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Accessing and selecting word meaning in autism spectrum disorder

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Background: Comprehension difficulties are commonly reported in autism spectrum disorder (ASD) but the causes of these difficulties are poorly understood. This study investigates how children with ASD access and select meanings of ambiguous words to test four hypotheses regarding the nature of their comprehension difficulties: semantic deficit, weak central coherence, reduced top-down control and inhibition deficit. **Methods:** The cross-modal semantic priming paradigm was used. Children heard homonym primes in isolation or as final words in sentences biased towards the subordinate meaning and then named picture targets depicting dominant or subordinate associates of homonyms. **Results:** When homonyms were presented in isolation, children with ASD and controls showed priming for dominant and subordinate pictures at 250ms ISI. At 1,000ms ISI, the controls showed dominant (but not subordinate) priming whilst the ASD group did not show any priming. When homonyms were presented in subordinate sentence contexts, both groups only showed priming for context-appropriate (subordinate) meanings at 250ms ISI, suggesting that context has an early influence on meaning selection. At 1,000ms ISI the controls showed context-appropriate (but not inappropriate) priming whereas the ASD group showed both appropriate and inappropriate priming. **Conclusions:** Children with ASD showed intact access to semantic information early in the time course of processing; however, they showed impairments in the selection of semantic representations later in processing. These findings suggest that a difficulty with initiating top-down strategies to modulate online semantic processing may compromise language comprehension in ASD. Implications for intervention are discussed. **Keywords:** Language comprehension, ambiguity resolution, semantic priming, homonyms, poor comprehenders.

Children with ASD show a range of communication difficulties often including impairments in language comprehension (Jolliffe & Baron-Cohen, 1999; Jones et al., 2009; Nation, Clarke, Wright, & Williams, 2006; Norbury, 2005; Norbury & Bishop, 2002). At present, the causes of language comprehension impairments in ASD are poorly understood, yet it is crucial to understand these causes in order to inform assessment and interventions. Comprehension is multifaceted; it depends on many cognitive processes and can fail for many reasons. The aim of the present study is to test four hypotheses regarding the causes of comprehension difficulty in ASD.

The first hypothesis is that comprehension difficulties arise from deficits in the semantic representations of words (semantic deficit hypothesis). Evidence for this comes from otherwise typically developing (TD) children who show weaknesses in reading and listening comprehension ('poor comprehenders') and have difficulties on tasks that require access to the meanings of words. Poor comprehenders are slower and less accurate at producing picture names, particularly when they depict words of low frequency (Nation, Marshall, & Snowling, 2001), and have difficulty making synonym judgements, particularly for low-imageable word pairs (Nation & Snowling, 1998). They also show reduced semantic priming (faster/more accurate responses for a second word in a pair when the first word is related rather than unrelated) for categorically related words that are not highly associated (e.g., bed – desk) (Nation & Snowling, 1999).

There is emerging evidence of a similar semantic deficit in ASD. Preschoolers with ASD show more severe impairments in word comprehension than word production (Charman, Drew, Baird, & Baird, 2003; Luyster, Kadlec, Carter, & Tager-Flusberg, 2008). McCleery et al. (2010) reported a verbal-semantic impairment in young children with ASD who showed a reduced N400 event-related potential effect in response to incongruous picture–word pairs and Kamio, Robins, Kelley, Swainson, and Fein (2007) reported reduced semantic priming for categorically related prime–target pairs in adolescents and young adults with ASD. Building on these findings, this study utilises the semantic priming paradigm to investigate whether, like 'poor comprehenders', children with ASD show impairments in accessing the meanings of words, particularly when they are low frequency.

An established cognitive theory of ASD, the weak central coherence theory (WCC; Frith, 2003; Happé, & Frith, 2006), also provides a framework for understanding comprehension difficulties. It

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proposes that individuals with ASD have an enhanced ability to process details coupled with impairments in context integration; they tend to process incoming information in a piecemeal fashion rather than connecting information to form contextual representations. Evidence to support this theory includes difficulties using sentence context to pronounce homographs (e.g., tear) (Happé, 1997; Jolliffe & Baron-Cohen, 1999; Lopez & Leekam, 2003). However, studies using methodologies which reduce the involvement of strategic processes have not supported WCC theory. Saldaña and Frith (2007) found that, like controls, adolescents with ASD read sentences faster when they were preceded by relevant rather than irrelevant sentences. Similarly, Brock, Norbury, Einav, and Nation (2008) reported that adolescents with ASD showed intact effects of spoken context on eye movements to a visual scene. The present study uses semantic priming as an 'online' measure with low task demands, to investigate whether children with ASD lack sensitivity to context at both single-word and sentence levels and at both early and later time points in semantic processing.

