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Right Hemisphere Dysfunction and Metaphor Comprehension in Young Adults with Asperger Syndrome

Rinat Gold · Miriam Faust

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Abstract This study examined whether the known difficulties in metaphor comprehension exhibited by persons with Asperger syndrome (AS) can be explained by a dysfunctional right hemisphere (RH). Using the divided visual field paradigm, 27 AS participants and 36 matched controls were presented with word pairs of four types (literal, conventional metaphors, novel metaphors, and unrelated word pairs), and were asked to perform a semantic judgment task. The main hypothesis was that whereas the control group participants will show RH superiority for novel metaphor processing, no RH superiority will be found in the AS group. Results indeed indicate much less RH contribution to novel metaphor comprehension in AS, and are discussed in light of linguistic models and the neurobiology of autism.

Keywords Asperger syndrome · Metaphors · Visual fields · Hemispheres · Semantic processing

Introduction

Asperger syndrome (AS) is a neuro-developmental disorder 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 (American Psychiatric Association 1994), people with AS often exhibit difficulties in comprehending specific linguistic forms, mainly nonliteral language (Gillberg and Gillberg 1989), such as metaphors, irony and indirect requests.

Previous research indicates severe disabilities in processing figurative language in people diagnosed with autism spectrum disorders (ASD) (e.g., Dennis et al. 2001; MacKay and Shaw 2004). However, this aspect of language comprehension in AS specifically has rarely been the subject of formal study. A few studies addressed the issue of irony comprehension (Martin and McDonald 2004) and context-appropriate interpretations (Jolliffe and Baron-Cohen 1999b) in AS. These studies viewed the difficulty in nonliteral language comprehension as part of the pragmatic impairment and as an index of the Theory of Mind deficit in AS (e.g., Jolliffe and Baron-Cohen 1999a, b, 2000; Losh and Capps 2003). The present study aimed to characterize the process of metaphor comprehension in AS from a purely neurolinguistic perspective. Specifically, we examined the relative contribution of the right (RH) and left (LH) cerebral hemispheres in AS to metaphor comprehension, regardless of social, linguistic or any other context.

Both cerebral hemispheres have access to word meanings. However, comprehension of semantic relations differs in the RH and LH (for reviews, see e.g., Chiarello 2003; Jung-Beeman 2005). According to Beeman (Beeman et al. 1994; Jung-Beeman 2005) whereas the LH is dominant for fine semantic coding, the RH is characterized by coarse semantic coding. The accumulated evidence from neurologically intact, split-brain, and brain-injured participants indicates that when a word is recognized by the LH only the most strongly related meanings are activated, whereas in the RH a broad set of meanings, including distant,

R. Gold · M. Faust
The Leslie and Susan Gonda (Goldschmied) Multidisciplinary Brain Research Center, Bar-Ilan University, Ramat-Gan, Israel

M. Faust (✉)
Department of Psychology, Bar-Ilan University, 52900 Ramat-Gan, Israel
e-mail: faustm@mail.biu.ac.il

unusual, nonsalient, subordinate and figurative meanings becomes available (Chiarello 2003; Faust and 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 et al. 1998; Mashal et al. 2007). As might be expected, research on RH-damaged patients shows that these persons have difficulties in the comprehension of metaphorical language that echo the findings on the role of the intact RH in metaphor processing (e.g., Bottini et al. 1994; but see also, e.g., Giora et al. 2000).

AS is frequently described as a specific neuropsychological disorder associated with RH dysfunction (Ellis et al. 1994; McKelvey et al. 1995). Several research groups have proposed that AS can be understood by analogy to RH damage, developmental disabilities involving RH dysfunction and nonverbal learning disabilities (NLD) (e.g., Klin et al. 1995; Rinehart et al. 2000; Weintraub and Mesulam 1983). Findings of brain imaging (e.g., Berthier et al. 1993) and event-related potential (ERP) studies (Jansson-Verkasalo et al. 2003; Kujala et al. 2005) as well as reports of neurological signs in AS (Berthier et al. 1990) support this assumption. Behavioral research provides additional support for possible RH dysfunction in AS. Thus, people with AS and RH-damaged patients show similar performance profiles on tasks testing cognitive skills, such as global processing (Rinehart et al. 2000), face recognition (Kracke 1994), paralinguistic processing (Baltaxe and Simmons 1992; Fine et al. 1991; Ovadia 1991) and metaphoric language comprehension (Sabbagh 1999).

