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Learning and consolidation of new vocabulary in autism spectrum disorder

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Research Highlights

- We take a novel approach to investigating spoken word learning in autism spectrum disorder (ASD), specifically examining the role of off-line consolidation in the strengthening and integration of new phonological forms over time.
- We find that verbally able children with ASD and typical peers show similar improvements in their ability to recall and recognise new phonological forms 24 hours after training, suggesting that overnight consolidation of explicit memory for new words is intact in ASD.
- For typical peers, we find that novel words show evidence of engaging in lexical competition with existing items 24 hours after training whereas children with ASD show immediate lexical competition that disappears after24 hours.
- These results suggest that word learning in ASD is characterised by both skill and deficit, specifically, enhanced sensitivity to phonological competitors early in the time course of word learning but impairments in the longer-term integration of new and existing lexical knowledge.

Abstract

Autism spectrum disorder (ASD) is characterized by rich heterogeneity in vocabulary knowledge and word knowledge that is not well accounted for by current theories. We take a novel approach and examine whether individual differences in vocabulary knowledge might be partly explained by a consolidation and/or integration impairment. Verbally able children with ASD and typical peers showed similar improvements in recognition and recall of novel words (e.g., *biscal*) 24-hours after training. Typical children showed competition for exiting words (e.g., *biscuit*) after 24-hours (suggesting that the new words had been integrated with existing knowledge) whereas children with ASD showed immediate competition effects that diminished after 24-hours. Thus, children with ASD showed *strengths* in the consolidation of explicit memory for new spoken word forms but *weaknesses* with the integration of new and existing word knowledge over time. These results are considered from the perspective of a dual-memory systems framework.

ASD is characterised by impairments in social interactions and social communication and repetitive and stereotyped patterns of behaviour (Lord & Jones, 2012). Many children with autism spectrum disorders (ASD) have pronounced and protracted delays in language acquisition and for a substantial proportion of these children problems with language and communication are life-long. Yet, there is striking heterogeneity in relation to vocabulary development and word knowledge, with some individuals achieving typical and even above average vocabulary scores (Kjelgaard & Tager-Flusberg, 2001; Mottron, 2004; Luyster, Lopez & Lord, 2007) and others showing clear vocabulary impairments despite age-appropriate cognitive skills (Loucas et al., 2008). Language impairments in ASD have been causally attributed to aspects of autistic pathology; for instance, a failure to follow speaker gaze cues, or understand the speaker's intention may derail early word learning (Baron-Cohen, Baldwin & Crowson, 1997). Similarly, a 'weak' drive to integrate information may disrupt the ability to learn new information from context (Happe, 1999). However, both theories anticipate pronounced language impairments across the autism spectrum; neither can explain the rich variation of language phenotypes that characterise ASD. While individual differences in social cognition or central coherence may inform our understanding language variation, it is likely that some variance is explained by other aspects of development. It is therefore imperative that we reveal the factors that contribute to language learning in ASD, in order to develop well-tailored intervention programmes. This study takes a novel approach to investigating language learning in ASD. We investigate the time course of new word learning, specifically examining the role of off-line consolidation in learning the phonological form of a new word and the extent to which it has been integrated with existing lexical knowledge.

Previous studies of vocabulary acquisition in ASD have largely relied on paradigms in which children are briefly exposed to a novel word and then assessed immediately after learning (e,g., the fast mapping paradigm). Traditionally, research has focused on the social deficits associated with impaired language acquisition (Baron-Cohen, Baldwin & Crowson, 1997; Preissler & Carey, 2005; McDuffie et al., 2006; Parish-Morris et al., 2007; Luyster & Lord, 2009). This research has demonstrated that although many children with ASD are impaired at interpreting social cues, they can learn new words when social cues are salient (Parish-Morris et al., 2007; Luyster & Lord, 2009) perhaps by relying on associative learning mechanisms (Parish-Morris et al., 2007; Preisseler, 2008). In non-social tasks, children with ASD can use mutual exclusivity to fast-map novel words to novel objects over objects they already know (de Marchena, Eigsti, Worek, Ono & Snedeker, 2011; Preissler & Carey, 2005). They also demonstrate the noun bias during word learning, in which a novel word is taken to represent an object rather than an action (Swensen, Kelley, Fein & Naigles, 2007).

Reported differences in speech perception in ASD are also relevant when considering how new vocabulary might be acquired (Kuhl, 2007). A number of studies have reported superior processing of auditory information, including enhanced performance relative to typically developing (TD) peers on neural responses to frequency changes (Kujala, Aho et al., 2007), frequency discrimination and categorisation (Bonnel et al., 2003), and processing of the pitch contours of sentences (Jarvinen-Pasley, Wallace, Ramus, Happe, & Heaton, 2008). Such enhanced performance may be more characteristic of individuals with ASD who go on to have structural language abilities that meet or exceed age expectations, despite earlier delays in language acquisition, suggesting that it may act as a compensatory or protective mechanism for language learning (Jones et al., 2009).