An alternative possibility is that children with ASD have a higher-level 'executive' deficit (Hughes, 1996; Ozonoff & Miller, 1996) that compromises comprehension. Executive function is an umbrella term for a range of skills, including inhibition, planning, monitoring, cognitive flexibility and working memory, which determine the extent to which an individual can achieve goal-driven voluntary behaviours and exert top-down control. Reduced top-down control has been described in ASD (Frith, 2003); the present study investigates this within the domain of semantic processing. Top-down control is particularly important for the later stages of semantic processing when meanings have been retrieved and must be selected for further processing. Semantic priming effects that occur when the prime and target are separated by long inter-stimulus intervals (ISIs) are thought to be partly underpinned by the generation of expectancy sets of potential targets (the participant predicts might be related to the prime) and/or retrospective comparison of the target with the prime (Neely, 1991).

Finally, individuals with ASD may have a more specific executive dysfunction preventing the inhibition of irrelevant information that affects their ability to understand language (inhibition deficit hypothesis). Hala, Pexman, and Glenwright (2007) found that when homonyms were preceded by single-word primes, children with ASD provided context-appropriate pronunciations of the homonym on the first trial (e.g., CRY – TEAR), but they maintained the same pronunciation on the second trial with a different prime (RIP – TEAR). This suggests a difficulty with the inhibition of recently encountered but now irrelevant information. An inhibition deficit has been identified as a key cause of comprehension difficulties (Gernsbacher, Varner, & Faust, 1990) because it interferes with the formation of coherent mental representations.

To clarify the causes of the comprehension difficulty in ASD we tested these four hypotheses, using ambiguity resolution as a framework. Homonyms are ambiguous words that have one pronunciation and spelling but multiple meanings (e.g., bank, match). Semantic priming studies with homonyms (e.g., Barnes, Faulkner, Wilkinson, & Dennis, 2004; Duffy, Kambe, & Rayner, 2001; Simpson & Foster, 1986; Swinney, 1979) suggest that multiple meanings are accessed immediately after a word is presented (when the inter-stimulus interval (ISI), from the offset of the prime to the onset of the target, is short). This occurs when homonyms are presented in isolation (bank – money/river) or as final words in sentences (John fished from the bank – money/river). Later in processing (when the ISI is longer), one meaning is selected based on lexical (e.g., meaning frequency) and/or contextual factors. However, word-meaning frequency interacts with context (Duffy et al., 2001; MacDonald, Pearlmutter, & Seidenberg, 1994; Tabossi & Sbisa, 2001): if a sentence prime is biased towards a subordinate meaning (e.g., John fished from the bank) then priming for both context-appropriate (e.g., river) and inappropriate (e.g., money) targets will likely emerge at short ISIs followed by a maintenance of priming for the context-appropriate (subordinate) meaning at long ISIs. However, if a sentence prime is strongly biased towards the dominant meaning (e.g., John stole from the bank), priming for inappropriate subordinate targets might not be detected at any ISI. Studying the time-course of homonym resolution can therefore provide insights into the semantic processes that occur in the selection of meaning.

We examined activation and selection of word meanings when homonyms are presented in isolation and in sentences. An ISI of 250ms was used to measure priming at an early point in processing, following previous studies that have reported priming for multiple meanings of homonyms at similar ISIs in TD children (Barnes et al., 2004; Simpson & Foster, 1986). An ISI of 1,000ms was used to measure a later point in processing, based on earlier studies which have found that a single meaning is primed at this ISI in children (Barnes et al., 2004; Booth, Harasaki, & Burman, 2006). To measure patterns of semantic processing associated with ASD, rather than verbal or nonverbal difficulties regardless of autistic status, children with ASD whose vocabulary, decoding and nonverbal abilities were within the normal range were selected, matched to controls on these variables.

This experiment comprised two tasks (single-word and sentence) completed by the same participants. The hypotheses, method and results for each task will be reported in succession.

Table 1 Descriptive measures for the ASD and Control groups

	ASD (*n* 17)		Controls (*n* 17)		
	Mean (SD)	Range	Mean (SD)	Range	*F (df = 1, 33)*
Age (yrs)	11.62 (2.47)	7.42–15.67	11.50 (2.89)	7.66–16.08	.02, $p = .90$
Matrices (T-score)	51.65 (12.38)	38–80	48.71 (7.41)	38–64	.71, $p = .41$
Receptive vocabulary (ss)	100.18 (17.17)	85–123	102.59 (16.61)	89–129	.17, $p = .68$
Listening Recall (ss)	95.18 (25.48)	64–142	99.18 (14.34)	76–126	.32, $p = .58$
Nonword Repetition (out of 40)	35.00 (3.87)	24–39	37.00 (2.58)	32–40	3.00, $p = .10$
Word Reading (ss)	108.06 (16.15)	85–135	108.59 (14.56)	86–133	.01, $p = .92$
Nonword reading (out of 25)	17.31 (5.51)	6–25	20.29 (4.87)	11–25	2.72, $p = .11$
Text reading accuracy (ss)	110.41 (14.12)	86–126	106.13 (12.57)	85–122	.81, $p = .38$
Text comprehension (ss)	92.53 (11.53)	70–113	103.07 (11.47)	91–127	6.68, $p < .02$*