The idea of a RH dysfunction in persons with AS (e.g., Ellis et al. 1994) may account for their observed difficulties in metaphor comprehension. Indeed, studies show that AS participants perform poorly on metaphor comprehension tests, similarly to people with disabilities associated with the RH, such as NLD (Gunter et al. 2002). Their findings suggest that the persons with AS were not impaired in processing either literal language or written and pictorial well-known metaphors. However, this group was severely impaired on the unusual metaphors comprehension task. The specific difficulties in understanding unusual metaphoric expressions experienced by persons with AS is consistent with recent findings that suggest enhanced RH involvement in novel metaphor comprehension and thus may reflect RH dysfunction in persons with AS. Recent behavioral (Faust and Mashal 2007; Mashal and Faust 2008), imaging (Mashal et al. 2005, 2007), ERP (Arzouan et al. 2007a, b) and TMS (Pobric et al. 2008) studies show that the two hemispheres are differentially involved in the processing of conventional versus novel metaphors and that RH involvement in metaphor comprehension is much more pronounced for novel than for conventional metaphors.

A study by Strandburg et al. (1993), examined high-functioning autistic adults using event-related potentials. For the linguistic processing task they designed an idiom recognition test that comprised of word pairs which had either an idiomatic (similar to conventional metaphors) or a literal meaning, and meaningless word pairs. Based on the results indicating poor comprehension of the autistic participants as compared to controls, the authors hypothesize that the comprehension process in the autistic participants is characterized by "less associative elaboration, less elicitation of alternative meanings, and hence less depth of processing of idioms by autistics" (p. 429). Although these findings support the notion of difficulties in metaphor comprehension in persons with AS, they do not indicate any significant laterality effects in autistic persons, and the authors do not attempt to interpret the difficulties in idiom comprehension within a neurolinguistic framework (e.g., RH dysfunction). Moreover, they designed a test which comprised of non-literal well-known word pairs (idioms), and did not test the processing of unfamiliar, novel metaphoric expressions.

The hemispheric differences in processing conventional versus novel metaphoric expressions found in the above described recent studies (Arzouan et al. 2007a, b; Mashal et al. 2007) are consistent with two recent theoretical models (Bowdle and Gentner 2005; Giora 2003) postulating that the processing of conventional and novel metaphors may depend on different cognitive and neural mechanisms. These models differentiate between metaphoric expressions which are familiar, frequent, and prototypic, i.e., conventional metaphors and new, original metaphoric expressions, such as those appearing in poetry, i.e., novel metaphors.

One of these models, the graded salience hypothesis (GSH, Giora 1997, 2003), explicitly relates the characteristics of the processed linguistic stimuli to underlying brain mechanisms. The GSH argues that degree of meaning salience of the linguistic stimuli primarily affects differences between the LH and RH in linguistic processing. In light of the GSH, evidence for RH specialization in the comprehension of metaphors and linguistic reinterpretation (e.g., Chiarello 1991) can be attributed to a greater sensitivity on the part of the RH to less salient linguistic material (Burgess and Simpson 1988). Conventional metaphor processing may be selectively associated with the LH because of LH sensitivity to salient (e.g., frequent) meanings.

Since RH involvement has been shown to be different for conventional and novel metaphors, showing much more involvement of the RH during the processing of novel as compared to conventional metaphors (Mashal et al. 2005, 2007; Faust and Mashal 2007), the present research tested the processing of both types of metaphoric expressions in persons with AS compared to matched controls. The main goal was to assess online metaphoric language comprehension in persons with AS, regardless of context and pragmatic abilities, i.e., from a purely neurolinguistic perspective. The study focused on the possible link between RH dysfunction and the observed difficulties in metaphor comprehension, especially novel metaphors.

The present research used the divided visual field (DVF) paradigm, which, as far as we know, has never been used in the study of semantic language processing in AS. This experimental paradigm, commonly used for the study of language processing by the LH and RH, is based on the anatomy of the visual system in which stimuli presented to the left half-field of vision (LVF) are directly transmitted only to the right visual cortex, and vice versa. Thus, by lateralizing visual input to one half-field, the opposite cerebral hemisphere can be selectively stimulated. This "head-start" on processing in the directly stimulated hemisphere allows a glimpse at hemisphere-specific processing. In the present study, a short (400 ms) SOA was used to track the more automatic stages of hemispheric processing (Chwilla and Kolk 1999).

Following previous studies (Mashal et al. 2005, 2007), we used two-word metaphoric expressions, such as those used in modern poetry (e.g., "misty scarf"), instead of the usual expressed identity statements (e.g., "mist is a scarf"). We took advantage of the construct state form, a form commonly used in Hebrew in which two words (usually nouns) are considered as a single unit (e.g., "blossom of hope", a two word expression in Hebrew). The meaning emerging from this construct is thus not a simple combination of the meaning of the two separate words. The construct state is widely used in poetry since it is an elegant way to connect the topic and the vehicle of a metaphor.

