Subskills associated with spelling ability in children with and without autism spectrum disorders

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Abstract
Background and aims: Effective literacy instruction demands a clear understanding of the subskills that underpin children’s reading and writing abilities. Some previous research on reading has questioned whether the same subskills support literacy acquisition for typically developing children and children with autism spectrum disorders. This study examined the subskills associated with spelling ability in a group of 20 children with ASD aged 5–12 years (ASD group). A group of 20 typically developing children matched for age and word spelling accuracy (TD group) provided comparative data.

Methods: Participants completed standardised assessments of vocabulary, phonological awareness, letter knowledge and word spelling. Errors produced in response to the word spelling assessment were analysed for evidence of phonological awareness. In addition, all spelling attempts were analysed for evidence of phonological, orthographic, and morphological awareness, ‘linguistic awareness’, using the Computerised Spelling Sensitivity System.

Results: Correlation and regression analyses showed statistically significant relationships between phonological awareness and word spelling accuracy for children in the ASD and TD groups. Spelling errors produced by both groups contained evidence of phonological awareness. Analysis of all spelling attempts showed that the overall level of linguistic awareness encoded by children in the ASD and TD groups was not significantly different.

Conclusions: These findings provide evidence that phonological awareness and other subskills support spelling in children with autism spectrum disorders as they do in typically developing children.

Implications: The similar spelling profiles exhibited by children with autism spectrum disorders and their typically developing peers suggest that these populations may benefit from literacy instruction that targets the same underpinning subskills.

Keywords
Autism spectrum disorders, computerised spelling sensitivity system, phonological awareness, spelling, spelling error analysis

Autism spectrum disorders (ASD) are a group of highly heterogeneous neurodevelopmental disabilities characterised by atypical social interaction skills in conjunction with restricted and repetitive patterns of behaviour or interests (American Psychiatric Association, 2013). These characteristics limit the ability of some children with ASD to participate in otherwise valuable learning opportunities, including classroom literacy instruction (Ruble & Robson, 2007; Williams, Wright, Callaghan, & Coughlan, 2002). Many children in this population also present with oral language difficulties which have been linked to impaired literacy development (Bishop & Clarkson, 2003; Jacobs & Richdale, 2013; Loucas et al., 2008; Nash & Arciuli, 2016). For these reasons, some children with ASD will experience difficulties in learning to read and spell. A key question for researchers, clinicians, and educators who wish to understand and remediate these difficulties is whether the same subskills
underpin literacy development in children with and without ASD.

Previous research on literacy and ASD has focused primarily on the skills underlying children’s reading development. Newman et al. (2007) investigated whether variables related to Seidenberg and McClelland’s (1989) connectionist model of single word recognition, namely phonological (awareness of sound structure), orthographic (awareness of spelling conventions) and semantic abilities (vocabulary), were associated with reading accuracy skills for a sample of 40 individuals with ASD aged 3–19 years. Eighteen typically developing individuals provided comparative data. Results showed no significant differences in the underlying phonological, orthographic, and semantic abilities of typically developing children and children with ASD who had normal word reading accuracy. In contrast, children with ASD who had low word reading accuracy exhibited significant deficits across all three target abilities. Jacobs and Richdale (2013) examined predictors of reading ability in children with ASD and typically developing children, also finding that the skills underlying reading accuracy are similar for the two populations.

As far as we are aware, only two studies have focused specifically on the skills underlying spelling in children with ASD. In the first of these, Wiggins, Diehl, Bahr, and Silliman (2010) analysed spelling errors produced by 29 children with ASD aged 8–15 years. Analysis using the Phonological, Orthographic, and Morphological Analysis of Spelling (POMAS; Silliman, Bahr, & Peters, 2006) showed that children with ASD, like typically developing children, had difficulty spelling derivational morphemes which involve a change in the pronunciation of the preceding root word (e.g. ‘majority’). These children were more accurate in their spelling of transparent derivational morphemes, which do not affect the pronunciation or spelling of the root word (e.g. ‘assignment’). Children with ASD also produced a high proportion of orthographic spelling errors (i.e. errors which encode the phonemes of the target). These findings indicate that children with ASD may utilise phonological abilities in a manner similar to typically developing children when spelling.