Despite strengths in the initial mapping of a new word to a new referent and with enhanced phonological processing of speech, children with ASD generally have smaller vocabularies than expected for their age (Charman, Drew, Baird & Baird, 2003; Hudry et al., 2010; Tager-Flusberg, Paul & Lord, 2005). Even when children with ASD are well matched to controls on measures of verbal ability they show qualitative differences in how they activate vocabulary knowledge in the service of language comprehension (Henderson, Clarke & Snowling, 2011; McCleery et al., 2010). Hence, the mechanisms underlying vocabulary acquisition in ASD remain poorly understood.

The predominance of findings from fast-mapping studies may not be revealing about the extent to which a new word is fully acquired into the mental lexicon (Bedford et al., 2013; Horst & Samuelson, 2008). Indeed, few studies have considered that word learning is protracted or that it relies on off-line consolidation. One exception is a word-learning study by Norbury, Griffiths and Nation (2010). Participants were asked to define and name novel objects (testing semantic and phonological knowledge, respectively), immediately after learning and four weeks later. For verbally able participants with ASD, recall of phonological information was impressive at both time points. In fact, they outperformed TD controls at mapping phonological forms to novel referents immediately after learning. Norbury et al. argued that this strength in mapping novel phonological forms to novel objects reflects enhanced phonological and associative (declarative) learning mechanisms. However, while TD children showed evidence of consolidation, with significantly improved performance on both tasks after four weeks, children with ASD did not show any such improvement. These results provide novel evidence of qualitative differences in the consolidation of new vocabulary in ASD.

The measurement of word learning in Norbury et al. was restricted to recognition and recall tasks, providing limited insights into the extent to which a new phonological form has become fully word-like. No studies have explicitly tested the time course with which new lexical representations are *integrated* with existing knowledge in ASD (cf. Gaskell & Dumay, 2003). According to dual-memory systems frameworks (e.g., Hasselmo, 1999; McClelland et al., 1995) new memories are integrated with existing knowledge slowly, to prevent new information from over-writing or distorting existing memories. Episodic memories (for events that occur at a specific place and time) are proposed to be initially encoded in the connections of the hippocampus but then through off-line consolidation a neocortical representation is strengthened and integrated with semantic memory.

Davis and Gaskell (2009) advocated a dual-memory systems approach to vocabulary acquisition, a key prediction being that competition during recognition between novel words and similar sounding well-established lexical neighbours occurs only after the new lexical entry has been integrated into the lexicon and has reshaped existing neocortical networks involved in language processing. Gaskell and colleagues have examined how lexical competition changes when adults (Dumay & Gaskell, 2007; Gaskell & Dumay, 2003) and children (Brown, Weighall, Henderson & Gaskell, 2012; Henderson, Weighall, Brown & Gaskell, 2012; Henderson, Weighall, Brown & Gaskell,

2013) learn fictitious novel nonwords (e.g., "*biscal*") that are close neighbours of established words (e.g., *biscuit*). Participants made speeded decisions about the presence of a pause inserted toward the offset of existing words (e.g., "*bisc_uit*"). Pause detection latencies in existing words became slower if participants had recently learned an onset competitor. This finding is argued to reflect the increased amount of lexical activity at pause onset once a novel competitor has been learned and a subsequent reduction in processing resources allocated to the task of detecting the pause (Mattys & Clark, 2002). Crucially, lexical competition emerged 12-hours after exposure to the nonword competitors, but only if sleep occurred (Dumay & Gaskell, 2007; Henderson et al., 2012). Children and adults were also able to recall significantly more newly learned nonwords after sleep than after a similar period of time awake. This suggests that off-line consolidation during sleep not only aids the integration of novel words into the mental lexicon[1] but also strengthens explicit memory. Importantly, previous studies with children have shown that improvements in explicit memory and the delayed emergence of lexical competition are not dependent upon re-exposure to the novel stimuli in the tests (Brown et al., 2012; Henderson et al., 2012) and they occur for real as well as fictitious words that are trained with or without meaning (Henderson, Weighall & Gaskell, 2013).

This body of research is strengthened considerably by two key findings. First, fMRI data show hippocampal sensitivity to the familiarity of nonwords encountered on the day of scanning, and neocortical consolidation effects of recently learned nonwords (Davis, Di Betta, MacDonald, & Gaskell, 2009). Second, sleep spindle activity (11-15 Hz oscillations lasting up to 3 seconds) is positively associated with overnight increases in lexical competition observed for existing word competitors of taught novel words suggesting that they play an active role in lexical consolidation (Tamminen, Payne, Stickgold, Wamsley & Gaskell, 2010). This is consistent with the view that spindles are implicated in hippocampal-neocortical consolidation (Diekelmann & Born, 2010). Spindles increase in activity during the up-state of slow oscillations (Molle, Marshall, Gais & Born, 2002) and are temporally aligned with hippocampal ripples (Sirota, Czicsvari, Buhl & Buzsaki, 2003).