Note: T-scores have a population mean of 50 and a standard deviation of 10, with scores of 40–60 falling within the normal range for a given age (scores below 40 are below average and scores above 60 are above average). Standard Scores (ss) have a population mean of 100 and a standard deviation of 15, with scores of 85–115 falling within the normal range (scores below 85 are below average and scores above 115 are above average).

Single-word processing

It was hypothesised that controls would show priming for dominant and subordinate meanings of homonyms at 250ms ISI but only dominant priming at 1,000ms ISI (Simpson & Foster, 1986). For children with ASD, the *semantic deficit hypothesis* predicts reduced priming particularly for subordinate meanings at the short ISI and slower responses at both ISIs. The *WCC theory* posits a general deficit with integrating information and therefore predicts a more general reduction in semantic priming (which involves connecting the target word to the prime) at both ISIs. The *reduced top-down control hypothesis* predicts intact priming at the 250ms ISI (when priming is more automatic) but impaired priming at the 1,000ms ISI (when priming becomes more strategic). Finally, if children with ASD have difficulty inhibiting one meaning whilst selecting another then the *inhibition deficit hypothesis* predicts intact priming effects at 250ms but sustained priming for both dominant and subordinate meanings at the 1,000ms ISI.

Method

Participants. Seventeen children (15 males) with ASD (13 autism, 4 Asperger syndrome) aged 7 to 15 years participated in the study.[1] One child was recruited from a mainstream primary school and 16 were recruited from four special schools for children with moderate/severe learning disabilities. Prior to the study, initial meetings were set up with the schools to select children for whom the school had a professionally confirmed diagnosis of autism or Asperger syndrome using established criteria (American Psychiatric Association, 1994). All children with ASD had a diagnosis on the autism spectrum; children with additional diagnoses such as Fragile X and tuberous sclerosis were excluded. The selected families were sent information packs about the study inviting them to take part. All parents provided written confirmation that their child had received a formal diagnosis of ASD through a general practitioner referral. The parents of 13 children returned the Social Communication Questionnaire (SCQ; Berument, Rutter, Lord, Pickles, & Bailey, 1999) which provides a dimensional measure of ASD symptomatology (based on the ADI-R; Rutter, Le Couteur, & Lord, 2003). The mean SCQ score was 23.40 (SD = 4.70, range 16–31) and all children scored above the recommended cut-off for ASD (>15). Seventeen typically developing (TD) controls (14 males) were recruited from mainstream schools. All children had normal hearing and normal or corrected-to-normal vision. Informed consent was obtained for all participants.

The groups were pairwise matched on chronological age, receptive vocabulary (BPVS-II; Dunn, Dunn, Whetton, & Burley, 1997), and word reading (BAS-II; Elliot, Smith, & McCulloch, 1996). The groups were matched on a group-basis for nonverbal ability (Matrices, BAS-II; Elliot et al., 1996). Moreover, there were no significant group differences for verbal working memory (Listening Recall, WMTB-C; Pickering & Gathercole, 2001), nonword repetition (CNRep; Gathercole, Willis, Baddeley, & Emslie, 1994) or nonword decoding (GNWRT; Snowling, Stothard, & McLean, 1996) (see Table 1). However, as anticipated, the ASD group scored significantly worse than controls on a measure of reading comprehension (NARA-II, Neale, 1997).

Materials. Twenty-two homonyms were selected through pre-testing with a word association task given to 27 TD 7–10-year-olds. The dominant associates were produced over the subordinate by >70% of children and the subordinate associates by 5–30%. There were 22 homonym prime–dominant target pairs (e.g., bank – money), 22 homonym prime–subordinate target pairs (e.g., bank – river), 22 unrelated prime–dominant target pairs (e.g., hook – money), and 22 unrelated prime–subordinate target pairs (e.g., cake – river). Unrelated unambiguous primes were matched to the homonym primes for neighbourhood size and frequency (Children's Printed Word Database; http://www.essex.ac.uk/psychology/cpwd), and for frequency, concreteness,

[1] These participants were selected from a larger group of 28 children with ASD of wider-ranging ability. From this larger group, 17 children who had normal range word reading and vocabulary skills were selected. Background and experiment data for all 28 children are provided in an online appendix.

familiarity, and imageability (MRC Psycholinguistic Database; Wilson, 1988). All picture targets had >80% naming agreement in the pretesting; 27 were taken from Snodgrass and Vanderwaart's (1980) database and 17 from http://www.clipart.com. Picture names for dominant and subordinate conditions were matched for length and frequency.