The main hypothesis of the present study was that the difference between AS and control participants will be manifested in the pattern of responses (RTs and error rates) given to RH and LH presented stimuli, depending on type of linguistic expression. For the control group, we predicted shorter RTs and lower error rates for novel metaphors in the LVF/RH as compared to the RVF/LH, and similar performance in the two visual fields/hemispheres for literal expressions. These predictions were based on previous research indicating enhanced RH involvement in novel metaphor processing and no significant hemispheric differences for the literal pairs (e.g., Mashal et al. 2007), and are consistent with the GSH (Giora 2003). For conventional metaphors, previous research yielded inconsistent finding, probably due to the different experimental material used. However, based on several recent studies that used similar stimuli, we predicted either shorter RTs and lower error rates for RVF/LH presentation as compared to LVF/RH (Arzouan et al. 2007a, b; Mashal et al. 2005) or no hemispheric differences (Mashal et al. 2007).

For the AS group we expected a similar pattern of performance (i.e., similar RTs and error rates) in both hemispheres for novel metaphors. This was based on the assumption that difficulties in novel metaphor comprehension are a result of RH dysfunction. This dysfunction may reduce RH superiority for novel metaphor processing, and thus results were expected to demonstrate no hemispheric difference in processing novel metaphors in this group. On the other hand, for literal expressions we expected that performance would be similar to controls. This was based on the assumption that LH-language processing in AS is intact, as indicated by their preserved comprehension of literal language, and relatively spared syntax (e.g., Ghaziuddin et al. 2000). Performance on processing conventional metaphors was expected to be poorer (i.e., longer RTs and higher error rates) in the AS group, reflecting the known difficulty to comprehend figurative language (e.g., Attwood 1998; Strandburg et al. 1993).

Methods

Participants

The distinction of AS and autism with normal intelligence (high functioning autism, HFA) is controversial, thus in many studies these two diagnoses are referred to interchangeably and are both included in the same study groups (e.g., Lombardo et al. 2007). However, in light of the growing body of epidemiological information, as well as genetic, neurobehavioural and neuropsychological evidence that distinguishes autism from Asperger's disorder (e.g., Ozonoff et al. 2006; for review see Rinehart et al. 2002), in the present study we chose to focus on AS. Thus, we recruited adults diagnosed as AS and excluded HFA on the basis of retrospective parental report regarding language developmental milestones. The study was prospectively reviewed and approved by a duly constituted ethics committee.

A total of 62 participants were included in this experiment. Twenty-seven (22 men, 5 women) comprised the AS group and 36 (21 men, 15 women) comprised the control group. The AS and control groups were marginally different in gender distribution, $\chi^2(1) = 3.81$, $p = .05$.

All participants were native Hebrew speakers who completed at least 12 years of formal education. All were right handed and yielded a laterality quotient of at least +80 on the Edinburgh Inventory (Oldfield 1971). Diagnosis of the participants with AS was carried out by an independent psychiatrist with extensive experience in this area following DSM-IV criteria (American Psychiatric Association 1994). To confirm this diagnosis, all AS participants completed the autism-spectrum quotient (AQ) (Baron-Cohen et al. 2001). All participants scored above 26, which has recently been suggested in two separate studies as a more sensitive cut off point for the AQ (Kurita et al. 2005; Woodbury-Smith et al. 2005), and fits the cut off point distinguishing the general Israeli population and Israeli persons diagnosed on the ASD (Golan et al. 2009). In addition, according to parental report, all participants had no significant language delay. Participants who suffered from co-morbid mental illness, reading disabilities, or substance abuse were excluded.

Since all participants were asked to perform a linguistic task, a factor that was controlled for is Verbal IQ. Thus, all of the research participants completed the Verbal section of the Hebrew adaptation of the Wechsler Adult Intelligence Scale—Third Edition (WAIS-III) (Wechsler 1997). They all had normal or corrected to normal vision. They all signed an informed consent form prior to the research session. The AS participants were paid for their participation, and the control group participants were University students who received course credit.

Descriptive statistics for the AS and control groups appear in Table 1. As can be seen in Table 1, the AS and control groups did not differ in age or VIQ.

Stimuli

The stimulus pool consisted of 240 pairs of words, all in Hebrew (see "Appendix" 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 and both prime and target words consisted of two to six letters. Word length was 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. Stimuli were also balanced between conditions according to word frequency, concreteness, grammatical category, and syntactic structure. Several

Table 1 Descriptive statistics for the Aspeger syndrome (AS) and control participants

	Mean (SD)		t
	AS	Controls	
Age	22.95 (3.93)	24.66 (3.83)	<1
Verbal IQ	101.52 (14.18)	100.17 (11.38)	<1

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 5-point familiarity scale ranging from 1 (highly non familiar) to 5 (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 1 (highly abstract) to 5 (highly concrete). Words with an average of less than 3 (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.