ASDs are characterised by aberrant structural and functional neural connectivity, which could disrupt hippocampal-neocortical interactions (Belmonte et al., 2004; Just et al., 2004; Herbert et al., 2004; Herbert, 2005). Furthermore, children and adults with ASD experience elevated rates of sleep disturbance relative to TD peers (Hoban, 2000; Wiggs & Stores, 2004), including decreased sleep spindle activity (Limoges et al., 2005), and disrupted sleep in ASD has been associated with poor receptive vocabulary (Malow et al., 2009). Many individuals with ASD (42-82%) show epileptiform activity during sleep in the absence of clinical seizures (Giovanardi Rossi, posar & Parmeggiani, 2000; Lewine et al., 1999; Richdale, 1999; Tuchman, Rapin & Shinnar, 1991; Tuchman, 2000). Hence, it is plausible that qualitative differences in vocabulary acquisition in ASD could stem from aberrant sleep-associated consolidation processes (Femia & Hasselmo, 2002). We do not know how individual differences in consolidation may be related to individual differences in language learning within ASD. No previous research has systematically investigated this issue; therefore, this study will have immediate implications for understanding language heterogeneity in children with ASD.

Children were trained on novel nonwords (e.g., "*biscal*") as used in Henderson et al. (2012). For TD children, it was hypothesized that lexical competition effects for existing words (e.g., "*biscuit*") would emerge 24-hours after exposure to the novel competitors but not immediately (Henderson et al., 2012; Henderson et al., 2013). We hypothesized that TD children would show significant improvements in their ability to explicitly recall and recognize the novel words 24-hours after exposure (Brown et al., 2012; Henderson et al., 2012, 2013). Such evidence would lend further support to the dual-systems account of vocabulary acquisition (Davis & Gaskell, 2007). For verbally able children with ASD, we anticipated similar performance to TD peers immediately after training (Norbury et al., 2010). However, based on the view that children with ASD have impairments in off-line consolidation, we predicted that children with ASD would show smaller improvements in explicit recall and recognition of the novel words (Norbury et al., 2010) and a reduced lexical competition effect 24 hours after exposure.

Method

Participants

Thirty-six children (8-13 years) were recruited from the South East of England. Children with ASD (n=20, 19 male) held an existing diagnoses of ASD based on DSM-IV/ICD-10 criteria derived by a multi-disciplinary team assessment external to the research group. ASD was the primary diagnosis cited on the Statement of Special Educational Need (SEN), a legal document in the UK that specifies entitlement to special educational provision; 11 were receiving specialist support for ASD in mainstream schools or units serving children with ASD. In addition to their current diagnosis, these children obtained scores of 7 or greater on Module 3 of the Autism Diagnostic Observation Schedule (ADOS; Lord, Rutter, DiLavore, & Risi, 1999). Nine children were in a specialist school for children with ASD; these children did not complete the ADOS. Children attending mainstream schools or units did not differ significantly from the children attending the special school with regard to age, any of the verbal or non-verbal measures, or autistic symptomatology as measured by the Social Communication Questionnaire (SCQ; Rutter, Bailey & Lord, 2003), all t-values <1; *p*s > .37. None of the children were receiving medication at the time of testing.

TD children (n = 16, 7 male[†]) were recruited from local schools in the community and did not have any reported SEN or a history of ASD. Verbal (VIQ) and non-verbal (NVIQ) abilities were assessed using the Matrix Reasoning and Definitions sub-tests of the Wechsler Abbreviated Scales of Intelligence (Weschler, 1999). Receptive vocabulary was measured using the Receptive One Word Picture Vocabulary Test (Gardner, 1990). All groups were matched for raw scores on measures of verbal and non-verbal ability and receptive vocabulary; thus, the TD group were significantly younger than ASD participants, $t(34)=3.62$, $p = .001$ (see Table 1).

Informed, written consent was obtained from all parents, verbal assent was obtained from all children, and the protocol was approved by the Research Ethics Committee at Royal Holloway, University of London.

On completing the consent forms parents were also invited to fill in a sleep questionnaire that was produced for the purpose of this study. Parents were asked questions regarding bed time and wake-up time, night time behaviors (e.g., snoring, waking, nightmares), sleep medication, daytime tiredness, caffeine consumption, and evening activities. Completed questionnaires were obtained from 11/16 of the typical children and all 20 of the ASD group. The maximum score was 37 and a higher score indicated more sleep related difficulties (e.g., waking in the night, snoring, nightmares, taking sleep medication, needs to be woken in the morning). There was no significant group difference on this measure (see Table 1).

Stimuli

Thirty-two stimulus triplets used in Henderson et al (2012) were used here and comprised an existing word (e.g., biscuit), a fictitious novel competitor (e.g., biscal), and a novel foil (e.g., biscan). The existing words were selected to be highly familiar to children aged 7-years-old and were picturable, morphologically simple nouns with a uniqueness point before or on this segment. The 32 stimulus triplets were divided into two equal lists matched on frequency, letter and syllable length, phonological neighbourhood size and uniqueness point (as based on the CELEX database). During training, children heard 16 of the novel words (from List 1 or List 2, counterbalanced across participants). During the lexical integration (pause detection) test, children heard all 32 existing words; half of these items had a trained competitor (competitor condition), whereas the other half did not (control condition). All stimuli were recorded on a Pioneer PDR 509 system by a female native English speaker.

Design

Children were exposed to the novel words (List 1/2) in the training phase and then completed the pause detection, cued recall, and 2AFC tasks immediately after and 24 hours later.

Training tasks

Children were exposed to each novel word 18 times in two phonological tasks (Brown et al., 2012; Henderson et al., 2012; Henderson et al., 2013). Stimuli in both tasks were presented via headphones and tasks were run on a laptop using DMDX (Forster & Forster, 2003). Feedback was provided during practice trials.