Design. Participants completed 250ms and 1,000ms ISI conditions at least one week apart. All 88 pairs were divided into two pseudo-randomised blocks (with a homonym/picture only appearing once in each), separated by a 10-minute break. The proportion of related/ambiguous trials was 50%. Blocks and ISI sessions were counterbalanced.

Procedure. The experiment ran on a laptop computer. A 'Ready?' screen initiated each trial for 1,000ms. A fixation cross was displayed in the middle of the screen as the prime word was played through speakers. At word offset, there was a 250ms or 1,000ms ISI, then the target picture appeared centrally. A naming response triggered a voice key which recorded naming RT from the picture onset. The experimenter recorded item accuracy.

Meaning familiarity post-test. In a post-test, each homonym was paired with dominant, subordinate and unrelated pictures and children decided if the pair was related or unrelated. Fillers made the relatedness proportion 50%. Although errors were low, the ASD group produced more errors for the dominant condition (mean out of 22 = .29, SD .59) than controls (mean = 0), (p < .05), and for the subordinate condition (mean = 1.06; SD 1.09) than controls (mean = .41; SD .71), (p < .05), but the unrelated conditions did not differ (ASD mean = .18, SD .53; control mean = 0) (p > .05).

Results

Naming RTs were removed if the homonym meaning was unfamiliar on the post-test or there was a microphone or naming error. For the 250ms ISI, a mean of 8.47% (SD 5.75) items were omitted per ASD participant, 5.41% (SD 3.36) for controls, (p < .07). For the 1,000ms ISI, 8.41% (SD 4.58) items were omitted per ASD participant, 4.71% (SD 4.62) for controls, (p < .05).

Mean picture naming RT for correct responses and naming errors are shown in Table 2. Errors were too low for meaningful analysis. A 2 (Relatedness; related, unrelated) × 2 (Association; dominant, subordinate) × 2 (ISI; 250ms, 1,000ms) × 2 (Group; ASD, control) mixed-design ANOVA was performed with naming RT as the dependent variable. There was a significant 4-way interaction, F (1, 32) = 4.36, p < .05, η_p^2 = .12, that was broken down by ISI.

250ms ISI. The ASD group was slower to name pictures than controls (Group, F (1, 32) = 11.36, p < .01, η_p^2 = .26). Children were faster to name pictures if they were preceded by homonyms than unrelated primes (Relatedness, F (1, 32) = 17.38, p < .001, η_p^2 = .35) and if the pictures were dominant rather than subordinate (Association, F (1, 32) = 9.37, p < .01, η_p^2 = .23). There was a significant Relatedness × Association interaction with larger priming effects for dominant than subordinate conditions, F (1, 32) = 5.15, p < .05, η_p^2 = .14. Across both groups, a significant priming effect was obtained for the dominant condition (mean difference 92ms, SD 120ms, 95% CI 51–134ms, p < .001) and there was a trend for a subordinate priming effect (mean difference 35ms, SD 111ms, 95% CI –3–73ms, p < .07) (see Figure 1). No other interactions were significant.

1,000ms ISI. The ASD group was slower to name the pictures than controls (Group, F (1, 32) = 5.92, p < .05, η_p^2 = .16). Children were faster to name pictures in the dominant than subordinate condition (Association, F (1, 32) = 10.11, p < .01, η_p^2 = .24). There were significant Relatedness × Association, F

Table 2 Mean picture naming RT (in ms) and mean naming errors (out of 22) for dominant and subordinate conditions and raw priming scores (in ms) for each ISI condition in Experiment 1a

	Dominant			Subordinate		
	Related	Unrelated	Priming	Related	Unrelated	Priming
250ms ISI						
Naming RT						
Controls	813 (207)	878 (275)	65	900 (182)	936 (251)	36
ASD	1112 (265)	1232 (353)	120	1233 (363)	1266 (416)	33
Naming Errors						
Controls	.12 (.33)	.18 (.39)	.06	.13 (.33)	.24 (.44)	.11
ASD	.12 (.33)	.29 (.47)	.17	.13 (.33)	.13 (.33)	0
1,000ms ISI						
Naming RT						
Controls	786 (196)	879 (240)	93	860 (193)	832 (170)	–28
ASD	969 (262)	986 (276)	17	1110 (318)	1078 (296)	–32
Naming errors						
Controls	.13 (.33)	.13 (.33)	0	.24 (.56)	.24 (.56)	0
ASD	.24 (.56)	.41 (.80)	.17	.41 (.62)	.35 (.61)	–.06

