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Hemispheric Processing of Idioms and Irony in Adults With and Without Pervasive Developmental Disorder

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Abstract Previous studies on individuals with pervasive developmental disorders (PDD) have pointed to difficulties in comprehension of figurative language. Using the divided visual field paradigm, the present study examined hemispheric processing of idioms and irony in 23 adults with PDD and in 24 typically developing (TD) adults. The results show that adults with PDD were relatively unimpaired in understanding figurative language. While the TD group demonstrated a right hemisphere advantage in processing the non-salient meanings of idioms as well as the ironic endings of paragraphs, the PDD group processed these stimuli bilaterally. Our findings suggest that brain lateralization is atypical in adults with PDD. Successful performance along with bilateral brain activation suggests that the PDD group uses a compensation mechanism.

Keywords Autism · Pervasive developmental disorder · Idioms · Irony · Divided visual field · Hemispheres · Lateralization

Introduction

It has been argued that individuals with autism spectrum disorders (ASD) show difficulties in comprehension of figurative language and a -tendency to interpret such language literally (Abrahamsen and Smith 2000; MacKay and Shaw 2004; Rundblad and Annaz 2010). Most studies have examined children and adolescents with ASD (MacKay and Shaw 2004; Olofson et al. 2014; Rundblad and Annaz 2010), some focusing specifically on idioms (Mashal and Kasirer 2011; Norbury 2004; Whyte et al. 2014) and irony (Colich et al. 2012; Pexman et al. 2011). Only a few studies included adults with ASD (Gold and Faust 2010; Kasirer and Mashal 2014; Martin and McDonald 2003; Williams et al. 2013). The aim of the present study is to examine hemispheric processing of idioms and irony in adults with pervasive developmental disorder (PDD) relative to typically developing (TD) adults.

Kerbel and Grunwell (1998) suggested that individuals with ASD interpret idioms literally. Indeed, Mashal and Kasirer (2011) found that adolescents with ASD (aged 12–15) had difficulties in selecting the correct meaning of idioms in a multiple choice task relative to TD adolescents (aged 12–13). However, studies on comprehension of irony in children and adolescents with ASD show inconsistent findings. For instance, Colich et al. (2012) reported that participants with ASD succeeded in judging speaker intent. In contrast, Wanget al. (2006a) found that children with ASD were less accurate than were TD children at interpreting the communicative intent behind ironic remarks, although their performance was above chance level. Pexman et al. (2011) maintained that children with ASD applied a processing strategy for irony comprehension that differed from the strategy that TD children applied, as suggested by their judgment latencies, eye gaze, and humor evaluation. According to Martin and McDonald (2004), adults with Asperger syndrome (mean age 19.64) were significantly worse than were TD participants when asked to interpret ironic jokes, and were more likely to conclude

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that a story protagonist was lying than that the protagonist was telling an ironic joke.

Gernsbacher and Pripas-Kapit (2012) proposed that individuals with ASD have no specific deficit in figurative language but rather a broader comprehension deficit. They pointed out that previous studies had matched groups inappropriately (using receptive vocabulary) and had thus underestimated the figurative language abilities of individuals with ASD. Indeed, children with or without ASD who demonstrated difficulties in language comprehension were also more impaired in their understanding of idioms than were children without general comprehension difficulties (Norbury 2004). Giora et al. (2012) noted that the ability to understand ambiguous terms is determined by general comprehension skills, not by autism. Recently, Whyte et al. (2014) compared idiom comprehension in children with ASD (ages 5–12) and in typically developing children by using two TD groups. One TD group matched the ASD group in chronological age and nonverbal IQ and the other TD group matched the ASD group in syntactic knowledge. Results indicated that children with ASD performed worse on idiom comprehension than did the age-matched TD group. In contrast, idiom comprehension in the ASD group did not differ from comprehension in the TD group that was matched in syntactic knowledge. Thus, differences in comprehension of figurative language can arise from general language difficulties or from difficulties in figurative language per se, and only appropriate group matching can indicate the actual origin of the deficit.

The current study focuses on hemispheric specialization in comprehension of figurative language, and in particular on idiom and irony comprehension. One of the well established findings in studies of brain lateralization is that the left hemisphere (LH) is the main processor for language for most right-handed individuals. However, there is evidence that several linguistic abilities are mediated in the right hemisphere (RH), including comprehension of discourse, humor, sarcasm, novel metaphors, irony, indirect requests, and emotional prosody (Eviatar and Just 2006; Mashal et al. 2007; Mitchell and Crow 2005). The fine versus coarse semantic coding theory (Beeman 1998) provides a theoretical framework for explaining the differential hemispheric involvement in language processing. According to this theory, the LH engages in fine semantic coding, in which a single interpretation of a word as well as several of its close associates are activated, and processing involves the dominant semantic features. In contrast, the RH engages in coarse semantic coding, in which distinct semantic relations of words or multiple interpretations of ambiguous words are activated (Jung-Beeman and Bowden 2000; Jung-Beeman et al. 2000). Since the figurative meaning of an unfamiliar utterance is usually more semantically distant than its literal interpretation, this model predicts that the RH will be more apt for interpretation of figurative speech in general and for the interpretation of irony in particular.

The fine versus coarse semantic coding theory is consistent with the graded salience hypothesis (Giora 1999, 2002, 2003), according to which salient meanings are given high priority, regardless of either literality or contextual fit. Salience is a matter of degree and it is determined primarily by frequency of exposure and familiarity with the meaning in question (Giora 1999, 2002; Giora and Fein 1999; Giora et al. 2007). Thus, the idiomatic meaning of familiar idioms is salient because it is already coded in the mental lexicon rather than being derived from the meaning of the individual words that make it up. The literal meaning of the same idiom is not salient because it is based on the interrelations between the meanings of the individual words (Giora et al. 2004). The graded salience hypothesis predicts LH involvement in processing of salient meanings and RH involvement in processing of non-salient meanings. Hence, these two models assume that the LH processes meanings of literal utterances and familiar idioms, while non-salient literal meanings of idioms or non-salient ironic interpretations of unfamiliar utterances engage the RH.