(i) Phoneme monitoring

Participants listened to each novel word and indicated whether a pre-specified phoneme was present at any position in the word. Five practice trials were administered. There were 6 blocks of experimental trials with the target phonemes /p/, /t/, /d/, /s/, /m/, and /b/ in this order. Each novel nonword occurred 12 times, twice per block. During each block the target phoneme and a picture of a highly frequent object beginning with that phoneme were displayed centrally on screen (e.g., pig for /p/), with images of a happy and sad face displayed in the bottom left and right corners of the screen respectively, above the response buttons. The inter-trial interval was 500ms. Instructions emphasised accuracy.

(ii) Phoneme segmentation

Children were asked to listen to each novel word, repeat it, and then say the first (Block 1) or the last sound (Block 2). Novel words were presented three times per block in a randomised order. Three practice trials were administered before each block. Accuracy was recorded.

Measures of Explicit Memory

In *cued recall*, children heard the first syllable (bis-) of the 16 novel words from the training phase and completed the cue using one of the new words. In the *2AFC task* children heard both the novel word (biscal) and its corresponding foil (biscan). Children listened to both items before responding with the number 1 or 2 to indicate which item had been heard during training. The order of the novel word – foil word pairs and the order of the two items within each pair were randomised. Accuracy was recorded for both tasks. No feedback was provided.

Lexical integration task

Participants heard 16 existing base words for which a novel competitor had been trained (competitor condition) and 16 for which no novel competitor had been trained (control condition). In both conditions, half the words contained a 200ms pause. Four versions were used so that each item was equally represented in the four cells of the design (competitor, pause present; competitor, pause absent; control, pause present; control, pause absent cf. Dumay & Gaskell, 2007). Participants indicated via button-press whether a pause was present or absent for each word. For the experimental items, pauses were inserted before the second vowel offset if the following consonant was a voiceless plosive and just after this vowel otherwise. Fillers were 32 bisyllabic words (half with pauses inserted at varying positions in the words). Pauses appeared in 50% of trials. Pause detection response time was measured from pause onset.

Control task: Ensuring familiarity with the basewords

A picture-matching task was administered to ensure children were familiar with the base words. For each trial, one target and three distracters (selected from www.fotosearch.com/clip-art) were displayed in a quadrant on the screen. A target baseword was played through headphones and the participant pointed to the matching picture. Distracters were matched on AoA to the basewords (according to the MRC Psycholinguistic Database). Trial order was randomised but the same distracter images always occurred with the same target and the position of these four images on screen remained constant. Target pictures were equally distributed across quadrants. Children's accuracy was at ceiling (ASD mean % correct = 99.61%, SD=0.16%; control mean % correct = 99.38%, SD=0.19%).

Procedure

The Day 2 testing followed the Day 1 testing by approximately 24 hours (see Figure 1). The ADOS and standardised background measures were administered on a separate occasion.

Results

Training

Both groups performed similarly on the training tasks as expected given the groups were carefully matched on receptive vocabulary knowledge and verbal and nonverbal ability. There was no significant group difference in children's accuracy on the phoneme monitoring task (ASD mean % correct 86.75%, SD=5.90%; TD mean % correct 89.19%, SD=5.33%), $F_1(1, 34) = 1.65$, $p>.05$). There was no difference between stimulus lists for children with ASD or TD (all *Fs*<1).

Children performed close to ceiling on the phoneme segmentation task. There were no significant group differences for initial segmentation (ASD % correct = 98.6%, SD=3.20%, TD % correct = 92.56%, SD=1.9%, $F(1,34)=2.11, p=.15$) or final segmentation (ASD % correct = 82.29%, SD=2.52%, TD % correct = 74.37%, SD=2.49%, $F(1,34)=0.89, p=.35$). Both groups showed similar accuracy when repeating the novel words aloud (ASD % correct = 98.96%, SD=3.42%, TD % correct = 97.60%, SD=4.82%, $F(1,34)=0.90$, $p=.35$).

Measures of explicit memory

Percent correct responses on the *cued recall task* (Table 2) were entered into a mixed-design ANOVA with Session (Day 1, 2) as a within-subjects factor and Group (ASD, TD) and List (1, 2) as a between-subject factor. Participants recalled more novel words on Day 2 than Day 1 (Session, $F_1(1, 32)=68.10$, $p<.001$, $\eta_p^2=.68$, $F_2(1, 30)=217.08$, $p<.001$, $\eta_p^2=.88$); this was significant for children with ASD ($F_1(1,18)=31.68$, $p<.001$, $\eta_p^2=.64$; $F_2(1, 30)=159.46$, $p<.001$, $\eta_p^2=.84$) and TD peers ($F_1(1,14)=45.48$, $p<.001$, $\eta_p^2=.77$; $F_2(1, 30)=105.71$, $p<.001$, $\eta_p^2=.78$). No other main effects or interactions were significant (Fs < 1).

