Orthography facilitates vocabulary learning for children with autism spectrum disorders (ASD)

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Abstract

This study investigated the extent to which children with autism spectrum disorders (ASD) can use orthography to facilitate vocabulary learning, as is the case for typically developing (TD) children. Forty-one children aged 7-12, 20 with a formal diagnosis of ASD and 21 TD peers, were taught 16 low frequency concrete science words, such as ‘breccia’. Half of the stimuli had the written word presented alongside a picture of the target item (orthography present: OP) while the remaining items were taught with orthography absent (OA). During the learning phase eye-movements were recorded; there were no group differences in the time spent fixating the written form. Production, comprehension and recognition of orthographic forms of new words were assessed immediately after learning and again after a 24 hour delay. The vocabulary learning of both groups was facilitated by the presence of orthography. Overall, the groups did not differ in comprehension of new words or recognition of new orthographic forms, although the children with ASD demonstrated superior phonological learning (as measured by a picture naming task) relative to TD peers. Additionally, both groups retained or increased new knowledge after 24 hours. The results suggest that presenting the written form during oral vocabulary teaching will enhance learning and provide a mechanism for children with ASD to increase word knowledge despite potential limitations in social learning.

Keywords: orthography; reading; vocabulary; word learning; autism spectrum disorder

Autism spectrum disorder (ASD) is a pervasive developmental disorder characterised by impairments in social interaction and social communication in the context of restricted, repetitive behaviours, interests and activities (APA, 2013). Limitations in social interaction and social understanding are thought to contribute to language learning difficulties in children with ASD, especially in the reduced ability to learn new words from social cues (Akechi et al., 2011, Baron-Cohen, Baldwin, & Crowson, 1997; Gliga et al., 2012, Parish-Morris, Hennon, Hirsh-Pasek, Golinkoff, & Tager-Flusberg, 2007; Preissler & Carey, 2005). Nevertheless, word knowledge is extremely variable within ASD; some children present with impoverished vocabularies while others develop extensive vocabularies that exceed expectations for age (Kjelgaard & Tager-Flusberg, 2001). While individual differences in social competence may explain some of the variance in vocabulary development (Luyster & Lord, 2009), such heterogeneity also suggests that some children with ASD may acquire vocabulary using alternative and less social mechanisms.

Reading is one avenue to vocabulary growth that might be especially beneficial for children with ASD. Once literacy is established, individual differences in typically developing (TD) children's vocabulary can be attributed to reading (Cunningham & Stanovich, 2001), as many new words are encountered via text. TD children are proficient at inferring new word meanings from surrounding linguistic context (Cain, Oakhill, & Elbro, 2003), but there is evidence that even the orthographic form of a new word in isolation may serve to enhance spoken word learning (Henderson, Weighall, & Gaskell, 2013; Ricketts, Bishop, & Nation, 2009; Rosenthal & Ehri, 2008). Children with ASD are often reported to be skilled at word recognition and decoding, despite general weaknesses in reading comprehension (Brown, Oram-Cardy, & Johnson, 2013; Randi, Newman, & Grigorenko, 2010). This suggests that while children with ASD may struggle to infer new meaning from connected text, they might be proficient at using orthography to support new word learning, an idea that supports the regular use of written text in picture-symbol communication systems (Frost & Bondy, 1994). Surprisingly, however, there is a dearth of research indicating that children with ASD actively use print to support learning. In this study we investigated whether children with ASD are able to use orthography to facilitate oral vocabulary learning to the same extent as typically developing peers.

The role of orthography in typical vocabulary development

Throughout the school years, there is a reciprocal relationship between vocabulary and literacy; word knowledge supports early reading comprehension, but once reading skill develops vocabulary can additionally be acquired through print (Nagy, Herman, & Anderson, 1985). Ehri (1992, 1998, 2005) suggested that familiarity with the written form of a word enhances word learning because the letters in the printed word provide cues to pronunciation, therefore facilitating mapping of orthography to phonology. Similarly, it has been suggested that the written form generates an orthographic image pertaining to the word and this supports memory of the pronunciation (Ricketts, et al., 2009; Rosenthal & Ehri, 2008). This is consistent with dual-coding theory (Sadoski, 2005) which proposes that additional sources of information, for example a visual representation supplementing a verbal representation, strengthens the mental representations of a word within the lexicon, aiding future access and retrieval. Exposure to the orthographic form may enable more fine-tuned specification of the phonological representation (Muneaux & Ziegler, 2004) and potentially enhances semantic learning. For example, adults learn definitions more rapidly for words presented with orthography, relative to those presented only in the auditory domain (Nelson, Balass, & Perfetti, 2005). Furthermore, children learn visual-verbal pairings more easily than verbal-verbal pairings (Hulme, Goetz, Gooch, Adams, & Snowling, 2007).

Experimental research has consistently demonstrated that orthography, in addition to phonological and semantic information, facilities oral vocabulary learning for TD children

(Reitsma, 1983; Ricketts, et al., 2009; Rosenthal & Ehri, 2008). These studies introduce children to novel phonological forms and referents while manipulating the presence of orthography. For instance, Reitsma (1983) taught 16 TD children (mean age 8;3) six non-words, three with orthography present (OP) and three with orthography absent (OA). During the learning phase they categorised the stimuli as either animals or fruits and this continued until the children could correctly classify all six words. During the test phase, children were asked to categorise each word six times; words taught with OP were categorised faster and more accurately than words in the OA condition.

Recently, Ricketts et al. (2009) taught 58 TD children (aged 8-9 years) 12 non-words paired with pictures of novel objects. Children were familiarised with the words prior to learning and then exposed to each stimulus six times in the learning phrase. Performance on a non-word to picture matching post-test was close to ceiling, but response times indicated that children responded more quickly to words learned in the OP condition relative to words learned without orthography. Similar findings have also been reported by Rosenthal and Ehri (2008), who taught 52 TD children (mean age 7;7) real, low-frequency concrete rare nouns (e.g. cur, wimple). This research indicates that TD children benefit from viewing the written form during oral vocabulary learning; specifically it helps them learn the pronunciation, meaning and spelling of the new word.

