), this type of expressions is most dependent on the coordination of brain regions. In line with the underconnectivity theory, we suggest that disruption of this necessary coordination between language areas in persons with AS may result in a major effort to integrate the two words comprising the novel metaphor, as reflected in the large N400 amplitude for this expression type in the AS group. Thus, the difficulties in novel metaphor comprehension may be an aspect of the reduced inter-hemispheric coordination, as proposed by the under-connectivity theory. This reduced inter-hemispheric coordination found using fMRI in Just's study may result in difficulties to semantically integrate novel metaphors, and may thus be manifested in larger N400 amplitudes when utilizing ERP.

The present results are also consistent with Wang et al's fMRI findings for irony comprehension in children with autism. Similar to the present findings, their findings support more effortful processing of linguistic utterances in the autistic group compared to controls (Wang, Lee, Sigman, & Dapretto, 2006).

There are no studies using N400 in people with Autistic Spectrum disorders directly comparable to the present study. Braeutigam and colleagues' (2008) MEG study indicates a RH dominance in the ASD group and the findings are interpreted as indicating that ASD participants attempt anomalous contextual integration, with an emphasis on the spectrum of possible meanings of the final word, because they do not take into account the preceding context.

Unlike previous studies that examined sentence level processing (Braeutigam et al., 2008; Just et al., 2004), the present study (and the study by Strandburg and colleagues (1993)) examined word level processing. Although these two processes are interrelated, it is important to bear in mind evidence suggesting that different neurolinguistic mechanisms are involved in these processes (Faust, 1998). At the sentence level, word meanings are syntactically combined and modified to yield a higher level integrated meaning representation (Chiarello, 2003). The Studies mentioned above that examined sentence level processing in ASD indicate deficiency in the integrative aspects of the process and may thus suggest difficulties to yield a higher level integrated meaning representation in ASD. As opposed to these studies, the present study examined word level processing, and thus focused on processing of basic semantic relations. As discussed above, results indicate a different pattern of semantic integration between AS and controls, and thus provide insight into more basic, word level, semantic information processing.

As mentioned above, Strandburg et al.'s (1993) findings are thus more relevant to the present study's findings. They examined N400 responses in people with high-functioning autism and the pattern of results for conventional metaphors was opposite to that of the present study. In Strandburg's study, conventional metaphor comprehension resulted in a decrease in N400 amplitudes compared to literal word pairs, whereas in the present study, conventional metaphors elicited larger N400 amplitudes compared to literal word pairs. It is worth mentioning that the pattern observed in the present study is consistent with Strandburg et al.'s (1993) predictions. It may be that in Strandburg's study this prediction was not supported by results due to the fact that the word pairs selected were not extensively balanced for different parameters except word frequency. Strandburg et al. interpret their findings as indicating less elaboration of meaning in the autistic group as compared to controls, resulting in the comprehension of idioms as literal expressions. However, novel metaphors were not included in that study. This additional unfamiliar condition (i.e. meaningful novel metaphors in addition to nonsensical, unrelated word pairs) in the present study may also account for the different pattern of results. Thus, introducing a condition that consists of unfamiliar yet meaningful metaphorical expressions (novel metaphors) may have caused the participants to engage more in the highly taxing on-line sense creation process involved in the comprehension of novel metaphors and to extend this process to conventional metaphors comprehension in order to come up with the potential meaning. This additional experimental condition may have been the cause for larger N400 amplitudes for conventional metaphors in the present study as opposed to the smaller N400 in Strandburg's study that used only conventional metaphors.

Another interesting finding of the present study relates to the discrepancy between behavioral and electrophysiological patterns of response to the different types of linguistic expressions. A similar pattern of behavioral measures (reaction times) for AS and controls was coupled with a difference between the two groups in electrophysiological measures (N400 amplitude). This discrepancy between behavioral and physiological measures is consistent with Coulson and Van Petten's (2002) claim that equivalent processing time need not imply equivalent effort. It also replicates previous findings obtained with both neurologically intact participants (Arzouan et al., 2007b), and persons with autism (Strandburg et al., 1993), indicating that differences in the ease of semantic access and integration are better reflected in the N400 amplitudes than in RTs. This pattern of results emphasizes the essential contribution of electrophysiological measures to clarifying the effort invested in processing different types of linguistic stimuli in both neurologically intact persons and in clinical populations such as AS.

This contribution of electrophysiological measures to behavioral measures is emphasized by the processing efficiency theory (Eysenck & Calvo, 1992), which offers a distinction between effectiveness and efficiency as ways of estimating cognitive performance. According to the theory, effectiveness refers to the quality of task performance as assessed by standard behavioral measures, such as RTs and error rates. In contrast, efficiency refers to the relationship between the effectiveness of performance and the effort invested in performance (e.g., as indicated by the N400), with efficiency decreasing as more resources are used in order to sustain performance level. In other words, the same end results as manifested by a similar pattern of RTs and error rates in the AS and control participants for metaphor comprehension, may be coupled with greater effort invested by the AS group in order to achieve this result. Thus, examining the end result, while neglecting how it was achieved, may misinterpret qualitative aspects of the cognitive process. Accordingly, the electrophysiological data serve as an index of the efficiency of semantic integration in AS, and suggest decreased processing efficiency for both conventional and novel metaphors as compared to literal and unrelated word pairs and as compared to controls.