Consistent with these theoretical frameworks, there is behavioral and neuroimaging evidence of RH specialization in processing non-salient interpretations of figurative language (Kasparian 2013; Schmidt et al. 2007), including novel metaphors (Faust and Mashal 2007; Mashal and Faust 2009; Mashal et al. 2005, 2007), as well as idioms (Mashal et al. 2008) and irony (Eviatar and Just 2006; Shibata et al. 2010). Using the divided visual field paradigm, Mashal et al. (2008) presented TD adults with target words in either the right visual field (RVF) or the left visual field (LVF). Participants were asked to perform a lexical decision on literal and idiomatic meanings of idioms. Responses to literal targets were faster when presented to the LVF/RH than when presented to the RVF/LH. No hemispheric differences were found in response to idiomatic meanings. These results indicated that the RH was more sensitive than was the LH to the non-salient literal meanings of idioms.

Evidence from functional neuroimaging suggests that individuals with ASD demonstrate atypical rightward language dominance (e.g., Cardinale et al. 2013; Gage et al. 2009). For example, Kleinhans et al. (2008) found that adolescents and adults with ASD showed greater activity in right frontal and right temporal lobes in the letter fluency task relative to TD controls. Using PET in a task of auditory perception, Muller et al. (1999) found reversed hemispheric dominance for language in adults with ASD. Eyler et al. (2012) found abnormal right lateralization of language already in toddlers with ASD, suggesting that this pattern may reflect a fundamental early neural developmental pathology. Other authors argued that rightward asymmetry may be a general feature of brain organization in ASD, affecting brain systems that do not specialize in language alone (Cardinale et al. 2013; Gage et al. 2009). Tesink et al. (2009) reported that the increased activation in the RH occurred during the processing of sentences at odds with the speaker identity. It has been suggested that this increased RH activation reflects a compensation strategy due to higher task demand to resolve social cues or due to less efficient processing (Prat and Just 2008; Prat et al. 2011). Thus, according to Prat et al. (2012), RH involvement depends on task demands as well as on the individual's language abilities.

No clear rightward asymmetry has been reported in individuals with ASD in studies of novel metaphors (Gold and Faust 2010) or irony (Colich et al. 2012). Gold and Faust (2010) examined hemispheric processing of novel metaphoric expressions in adults with Asperger syndrome. While TD participants showed a RH advantage in processing non-salient metaphoric meanings, no RH advantage was observed in the Asperger group (see also Gold and Faust 2012). Similarly, Colich et al. (2012) found that children and adolescents with ASD showed bilateral activation during the processing of ironic versus sincere remarks (Colich et al. 2012). These studies do not support the assumption that there is atypical rightward language dominance in ASD, and instead point to a RH dysfunction in ASD (Ellis et al. 1994; McKelvey et al. 1995).

The current study examines the processing of two subtypes of figurative language, idioms and irony. The first task investigates hemispheric differences in accessing literal versus idiomatic meanings of idioms. The second task tests comprehension of irony. Based on previous studies (Gold and Faust 2010; Mashal et al. 2008), and in accordance with Beeman's (1998) and Giora's (2002) accounts, we hypothesize that TD adults will respond to non-salient meanings of idioms, as well as to irony, more accurately and more quickly in the RH than in the LH. In contrast, the ASD group is expected to show bilateral pattern of brain activation.

Method

Participants

Forty-seven native Hebrew speakers participated in the study, 23 adults with PDD (six women) and 24 TD adults (ten women). There was no statistical difference in gender distribution across groups, χ^2 (1) = 1.27, $p = .26$. All participants were right-handed, had intact or corrected vision, and reported no neurological problems, and all completed at least 12 years of school.

All participants with PDD were previously diagnosed by an independent psychiatrist following DSM-IV-TR criteria (American Psychiatric Association 2000). Clinical diagnoses included PDD-NOS ($n = 6$, 26 %) as well as Asperger syndrome ($n = 17$, 74 %). To confirm this diagnosis, participants with PDD were also assessed with the autism-spectrum quotient questionnaire (Baron-Cohen et al. 2001), scoring above 26 ($M = 30.81$, $SD = 5.17$). This score is clinically acceptable as a cutoff for ASD (Golan et al. 2009; Gold et al. 2010; Kurita et al. 2005; Woodbury-Smith et al. 2005). Prior to their participation in the study, all participants signed a consent form. Individuals with PDD were paid for their participation. Participant recruitment adhered to institutional research guidelines.

All participants were screened with the test of nonverbal intelligence (TONI-3, Brown et al. 1997), and the vocabulary subtest from the Wechsler Adult Intelligence Scale WAIS-III (Wechsler 2001). In this task participants hear words and are asked to provide their definitions. As can be seen in Table 1, groups were matched in age, nonverbal IQ, and vocabulary scores.

Participants completed two experimental tasks that required processing of idiomatic expressions (Task 1) and ironic texts (Task 2).

Task 1: Hemispheric Processing of Idiomatic Expressions

The aim of this task was to examine whether adults with PDD differ from TD adults in hemispheric processing of literal and idiomatic meanings of idioms.

Stimuli

The stimuli pool consisted of 60 Hebrew idioms that had both a plausible literal meaning and an idiomatic meaning. Idioms consisted of 2–5 words each. Sixty target words were also selected, half were related to the literal meaning of the idiom and half were related to its idiomatic meaning. For instance, for the idiom *got cold feet*, the literal target word was *temperature* and the idiomatic target word was *afraid;* for the idiom *cut the wings,* the literal target word was *feather* and the idiomatic target word was *disabling*.