Vocabulary Learning in ASD

Previous studies of vocabulary acquisition in ASD have largely relied on the fast-mapping paradigm, in which children are briefly exposed to a novel word and then assessed on word recognition tasks immediately after learning. Traditionally, research has focused on the social-cognitive deficits associated with autism that may derail language acquisition (Baron-Cohen, et al., 1997; Luyster & Lord, 2009; McDuffie, Yoder, & Stone, 2006; Preissler & Carey, 2005). 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 (Norbury, Griffiths & Nation, 2010; Parish-Morris, et al., 2007), perhaps by relying on associative learning mechanisms (Parish-Morris et al., 2007; Preissler, 2008). Additionally, participant characteristics may contribute to individual differences in word learning; Luyster and Lord (2009) found that children with ASD who developed age-appropriate vocabularies learned word-object mappings as effectively as TD children matched for expressive language ability. Eight children with ASD were excluded from the study as they were unable to pass the entry task and these children had significantly lower verbal and non-verbal IQ scores than participating children. In non-social tasks, children with ASD can use mutual exclusivity to map novel words to novel objects over objects they already know (de Marchena, Eigsti, Worek, Ono, & Snedeker, 2011; Preissler & Carey, 2005). In addition, Norbury et al. (2010) found that children with ASD were especially proficient at learning the phonological forms of new words, as evidenced by superior performance on a picture naming task immediately after learning. The advantage for phonological learning was not evident four weeks later, however, as the performance of TD children increased over time, while the performance of the children with ASD remained stable.

Early proficiency in phonological learning mirrors early proficiency in phonological decoding and sight word reading that is characteristic of many, although not all, children with ASD (Nation, Clarke, Wright, & Williams, 2006; Norbury & Nation, 2011). Such word reading skill may provide an alternative or additional route to vocabulary learning. However, many children with ASD demonstrate a 'poor comprehender' profile in which reading comprehension skills lag behind chronological age expectations and word reading ability (Nation et al., 2006), which may limit the beneficial effects of orthography for aspects of new word learning. For instance, non-autistic poor comprehenders are able to use orthography to learn new phonological and orthographic forms, but have specific difficulty learning semantic information about those forms (Nation, Snowling, & Clarke, 2007; Ricketts, Bishop, & Nation, 2008). Thus, learning semantic information might remain challenging for children with ASD regardless of the availability of orthography.

Further insight into the role of orthography can be provided by considering whether children with other developmental disorders can use their reading skills to learn new words. Like children with ASD, individuals with Down Syndrome (DS) have decoding skills that are superior to text comprehension (Snowling, Nash, & Henderson, 2008). Mengoni, Nash and Hulme (2013) taught 17 children with DS and 27 younger TD children matched for word reading ability 10 non-words, five with the orthography present and five with orthography replaced by three randomly selected Greek or Cyrillic letters. The participants were exposed to each stimuli 12 times and learning was assessed 10-15 minutes after training. The presence of orthography aided spoken comprehension (word to picture matching) and production (picture naming) of the words and there were no significant differences between children with DS and the TD comparison group. These results are encouraging as they suggest that providing children with ASD with the written form of a word may enhance knowledge of phonological aspects of the word.

Retaining new knowledge over time

In order to be beneficial, knowledge must be retained after a delay. Research has demonstrated that both recognition and recall of non-words improves after a period of consolidation (typically involving sleep) for both children and adults (Brown, Weighall, Henderson & Gaskell, 2012; Henderson, Weighall, Brown & Gaskell, 2012; Dumay & Gaskell, 2007; Tamminen, Payne, Stickgold, Wamsley & Gaskell, 2010). There is little evidence regarding consolidation of phonological knowledge for children with ASD. However, Norbury, et al. (2010) taught 6-7 year old children with ASD non-word names for novel items and tested retention after four weeks. Initially, the children with ASD achieved greater accuracy on a picture naming task than the TD children, and their performance remained stable four weeks later. In contrast, naming ability increased significantly for TD children, despite no further exposure to the novel words.

There are contradictory findings regarding the consolidation of semantic knowledge. Nation et al. (2007) and Ricketts et al. (2008) taught TD children non-words and assessed semantic knowledge through a word to picture matching task. Performance remained stable over time, indicating that knowledge was retained but did not increase. In contrast, Henderson et al. (2013) found that the quality of definitions for taught science words were greater 24 hours after training than immediately after, and further increased after 7 days. The discrepancy between studies could be attributable to differences in task demands or the use of real-word versus non-word stimuli.

Poor comprehenders are significantly worse than TD peers at retaining new semantic information (Nation, et al., 2007; Ricketts, et al., 2008). Similarly, Norbury et al. (2010) found that children with ASD provided fewer semantic details about novel items than TD peers immediately after learning and group differences were more pronounced four weeks later, although in this study semantic details were learned incidentally, rather than explicitly presented. Therefore, although phonological information may be retained for children with ASD, this may not be the case for semantic information.

To date, little is known about consolidation of orthographic learning in children. Henderson et al. (2013) assessed phonological learning of new words in young, typically developing children aged 5-9 years and new words were presented with either additional semantic information, or additional orthographic information. Phonological recall was superior seven days later in the semantic condition, but not in the orthography condition. On an explicit measure of orthographic learning, the ability to recognise the new written forms was maintained over seven days, but did not significantly improve over time. However, in this case, the lack of a consolidation effect may be due to ceiling effects in the orthographic choice task immediately after learning.

One limitation of previous work is that, in the majority of cases, children have been asked to learn non-words (e.g. biscal), often presented as 'alien' words. Although this ensures that the stimuli are unfamiliar to all participants and allows stimuli characteristics to be rigorously controlled, it is questionable whether participants generally, and children with developmental disorders specifically, treat non-words in a similar fashion to words which have some relevant meaning (Potts, John, & Kirson, 1989). It may be that retention of information is improved when there is potential for longer term benefit of knowing the words for scholastic purposes. The inclusion of curriculum based vocabulary could also provide a test for word learning in more ecologically valid contexts. Indeed, Henderson et al. (2013) found improvements in the recall and recognition of newly learned science vocabulary in typically developing children 24 hours after instruction, with improvement continuing seven days later in the absence of further instruction. The current study focuses on learning science vocabulary as we felt that a focus on factual, curriculum based content would be more accessible and motivating for children with ASD and their TD peers.