Percent correct responses on the *2AFC task* were entered into a mixed-design ANOVA with Session (Day 1, Day 2) as a within-subjects factor and Group (ASD, TD) and List (1, 2) as between-subject factors. Participants recognised more novel words on Day 2 than Day 1 (Session, $F_1(1, 32)=4.51$, $p<.05$, $\eta_p^2=.12$, $F_2(1, 30)=24.71$, $p<.001$, $\eta_p^2=.45$); this difference did not reach significance for children with ASD by participants ($F_1(1, 18)=2.12$, $p=.16$, $\eta_p^2=.11$) but was significant by items ($F_2(1, 30)=27.66$, $p<.001$, $\eta_p^2=.48$) and was significant for TD peers ($F_1(1, 14)=5.70$, $p<.05$, $\eta_p^2=.29$, $F_2(1, 30)=6.59$, $p<.05$, $\eta_p^2=.18$). No other main effects or interactions were significant.

These results suggest that children with ASD and TD peers had acquired good explicit knowledge of the novel words immediately after learning and that their ability to recognise and recall the novel words improved at the 24-hr retest. This suggests that offline consolidation functions to enhance and/or stabilise explicit knowledge of new words in children with ASD as in TD peers.

Measure of lexical integration

Pause detection errors were low (<10% of total trials on average) and hence were not entered into statistical analysis (Table 2). RTs <200ms and >2.5 SDs from the condition mean were removed for each participant separately (ASD 3.87%, TD 4.39%, $F(1, 33)=0.67$, $p>.05$. RTs were analysed for correct responses only. The RT data were entered into a 2 (Group; ASD, control) x 2 (Condition; competitor, control), x 4 (Session; Day 1, Day 2) x 2 (List 1, List 2) mixed-design ANOVA.

There was a significant main effect of Group, $F_1(1,31)=5.30$, $p<.05$, $\eta_p^2=.15$, $F_2(1,30)=76.60$, $p<.001$, $\eta_p^2=.72$: Averaged across Conditions and Sessions children with ASD were faster to respond than TD peers (ASD mean RT 1203ms, SD = 213ms, TD mean RT 1383ms, SD = 241ms). There was a significant main effect of Condition, $F_1(1, 31)=9.53$, $p<.01$, $\eta_p^2=.24$, $F_2(1, 30)=8.44$, $p<.01$, $\eta_p^2=.22$: Responses were, overall, slower for the competitor than the control condition. A significant Group x Condition x Session interaction, $F_1(1,31)=6.67$, $p<.05$, $\eta_p^2=.18$, $F_2(1,30)=6.49$, $p<.05$, $\eta_p^2=.18$, suggested that the time course of competition effects differed for the two groups (Figure 2). The TD group did not show a lexical competition effect (i.e., significantly slower RT for competitor than control conditions) on Day 1 (-45ms, SD=280ms, 95% CIs -195ms-104ms, $t^1(15)=-0.65$,$p>.05$, $t^2(31)=-0.42$,$p>.05$) but showed a substantial lexical competition effect on Day 2 (173ms, SD=131ms, 95% CIs 103ms-243ms, $t^1(15)=5.28$,$p<.001$, $t^2(31)=3.25$,$p<.01$). In stark contrast, children with ASD showed a significant lexical competition effect on Day 1 (120ms, SD=206ms, 95% CIs 24ms-217ms, $t^1(19)=2.61$,$p<.05$, $t^2(31)=2.45$,$p<.05$) but this effect was no longer significant on Day 2 (60ms, SD=199ms, 95% CIs -36ms-156ms, $t^1(18)=1.31$,$p>.05$, $t^2(31)=1.48$,$p>.05$).

Discussion

This study examined the extent to which children are able to learn and consolidate new phonological forms and integrate these new phonological forms with existing lexical knowledge over time, based within a dual-memory systems view of vocabulary acquisition (Davis & Gaskell, 2009). The results are provocative in suggesting a dissociation of different aspects of word learning in ASD. Specifically, verbally able children with ASD showed intact initial learning and offline consolidation of explicit memory for new words but showed clear differences in the time course with which these new lexical representations were integrated with existing lexical information. Rather than suggesting a global deficit in the offline consolidation of new vocabulary, the data suggest a more specific consolidation difficulty with lexical integration. The data thus shed new light on the putative causes of vocabulary impairments in ASD.

Children with ASD and TD peers showed similar performance on the recall and recognition tasks immediately after training (see also Bennetto et al., 1996), counter to previous claims of enhanced phonological recall (e.g., Bowler et al., 2000; Norbury et al., 2010). The fact that children were learning novel phonological competitors may have attenuated any effect of enhanced recall. Consistent with the dual-memory systems framework and with previous studies (Brown et al., 2012; Dumay & Gaskell, 2007; Henderson et al., 2012, 2013), both groups showed gains in their ability to recognise and recall the novel words 24-hours after training. This suggests that the consolidation of explicit memory for new words is robust in ASD, at least over 24-hours. It has been suggested that word learning in ASD relies on associative learning mechanisms (Parish-Morris et al., 2007; Preisseler, 2008). Associative learning is supported by declarative memory and associated hippocampal and temporal lobe circuits; in ASD it has been suggested that aspects of declarative memory might be 'enhanced' (Walenski, Tager-Flusberg & Ullman, 2006), resulting in intact or outstanding performance on tasks of word processing (Walenski, Mostofsky, Gidley-Larson & Ullman, 2008). Nonetheless, it remains possible that the longer-term consolidation of explicit word knowledge may be impaired in children with ASD (cf. Norbury et al., 2010).