Since in Hebrew there is no extensive database for word frequency, the fourth pretest tested the 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 1 (highly non frequent) to 5 (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. This stimulus pool was divided in two, thus creating two separate pools (pool A and pool B), each containing 30 word pairs of four types (novel metaphors, conventional metaphors, literal, unrelated). In the process of dividing the stimuli, counterbalancing was kept according to all the parameters mentioned earlier.

Procedure

The experimental design included 240 experimental permutations (120 expressions × 2 visual fields). Each participant was presented with all 240-word pairs. Cell means were thus based on 30 trials per condition per participant. Stimulus presentation and responses were controlled and recorded by a PC Pentium 4.3 computer with Superlab software.

The word pairs were presented in a random order, one word at a time using white letters and black background. The first word of each pair was centrally presented followed by the target stimulus displayed 2.8° to the right or to the left of a central fixation point. Targets subtended, on average, 1.9° of horizontal visual angle (0.7° vertical) at a viewing distance of 60 cm. The participant placed his/her right index finger between two keys on the computer keyboard and waited for a focusing signal (200 ms duration), which appeared on the center of the screen and indicated the onset of a trial. Immediately following the disappearance of the focusing signal, the first word appeared for 300 ms. Next, the focusing signal reappeared for 100 ms (SOA = 400 ms) followed by the target word that was presented for 180 ms. The focusing signal remained on the screen until the end of the target stimulus presentation. To ensure full fixation (i.e., 280 ms fixation duration), every participant was instructed at the beginning of the session to focus on the central "+" and not to move his/her eyes while it was present. The participants read the words silently, and were instructed to indicate as rapidly and accurately as possible whether the target stimulus formed a meaningful expression with the preceding prime word by lifting and moving the right index finger from the middle position to the right or left keys. Assignment of the keys to "related" (meaningful expressions) and "unrelated" (meaningless expressions) responses was counterbalanced over participants. The next trial began with a fixation point 3,000 ms after the participant responded.

The session began with a practice list, consisting of 20 word pairs not used in the experimental list. The participants were informed that the meanings of metaphorical expressions contain an interpretation, which lies beyond the individual meanings of the words. For example, the expression "sweet sleep" is metaphorical since sleep is not really sweet (as opposed to "sweet cake"). We also informed them that some of the expressions are taken from poetry and that they might seem unfamiliar and meaningless (—pearl tears||) but still might have metaphorical meanings. The experimenter trained the participants in front of a computer screen, giving many examples, until the distinction between literally and metaphorically related expressions was clear. After completion of half of the experimental trials (either pool A or pool B, as described in "Stimuli" section), the participants were given a break of up to 10 min to avoid fatigue. Then, they completed the other half of the experiment (either pool A or pool B, depending on which part they did not yet complete). Half of the participants in each group began the experiment with pool A, and the other half with pool B.

Results

Mean RTs (in milliseconds) and error rates for all conditions were calculated for each participant. The overall error rate was 18.32% (SD = 22.5%). Response speed covaried positively with error rates across conditions and groups. Thus, the data show no evidence of a trade-off between RTs and error rates for each pair type for either the whole sample or separately for each group and visual field.

For the purpose of RTs and error rates analysis we calculated for each participant mean reaction times and error rates for each pair type, separately for each visual field. Tables 2 and 3 present averaged RTs and error rates and standard deviations of these scores. Because differences in gender distribution across groups were marginally significant, we first conducted multivariate analyses (MANOVAs) separately on RTs and errors rates, each analysis on all the eight experimental conditions (i.e., four Pair Types × two Visual Fields) with gender as independent variable. Both Fs < 1 indicating no gender effect on RTs and error rates.

Next, we conducted a 2 (Group: AS/Control) × 2 (Visual field: left/right) × 4 (Pair Type: novel/conventional/literal/unrelated) ANOVA for repeated measures on reaction times and error rates. Results revealed a significant effect of Group (see Fig. 1a), for both RTs and error rates,

Table 2 Mean (and SDs) reaction times for correct responses by pair type and hemisphere, for Asperger syndrome (AS) and control groups

Pair type	AS		Control	
	RVF/LH	LVF/RH	RVF/LH	LVF/RH
Novel metaphors	1497.36 (827.03)	1807.44 (1144.12)	1082.08 (325.07)	1003.45 (287.44)
Conventional metaphors	1091.48 (436.30)	1169.66 (584.17)	653.73 (141.86)	677.45 (195.31)
Literal	1040.15 (361.96)	927.05 (352.70)	641.40 (172.73)	645.55 (165.14)
Unrelated	1587.08 (659.37)	1668.37 (809.39)	1004.55 (284.66)	1007.37 (254.95)