The current study

The current study investigated whether orthography facilitates oral vocabulary learning for children with ASD, as it does for typically developing children and children with neurodevelopmental disorders such as Down syndrome. The study advances current research on word learning in ASD in a number of key ways. First, we test the extent to which children with ASD use relative strengths in phonological processing and single word reading, to learn new information. Second, we test word learning in a non-social yet ecologically relevant context. Third, we measure both initial learning and retention of knowledge in three domains, production (phonological learning), comprehension (semantic learning) and written form recognition (orthographic learning). Fourth, we presented children with real, low frequency science words from the UK National Curriculum. We anticipated that science topics would be particularly motivating for children and would be important for establishing evidence-based strategies for teaching and learning in ASD (cf. Henderson et al., 2013). Finally, we included an objective measure of the extent to which children visually focus on the orthographic form, in order to better understand any potential group differences in how children use orthography to support word learning. The study allowed us to answer three key questions:

1. Does the presence of orthography facilitate oral vocabulary learning of children with ASD? It was hypothesised that orthography would support the phonological, semantic and orthographic learning of both groups. However, we anticipated group differences on overall task accuracy. We predicted that children with ASD would be more proficient at picture naming than their TD peers (cf. Norbury et al., 2010), but poorer at semantic learning relative to TD peers (on the basis of the poor comprehender literature, cf. Nation et al., 2007; Ricketts et al., 2008). Group differences regarding orthographic learning were less certain, as orthographic learning has not been previously assessed in ASD.
2. Is newly learned information retained over a 24 hour period? Based on previous research, we anticipated that newly learned information would be maintained over a 24-hour period across all three tasks (Henderson et al., 2013). Henderson and colleagues did not observe improvements in word form recognition (orthographic choice) at 24-hours or seven days for TD children. However, after 24 hours there was an increase in semantic knowledge, as assessed by both spoken word to picture matching and definitions tasks. Additionally, previous studies have reported improvements in picture naming (an index of phonological learning) over time for TD

children, but not for children with ASD (cf. Norbury et al., 2010). We therefore expected similar improvements in naming for TD children over 24 hours that would not be evident in participants with ASD.

3. Are any group differences in learning and retention due to initial differences in visual attention to the orthographic form? Recent studies have highlighted both enhanced perceptual capacity in individuals with ASD (Remington, Swettenham, & Lavie, 2012) and differences in top-down control of visual attention (Kelly, Walker, & Norbury, 2013) either of which may contribute to group differences in visual fixations to orthographic forms. We therefore recorded eye-movements during learning trials to index the amount of time spent looking at the printed word relative to the image.

Method

Participants

Forty-seven children aged 7-12 years were recruited to the study. Children with ASD (n = 26, 19 male) all held an existing diagnosis based on DSM-IV/ICD-10 criteria from a multi-disciplinary team external to the research group and were currently in receipt of a statement of special educational need for placement in a specialist school or unit serving children with ASD. In addition, they met criteria for ASD on module 3 of the Autism Diagnostic Observation Schedule (ADOS; Lord, Rutter, DiLavore, & Risi, (2000). Twenty-one TD children (12 male) were recruited from local schools and communities and did not have any reported special educational needs or a history of ASD, language delay or literacy difficulties. The study protocol was approved by the Research Ethics Committee at Royal Holloway, University of London. Informed, written consent was obtained from all parents and verbal assent was obtained from all children prior to assessment.

Non-verbal and verbal abilities were assessed using the Matrix Reasoning and Vocabulary Definitions sub-tests of the Wechsler Abbreviated Scales of Intelligence (WASI;

Wechsler, 1999). Vocabulary was measured using the Expressive One Word Picture Vocabulary Test (Gardner, 1990a), a picture naming task, and the Receptive One Word Picture Vocabulary Test (Gardner, 1990b), a spoken word to picture matching task. Single word reading and phonological decoding was assessed using the sight word efficiency (SWE) and phonemic decoding efficiency (PDE) subtests of the Test of Word Reading Efficiency (TOWRE: Torgesen, Wagner, & Rashotte, 1999). The TOWRE requires children to read lists of words or non-words respectively and the number read accurately in 45 seconds is recorded, providing a measure that combines both reading accuracy and reading fluency.

In order to ensure that all children had sufficient reading skill to use the written form for learning, inclusion criteria stipulated that children achieved a minimum raw score of 10 (age equivalent of 7 years) on the PDE subtest of the TOWRE. This resulted in the exclusion of six children with ASD. Thus, 20 participants with ASD (15 male) were included in the study. Groups were matched on raw and standard scores of the PDE. We selected non-word, as opposed to real-word, reading because non-words provide a 'purer' measure of phonological decoding, less subject to the influences of existing vocabulary and reading comprehension abilities (Nation & Snowling, 1998). Indeed, although the groups did not differ significantly on chronological age or cognitive ability, they differed significantly on measures of measures of expressive and receptive vocabulary and sight word reading, though mean scores were within the average range (see Table 1).

INSERT TABLE 1 ABOUT HERE

Materials

Two lists of eight low-frequency words associated with secondary school (ages 11-16) science curriculum were constructed from stimuli created by Henderson et al. (2013, see Appendix for complete list of stimuli). Each list contained three words relating to animals (e.g. 'smolt'), two words relating to plants (e.g. 'lantana') and three words relating to neither animals nor plants (other category, e.g. 'breccia'). Lists were counterbalanced across participants. Words were rated for age of acquisition, familiarity, and imageability by 18 educational professionals (teachers, teaching assistants) and researchers who work with children (mean age 26.4 years; SD = 4.82 years; 4 males, 14 females; Henderson et al., 2013). As summarised in Table 2, the words in Set A and B were closely matched for age of acquisition (AOA), familiarity, imageability and length (number of letters and number of syllables). The images were colour photographs obtained from www.clipart.com and www.fotosearch.com/clip-art, as children are able to generalise word meanings from picture books better if the books contain realistic photographs or colour drawings rather than simple line drawings (e.g., Simcock & DeLoache, 2006, 2008; Tare, Chiong, Ganea, & DeLoache, 2010).