A key hallmark of proficient lexical processing, namely lexical competition, was used as a marker of lexical integration. For TD children, we replicated previous findings, showing that the lexical competition environment in children is altered as new competitors are learned, but, as in adults, these competition effects are not observed until after a period of offline consolidation (Brown et al., 2012; Henderson et al., 2012; Henderson et al., 2013). Children showed lexical competition for similar sounding existing words 24-hours after exposure but not immediately. This again supports the dual-memory systems account of vocabulary acquisition (Davis & Gaskell, 2009), which proposes that new lexical information is initially stored separately from existing knowledge and sparsely coded in the hippocampus as an ‘episodic’ memory of the first occurrence. Over time, this information is replayed offline, particularly during sleep, which results in the strengthening of a distributed lexical representation in long-term neocortical memory (French, 1999; Robins & McCallum, 1999). The distributed nature of this lexical representation enables it to compete with overlapping representations during speech perception (Davis & Gaskell, 2009).

In startling contrast to the intact time course of explicit aspects of novel word learning, children with ASD showed clear differences in the time course with which the novel words were integrated with existing knowledge and engaged in lexical competition. They showed lexical competition effects *immediately* after exposure and these effects significantly decreased after 24-hours. It is plausible that more detailed phonological processing in the ASD group led to enhanced sensitivity to the new onset competitors immediately after training. The theory of enhanced perceptual functioning (Mottron & Burack, 2001; Mottron, Dawson, Soulieres, Hubert, & Burack, 2006) proposes that neural networks underpinning perceptual processing are ‘over-specialised’ and predispose locally oriented and enhanced perceptual functioning in ASD. This is supported by an accumulation of evidence suggesting that speech perception and production are enhanced in ASD (Bonnel et al., 2003; Kujala, Aho, Lepisto, Jansson-Verkasalo & Nieminen-von, 2007; Jarvinen-Pasley, Wallace, Ramus, Happe, & Heaton, 2008; Mottron et al., 2000; Kjelgaard & Tager-Flusberg, 2001). When collapsing across conditions, children with ASD also showed faster pause detection latencies than TD peers, consistent with previous reports of faster response times in ASD (e.g., Walenski et al., 2008). Together, these findings provide an important contribution to the view that phonological (or acoustic) processing is enhanced in ASD, suggesting that newly learned words are processed at a higher level of phonological detail, to the extent that they engage in lexical competition with similar sounding words immediately after training. Fine-grained phonological learning may act as a compensatory mechanism that supports the initial stages of word learning in verbally able children with ASD (Jones et al., 2009).

The finding that lexical competition between new and existing words diminished for the ASD group on the day after training suggests that the phonological detail of the new words that was retained immediately after training was lost after 24 hours. This result is striking when considering that children with ASD showed substantial parallel gains in their ability to explicitly recall the same phonological forms. This suggests a dissociation between consolidation effects on novel items (i.e., improvements in recall and recognition) and consolidation effects on their integration (i.e., increases in lexical competition). Such a distinction has also been made in the normal (adult) population. For instance, Tamminen et al (2010) found a correlation between slow wave sleep and overnight gains in recognition speed to novel words but a correlation between sleep spindle density and lexical competition. This indicates that these two types of consolidation (for explicit memory and for integration) are governed by different neurological mechanisms that may dissociate in ASD.

The absence of a lexical competition effect on Day 2 suggests that children with ASD were still relying upon the episodic representation that was formed during training, and in contrast to TD peers, they had not incorporated the new words into the mental lexicon. If there is a tendency in ASD for word learning to be dominated by an associative learning mechanism within hippocampal and temporal lobe circuits, this could perturb the strengthening of a distributed representation within long-term neocortical memory. If new phonological forms are not interleaved with existing knowledge offline this could result in lexical representations that are less well connected within the lexicon. In the longer term, this could have negative consequences for the permanence of the newly learned words within the lexicon (as demonstrated by Norbury et al., 2010).

Dual-memory systems frameworks (e.g., McClelland et al., 1995) were proposed as a solution to the problem of catastrophic interference. That is, how a single system can have enough plasticity to acquire new knowledge at the same time as protecting existing knowledge from damage. Therefore, a dominance towards associative (hippocampal) learning coupled with enhanced phonological encoding could arguably compromise the stability of existing representations as well as the acquisition of new representations, and in these ways contribute to vocabulary impairments in ASD.

Reduced interactivity between hippocampal and neocortical circuits in ASD is consistent with hypotheses that ASD reflects reduced cortical synchronisation between multiple brain regions (Belmonte et al., 2004; Just et al., 2004; Herbert et al., 2004; Herbert, 2005).

The present study was carried out over a 24-hour period and hence provides only a limited time-window on the time course of word learning in ASD. We cannot speak directly to the issue of whether sleep-associated consolidation problems contributed to the aberrant pattern of integration in the ASD group. Thus, our findings call for further examination of the role of sleep and neural connectivity in word learning in ASD over a longer time frame.