Table 3 Mean (and SDs) error rates by pair type and hemisphere, for Asperger syndrome (AS) and control groups

Pair type	AS		Control	
	RVF/LH	LVF/RH	RVF/LH	LVF/RH
Novel metaphors	46.41 (23.42)	49.50 (21.98)	41.75 (26.27)	46.80 (26.51)
Conventional metaphors	15.67 (13.61)	11.60 (12.98)	5.01 (5.90)	4.46 (6.15)
Literal	8.51 (9.16)	7.53 (9.80)	3.62 (8.72)	5.05 (9.11)
Unrelated	19.50 (13.88)	18.39 (17.20)	8.85 (7.65)	8.15 (10.63)

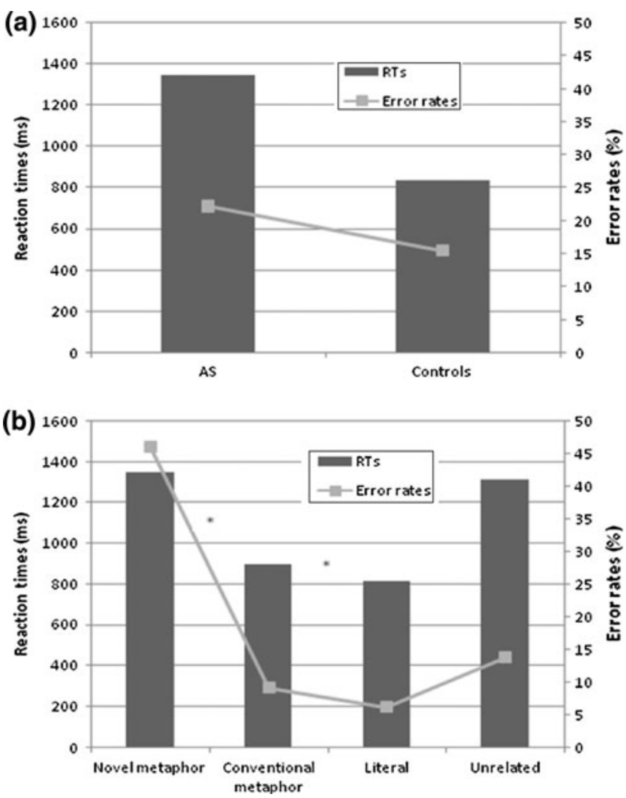

Fig. 1 Significant main effects of Group × Visual Field × Pair Type ANOVA conducted for reaction times (RTs) and error rates. **a** Group effect. **b** Pair type effect. For RTs "*" indicate $Ps < .05$. For error rates, Bonferroni's post hoc analyses indicated that error rates were higher for the novel metaphors than for both the unrelated and conventional metaphors which in turn were higher than that for the literal (p's $< .05$)

$F(1, 61) = 25.89$, $p < .001$, and $F(1, 61) = 9.34$, $p < .01$, respectively. In addition, the Pair Type effect was significant for both RTs and error rate (Fig. 1b), $F(3, 59) = 37.18$, $p < .001$, and $F(3, 59) = 112.93$, $p < .001$, respectively. The Visual Field effect was not significant.

For RTs, all two-way interactions were significant: Group × Visual Field, $F(1, 61) = 3.69$, $p < .01$; Group × Pair Type, $F(3, 59) = 4.58$, $p < .01$; Visual Field × Pair Type, $F(3,59) = 5.45$, $p < .01$). The Group × Visual Field interaction showed an opposite pattern of hemispheric difference for the two groups, such that RTs in the LVF/RH were faster in the control group ($M = 842.53$ vs. $M = 891.35$, for the LVF/RH and RVF/LH, respectively), whereas the RVF/LH was faster for the AS group ($M = 1380.58$ vs. $M = 1326.79$, for the LVF/RH and RVF/LH, respectively) (p's $< .05$ after Bonferroni's correction). The Group × Pair Type interaction showed that whereas for the control group, RTs for the conventional metaphors ($M = 664.27$) and literal expressions ($M = 643.82$) did not differ, for the AS group, RTs for the conventional metaphors ($M = 1137.68$) were much lower than for the literal ($M = 1002.59$), $p < .01$ after Bonferroni's corrections.