Cardoso-Martins, Gonçalves, de Magalhães, and da Silva (2015) investigated the spelling abilities of 19 Portuguese-speaking individuals with ASD aged 6–18 years and 19 typically developing individuals who were matched on the basis of reading accuracy. Errors produced in response to a standardised spelling assessment (in Portuguese) were analysed in terms of phonological distance from their respective target words. Errors were awarded one point for each letter addition, letter omission or phonologically implausible letter substitution. The number of additions, omissions and substitutions produced by each participant was then divided by their total number of spelling errors to produce a mean distance score. Results showed that the mean distance score achieved by individuals with ASD was significantly higher than that of the typically developing group. Thus, while individuals with ASD seem to draw on phonological abilities when spelling just like their typical peers, the findings of this study suggested that they may experience increased difficulty encoding phonemic information.

An alternative perspective is that literacy is supported by different subskills in children with ASD versus typically developing children. Findings which challenge the role of phonological awareness in supporting reading in children with ASD are particularly noteworthy. For example, Smith-Gabig (2010) investigated the reading accuracy and phonological awareness skills of 14 children with ASD aged 5–7 years. Participants completed a battery of assessments which included the Word Identification and Word Attack subtests from the Woodcock Reading Mastery Test–Revised (WRMT-R; Woodcock, 1988) and the Elision and Blending Words subtests from the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, & Rashotte, 1999). Results revealed no statistically significant relationships between measures of phonological awareness and reading accuracy. This is consistent with findings reported by Cronin (2014) and suggests that phonological awareness may not support reading accuracy for children with ASD.

Based on the findings of Smith-Gabig (2010), some in the field have advocated for the use of non-phonological or ‘sight word’ literacy instruction for children with ASD (e.g. see the case study reported by Yaw et al., 2011). By contrast, others have suggested that children with ASD may benefit from literacy instruction based on the recommendations for typically developing children which includes a strong focus on phonological awareness and phonics (e.g. Bailey, Arciuli, & Stancliffe, 2017a, 2017b). As there is much at stake in the quest for appropriate methods of literacy instruction for children with ASD, additional research is required to clarify the relationship between phonological awareness and literacy for children in this population. As mentioned, previous investigations have often focused on reading. However, the nature of children’s spelling attempts can be revealing in terms of whether they reflect underlying phonological awareness, as well as orthographic and morphological awareness.

**Spelling error analysis**

Spelling errors contain a wealth of information about children’s knowledge of the sounds in words and their ability to represent these sounds in a way consistent with spelling conventions (Bourassa & Treiman,
2001). These insights have been instrumental in shedding light on the types of knowledge underlying literacy for typically developing children. In a study involving spelling error analysis, Caravolas, Hulme, and Snowling (2001) evaluated the spelling, cognitive and oral language abilities of 153 typically developing children over their first 18 months of schooling. These children underwent an assessment battery which included a subtest of the Wechsler Objective Reading Dimensions (WORD; Rust, Golombok, & Trickey, 1993) and an experimental spelling accuracy assessment. Results revealed high correlations between the production of phonologically plausible errors (e.g. *buc* for ‘book’) and word spelling accuracy. High correlations were also found between the production of phonologically plausible errors and both letter-sound knowledge and phoneme isolation ability (i.e. ability to identify specified phonemes in nonwords, such as the word-final ‘p’ in ‘hisp’). These findings show that phonological awareness is strongly associated with spelling accuracy for typically developing children.