Specific difficulties with lexical integration may help to explain the apparent inconsistencies in findings that suggest both 'enhanced' processing and performance deficits. For instance, as well as showing strengths in aspects of speech perception and with mapping new words to new referents, children with ASD often lag behind TD peers with regard to vocabulary knowledge (e.g., Loucas et al., 2008). Even when children with ASD are matched to TD peers on measures of offline vocabulary knowledge (e.g., recognition tasks), they show qualitative differences in their ability to activate the same vocabulary knowledge automatically when online measures are used (e.g., semantic priming, event related potentials) (Henderson et al., 2011; McCleery et al., 2010).

How might the present data apply to other aspects of language learning? There is evidence that children with ASD have difficulties in applying a concept learned in a specific episode to other more general circumstances, suggesting that newly learned semantic knowledge is not integrated with existing semantic knowledge. For instance, Tek et al (2008) demonstrated that children with ASDs do not tend to map a recently learned word to an object with a similar shape to the object used during training in contrast to TD children. Applied to language learning, when taught that ducks have beaks, a TD child will be able to generalize to use the description of the feature in other circumstances (e.g., parrots have beaks). In contrast, a child with ASD can learn that ducks have beaks, but may not generalise, suggesting a difficulty in integrating newly learned semantic knowledge with existing semantic knowledge. Plausibly, deviant patterns of lexical integration could impair the semantic content of language, pragmatic aspects of language such as metaphor comprehension, as well as more specific features such as phonology (as shown here) and syntax.

Clearly, the present data apply to a narrow range of verbally able children within the autism spectrum. Given the heterogeneity that characterises language ability in ASD, a crucial future direction concerns the extent to which the present findings will generalise to the broader ASD population. Indeed, children with ASD who also have documented diagnoses of language impairment show clear impairments in phonological processing that likely hamper word learning abilities (Loucas et al., 2008; Lindgren et al., 2009). Further studies are therefore needed to compare children with ASD with and without language impairment on measures of word learning and lexical integration. Such studies will be important to examine the extent to which qualitative differences in initial phonological encoding influence the subsequent consolidation and integration of new lexical representations.

In conclusion, our findings indicate that word learning in verbally able children with ASD is characterised by both skill and deficit. We demonstrate that children with ASD can acquire explicit knowledge about new phonological forms and that this knowledge is strengthened following a period of offline consolidation, similar to TD peers matched on vocabulary knowledge. Despite this, however, children with ASD show dramatically different patterns of lexical integration. For children with ASD, a key hallmark of proficient lexical processing, namely lexical competition, was observed immediately after exposure to the new phonological forms but after not a period of consolidation, precisely the opposite pattern to that seen in TD children. Hence, despite showing explicit knowledge of the novel words that strengthened over time, likely supported by associative learning mechanisms, children with ASD did not effectively integrate these new phonological forms with existing knowledge to the extent that they behaved like existing words. Initial enhanced sensitivity to phonological competitors and a bias towards associative learning may have worked to compromise the integration of new lexical representations. It has been argued that a low-level perceptual processing bias reflects a difference in cognitive style rather than a deficit (e.g., Happe & Frith, 2006).

However, the present data question the benefits of a perceptual processing bias for longer-term language learning, and suggest that such a bias may be suboptimal for the development of an efficient lexical system. Therefore, these data also highlight the functional importance of slow, protracted word learning and provide further support for importance of a dual-memory system for vocabulary acquisition (Davis & Gaskell, 2009). Future research is needed to tease apart the effects of qualitative differences in initial phonological encoding and sleep-associated mechanisms on the time course of word learning in ASD.

Footnotes

[1] It should be noted that whilst sleep has shown to be an important state for memory consolidation, there are conditions in which lexical integration can occur without sleep. For instance, a recent study showed that spaced exposure to novel words (e.g., biscal) and their neighbours (e.g., biscuit) led to within-day lexical competition effects (Lindsay & Gaskell, 2013).

[2] The TD and ASD groups were not matched for gender (5% males in ASD group; 44% in the TD group). A previous study has shown that adult females show better explicit memory for phonologically familiar (but not unfamiliar) novel words than adult males (Kaushanskaya, Marian & Yoo, 2011). Thus, we reanalysed the child data from one of our previous experiments (Henderson et al, 2013) using a similar sample size (n=18; 9 males), the same stimuli and 0-hr/24-hr design, and a similar age group (7-8 years) as used here and checked for interactions with Gender using mixed-design ANOVAs. For pause detection, there was no significant main effect of Gender (p=.61) and no significant interactions (all ps>.39). Similarly, for cued recall, there was no main effect of Gender (p=.98) or a Day x Gender interaction (p=.28). This suggests that there are no gender effects on the strengthening and integration of memories for new words, at least for TD children.

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Figure 1. Outline of the procedure.