More importantly, these interactions were modified by a Group × Visual Field × Pair Type interaction, $F(3, 59) = 5.36$, $p < .01$ (Fig. 2). Four-two-way ANOVAs for repeated measures conducted on RTs separately for each Pair Type by Group (AS/Control) and Visual Field (left/right) revealed significant interactions for the novel metaphors, $F(1,61) = 8.01$, $p < .01$, and literal word pairs, $F(1, 61) = 10.93$, $p < .002$, but not for the conventional metaphors, $F(1, 61) = 1.31$, $p > .05$, and unrelated pairs, $F(1, 61) = 1.40$, $p > .05$.

For error rates, all two-way interactions were found to be significant. For Group × Visual Field, $F(1, 61) = 4.99$, $p < .05$; for Group × Pair-Type, $F(3, 59) = 3.11$, $p < .05$; Visual Field × Pair-Type, $F(3, 59) = 5.76$, $p < .01$. The

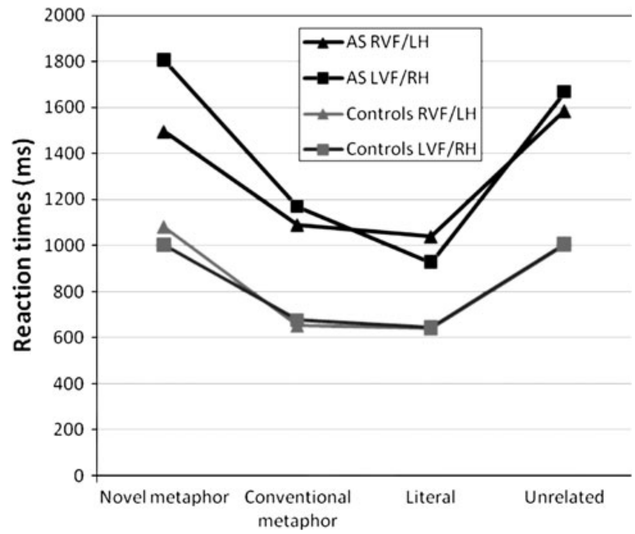

Fig. 2 Group × Visual Field × Pair Type interaction on reaction times

Group × Visual Field interaction showed that the control group made more errors in the LVF/RH ($M = 16.12$) than in the RVF/LH ($M = 14.67$) ($p < .05$ after Bonferroni's correction), whereas for the AS group there was no significant difference in error rates between the two visual fields ($p > .05$). The Group × Pair Type interaction resulted from the group difference in error rates to conventional metaphors, literal and unrelated word pairs: whereas for controls, error rates were similar for the conventional metaphors ($M = 4.81$), literal ($M = 4.18$) and unrelated word pairs ($M = 7.71$), p's $> .05$, AS after Bonferroni's correction, AS made significantly more errors for conventional metaphors ($M = 13.89$) and unrelated word pairs ($M = 20.80$) as compared to literal expressions ($M = 8.08$) p's $< .05$ after Bonferroni's correction.

Discussion

The present study examined the hypothesis that difficulties in metaphor comprehension, especially novel metaphors, in persons with AS may be attributed to a different pattern of RH involvement as compared to healthy controls. To test this hypothesis, we designed a DVF experiment that included word pairs of four different types: novel metaphors, conventional metaphors, literal word pairs and unrelated word pairs. The AS and control group participants were asked to decide whether the two words comprised a semantically meaningful expression or not. As hypothesized, for the control group, significantly shorter RTs were found for novel metaphors presented to the LVF/RH as compared to the RVF/LH. These findings are similar to previous findings indicating RH involvement in novel metaphor comprehension in healthy participants (Mashal et al. 2005, 2007; Faust and Mashal 2007), and are also consistent with the GSH (Giora 2003). In addition, as expected for the control group, no hemispheric differences in RTs were found for conventional metaphors and literal expressions.

For the AS group, we hypothesized that reduced RH involvement may be the underlying neurolinguistic mechanism for difficulties in novel metaphor comprehension. Thus, we expected no RH advantage for novel metaphor comprehension, i.e., similar RTs for novel metaphors presented to the LH and RH. For literal expressions presented to the AS group, we expected a pattern similar to that found in the control group, based on findings that indicate intact LH language processing. As can be seen in the following discussion of the RTs and error rate data, the results partly confirmed this study's hypotheses.