INSERT TABLE 2 ABOUT HERE

Procedure

The experiment had a 'learning' phase and a 'test' phase and was programmed using E-Prime (Psychology Software Tools, Pittsburgh, PA). Prior to the learning phase each word was heard once by the children and they were asked whether they knew the word. Any YES responses were probed further (i.e.by asking children to provide a definition 'what is an X; what do you know about an X'). None of the children provided an accurate definition for any of the words. In addition to ensuring that the stimuli were unknown, this procedure familiarised the children with the words prior to learning (cf. Ricketts et al., 2009).

Learning phase.

During the learning phase, eye-movements were recorded binocularly using a Tobii T120 eye tracker, which has an average gaze position error of 0.5° and a spatial resolution of 0.2°. Although the T120 can sample at a maximum rate of 120Hz, it is less tolerant of the extreme head movements observed in some of our ASD participants. Consequently, a 60 Hz sampling rate was utilised for this study. Children viewed the screen from a distance of 60cm. Prior to testing, a 5-point calibration and validation procedure was conducted in Tobii Studio software and repeated throughout the testing session as required. Raw data were extracted and analysed using custom written Matlab (The Mathworks, MA) code. Two regions of interest (ROIs) were identified: the picture region measuring 10.5° x 10.7° visual angle and the word region measuring 7° x 2.8°. Fixations were defined as stable looking (±0.5°) for a minimum of 100 ms. Eye-tracking data was unavailable for one TD participant due to technical error.

During the learning phase, children heard a word paired with the corresponding picture. The picture remained on the screen for 500ms. The 16 stimuli (eight presented with OP and eight OA) were presented in random order. During the first exposure, children listened to the words whilst viewing the pictures on the computer screen. On the second exposure, trials were followed with the question 'Is this to do with animals or plants or neither?' Children responded by pressing the relevant keyboard key (marked a, p, o with stickers). Visual feedback regarding accuracy was provided. During the learning phase children were exposed to each stimulus twice, as piloting with four exposures yielded ceiling effects on two of the three post-tests for TD children.

Test phase.

Phonological, semantic and orthographic learning were assessed through three tasks.

1. Picture naming: Children were presented with a picture and asked to name it, providing an index of phonological learning. Presentation order was randomised and accuracy was recorded.
2. Spoken word-picture matching: Children heard a spoken word accompanied by four images. One of these was the target stimuli and the other three items were distracter items from the stimulus set. Children were asked to identify the relevant picture by pressing the

appropriate keyboard key (marked 1, 2, 3 or 4 with stickers). Presentation order was randomised and accuracy was recorded. This task measures comprehension of newly learned words and taps very basic semantic knowledge.

3. Orthographic choice task: Children heard a word accompanied by the written form and a foil (e.g. 'catalyst' and 'catalist'). They were instructed to identify the correct spelling by pressing the corresponding key on the keyboard. Presentation order was randomised and accuracy was recorded.

On Day 1, there was a 5-10 minutes break between the learning and the test phase during which time children completed the matrix reasoning task. The three learning outcome measures were re-administered the following day.

Results

Do Children with ASD Fixate on Orthography to the Same Extent as TD Peers?

The average duration of fixations to each of the word and picture ROIs, as well as the percentage of total fixations to each of these regions was examined (Table 3). In the orthography present condition, there were no significant group differences in average fixation duration or percentage of total fixations to the word region, ts < 1. There were, however, marginal differences in the duration of looking time to the picture, with the TD group gazing on average 300ms longer than ASD peers, $t(38) = 1.96$, $p = .057$. The percentage of total fixations made to the picture region was similar between groups in the OP condition, $t(38) = .19$, $p = .85$. In the OA condition, both groups spent considerably more time fixating the picture region and there were no group differences in total fixation time, $t(37) = 1.70$, $p = .10$, or percentage of fixations to the picture region, $t(37) = 1.56$, $p = .13$. There were marginal differences in the duration, $t(37) = 2.00$, $p = .05$ and percentage of looking times, $t(37) = 1.96$, $p = .058$, to the word region. The ASD group looked slightly more frequently to this region, even though there was nothing in it.

INSERT TABLE 3 ABOUT HERE

Does Orthography Facilitate Vocabulary Learning and is Knowledge Retained?

Picture naming.

This was a challenging task, with mean accuracy rates of less than 12% on Day 1, rising to 38% on Day 2. Four children (two TD and two with ASD) were unable to name any pictures correctly. Nevertheless, as illustrated in Figure 1, the presence of orthography did support picture naming accuracy in both groups. Raw scores were entered into a 2 (group: TD versus ASD) x 2 (orthography: OP versus OA) x 2 (day) repeated measures analysis of variance. There was a main effect of orthography by participants $F_1(1, 39) = 32.08$, $p < .001$, $\eta_p^2 = .45$ and by items $F_2(1, 15) = 16.43$, $p = .001$, $\eta_p^2 = .52$, confirming that items learned in the OP condition were named more accurately than the items in the OA condition. There was also a main effect of day $F_1(1, 39) = 34.69$, $p < .001$, $\eta_p^2 = .47$; $F_2(1, 15) = 12.48$, $p = .003$, $\eta_p^2 = .45$, with higher accuracy scores attained on Day 2. There was a small, but significant main effect of group by participants, $F_1(1, 39) = 4.14$, $p = .049$, $\eta_p^2 = .10$, but this was not significant by items, $F_2(1,15) = 1.74$, $p = .21$, $\eta_p^2 = .10$. Children with ASD tended to name more pictures accurately than TD peers, although the effect size was small. There was a day x orthography interaction by group, $F_1(1, 39) = 4.76$, $p = .035$, $\eta_p^2 = .11$, but not by items, $F_2 < 1$. In general, the effect of OP was more pronounced on Day 2. None of the other interaction terms were significant, all Fs < 1.