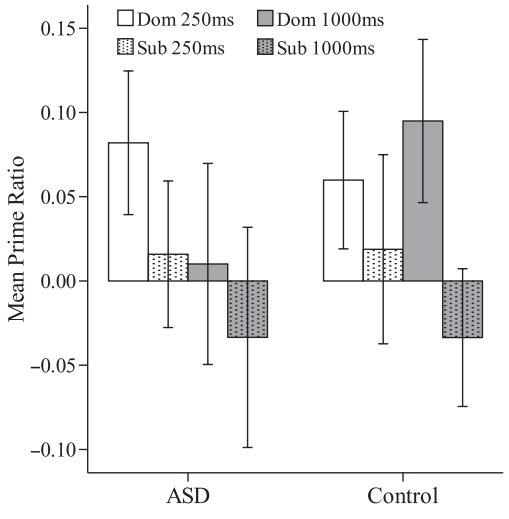

Figure 1 Dominant and subordinate prime ratio scores for the 250ms and 1,000ms ISIs, for the ASD and control groups. Prime ratios were calculated as the difference between related and unrelated conditions divided by the unrelated condition, to control for baseline RT. Error bars are 95% confidence intervals

(1, 32) = 21.22, $p < .001$, $\eta_p^2 = .40$, and Association × Group interactions, $F(1, 32) = 6.30$, $p < .05$, $\eta_p^2 = .17$, and a marginal Relatedness × Association × Group interaction, $F(1, 32) = 3.82$, $p < .06$, $\eta_p^2 = .11$. Controls showed significant dominant priming (mean difference 93ms, SD 99ms, 95% CI 42.76–144.14ms, $p < .001$) but no subordinate priming (mean difference –28ms, SD = 67ms, % CI –6–63ms, $p > .05$); the ASD group did not show significant priming in either condition (dominant; mean difference 17ms, SD 127ms 95% CI 48–83ms, subordinate; mean difference –32ms, SD 140ms, 95% CI –104–41ms) (see Figure 1).

Discussion

The ASD group were slower to name picture targets than controls, consistent with the semantic deficit hypothesis. However, for the 250ms ISI, both groups showed semantic priming, with larger priming for dominant than subordinate meanings similar to previous studies (Simpson & Foster, 1986). Thus, counter to the semantic deficit and the WCC hypotheses, both groups accessed relevant semantic information from spoken homonym primes which speeded their response to the dominant and subordinate picture targets. Moreover, both groups were equally sensitive to meaning frequency.

For the 1,000ms ISI, as predicted, controls showed significant dominant priming but no subordinate priming. In contrast, the ASD group did not show priming for either condition. This suggests that children with ASD have difficulties at the later stages of semantic processing as it becomes more strategic and a single meaning has to be selected. Hence, these findings support the reduced top-down control hypothesis. The inhibition deficit hypothesis was not supported since multiple meanings were not active at the long ISI.

It is unclear whether the slower picture naming in the ASD group was due to slower retrieval or production of verbal information, difficulties with object recognition, or slower processing speed. Since group differences in baseline speed can lead to spurious group differences in priming (Chapman, Chapman, Curran, & Miller, 1994), we confirmed that the pattern of priming remained the same when prime ratio scores were used that control for baseline RT. It is unlikely that processing speed accounts for the pattern of priming observed since group differences in priming only occurred at the long ISI whereas group differences in naming RT occurred at both ISIs.

Sentence processing

In the sentence task the same homonyms appeared in four different conditions (see also Norbury, 2005); *biased* and *neutral* conditions measured contextually 'appropriate priming' and were followed by appropriately related subordinate pictures (e.g., 'John fished from the bank' – RIVER and 'John walked to the bank' – RIVER, respectively). *Inappropriate* and *control* conditions measured contextually 'inappropriate priming' and were followed by inappropriately related dominant pictures (e.g., 'John fished from the bank' – MONEY and 'John fished from the stream' – MONEY, respectively). It was hypothesised that controls would show faster responses to subordinate pictures when they were preceded by biased rather than neutral sentences at both ISIs, and would show faster responses to dominant pictures when preceded by inappropriate rather than control sentences at the 250ms ISI only.

Since the *semantic deficit hypothesis* was not supported by the single-word data and makes specific predictions about word-level priming, it was not tested at the sentence level. Based on the *WCC hypothesis*, we predicted that children with ASD would show reduced or absent priming effects at both ISIs for both appropriate and inappropriate conditions. Although this hypothesis was not supported by the single-word data, it is possible that children with ASD may have more difficulties integrating sentence context, which carries higher processing demands (Lopez & Leekam, 2003). Based on the *reduced top-down control* hypothesis, individuals with ASD should show intact priming effects at the short ISI for both appropriate and inappropriate conditions but impaired priming for both conditions at the long ISI (when processing is more strategic), as for single-word processing. Based on the *inhibition deficit hypothesis* individuals with ASD should show appropriate and inappropriate priming at the short and long ISIs.