Other studies have used spelling error analysis to identify specific factors associated with spelling accuracy for typically developing children. For example, Ehri (1987) noted that young children tend to encode phonemes occupying the phonologically salient word-initial and word-final positions with greater accuracy than word-medial phonemes. Young children also tend to overextend specific orthographic conventions, such as the final *e* in ‘rate’ (e.g. *sate* for ‘sat’), while failing to comply with others, such as the doubling of consonant letters in ‘miss’ (e.g. *wel* for ‘well’; Bourassa & Treiman, 2003). Such findings have played an essential role in profiling the spelling abilities of typically developing children, further illustrating the utility of spelling error analysis.

Investigations involving spelling error analysis and children with developmental disabilities have begun to emerge (e.g. Critten, Connelly, Dockrell, & Walter, 2014). In a recent study, Lim, Arciuli, Rickard Liow, and Munro (2014) evaluated the spelling errors of 22 children with Down syndrome aged 7–13 years and 22 typically developing children aged 6–10 years who were matched on the basis of receptive vocabulary. Both groups produced spelling errors in response to an experimental assessment which contained clear evidence of phonological awareness, such as errors that adhered to the target word consonant–vowel (CV) structure (e.g. *cluid* [CCVC] for ‘club’ [CCVC]). The authors concluded that phonological awareness is important for literacy development in children with Down syndrome, as it is for typically developing children. However, they also noted that children with Down syndrome have poorer phonological awareness than typically developing children, most likely due to deficits in phonological short-term memory – something which may affect their ability to utilise phonological knowledge. These findings demonstrate that analysis of spelling errors is useful when examining the literacy skills of children with developmental disabilities.

**Analysis of all spelling attempts**

Another approach to spelling analysis is to consider all spelling attempts (correct and incorrect). One tool designed to assist in this process is the Computerised Spelling Sensitivity System (CSSS; Masterson & Hrbec, 2011). Unlike the analyses outlined in the preceding section, the CSSS has the advantage of being able to quantify evidence of phonological, orthographic and morphological awareness simultaneously. The CSSS also takes a slightly different approach to identifying evidence of phonological awareness. For example, where the analyses undertaken by Caravolas et al. (2001) view phonologically plausible spelling errors as evidence of phonological awareness (e.g. *scip* for ‘skip’), the CSSS considers spelling errors which encode the correct number of phonemes, regardless of pronunciation, as entailing phonological awareness (e.g. *stip* for ‘skip’). The CSSS thus provides an additional perspective on the linguistic skills underlying spelling.

Using the CSSS, word spelling attempts are first broken down into smaller segments called elements. These elements include phonemes in base words (e.g. *a–n–d*), juncture changes in multi-morphemic words (e.g. *p–u–t*–*i*–*ng*), and affixes (e.g. *w–a–tch*–*ed*). Segmented spelling attempts are then aligned and compared with their corresponding targets using the CSSS dictionary. Omitted elements indicate a deficit in phonemic awareness and attract a score of 0 (e.g. *lis* for ‘list’). Illegally spelled elements show some level of phonemic awareness but an incomplete understanding of orthographic or morphological spelling conventions and therefore receive a score of 1 (e.g. *lamp* for ‘lamp’, *walkd* for ‘walked’). Elements which are spelled legally suggest intact phonemic, orthographic and morphological awareness and are assigned a score of 2 (e.g. *phish* for ‘fish’, *arrogence* for ‘arrogance’). Correctly spelled elements are given a score of 3. In this way, the CSSS awards higher scores to elements which encode greater levels of linguistic knowledge.