INSERT FIGURE 1 ABOUT HERE

Spoken word to picture matching.

Overall, accuracy scores averaged between 62% and 81% correct for both groups, indicating that despite relatively few exposures, children were able to learn the words well enough to distinguish them from other items to which they had been exposed. A 2 (group) x 2 (orthography) x 2 (day) repeated measures ANOVA was conducted on word to picture matching accuracy scores (maximum score = 8). As illustrated by Figure 2, there was a main effect of orthography by participants $F_1(1, 39) = 6.33$, $p = .016$, $\eta_p^2 = .14$ and by items $F_2(1, 15) = 5.04$, $p = .04$, $\eta_p^2 = .25$, with higher accuracy scores for items learned with OP. There was no main effect of day $F_1(1, 39) = 1.69$, $p = .20$, $F_2(1, 15) = .34$, $p = .57$, and no main effect of group $F_1(1, 39) = .09$, $p = .77$, $F_2(1, 15) = .51$, $p = .49$. There was a significant orthography x group interaction by group, $F_1(1, 39) =5.01$, $p = .031$, $\eta_p^2 = .14$, but not by items, $F_2 < 1$. Paired samples t-tests demonstrated that there was no significant difference between the OP and OA accuracy scores for the TD group, $t(20) = .22$, $p = .825$. The ASD group, however, achieved significantly higher scores for words learned in the OP condition relative to the OA condition, $t(20) = 3.00$, $p = .007$, $\eta^2 = .32$.

INSERT FIGURE 2 ABOUT HERE

Orthographic choice.

As with the word to picture matching task, accuracy on the orthographic choice task was uniformly high, averaging between 62% and 87% correct. A 2 (group) x 2 (orthography) x 2 (day) repeated measures ANOVA revealed a main effect of orthography by participants $F_1(1,39)= 20.27$, $p < .001$, $\eta_p^2 = .34$ and by items $F_2(1, 15) = 9.09$, $p = .009$, $\eta_p^2 = .38$, such that items learned with OP were more accurate than the items learned without orthography. There were no main effects of day, F_1 and $F_2 < 1$. The main effect of group approached significance, $F1(1, 39) =3.52$, $p = .068$, $\eta_p^2 = .08$; $F_2(1, 15) = 4.13$, $p = .06$, $\eta_p^2 = .22$, with tendency for the TD group to achieve higher accuracy scores than the ASD group. None of the interaction terms were significant by group or by items, all Fs < 1.

INSERT FIGURE 3 ABOUT HERE

Summary.

Orthography facilitated the learning of phonological, semantic and orthographic characteristics of new words for children with ASD and their TD peers. Children with ASD learned phonological information more readily than their TD peers. While there was a trend for the TD group to show superior orthographic learning overall, children with ASD benefitted more from the presence of orthography in learning new orthographic forms. There were no group differences in terms of semantic learning. Both groups retained semantic and orthographic knowledge from Day 1 to Day 2, and naming accuracy (an index on phonological learning) increased overnight for both groups.

Discussion

This study investigated whether orthography facilitates oral vocabulary learning for school-aged children with ASD who, as a group, had age appropriate decoding skills. Children were taught 16 low-frequency science words and learning was assessed via three post-tests; picture naming, spoken-word to picture matching and orthographic choice. The key finding is that orthography facilitated learning for both groups of children, particularly phonological and orthographic details of new words, and that new information was retained over a 24-hour period. In the remainder of this paper we return to the questions posed in the introduction.

Does orthography support oral vocabulary learning for children with ASD?

Vocabulary learning is facilitated by the presence of orthography for TD children (Reitsma, 1983; Ricketts, et al., 2009; Rosenthal & Ehri, 2008) and children with Down syndrome (Mengoni, et al., 2013). The present study extends these findings by demonstrating for the first time that this is also the case for children with ASD who had developed proficient phonological decoding and single word reading skills.

There were, however, subtle differences between children with ASD and their typically developing peers. Consistent with previous research (Norbury, et al., 2010), children with ASD learned the names of the new items more readily than their TD peers, suggesting that immediate phonological learning may be an area of strength for some children with ASD and may circumvent social-cognitive limits to word learning. However, the performance of the children with ASD was significantly poorer than the TD group on standardised measures of vocabulary knowledge and single, sight-word reading proficiency. Thus, there is a disparity between children with ASD's ability to acquire information about new word forms and meanings, and the storage, integration and retrieval of this lexical information over a longer period of time. In addition, while recognition of new words was very good, overall rates of naming accuracy in this study were disappointingly low in both the ASD and TD groups (cf. Mengoni et al., 2013). It is likely that this reflects the relatively large number of words to be learned (n = 16) and the limited number of exposures children received (one pre-learning exposure and two exposures during the learning phase). Future research will need to vary both the number of new words to be learned and the number of exposures required for each word in order to determine an optimal learning environment.

Orthography was particularly beneficial for children with ASD when learning novel orthographic forms, more so than for TD peers. Analyses suggested that this was because TD children outperformed children with ASD in the OA condition, and thus did not need to make use of orthography in the same way. The TD children had greater existing orthographic knowledge, as indexed by higher TOWRE SWE scores; it is therefore possible that they were able to generate the orthography independently, whereas children with ASD were less likely to do so. A more direct test of this hypothesis would be to ask children to spell words that had been learned in OA and OP conditions. An alternative strategy would be to see whether actively engaging orthographical learning, for example by instructing the children to read aloud the written form, would generalise to the OA condition.

One could ask whether it is the orthography specifically that supports learning, or just the presence of additional information or cues that supports representations of new words. Mengoni et al. (2013) attempted to distinguish these two possibilities by including unfamiliar symbols in the 'OA' condition and found that indeed, only the presence of meaningful orthography facilitated vocabulary learning. We chose not to include such a control in our experiment. First, it is not apparent that having additional visual stimuli is necessarily helpful, and is arguably only helpful if children can implicitly form associations between these visual symbols and the new words. There is considerable debate as to whether or not associative learning mechanisms develop appropriately in ASD and little evidence that such mechanisms would be employed implicitly. Furthermore, there is evidence that at least some individuals with ASD may attend more to visual items in the periphery (Remington, et al., 2012) and this could serve to distract children with ASD from the task at hand (cf. Kelly et al., 2013). Future studies could usefully contrast learning with orthography to learning in other conditions in which meaningful information (i.e. definitions or semantic cues) are also provided (cf. Henderson et al., 2013).