Method

Materials. For each homonym used in the single-word task, four sentences (containing 4/5 words) were constructed, giving a total of 88. Half of the sentences measured appropriate priming. These sentences ended with homonyms and were followed by the subordinate pictures. Neutral sentences granted either meaning acceptable (e.g., Amy bought the bulb – FLOWER); biased sentences manipulated the context to render the subordinate meaning appropriate by altering the verb (e.g., Judy planted the bulb – FLOWER). The other half of the sentences measured inappropriate priming. These sentences contained the same verbs and were followed by the dominant pictures. Inappropriate sentences were biased towards the subordinate meaning of a sentence-final homonym (e.g., Richard planted the bulb – LAMP); control sentences ended with unambiguous synonyms (e.g., Chris planted the seed – LAMP). In pre-testing it was ensured that the biased versus neutral verbs did not prime the subordinate targets when they were presented in isolation.

Design. All sentence–target pairs were randomly divided into blocks (separated by a 5-minute break) so that each homonym appeared only once in each. Block presentation was fully counterbalanced and list order was pseudo-randomised.

Procedure. The procedure was the same as for the single-word task but children listened to sentences. ISI conditions were counterbalanced and administered a week apart. The sentence task was administered approximately two weeks after the single-word task.

Results

Item RTs were removed using the same criteria as for the single-word task. For the 250ms ISI, a mean of 9.65% (SD 5.51) items were omitted per ASD participant, 5.06% (SD 3.91) for controls ($p < .01$). For the 1,000ms ISI, a mean of 9.53% (SD 6.21) were omitted per ASD participant, 5.24% (SD 4.13) for controls ($p < .05$). Table 3 shows mean picture naming RT (for correct items) and naming errors. Since the appropriate and inappropriate priming conditions were designed to test different questions (e.g., the influence that biased sentence context has on accessing relevant information versus the extent to which children can inhibit information that is irrelevant to context), the levels of each condition are not directly comparable. The data from these two conditions were therefore analysed separately.

Appropriate priming. The ASD group were slower to name the pictures than controls (Group, $F(1, 32) = 6.53$, $p < .05$, $\eta_p^2 = .17$). Overall, children were faster to name subordinate picture targets if they were preceded by subordinately biased than neutral sentences (Context, $F(1, 32) = 32.22$, $p < .001$, $\eta_p^2 = .50$). The Context × ISI interaction was significant ($F(1, 32) = 5.38$, $p < .05$, $\eta_p^2 = .14$): larger appropriate priming effects were found at the 250ms ISI ($p < .001$) than at the 1,000ms ISI ($p < .01$) (see Figure 2). No other interactions or effects were significant.

Inappropriate priming. The ASD group were slower to name the pictures than controls (Group, $F(1, 32) = 4.04$, $p < .05$, $\eta_p^2 = .11$). No other main effects were significant but there were significant ISI × Group, $F(1, 32) = 7.59$, $p < .01$, $\eta_p^2 = .19$, and Context × ISI × Group interactions, $F(1, 32) = 5.72$, $p < .05$, $\eta_p^2 = .15$. The controls did not show inappropriate priming at 250ms ISI (mean difference 6ms, SD 143ms, 95% CI –67–80ms, $p > .05$) and showed faster responses to control than inappropriate targets at 1,000ms ISI (mean difference –91ms, SD 130ms, 95% CI –157–24ms, $p < .01$). The ASD group did not show inappropriate priming at 250ms ISI (mean difference 38ms, SD 140ms, 95% CI –33–109ms, $p > .05$) but

Table 3 Mean picture naming RT (in ms) and mean naming errors (out of 22) for appropriate and inappropriate priming conditions and raw priming scores (in ms) for each ISI condition for the controls (*n* 17) and ASD group (*n* 17)

	Appropriate priming			Inappropriate priming		
	Neutral	Biased	Priming	Control	Inappropriate	Priming
250ms ISI						
Naming RT						
Controls	989 (324)	880 (296)	109	943 (402)	937 (330)	6
ASD	1275 (434)	1034 (315)	241	115 (406)	1118 (334)	38
Naming Errors						
Controls	.18 (.39)	.06 (.24)	.12	.06 (.24)	.12 (.33)	–.06
ASD	.06 (.24)	.13 (.33)	–.07	.13 (.33)	.18 (.39)	–.05
1,000ms ISI						
Naming RT						
Controls	910 (270)	828 (248)	82	855 (264)	946 (278)	–91
ASD	1245 (441)	1132 (314)	113	1196 (413)	1074 (279)	122
Naming errors						
Controls	0 (0)	0 (0)	0	.06 (.24)	.13 (.33)	–.07
ASD	0 (0)	0 (0)	0	.35 (.61)	.29 (.59)	.06