Table 1 Descriptive statistics for the PDD and control participants

	ASD *M (SD)*	Control *M (SD)*	*t*	*p*
Age	26.22 (6.03)	27.04 (4.08)	−0.55	.58
Nonverbal IQ	38.96 (3.13)	39.17 (3.87)	−0.20	.84
Vocabulary	44.83 (7.54)	48.39 (4/36)	−1.96	.058

Fifteen TD judges (age 18–35), who did not participate in the experimental tasks, were presented with an initial list of 100 idioms and two target words per idiom. Each idiom was presented with an idiomatic and a literal target word. Participants were asked to determine whether each idiomatic target word was idiomatically related or unrelated to the idiom and whether each literal target word was literally related or unrelated to the idiom. The idioms were taken from a previous study (Mashal et al. 2008) and were based on a Hebrew idiom dictionary (Cohen 1990). Every target word that was judged by least 85 % of the judges as related (either idiomatically or literally) to the idiom was included in the second pretest. Next, 20 other judges (age 18–35) were presented with the list of 60 idioms and target words (30 literal target words and 30 idiomatic target words), and were asked to rate each target word on a five-point scale ranging from 1 (highly unrelated) to five (highly related). We selected target words that received an average rating of 4 or above. Literal target words received a mean rating of 4.13 and idiomatic target words received a rating of 4.30. Finally, word frequency (based on Linzen 2009) was matched across the two experimental conditions.

In addition, a set of 60 matching idioms was constructed to serve as fillers. Sixty non-word stimuli were created by replacing two letters in the target words selected for the experimental conditions. There was no difference in number of letters between literal and idiomatic target words and non-word stimuli.

Task 2: Hemispheric Processing of Ironic Expressions

The aim of this task is to examine whether adults with PDD differ from TD adults in hemispheric processing of ironic expressions.

Stimuli

We constructed 84 short passages in which the final word was missing, and selected 56 target words that provided either a literal ending ($n = 28$) or an ironic ending ($n = 28$) to the passage. We also selected 28 words that provided meaningless endings to the passages. Words of all three types were matched for length and familiarity. For example, the passage was: "Exhausted after a long day at work, David planned to go to bed early. Just as he was ready for bed, he heard a knock on the front door. David opened the door and saw that some friends came by for a visit. David said: 'The timing is…'." The literal target ending was "bad", the ironic target ending was "perfect", and the meaningless target ending was "hungry". Another passage was: "The final exam lasted for about 3 h and included a lot of material, not all of it has been studied before. At the end of the test the students told the teacher: 'The test was…'." The literal target ending was "difficult", the ironic target ending was "simple", and the meaningless target ending was "barefoot".

To select the target words we asked 20 judges (age 18–35), who did not participate in the experimental tasks, to write down a single word that could end each of the 84 passages either literally or ironically. Words that were used by at least 80 % of the judges were chosen for the study. Meaningless target words were created by the authors. Next, passages were presented along with the selected target words to 20 additional judges (age 18–35), who were asked to indicate whether the ending was literal, ironic, or meaningless. The mean percentage of judges who rated the literal endings as literal was 97 % ($SD = .06$), the mean percentage of judges who rated the ironic endings as ironic was 96 % ($SD = .81$), and the mean percentage of judges who rated meaningless endings as meaningless was 92 % ($SD = .11$).

Paragraph length ranged between 11 and 30 words. The mean number of words of each paragraph was 19.32 ($SD = 4.64$) for literal passages, 19.37 ($SD = 4.37$) for ironic passages, and 16.2 ($SD = 3.89$) for meaningless passages. To determine presentation time for each paragraph we conducted a pilot study with 25 undergraduate students (age 18–35) who did not participate in the experimental task.

Finally, word frequency (based on Linzen 2009) was matched across the three experimental conditions.

Procedure

On both tasks participants sat in front of a computer screen, at a viewing distance of 60 cm. A fixation point appeared at the center of the screen for 2000 ms, and once it disappeared the idiom in task 1 or the passage in task 2 were presented at the center of the screen. In task 1 the idioms were presented for 2000 ms, in task 2 the passage appeared at the center of the screen for 2500–7000 ms, depending on the number of words in the passage (presentation time was determined in the pilot study). Next, a fixation point was presented for 300 ms, after which the target stimulus appeared and remained on the screen for 180 ms. Target stimuli were presented at 2.8° to the right or to the left of the fixation point, so that they were presented either to the RVF or to LVF. The fixation point remained on the screen until the target stimulus disappeared. In the idioms task (task 1) participants placed two right-hand fingers between the key that represented a word answer and the key that represented a non-word answer. Participants were instructed to read the idiom silently, focus on the fixation point without moving their eyes, and then indicate as accurately and as quickly as possible whether the target stimulus was a word or a non-word by pressing the designated key. In the irony task (task 2) participants placed two right-hand fingers between the key that denoted that the passage had meaning and the key that denoted that the passage was meaningless. Participants were instructed to read the passage silently, focus on the fixation point without moving their eyes, and then indicate as accurately and as quickly as possible whether the passage that ended with the target word was meaningful or not by pressing the designated key.

Each session began with a practice list, consisting of nine trials that were not used in the experiment. Idioms and passages were presented in a random order, with a short break offered after completion of half of the experimental trials.

Results

Results of Task 1: Hemispheric Processing of Idiomatic Expressions

Two 2X2X2 repeated-measures analyses of variance (ANOVA) were conducted, with hemisphere (left, right) and type of target word (literal, idiomatic) as the within-subject factors, and group (PDD, TD) as the between-subject factor. One analysis was conducted for accuracy and another was conducted for reaction times.

Accuracy rates are presented in Table 2. A significant main effect of hemisphere was found, $F(1, 45) = 9.43$, $p < .01$, $\eta^2 = .17$, indicating that responses to stimuli processed in the RH ($M = 89.98$ %, $SD = 11.10$) were significantly more accurate than were responses to stimuli processed in the LH ($M = 85.10$ %, $SD = 10.93$). No significant difference was found between the two types of target words, $F(1, 45) = 1.70$, $p = .20$, $\eta^2 = .04$. A significant main effect of group was also found, $F(1, 45) = 7.85$, $p < .01$, $\eta^2 = .15$, indicating that the PDD group performed significantly less accurately ($M = 83.82$ %, $SD = 11.56$) than did the TD group ($M = 91.10$ %, $SD = 5.23$). No significant two-way interactions were found: hemisphere X group, $F(1, 45) = 2.93$, $p = .09$, $\eta^2 = .06$, target word X group, $F(1,45) = .17$, $p = .69$, $\eta^2 = .00$, and hemisphere x target word, $F(1, 45) = 3.92$, $p = .054$, $\eta^2 = .08$.