Orthography is thought to support oral vocabulary learning because the written form provides cues to pronunciation. On this view, orthography should be particularly beneficial when the words to be learned have consistent grapheme-phoneme correspondences. Indeed, previous research has demonstrated that regular words are learned more readily than irregular words (Wang, Castles, & Nickels, 2012), though orthography is most beneficial for learning new words with irregular spellings (Ricketts et al., 2009, but see Rastle, McCormick, Bayliss & Davis, 2011). We did not control for regularity in the present study; to provide such a control would require use of non-word stimuli, as employed by Ricketts et al. (2009) and Mengoni et al. (2013). Given the educational challenges children with ASD face, we felt it would be more beneficial to see if we could support learning of words that had scholastic relevance. In addition, it is questionable whether participants generally, and children with developmental disorders in particular, treat non-words in a similar fashion to words which have some relevant meaning (Potts, et al., 1989). We felt that science words in particular would be motivating to school-aged children and tap an area of interest for many individuals with ASD.

Is newly learned information retained?

The ultimate goal of learning is to provide long term, stable representations of new word knowledge, something that requires a prolonged process of memory consolidation. Few previous studies of word learning in ASD have measured longer term retention of newly learned words. Norbury et al. (2010) reported that in ASD, phonological learning, as indexed by a picture naming task, remained stable over a four-week period. In contrast, performance by typically developing peers improved over the same period. In the current study, naming performance improved for both groups over a 24-hour period, and this improvement was particularly evident if the word was learned with orthography present. It is therefore possible that orthography influences consolidation processes, which may be qualitatively different in children with ASD (Henderson, Powell, Gaskell, & Norbury, under revision). A more stringent test of consolidation would be to measure the extent to which newly learned words engage in lexical competition with similar known words (cf. Henderson et al., 2012). Exploration of knowledge retention over a longer period is also necessary.

In contrast, though consistent with previous research (Nation et al., 2007; Norbury et al., 2010; Ricketts et al., 2008), in the current study there was no improvement in either group on the word to picture matching task or the orthographic choice task, but neither did children ‘forget’ newly learned material.

Are there any group differences in visual attention to the orthographic form?

Unlike previous studies, we used eye-tracking methods to ensure that participants at least inspected orthographic forms to a similar degree. The inclusion of eye-tracking during learning revealed that both groups of children fixated on the written form to a similar extent. In the orthography absent condition, children with ASD looked longer to the word region, perhaps suggesting that they actively sought this additional cue to learning. There were small, but significant differences in fixation duration to the picture, with the TD group gazing longer at the image. Subtle differences in the allocation of visual attention to different sources of information during the learning process did not interfere with performance in this task, but may contribute to the quality of representations acquired over time.

Future directions

Our results are encouraging in demonstrating that providing orthography supports learning of complex concepts for children with ASD. However, our participants were a relatively able group with word and non-word reading scores within the normal range. A significant proportion of children with ASD are not proficient at decoding text (Nation et al., 2006) and it is therefore unlikely that presenting orthography alone would facilitate word learning in the same way. An important question for future research is whether presenting the orthographic form supports learning for beginning readers or actually hinders vocabulary development by diverting attention and processing resources from other aspects of word learning. For example, a child struggling to read may spend more processing effort trying to decode a word and not attend to the referent or link the referent with the spoken phonological form. Application of eye-tracking measures in word learning tasks aimed at a more diverse group of learners with ASD should elucidate this matter. However, our research does suggest that there are potential alternative routes to word learning in ASD. Thus, in order to understand the heterogeneity that exists in vocabulary development within this population, it is necessary to consider individual differences in a range of cognitive skills, including social-cognitive abilities (Luyster & Lord, 2009), phonological skill (cf. Jones et al., 2009) and reading competence (Nation et al., 2006).

We did not measure text comprehension in this study but this is an important skill that may also assist vocabulary development; typically developing children infer new word meanings from written contexts (Carnine, Kameenui, & Coyle, 1984; Herman, Anderson, Pearson, & Nagy, 1987; Jenkins, Stein, & Wysocki, 1984; Nagy, et al., 1985). Many verbally able children with ASD have difficulties comprehending texts and are particularly poor at making inferences, despite age appropriate decoding skills (Norbury & Nation, 2011). This suggests that children with ASD may be able to learn vocabulary that has been explicitly taught, but have difficulty spontaneously using text to learn new words. There is some indication in our data that this is indeed the case; although groups were matched for decoding skill, the children with ASD had significantly poorer expressive and receptive vocabulary scores.

Developmental and clinical implications

Early in development, children's exposure to new words comes almost exclusively through their interactions with other people, and the ability to 'tune-in' to the social cues and intentions of the conversational partner is paramount to learning meaning and uncovering the structural regularities of speech (Kuhl, 2007; Kuhl, Coffey-Corina, Padden, & Dawson, 2005). The social differences that characterise ASD are therefore likely to contribute to the significant delays in acquiring first words and phrases and the often protracted rate of vocabulary development in this group (Hudry et al., 2010). In the pre-school years, individual differences in vocabulary growth are likely to be associated with individual differences in social behaviour (Luyster & Lord, 2009; Smith, Mirenda, & Zaidman-Zait, 2007) and phonological and perceptual aptitude (cf. Jones et al., 2009). As children get older, their ability to learn independently from context grows. Here, children with ASD are also likely to be disadvantaged. However, our results suggest that those children who can read will have some facility for learning from print. The National Institute of Child Health and Development (NICHD, 2010) has argued that at least some vocabulary should be explicitly taught, particularly concepts that are complex and not part of a child's everyday experience.