As expected, the RT data for the AS group show an insignificant difference between the two hemispheres for novel metaphor processing. This finding may reflect a lack of RH advantage for processing this type of linguistic expressions, and thus supports our hypothesis that the RH in AS participants may be less efficiently involved in the process of novel metaphor comprehension. This reduced RH efficiency in AS participants seems to be consistent with results reported in a study by Just et al. (2004). In their study, brain activation of a group of high-functioning autistic participants during sentence comprehension was measured using fMRI. 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 underconnectivity 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 nonetheless required 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 et al. 2007b; Mashal et al. 2007), this type of expressions is most dependent on the coordination of brain regions. In line with the under-connectivity theory, we suggest that reduced RH involvement during NM comprehension may be associated with a disruption of this necessary coordination between language areas in persons with AS. Thus, the difficulties in novel metaphor comprehension could reflect the reduced inter-hemispheric coordination, as proposed by the underconnectivity theory. This reduced inter-hemispheric coordination found using fMRI in Just's study may thus be manifested in reduced RH involvement during novel metaphor comprehension, as found in the present study.

It may seem surprising that the present study's results show no hemispheric differences for literal processing in the control group and a RH advantage in the AS participants. When looking at the data, it can be clearly seen that the RTs for the control group were relatively swift and accuracy was very high. It is possible that under these ceiling effect circumstances, especially when processing word level information, both intact hemispheres show similar performance. Another explanation for these unexpected results in the control group could be related to the experimental task used. In the present study, participants had to explicitly judge and decide about the relationship between the two words comprising the different types of expressions. Thus, it could be that the lack of LH superiority for literal expressions partially reflects the current task demands. Nevertheless, this finding is consistent with previous studies using a similar stimulus pool and the same experimental task (e.g., Faust and Mashal 2007), indicating that literal expressions were processed similarly in both hemispheres in the control group. As mentioned above, the AS group showed a different pattern of hemispheric involvement for the comprehension of literal expressions, pointing to a RH superiority.

Results also show that, overall, AS participants experienced greater difficulties in performing the linguistic task as compared to controls (as indicated by longer RT and higher error rates). This is consistent with recent evidence showing that the autistic brain is significantly slower than the normal brain (Courchesne et al. 1994; Inui and Suzuki 1998), especially when the task is relatively demanding. The task used in the present study involved very rapid word presentation, lateral presentation of the target word and time pressure in responding (the participants were directed to respond as fast as possible) and thus may have emphasized the processing difficulties in the AS participants.

The difficult task used in the present study may also account for the high error rates for novel metaphors in both groups. As described in the "Methods" section, expected error rate for all pair types was determined in a pretest, during which 40 judges were asked to decide whether the word pairs were meaningful or not. This pretest was conducted offline with no time limitation. Only novel metaphoric expressions judged as meaningful by at least 80% of the judges were included in the experiment. Thus, one might have expected similar accuracy rates for novel metaphors in the experiment. However, as opposed to the relatively relaxing pretest conditions, the experiment's conditions were far more demanding. According to this claim, the combination of demanding experimental conditions and unfamiliar linguistic stimuli can explain the high error rates for novel metaphors in both the AS and control groups. It is worth noting that a similar error rates were also found in the previous studies that used similar linguistic stimuli (e.g., Faust and Mashal 2007).

Despite the essential difference between the pretests and the experiment's conditions, and consequently the difference in percent of correct responses to novel metaphors between the pretests and the experiment, the pattern of results was completely different for the two unfamiliar word pairs presented in the experiment, novel metaphors and unrelated, in both participant groups. This different pattern emerges when comparing the percent of responses for the word pairs, either novel metaphor or unrelated, that were judged as meaningful. Thus, novel metaphors were judged as meaningful by the two groups in 50–60% of responses, whereas only 8–19% of the unrelated expressions were judged as meaningful. This pattern of results shows that the response "meaningful" was much more frequent for novel metaphors than for unrelated pairs in both the AS and control participants, indicating a clear differentiation between the two types of novel, unfamiliar linguistic expressions. In addition, as mentioned earlier, there was significantly less RH involvement in processing novel metaphors in the AS participants as compared to controls, although the pattern of hemispheric involvement was similar in both groups for the unrelated word pairs.

An additional possible explanation for the similar error rates for novel metaphors in the two groups could relate to the quality of this measure. The percent of error rates indicates merely whether the participant was right or wrong in his judgment of the novel metaphoric expressions as compared to the majority of judges (see the "Methods" section for detail). Therefore, the error rates cannot indicate in what way the participant interpreted these expressions. Thus, it may be the case that the AS participants were correct in judging a novel metaphoric expression as meaningful, but at the same time, did not understand it. This phenomenon is similar to what occurs in hyperlexia, a disorder that is frequently associated with autism. In hyperlexia, reading is accomplished without comprehension of the word's meaning (Whitehouse and Harris 1984). Indeed, when asked to interpret several novel metaphoric expressions selected from the split-visual field experiment (following its completion), it was clear that the AS participants interpret these expressions in a different way than controls. Thus, whereas the control participants gave metaphoric meanings to the novel metaphoric expressions, the AS participants tended to interpret them literally.