The three-way interaction of hemisphere X target word X group was significant, $F(1, 45) = 4.41$, $p < .05$, $\eta^2 = .09$ (see Fig. 1). Bonferroni post hoc analyses indicated that there were no hemispheric differences in processing either idiomatic ($p = .38$) or literal ($p = .52$) target word within the PDD group. In contrast, in the TD group there were hemispheric differences for literal target words ($p < .001$), indicating that the RH was significantly more accurate than was the LH. No hemispheric differences were found for idiomatic target words ($p = .32$) in the TD group.

An analysis of reaction times revealed a significant main effect of hemisphere, $F(1, 45) = 4.86$, $p < .05$, $\eta^2 = .10$, indicating that responses to stimuli processed by the RH ($M = 755.87$, $SD = 135.13$) were significantly faster than were responses to stimuli processed by the LH ($M = 776.78$, $SD = 134.50$). Furthermore, a significant main effect of target word was found, $F(1, 45) = 4.86$, $p < .05$, $\eta^2 = .10$, indicating that responses to literal target words ($M = 757.53$, $SD = 137.92$) were significantly faster than were responses to idiomatic target words ($M = 775.11$, $SD = 129.38$). No significant group differences were found, $F(1, 45) = 0.49$, $p = .49$, $\eta^2 = .01$. All interactions were non-significant: hemisphere X target word, $F(1, 45) = 1.17$, $p = .28$, $\eta^2 = .02$, hemisphere X group, $F(1, 45) = .18$, $p = .67$, $\eta^2 = .00$, target word X group, $F(1, 45) = .62$, $p = .44$, $\eta^2 = .01$ and hemisphere X target word X group, $F(1, 45) = .25$, $p = .62$, $\eta^2 = .01$. Table 2 presents reaction time data in all specific cells.

In summary, the TD group was more accurate overall than was the PDD group. As expected, TD participants processed the non-salient literal meaning of the idioms more accurately in the RH than in the LH. This hemispheric difference was not found in the PDD group.

Results of Task 2: Hemispheric Processing of Ironic Expressions

Two 2X2X2 repeated-measures ANOVAs were conducted, with hemisphere (left, right) and type of target word (literal, ironic) as the within-subject factors, and group (PDD, TD) as the between-subject factor. One analysis was conducted for accuracy and another was conducted for reaction times.

Table 2 Mean accuracy rate (% correct) and reaction times (in milliseconds) in Task 1, by hemisphere, target word, and group

	PDD				TD			
	Accuracy		RTs		Accuracy		RTs	
	LH	RH	LH	RH	LH	RH	LH	RH
Literal	82 (16.70)	84 (17.60)	782 (139.30)	753 (147.00)	83 (9.60)	96 (5.10)	761 (159.00)	733 (133.40)
Idiomatic	83 (14.20)	86 (16. 20)	802 (139.20)	781 (163.30)	91 (10.50)	94 (590)	762. (120.40)	756 (115.60)

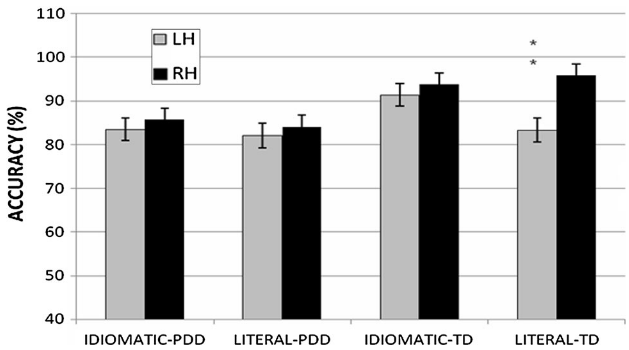

Fig. 1 Percent of correct responses (and SE) in Task 1 within each hemisphere, by group and word type

Accuracy rates are presented in Table 3. A significant main effect of hemisphere was found, $F(1, 45) = 8.01$, $p < .01$, $\eta^2 = .151$, indicating that responses to target words presented to the RH ($M = 81.84$ %, $SD = 13.69$) were more accurate than were responses to target words presented to the LH ($M = 77.92$ %, $SD = 12.88$). The main effect of target word was also significant, $F(1, 45) = 38.35$, $p < .001$, $\eta^2 = .460$, indicating that responses to literal target words ($M = 89.06$ %, $SD = 7.65$) were more accurate than were responses to ironic target words ($M = 70.70$ %, $SD = 21.67$). Furthermore, a significant main effect of group was found, $F(1, 45) = 14.80$, $p < .001$, $\eta^2 = .247$, as the PDD group was less accurate ($M = 73.63$ %, $SD = 12.91$) than was the TD group ($M = 85.86$ %, $SD = 8.54$). No interaction was significant: hemisphere X target word, $F(1, 45) = 3.78$, $p = .06$, $\eta^2 = .08$, hemisphere X group, $F(1, 45) = 1.14$, $p = .29$, $\eta^2 = .02$, target word X group, $F(1, 45) = 3.25$, $p = .08$, $\eta^2 = .07$, hemisphere X target word X group, $F(1, 45) = 3.17$, $p = .08$, $\eta^2 = .07$. Although the PDD group comprehended ironic passages less accurately than did the TD group, further inspection of the accuracy rate using a χ^2 test indicated that their processing of ironic endings was above chance in each hemisphere ($p < .05$).