Metrics obtained using the CSSS have been used to explore the spelling profiles of typically developing children and children with some disabilities other than ASD (e.g. Apel & Masterson, 2015; Bowers, McCarthy, Schwarz, Dostal, & Wolbers, 2014). In one such study, Werfel and Krimm (2015) used a non-computerised version of the CSSS, the Spelling Sensitivity Score (SSS; Masterson & Apel, 2010), to
investigate the spelling profiles of children with and without Specific Language Impairment (SLI) aged 7–11 years. On average, children with SLI achieved SSS scores which were significantly lower than their typically developing peers. Effect size estimates showed that these group differences were large in magnitude, suggesting that children with SLI were less able to encode linguistic information (i.e. phonological, orthographic and morphological information) relative to typically developing children. These results demonstrate that analysis using the CSSS may be useful in characterising the spelling profiles of typically developing children as well as children with disabilities.

The current study

This study was designed to examine the subskills underlying literacy in children with ASD by focusing on spelling. We first examined whether phonological awareness predicted word spelling accuracy for a group of children with ASD and a group of typically developing children. We then analysed children’s spelling errors for evidence of underlying phonological awareness. All spelling attempts, including both correct and incorrect responses, were then evaluated using the CSSS in order to gain another perspective on the linguistic knowledge underlying spelling for children with ASD.

We formulated three hypotheses. First, we anticipated that phonological awareness would be a significant predictor of word spelling accuracy for children with ASD. Second, we hypothesised that children with ASD, like their typically developing peers, would produce spelling errors that reflect some underlying phonological awareness, such as phonologically plausible spelling errors. Third, we expected that analyses using the CSSS would reveal similarities in the types of linguistic knowledge encoded in word spelling attempts produced by children with ASD and their typically developing peers. Findings in support of these hypotheses could have important implications regarding the design and provision of effective literacy instruction for children with ASD.

Method

Participants

Data presented in this study were collected as part of a larger research project on literacy and ASD with approval from the University of Sydney Human Research Ethics Committee (see Bailey et al., 2017a). There were two participant groups: one group of children with ASD (ASD group) and another comprised of typically developing children (TD group). Inclusion criteria for participants with ASD were designed to recruit a broad sample of children varying in oral language and literacy abilities. Participants were required to be 5–12 years of age, have a formal diagnosis of ASD, have measurable oral language ability, speak English as a first language, and have no serious hearing or vision impairments. A post-hoc decision was made to exclude participants with below Kindergarten-level spelling accuracy as measured using normative data from the Wide Range Achievement Test – 4th Edition (WRAT-4; Wilkinson & Robertson, 2006). Children from two classes (Year 1 and Year 2) in a local mainstream primary school were invited to provide comparative data. Twenty children were selected from the resulting data pool to form the TD group.

Of an initial group of 25 children with ASD who met inclusion criteria, five were excluded on the basis of having below Kindergarten-level spelling abilities. This resulted in an ASD group comprised of 20 children (2 males). Participants in this group had a previous clinical diagnosis of ASD (n = 11), Aspergers Syndrome (n = 3), or Pervasive Developmental Disorder – Not Otherwise Specified (n = 6). The mean age in the ASD group was 95.45 months (SD = 19.61). Eighteen participants were enrolled in mainstream educational settings (i.e. classroom with typically developing peers within a school for typically developing students) and two participants attended a supported educational setting (i.e. classroom with developmentally delayed peers within a school for typically developing students). The TD group was comprised of 20 children (11 females) with a mean age of 90.40 months (SD = 6.47). ASD and TD groups were group-wise matched on the basis of age, $t(23.08) = 1.09, p = .21, d = .35$, and word spelling accuracy, $t(34.40) = .67, p = .51, d = .21$.

Procedure

Participants completed a test battery made up of standardised assessments as part of a broader assessment protocol designed to test literacy and language skills. Assessments were administered during a single 60- to 90-minute session which was conducted in a quiet room at the University or the participants’ home or school. Variation in assessment duration was due to some participants in the ASD group requiring additional breaks during testing.