Direct instruction, supported by orthography, is likely to strengthen phonological, semantic and orthographic connections within the lexicon and support longer term retention of new information. In ASD, orthography represents an opportunity to capitalise on strengths in phonology and word reading, to compensate for weaknesses in semantic and social learning. Future research should include classroom-based studies that vary the social context, the number of exposures and the amount of semantic and orthographic information provided to determine the optimal learning contexts for children with ASD.

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Table 1

Descriptive statistics for age and background variables for typically developing (TD) children and children with autism spectrum disorder (ASD).

Variable		TD n=21	ASD n=20	*t*(39)	*p-value*
Chronological age (years)		10.46 (.92)	10.57 (1.37)	-.30	.766
Gender:					
Male		12	15	1.45	x^2 = .23
Female		9	5		
Cognitive ability[1]:					
WASI matrix reasoning		50.29 (6.04)	51.75 (8.89)	.62	.542
WASI verbal definitions		54.05 (10.41)	57.85 (13.10)	1.68	.101
Language[2]:					
Expressive one-word picture vocabulary test		110.05 (9.64)	98.52 (14.54)	2.93	.006
Receptive one-word picture vocabulary test		110.19 (11.68)	95.60 (20.01)	2.83	.008
Literacy[2]:					
TOWRE SWE	Raw score	69.88 (6.18)	63.10 (15.25)	1.85	.076
	Standard Score	104.10 (9.61)	95.48 (13.11)	2.41	.022
TOWRE PDE	Raw score	38.00 (8.32)	34.53 (11.41)	1.19	.270
	Standard Score	105.69 (12.48)	101.13 (16.94)	.99	.335
Autistic symptomatology[3]:					
SCQ		3.47 (2.67)	22.27 (5.91)	11.83	< .001
ADOS (Total)			11.92 (3.84)		

Note: [1] scores are presented as t-scores, with a normative mean of 50, SD 10. [2] scores are presented as standard scores, with a normative mean of 100, SD 15. [3] raw scores are presented; SCQ scores of ≥15 and ADOS scores of ≥ 7 are indicative of autism spectrum disorder.

Table 2

Stimuli characteristics: mean (SD) and range

	Set 1	Set 2	*t*-value	*p* value
Age of Acquisition	17.15 (2.66) 14.20-23.00	16.08 (1.93) 14.00-19.50	.92	.375
Familiarity	2.55 (2.67) 0.27-8.83	2.75 (2.21) 0.30-5.40	-.16	.873
Imageability	1.64 (1.16) 0.20-3.40	2.11 (1.93) 0.70-5.40	-.59	.567
Number of letters	7.38 (1.85) 5-11	6.88 (1.46) 4-9	.60	.557
Number of syllables	2.50 (.76) 1-3	2.50 (.54) 2-3	.00	1.00

Table 3

Mean percentage of fixations to word and picture regions of interest (ROI), and mean fixation duration (in seconds) to each ROI during the learning phase

	TD	ASD	*t*-value	*p*-value
Orthography present:				
Percent fixations to word region	30.09 (8.29)	30.66 (8.08)	.07	.793
Percent fixations to picture region	66.08 (7.00)	65.62 (8.40)	.19	.850
Duration of fixations on the word region	.86 (.29)	.83 (.35)	.24	.514
Duration of fixations on the picture	2.23 (.50)	1.92 (.47)	1.96	.057
Orthography absent:				
Percent fixations to word region	3.84 (2.56)	6.59 (5.58)	1.96	.058
Percent fixations to picture region	89.02 (6.05)	85.91 (6.41)	2.44	.127
Duration of fixations on the word region	.17 (.11)	.29 (.23)	2.00	.053
Duration of fixations on the picture	3.91 (.68)	3.43 (1.03)	2.90	.097

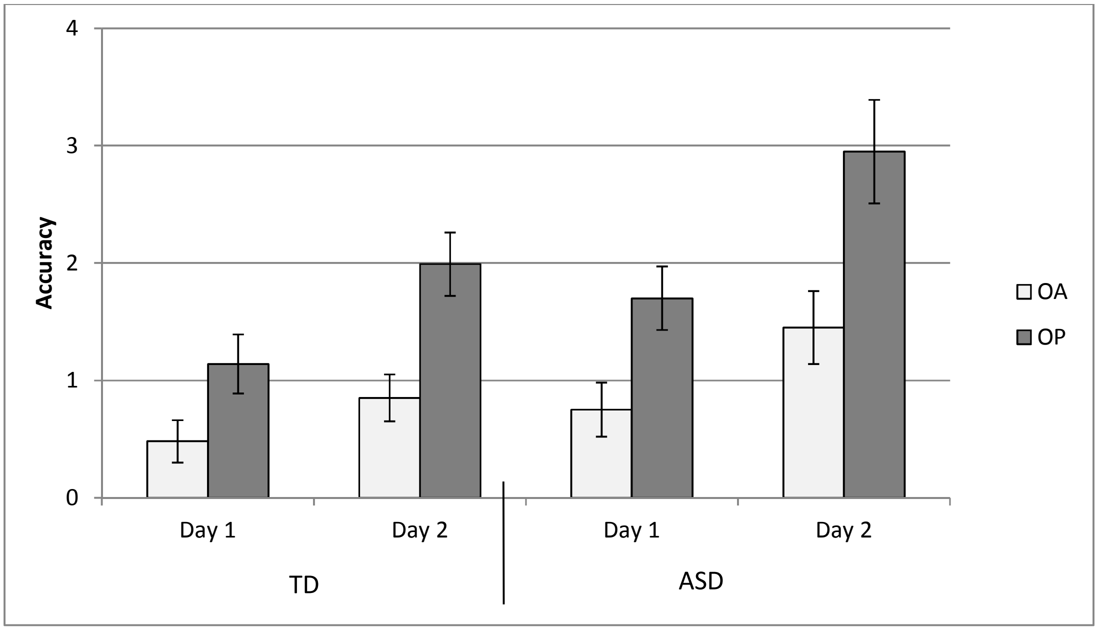

Figure 1. Mean accuracy on the picture naming task for TD and ASD children (maximum score = 8). There were significant main effects of group, orthography and day, as well as a significant day x orthography interaction. Error bars represent standard error.