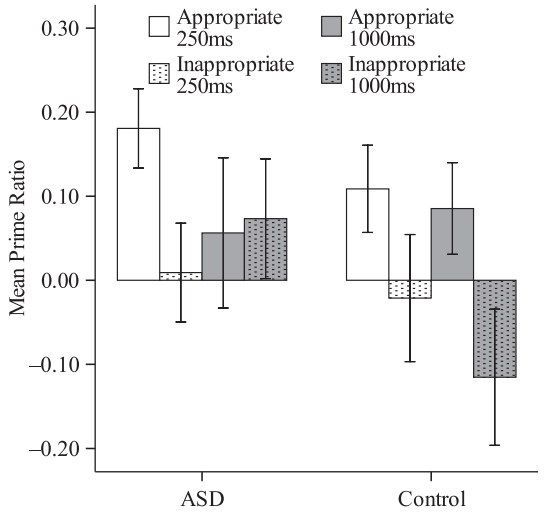

Figure 2 Mean appropriate and inappropriate prime ratios for each ISI, for the ASD and control groups. Appropriate prime ratios were calculated as the difference between neutral and biased conditions divided by the neutral condition. Inappropriate prime ratios were calculated as the difference between control and inappropriate condition divided by the control condition. Error bars are 95% confidence intervals

showed significant inappropriate priming at 1,000ms ISI (mean difference 122 ms, SD 241ms, 95% CI –3–245ms, $p < .05$) (see Figure 2).

Discussion

Similar to their performance on the single-word task, children with ASD were slower to name pictures than controls. Both groups were sensitive to biased context and showed significant appropriate priming at both ISIs. Furthermore, neither group showed inappropriate priming at the 250ms ISI. However, in contrast to the controls, the ASD group showed inappropriate priming at the 1,000ms ISI. Therefore, counter to the WCC hypothesis, both groups were able to integrate the biased verb with the sentence-final homonym and use this information to activate only the contextually appropriate meaning early in processing. Consistent with the results from the single-word task and the reduced top-down control hypothesis, these data suggest that children with ASD have impairments at a later, rather than early, stage of semantic processing. In contrast with the results from the single-word task, this impairment manifested as a failure to inhibit contextually inappropriate meanings.

General discussion

To clarify the nature of semantic processing and identify potential causes of comprehension difficulties in ASD, we investigated children's ability to access and select meanings of homonyms when the homonyms were presented in isolation (where meaning selection is shaped by meaning frequency) and as final words of sentences (where meaning selection is influenced by context).

For single-word processing, both groups showed intact priming for multiple meanings of homonyms early in semantic processing (at the 250ms ISI) and showed normal sensitivity to word frequency. In sentence context, both groups showed intact sensitivity to sentence context early in the time course, in the form of speeded access for contextually appropriate (subordinate) meanings following subordinately biased rather than neutral sentences. Furthermore, neither group showed priming for contextually inappropriate (dominant) meanings at the 250ms ISI. Therefore, despite being slower to name the pictures overall, children with ASD were able to access semantic information at an early stage in processing and use meaning frequency and context to drive this process. Studies with masked primes will be important to ensure that these children show intact *automatic* semantic priming.

However, children with ASD were impaired later in semantic processing (at the 1,000ms ISI). In the single-word task, the controls showed significant dominant priming but no subordinate priming whereas the ASD group did not show any priming and thus failed to select a single meaning on the basis of frequency. In sentence context, the controls showed only appropriate (subordinate) priming whereas the ASD group also showed inappropriate (dominant) priming and thus failed to select a single meaning based on context. One interpretation of these findings could be that children with ASD construct their initial semantic representations adequately but that they subsequently fail to maintain or develop these representations. Children with ASD may become distracted at long ISIs, such that the preceding context is no longer active when the picture is presented.

Although the ASD group were slower to name the pictures overall, the findings do not fully support the semantic deficit hypothesis since the ASD group did not have difficulties accessing semantic information at the short ISIs and showed intact sensitivity to meaning frequency. This suggests that the comprehension difficulties in ASD may be caused by different underlying deficits from those observed in poor comprehenders who are otherwise TD. The present findings cannot be clearly explained by the WCC hypothesis because it was not until later in processing that a difficulty with integrating the picture with the preceding word or sentence prime emerged. Rather, our data concur with recent findings from online paradigms that suggest this theory needs refining if it is to provide a good explanation of comprehension difficulties in ASD (Brock et al., 2008; Saldaña & Frith, 2007).

The inhibition deficit hypothesis was only partially supported by the present study. The ASD group

showed priming for both appropriate and inappropriate sentence conditions at 1,000ms ISI, which is in line with the inhibition deficit hypothesis. However, they did not show any priming for single words at 1,000ms ISI, which suggests a more general difficulty with strategic semantic processing. Deficits in inhibition may be more pronounced when there is more information to be processed and/or when the information to be inhibited is high frequency (as in the sentence task) or has been recently encountered (as in Hala et al., 2007).