Outcome variable

Word spelling accuracy. Word spelling accuracy was assessed using the word spelling component of the WRAT-4 (Wilkinson & Robertson, 2006). Participants were instructed to write a list of 42 single words presented in order of least (e.g. ‘on’) to most difficult (e.g.
‘lucidity’). For each item, the experimenter read the target word aloud, read the word aloud in a sentence, and then repeated the target word aloud once more. Participants were then given 15 seconds to write a response on the test form. Participants were encouraged to produce an attempt for each test item regardless of whether they felt they knew how to spell the target. Task administration was discontinued following 10 consecutive word spelling errors.

**Predictor variables**

**Vocabulary.** Receptive vocabulary was assessed using the Peabody Picture Vocabulary Test – 4th edition (PPVT-4; Dunn & Dunn, 2007). Participants heard a series of single words and were asked to select one of four images best depicting each of the targets. The PPVT-4 is designed for children aged two years, six months and older, making it suitable for use in the current study which involves school-aged children, including those with ASD who may be functioning at a level lower than expected based on their chronological age.

**Phonological awareness.** The Elision and Blending Words subtests from the Comprehensive Test of Phonological Processing – 2nd edition (CTOPP-2; Wagner, Torgesen, Rashotte, & Pearson, 2013) were used to assess phonological awareness. In the Elision subtest, participants were instructed to repeat a series of single words read aloud by the researcher but omit a specified phoneme or syllable (e.g. ‘say winter without saying /t/’). In the Blending Words subtest, participants were required to blend together a sequence of phonemes or syllables to form a whole word.

**Letter knowledge.** The letter writing component of the WRAT-4 (Wilkinson & Robertson, 2006) was used to assess letter knowledge. Participants were instructed to print their name on a test form. Using this same form, participants were then directed to write a series of 13 letters which were read aloud by the experimenter. One point was awarded for each correct letter produced in the name writing task (maximum of two points), and one point was awarded for each correct letter produced in the letter writing task.

**Analysis of spelling errors**

Spelling errors produced in response to the WRAT-4 were examined for evidence of underlying phonological awareness using analyses described in the Introduction. Letters appearing in the phonologically salient word-initial and word-final positions were first evaluated for accuracy (e.g. *entu* for ‘enter’) and phonological plausibility (e.g. *entu* for ‘enter’). Next, word-level phonological structure was assessed using an analysis of CV adherence (e.g. *must* [CVCC] for ‘must’ [CVCC]). Spelling errors were finally analysed for word-level phonological plausibility (e.g. *koop* for ‘cook’).

**Analysis of all spelling attempts**

All word spelling attempts, including those which were correct and incorrect, were analysed using the CSSS (Masterson & Hrbec, 2011). The CSSS automatically segmented spelling attempts into elements (i.e. letters representing phonemes, affixes and juncture changes). Elements in each spelling attempt were then aligned with those of their respective targets and assigned a score ranging from 0 to 3. Omitted elements were awarded a score of 0 (e.g. *hm* for ‘him’). Elements that were represented with an orthographically or morphologically illegal letter or letters were awarded a score of 1 (e.g. *trapped* for ‘trapped’). Legally spelled elements were awarded a score of 2 (e.g. *staff* for ‘staff’), and correct elements received a score of 3.

Analysis using the CSSS generated two scores for each participant: SSS-Elements (SSS-E) and SSS-Words (SSS-W). SSS-E scores were calculated by averaging the mean element score achieved in each spelling attempt across the participant’s sample. In this way, SSS-E scores indicate the average level of linguistic knowledge encoded in children’s spelling attempts at the element level. SSS-W scores were calculated by identifying the lowest scoring element in each spelling attempt and then averaging these scores across the participant’s sample. SSS-W scores thus show the mean level of linguistic knowledge encoded in children’s spelling attempts at the word level.

In addition to the SSS-E and SSS-W scores, the CSSS provided data on the frequency of omitted, illegal, legal and correct elements produced by each participant. These data were examined to gain further insight into the types and levels of linguistic knowledge encoded in participants’ spelling attempts. Here, omitted elements are thought to reflect deficits in phonemic awareness, while illegal elements entail adequate phonemic awareness but deficits in orthographic or morphological awareness. Legal elements, on the other hand, are evidence of intact phonemic, orthographic and morphological awareness but difficulties with word-specific spelling knowledge.