The similar N400 latency in the AS and control groups may add to our knowledge by comparing it to overall response times. Thus, behavioral data indicates that AS participants were slower to respond than controls, although it seems that semantic integration was not delayed. This suggests that the stages following semantic integration may be slower in AS as compared to controls. According to Jung-Beeman (2005), following the stage of semantic integration is a stage of semantic selection, in which competing activated concepts are sorted out, and one concept is selected.

Studies suggest that this stage relies on inferior frontal brain mechanisms (e.g., Barch et al., 2000). The inferior frontal gyrus plays a role also in executive processes (Bookheimer, 2002), which have been found to be deficient in AS (e.g., Kleinhans, Akshoomoff, & Delis, 2005; Rinehart et al., 2006). Thus, it may be that whereas semantic integration is achieved within the same time window as in controls, the process of selection is delayed in the AS group as compared to the control participants, which leads to longer RTs in AS. Alternatively, the reduced efficiency in the semantic integration stage might also affect the later stage of selection, in addition to deficient executive processes.

One limitation of the present study relates to the differentiation between novel and conventional metaphors. Considering the dynamics of linguistic expressions and the process of familiarization and conventionalization, the most efficient way to distinguish these two types of expressions was by presenting them to a large group of adult judges that were asked to rate the familiarity of expressions. In the present study, only word pairs scoring extreme ratings were included (high familiarity ratings for conventional metaphors, as opposed to low familiarity scores for novel metaphors), and word pairs receiving median familiarity rates were excluded. Although "median familiarity" ratings were excluded, and a large sample of judges were asked to rate the expressions, it is nevertheless important to bear in mind that these ratings were subjective and based on that specific sample of adults.

These subjective ratings may account for the slight difference in the N400 grading pattern observed in the present study's control group and the pattern obtained for the healthy participants that were examined in Arzouan et al. (2007b). This difference may have resulted from the somewhat different stimulus lists used in both studies (i.e., more or less familiar conventional metaphors). Since the stimulus sets are constructed based on the judgments of adults (see Section 2 dealing with stimuli), each set might yield slightly different judgments resulting in slightly different results. Nevertheless, it is most important to note that the pattern of results in the present study's control group is generally similar to the previously reported pattern found for healthy participants in Arzouan et al. (2007b).

A second limitation of the present study relates to language abilities of the AS group and controls. Although verbal IQ is a standard and accepted measure utilized by many studies to determine language abilities and to control for them as a background factor, this measure has its limitations. Performance on verbal IQ tests does not necessarily eliminate language difficulties. The paradigm in the present study required metalinguistic skills that are not assessed in the verbal IQ test. Thus, it may be useful in future research to assess metalinguistic abilities when studying metaphor comprehension in AS.

In summary, the present research demonstrates a different pattern of semantic integration in AS persons as compared to controls when attempting to comprehend visually presented conventional metaphors, novel metaphors and literal two-word expressions that were not embedded in larger context. The known difficulty experienced by AS persons to comprehend metaphors was reflected by the significantly large N400 amplitudes to metaphors, both novel and conventional. For novel metaphors, responses of AS persons to these potentially meaningful expressions were not different than the responses to meaningless unrelated pairs, suggesting that although these expressions were judged in a pretest as meaningful, AS persons have difficulties to semantically integrate them as if they were meaningless.

These findings lend themselves to the neurobiology of both normal and pathological language processing. In the healthy brain, semantic integration becomes more taxing as the linguistic expression becomes less familiar and the semantic distance between the words forming it is greater. Nevertheless, semantic integration for both literal and metaphoric expressions occurs in the same time window. This may indicate that meaning of both metaphorical and literal word pairs is accessed, at least initially, in a similar manner, consistent with direct access models (Glucksberg, 2003).

Findings for the AS group suggest that similarly to controls, conventionality and semantic distance are critical parameters in language information processing as well, and that the initial stage of semantic integration for different expressions requires the same time as for controls.

These results do not negate the well-known notion of the deficient pragmatic abilities characteristic of AS, but rather extend our understanding of these deficits from a new perspective. Specifically, it seems that differences in linguistic information processing are related to difficulties in metaphor comprehension in AS. The findings regarding objective measures of the initial stages of comprehension are a reflection of the well-known subjective difficulties that persons with AS cope with while attempting to engage in everyday soaked-in metaphors linguistic interaction.

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Appendix A

A.1 Examples of the four types of word pairs

Novel metaphors	Conventional metaphors	Literal expressions	Unrelated word pairs
Firm words	Blossoming smile	Pearl necklace	Violin tiger
Stormy dream	Sealed lips	Cement mixer	Ban bucket
Leaden rain	Sweeping decision	Ant nest	State uncle
Silent tears	Juicy gossip	Rainy winter	Operation melon
Winding plot	Hovering danger	Emergency button	Salty rescue
Misty scarf	Firm opinion	Protected document	Contagious inclination
Dying star	False smile	Equipment warehouse	Summit pen
Dead words	Iron discipline	Personal confession	Photograph laundry
Fragile pride	Frozen relations	Military action	Childish straw
Wave dance	Blue blood	Stabbing thorn	Issue materials

Appendix A (*continued*)

Novel metaphors	Conventional metaphors	Literal expressions	Unrelated word pairs
Loneliness chill	Open mind	Birth weight	Pillow tap
Locked cry	Sweet victory	Medical diagnosis	Pocket failure

Appendix B. Supplementary material

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.bandl.2010.03.002.

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