The present study's results are consistent with the GSH (Giora 1997, 2003). This model predicts selective RH or LH involvement in the comprehension of novel metaphors and conventional metaphors, respectively, depending on degree of familiarity of the metaphor. Indeed, the present study's findings suggest that the intact RH plays an important role in novel metaphor comprehension, and that a dysfunctional RH may fail to support this process. In addition, no differences between the two groups were found for the conventional metaphors, as understanding them does not depend, or at least are less dependent, on RH processing mechanisms, supporting the GSH predictions of a differential brain representation for novel and conventional metaphors.

These differential brain representations could stem from the asymmetries in cortical micro-circuitry of language areas. In the normal human brain, there are significant differences in mini column organization between the LH and RH (for review, see Hutsler and Galuske 2003). For example, Seldon (1982) showed that pyramidal cells in the posterior language cortex on the LH contacted fewer columnar units than in the RH. Jung-Beeman (2005) has proposed that these differences provide a neurobiological infrastructure for a different semantic coding mechanism in the two hemispheres of the intact brain, supporting different linguistic processing, such as comprehension of literal expressions (relatively more LH based) or novel metaphors (relatively more RH based).

Studies of the microstructure of autistic brains consistently report different types of alterations, such as mini-column abnormalities (for review, see Minshew and Williams 2007), and altered intra-hemispheric and corticocortical connections (Herbert et al. 2004). Thus, it has been suggested that these abnormalities may have a profound impact on language processing in autism (Chugani 2004). Similarly, it is likely that these abnormalities are the basis of the relatively low performance of the AS participants in the present study as compared to controls. Specifically, the reduced involvement of the RH in the AS participants during novel metaphor comprehension supports the possibility of existing abnormalities in this hemisphere which result in its dysfunction in AS.

RH dysfunction in AS participants can also explain previously reported difficulties in nonliteral language comprehension, such as irony (Martin and McDonald 2004), ambiguity resolution (Jolliffe and Baron-Cohen 1999b, 2000; Losh and Capps 2003), and humor (Emerich et al. 2003). Thus, the present research can contribute to our understanding of AS as a clinical condition involving specific linguistic deficits associated with RH dysfunction. In addition, this study's findings are consistent with the previously proposed notion of a dysfunctional RH in AS, and with previous research on neurologically intact persons indicating a unique role for the RH in novel metaphor processing.

Finally, we would like to address a methodological issue that could have, potentially, affected the results of the present experiment. The first is the uneven ratio of related and unrelated word pairs. The experimental design contained a bias towards related responses, given that there are three times more related stimuli novel metaphors, conventional metaphors, literal than unrelated stimuli. It might be the case that the results obtained for the novel metaphor condition were due to this bias in the experimental design. To control for this bias, in a previous experiment, Mashal and Faust (2008) who used the same stimuli and paradigm, presented 50% related and unrelated word pairs. The pattern of results was similar to the pattern obtained in the current experiment, i.e., the RH was faster than the LH in identifying novel metaphors. Thus, RH advantage for novel metaphors is replicated even when the ratio of related and unrelated word pairs is equal.

Another potential limitation of the present study is the absence of language assessment results for the AS participants. Although normal language development was reported by parents, and participants with reading disabilities were excluded, performance on verbal IQ tests does not necessarily eliminate language difficulties. Future studies examining skills that entail language processing should control for language level by conducting formal language assessments.

In summary, the present findings confirm the main hypothesis, showing RH advantage for novel metaphor processing in the intact brain, and a lack of such RH advantage for novel metaphor comprehension in persons with AS. These findings support the hypothesis that RH dysfunction may be the underlying neurolinguistic mechanism associated with difficulties in metaphor comprehension. Furthermore, the reduced RH involvement during NM comprehension may reflect a disruption of the pattern of inter-hemispheric coordination during language comprehension in persons with AS. Thus, the findings suggest that the difficulty in metaphor comprehension in AS persons may have a neurolinguistic, semantic basis, in addition to the well documented pragmatic deficits in these persons. Specifically, by testing the RH's semantic processing out of social or linguistic context, it is clearly demonstrated that the ability to understand two-word novel metaphoric expressions is deficient in AS. Moreover, the results demonstrate the well-known difficulty experienced by persons with AS to comprehend metaphors, even frequently used conventional metaphors.

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Appendix

Table 4.

Table 4 Examples of eight items from each condition

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	Corner grandmother
Dying star	False smile	Equipment warehouse	Clothing flag
Dead words	Iron discipline	Personal confession	Photograph laundry
Fragile pride	Frozen relations	Military action	Childish straw

Note that items were translated from Hebrew. The order of the two words comprising the linguistic expression may be reversed

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