**Results**

Descriptive statistics for the predictor variables and outcome variable for the ASD and TD groups are provided in Table 1.
Participants in the ASD group produced 339 word spelling attempts on the WRAT-4, with a total of 123 (36%) accurate responses. Of the 359 word spelling attempts produced by the TD group, 131 (37%) were accurate. Age-based spelling accuracy percentile ranks calculated using normative data from the WRAT-4 showed that participants with ASD, as a group, performed within the normal range ($M = 42.25$). However, performance varied widely within the ASD group ($SD = 33.14$, range $= 1–94$). As expected, participants in the TD group achieved a mean age-based percentile rank within the normal range ($M = 53.90$, $SD = 25.16$, range $= 14–93$). Percentile rank scores were not significantly different for the ASD and TD groups, $t(38) = 1.25$, $p = .22$, $d = .39$.

Table 2 shows the correlation matrices for children in the ASD group (below the diagonal) and the TD group (above the diagonal). Age was partialed out in these analyses due to the different ages within each group. Phonological awareness, as measured using the Elision subtest, was significantly correlated with word spelling accuracy for children in the ASD and TD groups. The remaining variables were not significantly correlated with word spelling accuracy except for letter knowledge which was significantly correlated for children in the ASD group only. Non-parametric Spearman correlation analyses were conducted to further explore the links between letter knowledge and spelling accuracy as letter knowledge scores were not normally distributed in either participant group. After controlling for age, these analyses again showed a significant correlation between letter knowledge and word spelling accuracy in the ASD group only ($r= .46$, $p = .046$).

Separate multiple regression analyses were conducted for each group to examine the role of age (in months), vocabulary (PPVT-4), letter knowledge (WRAT-4), and phonological awareness (CTOPP-2: Elision and Blending Words subtests) in explaining variability in word spelling accuracy. Forced entry with backward elimination identified significant predictors of word spelling accuracy. Table 3 presents results for the full and final models for the regression analyses. The proportion of unique variance explained by significant predictors was measured by adding these predictors in a separate step in the regression model. Unique variance is not reported in the table but in the following text.

The full and final regression models were statistically significant for the ASD group: $F(5, 14) = 8.00$, $p = .001$, and $F(2, 17) = 15.56$, $p < .001$, respectively. Performance on the Elision subtest accounted for a significant

### Table 1. Descriptive statistics for autism spectrum disorders (ASD) and typically developing (TD) groups.

| Measure                  | ASD group ($n = 20$) | TD group ($n = 20$) |
|--------------------------|----------------------|---------------------|
|                          | $M$  | $SD$  | Range  | $M$  | $SD$  | Range  |
| Vocabulary               | 116.25 | 29.76  | 73–175 | 132.65 | 22.77  | 90–180 |
| Elision                  | 17.00  | 10.67  | 0–33   | 19.75  | 5.78   | 5–31   |
| Blending words           | 13.50  | 5.24   | 1–20   | 19.25  | 3.86   | 13–27  |
| Letter knowledge         | 12.50  | 9.5    | 10–13  | 12.90  | .31    | 12–13  |
| Word spelling accuracy   | 6.15   | 4.08   | 0–14   | 6.90   | 2.92   | 3–15   |

Note: Data are raw scores. Vocabulary: PPVT-4; elision: elision subtest, CTOPP-2; blending words: blending words subtest, CTOPP-2; letter knowledge: letter spelling component, spelling subtest, WRAT-4; word spelling accuracy: word spelling component, spelling subtest, WRAT-4.