An analysis of reaction times revealed a significant main effect of hemisphere, $F(1, 45) = 8.05$, $p < .01$, $\eta^2 = .15$, indicating that responses to stimuli processed by the RH ($M = 876.74$, $SD = 201.63$) were significantly faster than were responses to stimuli processed by the LH ($M = 919.03$, $SD = 194.30$). The main effect of target word was not significant, $F(1, 45) = 2.62, p = .11, \eta^2 = .05$, and the same was true for the main effect of group, $F(1, 45) = 3.97$, $p = .052$, $\eta^2 = .08$. The two-way interaction of hemisphere X target word was significant, $F(1, 45) = 8.64$, $p < .01$, $\eta^2 = .16$, indicating that the RH was faster when processing ironic target words ($M = 876.74$, $SD = 201.63$) than was the LH ($M = 919.03$, $SD = 194.30$). Neither the two-way interaction of hemisphere X group was significant, $F(1, 45) = .62$, $p = .43$, $\eta^2 = .01$, nor the two-way interaction of target word X group, $F(1, 45) = 1.44$, $p = .24$, $\eta^2 = .03$.

The three-way interaction of hemisphere X target word X group was significant, $F(1, 45) = 4.45$, $p < .05$, $\eta^2 = .09$ (see Fig. 2). Bonferroni post hoc analyses revealed no hemispheric differences for either ironic ($p = .06$) or literal ($p = .10$) target words in the PDD group. In contrast, within the TD group, there were hemispheric differences in processing ironic target words, indicating that the RH was significantly faster than was the LH ($p < .01$). No hemispheric differences were found for literal target words ($p = .06$) in the TD group. Table 3 presents reaction time data in all specific cells.

In summary, Task 2 shows that the TD group was more accurate overall than was the PDD group. As expected, the TD group processed ironic endings more quickly in the RH than in the LH. In contrast, there was no significant difference between the two hemispheres for either literal or ironic endings in the PDD group.

Analysis of Vocabulary-Matched Subgroups

Although not statistically different, there was a trend for greater vocabulary abilities in the TD group than in the PDD group. We thus adjusted group matching and reanalyzed the results in both tasks for these subgroups.

Data analysis was performed on a subgroup of 18 adults with PDD (five women) and a subgroup of 22 TD adults (nine women). There was no statistical difference in gender distribution across groups, χ^2 (1) = .75, $p = .39$. As can be seen in Table 4, groups were perfectly matched on age, non-verbal IQ, and vocabulary scores.

Table 3 Mean accuracy rate (% correct) and reaction times (in milliseconds) in Task 2, by hemisphere, target word, and group

	PDD				TD			
	Accuracy		RTs		Accuracy		RTs	
	LH	RH	LH	RH	LH	RH	LH	RH
Literal	84 (11.50)	87 (9.90)	951 (219.90)	910 (221.00)	93 (5.80)	92 (6.30)	819 (139.30)	865 (138.80)
Ironic	60 (21.90)	63 (26.95)	1009 (235.60)	942 (286.00)	74 (20.60)	85 (16.10)	902 (212.70)	795 (162.20)

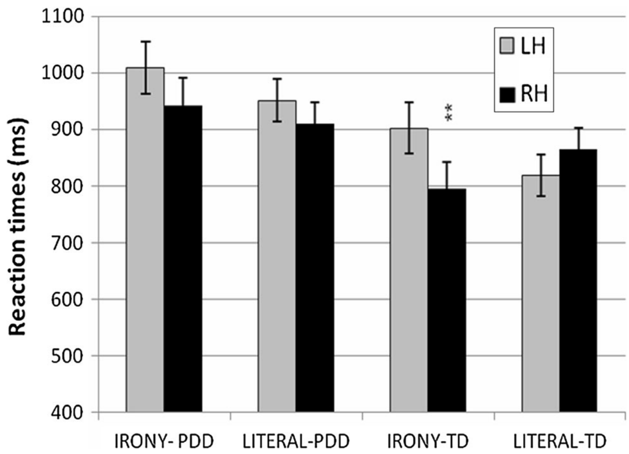

Fig. 2 Reaction times in Task 2 (and SE) within each hemisphere, by group and word type

Reanalysis of Results on Idiom Task

Two 2X2X2 repeated-measures ANOVAs were performed, one for accuracy rates and one for reaction times, with hemisphere (left, right) and type of target word (literal, idiomatic) as the within-subject factors, and group (PDD, TD) as the between-subject factor.

Accuracy rates are presented in Table 5. The main effect of hemisphere was significant, $F(1, 38) = 9.81$, $p < .01$, $\eta^2 = .20$, indicating that responses to stimuli processed in the RH were significantly more accurate than were responses to stimuli processed in the LH. The main effect of target word was significant, $F(1, 38) = 7.21$, $p < .05$, $\eta^2 = .16$, indicating that responses to idiomatic target words were significantly more accurate than responses to literal target words. The main effect of group was not significant. TD participants ($M = 90.45$ %, $SD = 4.92$) are no longer more accurate than the PDD group ($M = 85.71$ %, $SD = 10.66$), $F(1, 38) = 3.45$, $p = .07$, $\eta^2 = .08$.

All two-way interactions remained non-significant: hemisphere x target word, $F(1, 38) = 2.12$, $p = .15$, $\eta^2 = .05$, hemisphere X group, $F(1, 38) = 3.32$, $p = .08$, $\eta^2 = .08$, and target word X group, $F(1, 38) = 0.35$, $p = .56$, $\eta^2 = .01$.

The three-way interaction of hemisphere X target word X group was significant, $F(1, 38) = 5.11$, $p < .05$, $\eta^2 = .12$ (see Fig. 3). Similar to the results of the entire groups, Bonferroni post hoc analyses indicated that there were no hemispheric differences in processing either idiomatic ($p = .23$) or literal ($p = .77$) target words within the PDD group ($p = .21$). In contrast, in the TD group there were hemispheric differences for literal target words ($p < .001$), indicating that the RH was significantly more accurate than was the LH. No hemispheric differences were found for idiomatic target word ($p = .21$) in the TD group.