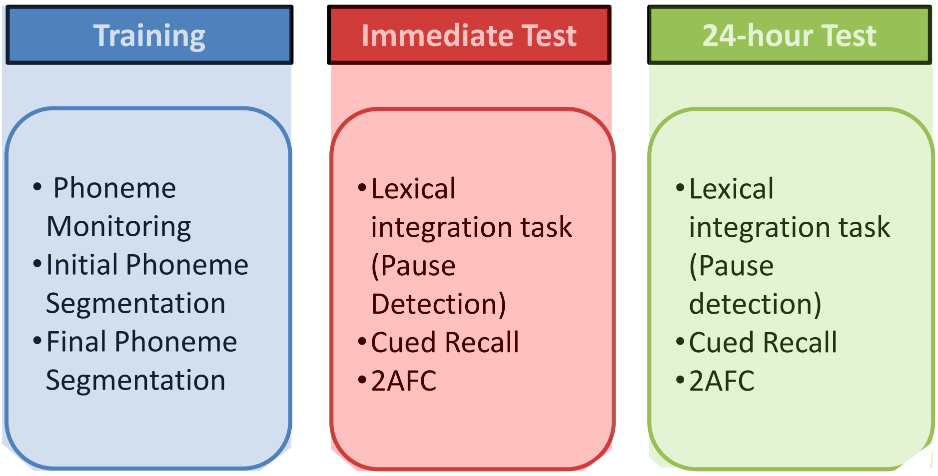

Figure 2. Day 1 and Day 2 lexical competition effects (competitor RT – control RT) for children with ASD and typically developing (TD) peers

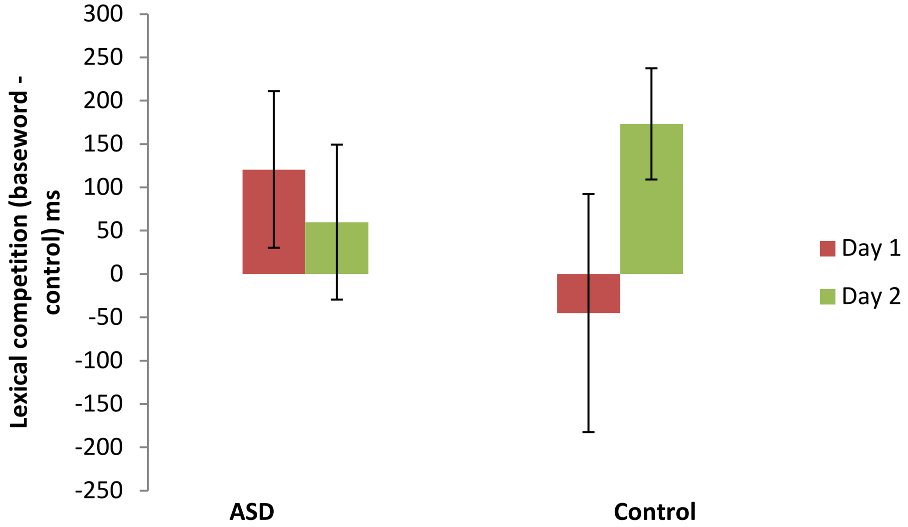

Table 1. Participant characteristics.

	TD (n=16)		ASD (n=20)		
	Mean (SD)	Range	Mean (SD)	Range	*F*
Age (years)	9.21 (1.38)	7.42-11.75	11.12 (1.70)	7.94-13.01	13.09***
ROWPVT	114.56 (13.34)	87-145	111.53 (19.99)	121.16-83	0.27
WASI Matrix Reasoning (T score)	57.25 (8.19)	33-67	56.15 (7.65)	44-67	0.17
WASI Matrix Reasoning (raw score)	21.75 (6.31)	5-29	24.65 (4.72)	15-33	2.49
WASI Vocabulary (T score)	61.63 (15.07)	19-77	52.25(14.21)	58.90-75.0	3.67
WASI Vocabulary (raw score)	41.50 (8.93)	27-57	41.60 (13.01)	22-62	0.001
WASI Full Scale IQ	116.69 (14.98)	84-134	108.05 (17.05)	80-138	2.53
SCQ	3.36 (2.16)	0-7	19.90 (8.01)	7-34	44.51***
Sleep Questionnaire Score	5.73 (3.79)	0-12	8.30 (6.23)	0-20	1.54
Sleep amount	10.89 (0.56)	9.50-11.50	9.98 (0.90)	8.50-11.50	9.16**

Note: SCQ, Sleep Questionnaire and Sleep Amount scores were obtained for 11/16 TD children and all 20 children with ASD. ****p*<.001, ***p*<.01. 'Sleep Amount' reflects the typical hours of nocturnal sleep as calculated from usual bed time and usual rise time provided by the parents in the Sleep Questionnaire.

Table 2. Performance on measures of explicit word learning and lexical integration (SDs are shown in parenthesis)

	ASD		TD	
	Day 1	Day 2	Day 1	Day 2
2-AFC acc (%)	80.63 (22.39)	88.44 (16.76)	87.50 (10.95)	92.97 (6.80)
Cued Recall acc (%)	35.94 (33.13)	70.31 (28.81)	32.42 (25.02)	65.3 (27.57)
Pause Detection				
Competitor RT (ms)	1280 (298)	1225 (248)	1324 (266)	1505 (357)
Control RT (ms)	1160 (234)	1165 (203)	1369 (312)	1332 (338)
Competitor acc (%)	.93 (.08)	.91 (.11)	.89 (.14)	.88 (.19)
Control acc (%)	.92 (.09)	.87 (.06)	.90 (.13)	.85 (.15)

Note. Acc = accuracy

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