### Table 2. Partial correlations for autism spectrum disorders (ASD) and typically developing (TD) groups after controlling for age.

|                  | 1     | 2     | 3     | 4     | 5     |
|------------------|-------|-------|-------|-------|-------|
| 1. Word spelling accuracy | –     | .36   | .55*  | .28   | –     |
| 2. Vocabulary    | .32   | –     | .37   | .28   | .04   |
| 3. Elision       | .71***| .70***| –     | .41   | –.12  |
| 4. Blending words| .41   | .62** | .48*  | –     | –.01  |
| 5. Letter knowledge| .59***| .26   | .42   | .48*  | –     |

Note: Vocabulary: PPVT-4; elision: elision subtest, CTOPP-2; blending words: blending words subtest, CTOPP-2; letter knowledge: letter spelling component, spelling subtest, WRAT-4; word spelling accuracy: word spelling component, spelling subtest, WRAT-4.

*p < .05. **p < .01. ***p < .001.

**Word spelling accuracy**

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The full and final regression models were statistically significant for the ASD group: $F(5, 14) = 8.00$, $p = .001$, and $F(2, 17) = 15.56$, $p < .001$, respectively. Performance on the Elision subtest accounted for a significant
proportion of unique variance in word spelling accuracy in both the full (24.2%) and final regression models (26.2%). Letter knowledge predicted unique variance in word spelling accuracy for children with ASD in the final model only (10.0%). For children in the TD group, only the final regression model was statistically significant, $F(1, 18) = 7.73, p = .012$. In this model, performance on the Elision subtest was the only significant predictor of unique variance in word spelling accuracy (accounting for 30.0% of the variability in spelling accuracy).3

### Analysis of spelling errors

Children in the ASD group produced a total of 216 word spelling errors in response to the WRAT-4. Children in the TD group produced 228 word spelling errors. Letters occupying the phonologically salient word-initial and word-final positions were analysed for conventional accuracy and phonological plausibility. Table 4 shows the mean percentage of correct, phonologically plausible, and phonologically unrelated word-initial and word-final letter spellings for children in the ASD and TD groups.

As shown in Table 4, children in the ASD and TD groups both produced a high proportion of correct word-initial and word-final letter spellings, as well as some phonologically plausible letters. Independent samples $t$-tests with Bonferroni adjusted alpha levels of .017 (.05/3) showed that children with ASD produced a significantly greater proportion of word-initial letter spellings with no phonological link to the target ($t(20.89) = 2.69, p = .01$). Group differences in the production of correct ($t(30.02) = 1.05, p = .30$) and phonologically plausible word-initial letters ($t(38) = 1.84, p = .07$) were not statistically significant. Analysis of word-final letters revealed that children with ASD produced fewer phonologically plausible errors ($t(38) = 3.00, p = .01$) and more phonologically unrelated errors ($t(21.83) = 3.00, p = .01$) as compared to the TD group. Children with ASD also tended to produce fewer correct word-final letters. However, this difference was not statistically significant, $t(27.15) = 1.49, p = .15$.

Word-initial and word-final letter spellings were compared a second time using Mann Whitney U tests as data for some categories (correct, plausible, phonologically unrelated) were not normally distributed. With the adjusted alpha level of .017, these analyses returned the same pattern of results as the $t$-tests reported above with two exceptions. First, the ASD

### Table 3. Word spelling accuracy regression results for autism spectrum disorders (ASD) and typically developing (TD) groups.

| Group model | Variable     | Std. β | t   | Adj. $R^2$ | $\Delta R^2$ |
|-------------|--------------|--------|-----|------------|--------------|
| ASD group   | Full         | Age    | .40 | 2.19       | .65          | .74          |
|             |              | Vocabulary | -.46 | -1.71      | .17          | .45          |
|             |              | Elision  | .77 | 3.61       | .66          | .77          |
|             |              | Blending | .13 | .66        | .13          | .13          |
|             |              | Letter knowledge | .27 | 1.57      | .27          | .27          |
|             | Final        | Elision  | .58 | 3.55       | .61          | .58          |
|             |              | Letter knowledge | .36 | 2.19      | .36          | .36          |
| TD group    | Full         | Age    | .11 | .45        | .17          | .39          |
|             |              | Vocabulary | .21 | .79        | .21          | .21          |
|             |              | Elision  | .43 | 1.77       | .43          | .43          |
|             |              | Blending | .05 | .20        | .05          | .05          |
|             |              | Letter knowledge | -.14 | -1.66  | -.14         | -.14         |
|             | Final        | Elision  | .55 | 2.78       | .26          | .55          |