Analyses of reaction time revealed no significant main effects, hemisphere: $F(1, 38) = 3.37$, $p = .07$, $\eta^2 = .08$; target word: $F(1, 38) = 2.11$, $p = .15$, $\eta^2 = .05$; group: $F(1, 38) = 0.25$, $p = .62$, $\eta^2 = .01$. Similarly, no interaction was significant: hemisphere X target word, $F(1, 38) = 2.56$, $p = .12$, $\eta^2 = .06$, hemisphere X group, $F(1, 38) = .01$, $p = .91$, $\eta^2 = .00$, target word X group, $F(1, 38) = .21$, $p = .65$, $\eta^2 = .00$, and hemisphere X target

Table 4 Descriptive statistics of PDD adult's subgroup and TD adult's subgroup

	PDD *M* (*SD*)	Control *M* (*SD*)	*t*	*p*
Age	26.34 (6.03)	27.27 (4.19)	−0.57	.57
Nonverbal IQ	39.00 (3.24)	38.91 (3.95)	0.08	.94
Vocabulary	47.50 (6.16)	47.67 (3.81)	−0.10	.92

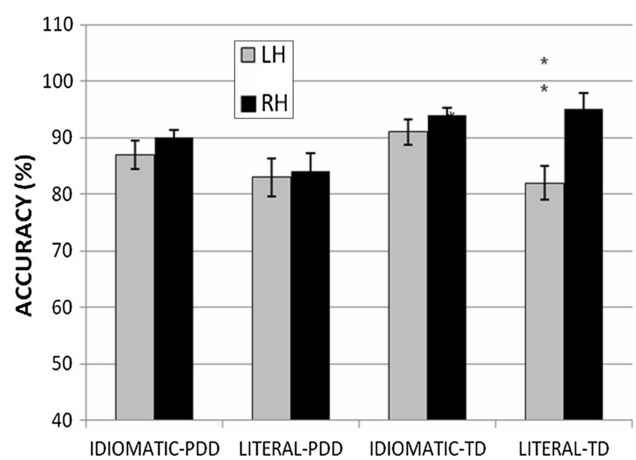

Fig. 3 Percent of correct responses (and SE) in Task 1 within each hemisphere by word type and vocabulary-matched subgroups

Table 5 Mean accuracy rate (% correct) and reaction times (in milliseconds) in Task 1, by hemisphere, target word, and subgroup

	PDD				TD			
	Accuracy		RTs		Accuracy		RTs	
	LH	RH	LH	RH	LH	RH	LH	RH
Literal	83 (19)	84 (20)	785 (127)	755 (136)	82 (9)	95 (5)	771 (161)	736 (135)
Idiomatic	87 (11)	90 (6)	790 (127)	783 (151)	91 (11)	94 (6)	767 (119)	759 (114)

word X group, $F(1, 38) = .03$, $p = .86$, $\eta^2 = .00$. Table 5 presents reaction time data in all specific cells.

The correlations between accuracy and reaction times were all negative (*rs* ranging from −.01 to −.33, $p = .96$, $p < .05$ respectively), indicating no speed-accuracy tradeoff.

Reanalysis of Results on Irony Task

Two 2X2X2 repeated-measures ANOVAs were conducted, with hemisphere (left, right) and type of target word (literal, ironic) as the within-subject factors, and group (PDD, TD) as the between-subject factor. One analysis was conducted for accuracy and another was conducted for reaction times.

Accuracy rates are presented in Table 6. All main effects were significant, hemisphere: $F(1, 38) = 14.91$, $p < .001$, $\eta^2 = .28$, target word: $F(1, 38) = 29.06$, $p < .001$, $\eta^2 = .43$, and group: $F(1, 38) = 8.37$, $p < .01$, $\eta^2 = .18$. No interaction was significant: hemisphere X target word, $F(1, 38) = 3.04$, $p = .09$, $\eta^2 = .07$, hemisphere X group, $F(1, 38) = .13$, $p = .72$, $\eta^2 = .00$, target word X group, $F(1, 38) = 1.89$, $p = .18$, $\eta^2 = .05$, hemisphere X target word X group, $F(1, 38) = 3.46$, $p = .07$, $\eta^2 = .08$.

An analysis of reaction times revealed a significant main effect of hemisphere, $F(1, 38) = 5.69$, $p < .05$, $\eta^2 = .13$. The main effect of target word was not significant, $F(1, 38) = 2.65$, $p = .11$, $\eta^2 = .06$, and so was the main effect of group, $F(1, 38) = 2.04$, $p = .016$, $\eta^2 = .05$. The two-way interaction of hemisphere X target word was significant, $F(1, 38) = 4.62$, $p < .05$, $\eta^2 = .11$. Neither the two-way interaction of hemisphere X group was significant, $F(1, 38) = .58$, $p = .45$, $\eta^2 = .01$, nor was the two-way interaction of target word X group, $F(1, 38) = .35$, $p = .55$, $\eta^2 = .01$.

The three-way interaction of hemisphere X target word X group was significant, $F(1, 38) = 5.48$, $p < .05$, $\eta^2 = .13$ (see Fig. 4). Bonferroni post hoc analyses revealed no hemispheric differences for either ironic ($p = .23$) or literal ($p = .10$) target words in the PDD group. In contrast, within the TD group, there were hemispheric differences in processing ironic target words, with faster responses in the RH than in the LH ($p < .01$). No hemispheric differences were found for literal target words

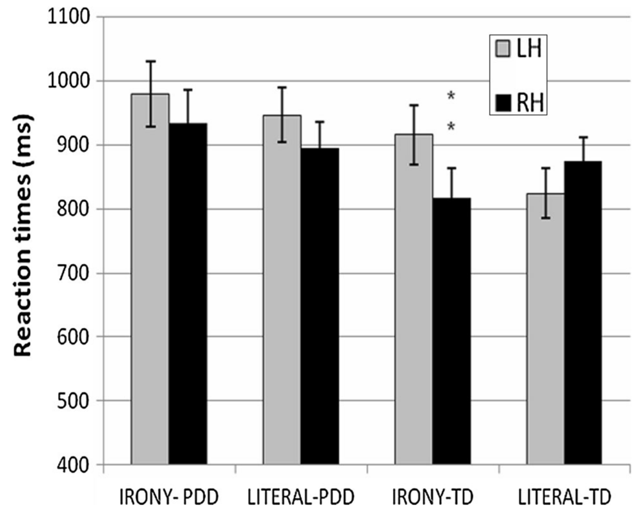

Fig. 4 Reaction times (and SE) in Task 2 within each hemisphere by word type and vocabulary-matched subgroups

($p = .07$) in the TD group. Table 6 presents reaction time data in all specific cells.