The most fitting explanation of the present results is in terms of impaired top-down (voluntary/goal-driven) semantic processing that occurs alongside intact bottom-up (involuntary/stimulus driven) semantic processing. For children with ASD, bottom-up semantic processes (early automatic access to meaning) may be somewhat impervious to top-down processes (strategic processing and meaning selection) which fail to modulate performance. At longer ISIs, semantic priming effects are considered to be underpinned by strategic processes, including the generation of expectancy sets and retrospective comparison of target with the prime (Neely, 1991). Thus, difficulties with top-down/strategic semantic processing may impede meaning selection at the long ISI conditions and under some conditions manifest as a failure to inhibit irrelevant information. A difficulty with regulating incoming text or discourse online through the monitoring of current goals could conceivably hinder language comprehension and lead to children failing to maintain a *standard of coherence*. According to Perfetti, Landi, and Oakhill (2005) standard of coherence '... determines the extent to which a reader will read for understanding, make inferences, and monitor his or her own comprehension' (p. 233). Reduced top-down control could also explain why children with ASD often have difficulties comprehending figurative language (e.g., 'raining cats and dogs'); that is, if these children are able to access dual representations of language but fail to select a single representation. This explanation could therefore account for the higher prevalence of comprehension difficulties in ASD, in both written and spoken domains.

Using an 'off-line' meaning judgement task, Norbury (2005) investigated lexical ambiguity resolution in children with ASD with and without language impairment. Regardless of autistic status, children without language impairment were better at deciding whether pictures that depicted homonyms (e.g., stereo speaker/public speaker) were related or unrelated to preceding sentence primes that ended in a homonym (e.g., Julie connected/thanked the speaker) after an ISI of 1,000ms, compared to children with language impairment. Therefore, in contrast to the present data, children with ASD (without language impairment) were comparable to TD controls and did not show elevated levels of interference from context-inappropriate information. The off-line meaning judgement task used in Norbury (2005) was more directive in terms of the strategies required, in comparison to the naming task used here. Thus, in keeping with the reduced top-down control hypothesis, the ASD group (without language impairment) in Norbury (2005) may have benefited from the explicit nature of this task. Electroencephalographic (EEG) studies with children with ASD have reported semantic impairments that are present in passive tasks but not in directive tasks (Breautigam, Swithenby, & Bailey, 2008; McCleery et al., 2010).

The present findings have practical implications for individuals with ASD who have profiles akin to those in this sample. In light of the findings, intervention to develop metacognitive strategies to improve comprehension monitoring may be beneficial (e.g., look back, re-read, think aloud, explain and reflect, reciprocal teaching). Intervention programmes that incorporate such strategies have been shown to improve reading comprehension in TD children with comprehension difficulties (Clarke, Snowling, Truelove, & Hulme, 2010). For children with ASD with broader language difficulties, oral language intervention that incorporates rich vocabulary training may also be important.

This study has shown that children with ASD have intact early semantic processing but impairments at a later stage in processing. Although these results need replicating with larger sample sizes within a smaller age range, we argue that the results support the hypothesis that children with ASD have reduced top-down control and hence fail to regulate and monitor incoming information. The processes involved in accessing multiple meanings followed by a narrowing of meaning retrieval over time may be useful not only for homonyms, but for all words as they take on slightly different meanings in different contexts.

Supporting information

Additional Supporting Information may be found in the online version of this article:

Table S1 Background measures for the 28 children with ASD.

Table S2 Mean picture naming RT in ms for dominant and subordinate conditions and mean raw priming scores in ms (with 95% confidence intervals in parentheses) for each ISI condition in Experiment 1a.

Table S3 Mean picture naming RT (in ms) for appropriate and inappropriate priming conditions and mean raw priming scores (in ms) for each ISI condition in Experiment 1b (Word document)

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Key points

- Difficulties with language comprehension are common in children with ASD.
- Using cross-modal semantic priming, this study rejects three hypotheses regarding the causes of language comprehension impairments in ASD: the semantic deficit hypothesis, the weak central coherence hypothesis and the inhibition hypothesis.
- Consistent with the reduced top-down control theory, the ASD group showed intact semantic priming early in processing of homonyms but impaired priming at later stages when processing is more strategic.
- Tests of listening and reading comprehension should be incorporated into clinical assessments of ASD to prevent clinicians from missing these subtle difficulties. Measures that incorporate strategic cues and encourage children to actively consider meaning relationships (e.g., picture–word matching, meaning judgements) may overestimate ability in ASD relative to when these children are required to use the same skills spontaneously.
- Comprehension interventions for children with ASD without language impairment should incorporate strategy-based approaches to improve metacognition.

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