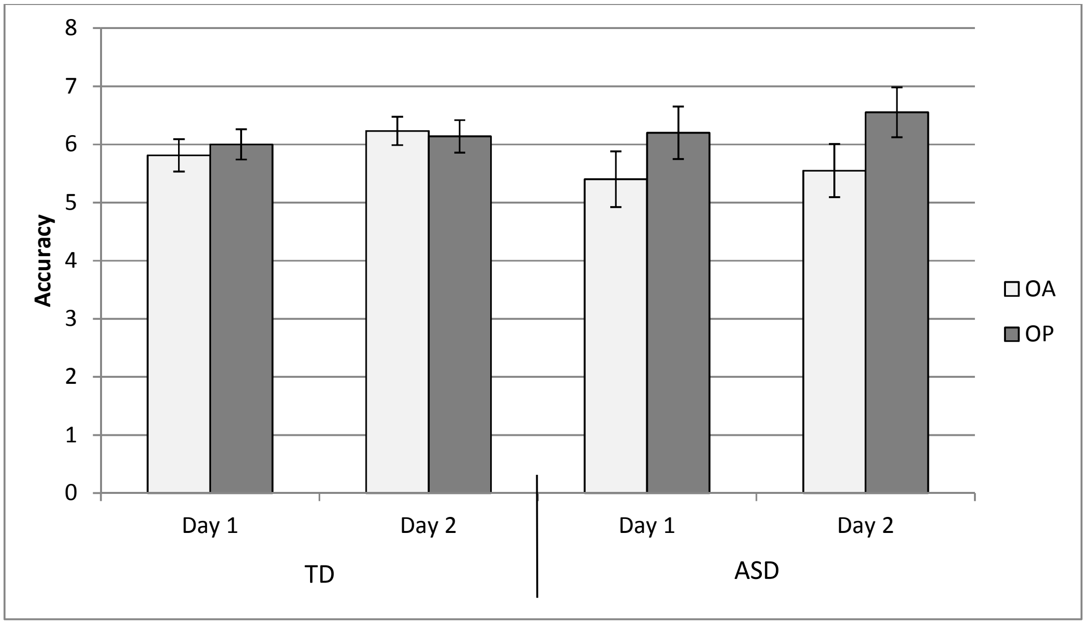

Figure 2. Mean accuracy on the spoken word to picture matching task for TD and ASD children. There was a significant group x orthography interaction, with OP facilitating learning for the ASD group, but not for the TD group. Error bars represent standard error.

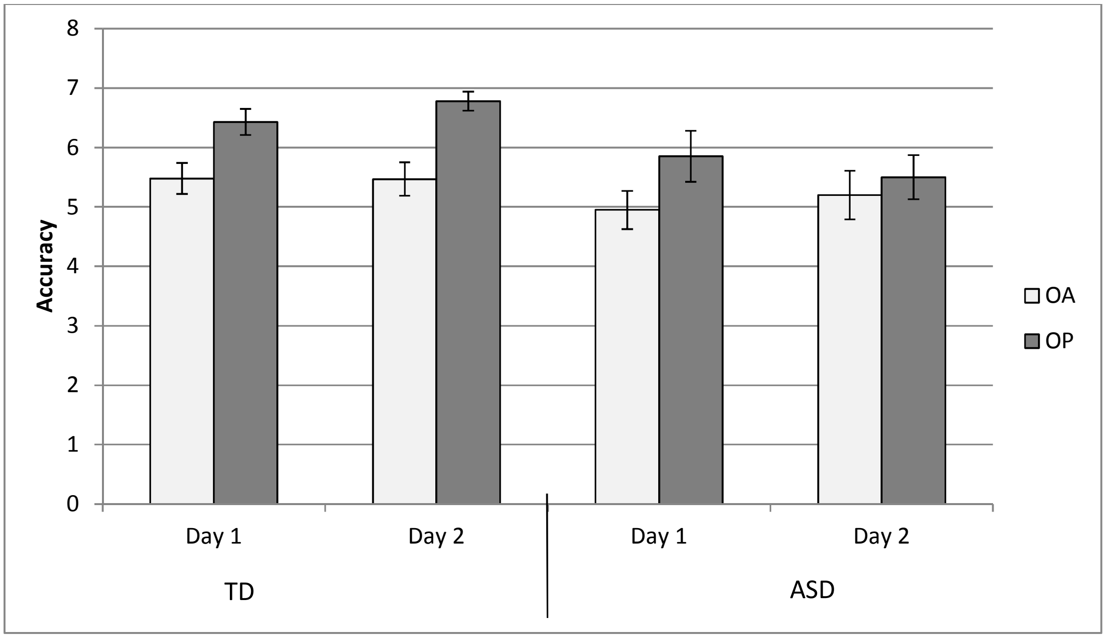

Figure 3. Mean accuracy on the orthographic choice task for TD and ASD children. There was a significant main effect of orthography only. Error bars represent standard error.

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Appendix

Stimuli characteristics

Stimuli	Age of acquisition	Familiarity	Imageability	Syllables
Set A				
catalyst	15.70	8.53	3.40	3.00
gadfly	18.00	2.47	2.07	2.00
lantana	17.67	0.27	0.20	3.00
miscible	14.20	2.40	1.87	3.00
palisade	15.50	2.47	1.60	3.00
ratite	16.25	0.33	0.60	2.00
smolt	23.00	0.70	0.50	1.00
troposphere	16.86	3.20	2.90	3.00
Average	17.15	2.55	1.64	2.50
Set B				
breccia	14.00	0.30	2.90	3.00
crawdad	17.67	0.50	0.20	2.00
mastodon	19.50	2.40	0.60	3.00
photon	15.20	5.40	1.60	2.00
pupa	14.86	5.10	2.80	2.00
quartzite	16.43	2.10	5.40	2.00
stomata	17.00	5.30	2.00	3.00
tropism	14.00	0.87	4.20	3.00
Average	16.08	2.75	2.11	2.50