In addition, no speed-accuracy tradeoff was observed, as the correlations between accuracy and reaction times were all negative (*rs* ranging from −.15 ($p = .35$) to −.54 ($p < .001$)).

The Relationship Between Vocabulary Scores and Hemispheric Lateralization

Next we wanted to examine whether higher vocabulary abilities are related to increased lateralization in individuals with PDD. We calculated an index of hemispheric lateralization by subtracting RH performance (separately for accuracy and reaction times) from LH performance for each type of target word. When looking at accuracy, higher scores on this index indicate left lateralization (greater accuracy in the LH). When looking at reaction times, higher index scores indicate right hemisphere lateralization (slower responses in the LH). We then calculated Pearson correlations between vocabulary scores and this hemispheric lateralization index (see Table 7).

Within the PDD group vocabulary was not associated with hemispheric lateralization in the idiomatic task. In

Table 6 Mean accuracy rate (% correct) and reaction times (in milliseconds) in task 2, by hemisphere, target word, and subgroup

	PDD				TD			
	Accuracy		RTs		Accuracy		RTs	
	LH	RH	LH	RH	LH	RH	LH	RH
Literal	84 (13)	89 (7)	946 (224)	894 (211)	93 (6)	92 (6)	824 (134)	874 (133)
Ironic	62 (23)	66 (28)	979 (232)	934 (279)	73 (21)	85 (16)	915 (208)	816 (152)

Table 7 Person correlations between hemispheric specialization and vocabulary

	Task 1 idioms				Task 2 irony			
	RT idioms	RT literal	Accuracy idioms	Accuracy literal	RT irony	RT literal	Accuracy irony	Accuracy literal
PDD vocabulary	−.03	.02	.21	.34	.12	−.49*	−.34	.29
TD Vocabulary	−.02	−.44*	.07	−.02	−.04	.19	.08	.00

* $p < .05$

contrast, a significant negative correlation was found in the TD group between vocabulary scores and reaction times to literal target words, r(19) = −.44, $p < .05$. This finding suggests that higher vocabulary is related to faster processing of literally related words in the LH. In addition, a significant negative correlation was found in the PDD group between vocabulary scores and reaction times to literal passages, $r(16) = -.49$, $p < .05$. Thus, in the PDD group better vocabulary knowledge was related to processing of literal passages in the LH.

Discussion

Two main findings emerged from the present study. First, adults with PDD were less accurate than were TD adults on tasks that examined comprehension of figurative language. Nevertheless, their performance indicated no major impairment. Second, the PDD group demonstrated bilateral pattern of hemispheric processing for non-salient stimuli (i.e., literal meanings of idioms as well as ironic paragraph endings), whereas TD participants demonstrated the typical RH advantage. This bilateral pattern of hemispheric processing was seen even in individuals with PDD who were vocabulary-matched to controls.

In both tasks, participants with PDD performed less accurately than did TD participants but well above chance level. In particular, individuals with PDD demonstrated a relatively high accuracy rate in idiom comprehension (83–86 %) and above chance accuracy rate in irony comprehension (60–63 %). Although previous studies reported difficulties in interpretation of figurative language in ASD (Abrahamsen and Smith 2000; MacKay and Shaw 2004; Rundblad and Annaz 2010), other studies concluded that individuals with ASD possess the ability to comprehend such language (e.g., Giora et al. 2012; Kasirer and Mashal 2014; Pexman et al. 2011). Olofson et al. (2014) reported that children and adolescents with ASD performed above chance levels when processing lexicalized as well as novel formulations of conceptual metaphors. The fact that we studied adults who have gained language experience over the years might have contributed to the understanding of figurative language in the PDD group. Indeed, there is evidence for developmental changes in irony comprehension in both TD participants (Wang et al. 2006b) and in individuals with ASD (Williams et al. 2013).

It has been suggested that individuals with PDD have no specific deficit in figurative language but rather a more general comprehension deficit (Gernsbacher and Pripas-Kapit 2012). Consistent with this argument, we found that the large PDD group was less accurate than was the TD group on the idiom task. However, this group difference disappeared after more careful matching in terms of vocabulary knowledge (as in Giora et al. 2012; Norbury 2004; Whyte et al. 2014). Although individuals with PDD were not significantly slower than was the TD group on the irony task, they were less accurate even when matched in terms of vocabulary. Thus, on the less demanding task of lexical decision to idiomatic expressions, no group differences were observed. However, when task demands increased and participants were asked to perform a semantic judgment task, and more semantic integration with the unfolding text was required (during text reading) the PDD group did less well, even when matched for vocabulary. Importantly, word type did not interact with group on either task, and thus we cannot conclude whether individuals with PDD have specific difficulty with figurative language.

With regards to our second main finding, TD participants demonstrated a rightward asymmetry when processing non-salient meanings of both idioms and irony. In line with Mashal et al. (2008), responses were more accurate to literal meanings of idioms when presented to the RH than when presented to the LH. Similarly, after reading a passage, TD adults processed ironic interpretations more quickly when passage endings were presented to the RH than when presented to the LH. These findings are consistent with Beeman's (1998) fine vs. coarse semantic priming theory as well as with Giora's (2002, 2003) graded salience hypothesis. In contrast, the salient interpretations (i.e., the idiomatic meanings in Task 1 and the literal endings in Task 2) demonstrated no RH advantage. Thus, our results show that the RH is involved in processing non-salient interpretations, be they literal or figurative. Unlike salient meanings that follow from the preceding context, the non-salient interpretations are unexpected. The discrepancy between predictable and unpredictable stimuli may further contribute to the hemispheric differences observed in the TD group. Indeed, it has been argued that processing in the RH is more integrative, involving direct comparisons between the features of the concepts that appear in the preceding context and the features of the ensuing word. Processing in the LH is assumed to be more predictive, resulting in the activation of features that are associated with the most likely continuation of the text (Federmeier and Kutas 1999). Thus, the literal meanings of idioms as well as the ironic endings of the passages activate the more integrative processing of the RH.

In contrast to TD participants, adults with PDD showed no rightward advantage in either task. This pattern of results fits well with findings of previous studies (Colich et al. 2012; Gold and Faust 2010; Joseph et al. 2014; Wang et al. 2006a). Furthermore, our results support the argument that ASD is associated with RH dysfunction (Ellis et al. 1994; McKelvey et al. 1995), thus indicating that the RH does not function properly when adults with ASD process some forms of figurative language. These findings may point to the difficulties that the ASD group experienced in comprehending the non-salient and less predictive interpretations of figurative language. In Jung-Beeman's (2005) terms, it is possible that participants with ASD have deficient coarse semantic coding. In Federmeier and Kutas's (1999) terms, the integrative mechanisms of the RH might be impaired in ASD, requiring LH support. In terms of the graded salience hypothesis (Giora 2003), the idiomatic meanings and the literal texts are probably not as salient for the PDD group as they are for the TD group, and therefore no RH advantage is seen for non-salient interpretations in the PDD group. Previous research suggested that the coordination between language brain regions may be disrupted in ASD (Gold and Faust 2010; Just et al. 2004), and this disruption might reduce the ability to engage in integrative aspects of text processing.

On the one hand, our findings show that while performance of the PDD group can differ significantly from performance of the TD group (even when perfectly matched for vocabulary), adults with PDD can still understand figurative language. On the other hand, the groups showed a different pattern of hemispheric processing of non-salient interpretations, with a rightward lateralization in the TD group but bilateral activation in the PDD group. Furthermore, a correlation analysis between vocabulary and hemispheric lateralization indicated that greater vocabulary scores are associated with decreased RH lateralization during processing of literal passages in the PDD group. However, vocabulary scores were not associated with figurative language processing in either hemisphere. Taken together, these results may indicate that individuals with PDD use different processing strategies, in line with the conclusions of previous studies that examined irony comprehension in children with ASD (Pexman et al. 2011; Wang et al., 2006a). It is possible that individuals with ASD thus use compensation mechanisms in processing figurative language, as has been suggested with regard to social inference (Bauminger et al. 2008) and semantic priming (Kamino et al. 2007). Future research should examine whether adults with ASD activate brain areas that are not activated in TD adults when processing complex figurative language.

It has been shown that familiarity or decomposability of idioms can affect task performance. According to Libben and Titone (2008), the idiomatic meanings of highly familiar idioms are retrieved directly, irrespective of their decomposability (i.e., whether the component words bear any relation to the figurative meaning). In the current study we used highly familiar idioms and therefore the idiomatic meaning was highly salient and the literal interpretation was not salient. Although we did not control for idiom decomposability, we observed the expected RH advantage for literal interpretation of familiar idioms in the TD group. It will be interesting to test hemispheric processing for lower familiarity idioms for which the figurative meaning is less salient. In line with Cacciari and Tabossi (1988) and Titone and Connine (1999), unfamiliar or unpredictable idioms may be compositionally analyzed during comprehension, suggesting that the figurative meaning could be less salient and therefore may show a right lateralized pattern of hemispheric processing.

It should be noted that only two of our four three-way interaction analyses were significant. Although such an interaction was found for the accuracy data on the idiom task, no equivalent interaction was found for the reaction time data on this task. On the irony task, the opposite pattern of results was found, with a significant three-way interaction for reaction times but not for accuracy. However, a closer inspection of the results (although not significant) revealed a trend in the right direction. Thus, TD adults showed a trend toward faster responses in the RH (733 ms) than in the LH (761 ms) on the idiom task, although this difference was not significant. Similarly, they were more accurate in the RH (85 %) than in the LH (74 %) on the irony task although the difference was not significant. It is possible that with a larger sample these findings would have reached significance.

Some limitations of the study should be addressed. First, processing figurative language is normally embedded in a rich context, involving many cues, such as facial expressions and prosody, which were not available in our study. More research is required to understand the processing of figurative language within more ecologically valid situations. Second, the tasks that we used are quite different from each other and task demands could have contributed to group differences. The lexical decision task used in Task 1 taps into automatic processes and requires word recognition, whereas the semantic judgment task used in Task 2 requires a more elaborative process of semantic integration (Faust and Lavidor 2003). Future research should investigate the processing of idioms and irony with the same task. Third, participants in Task 2 were required to read short passages. Although we gave the texts to participants with PDD prior to the study in order to assess the time required for reading a future study should screen for reading ability of all participants. Finally we note that when adjusting the group matching on vocabulary scores we reduced the study sample by excluding TD participants with high vocabulary scores or PDD participants with low vocabulary scores and thus created non representative groups.

In summary, the results of the present experiment converge on the finding that individuals with PDD do not show the typical RH advantage in processing figurative language, and instead process such stimuli bilaterally. While a RH advantage in processing literal meanings of idioms and ironic endings of paragraphs (i.e., non-salient interpretations) was found in the intact brain, no such RH specialization was found in adults with PDD. Our results extend previous findings, showing that a simple behavioral approach can also provide information regarding brain lateralization in PDD during processing different types of figurative language, syntactic structures, and tasks. Furthermore, we found similar results in individuals who were matched for vocabulary knowledge. This finding suggests that the atypical pattern of hemispheric processing in PDD is not due to lack of knowledge. Importantly, although adults with PDD were less accurate than were TD adults, they demonstrated above chance performance on both tasks. Taken together, our research suggests that adults with PDD use compensation mechanisms when interpreting figurative language.

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