Note: Vocabulary: PPVT-4; elision: elision subtest, CTOPP-2; blending words: blending words subtest, CTOPP-2; letter knowledge: letter spelling component, spelling subtest, WRAT-4; word spelling accuracy: word spelling component, spelling subtest, WRAT-4.

### Table 4. Mean percentage of word-initial and word-final letter spellings for autism spectrum disorders (ASD) and typically developing (TD) groups.

| Word position | Examples          | ASD group     | TD group     |
|---------------|------------------|---------------|--------------|
| Initial letter|                  |               |              |
| Correct       | *hov* for ‘him’  | 83.52 (19.25) | 88.68 (10.88) |
| Phonologically plausible | *sircoel* for ‘circle’ | 4.71 (6.69)  | 9.60 (9.83) |
| No phonological link  | *hak* for ‘make’ | 11.78 (16.31) | 1.72 (3.64) |
| Final letter   |                  |               |              |
| Correct       | *ntiril* for ‘material’ | 48.83 (27.89) | 59.08 (13.24) |
| Phonologically plausible | *mak* for ‘make’ | 18.70 (15.19) | 31.94 (12.64) |
| No phonological link  | *het* for ‘him’ | 32.48 (34.10) | 8.98 (9.33) |

Note: Data in parentheses are standard deviations.
and TD groups were not significantly different in their production of word-initial letters which were unrelated to the target \( (U = 136.50, z = -2.07, p = .04) \). Second, there was no significant group difference in the production word-final letters which were unrelated to the target \( (U = 123.50, z = -2.11, p = .04) \).

**CV adherence.** The word-level phonological structure of spelling errors was evaluated by comparing the CV composition of each error with that of its respective target. Errors were identified as either adhering to, or violating the CV structure of the target word. The attempt *enter* (VCCV) for ‘enter’ (VCCV) is an example of CV violation. Instances where a letter could represent more than one phoneme (e.g. *x* could represent the phoneme sequence /ks/) were identified as adhering to the target CV structure if it accurately reflected the CV composition of the target (e.g. *success* [CVCCVC] for ‘success’ [CVCCVC]). Likewise, letter combinations which could represent a single phoneme (e.g. *ss* could represent the phoneme /s/) were considered correct if they accurately reflected the CV composition of the target (e.g. *success* [CVCCVC] for ‘success’ [CVCCVC]). A smaller proportion of word-spelling attempts produced by children in the ASD group adhered to the target word CV structure \( (M = 48.49, SD = 27.37) \) as compared to those produced by the TD group \( (M = 54.26, SD = 19.66) \). However, independent samples \( t \)-tests showed that this difference was not statistically significant, \( t(38) = .77, p = .45 \).

**Word-level phonological plausibility.** Errors were judged to be phonologically plausible if they accurately encoded the phonological composition of their target (e.g. *bread* for ‘brief’). Errors which encoded the phonological composition of the target but failed to represent /s/ phonemes were also identified as being phonologically plausible (e.g. *crect* for ‘correct’). On average, a smaller proportion of word spelling attempts produced by children in the ASD group were phonologically plausible \( (M = 28.17, SD = 26.14) \) as compared to those produced by the TD group \( (M = 41.81, SD = 22.80) \). However, independent samples \( t \)-tests showed that this difference was not statistically significant, \( t(38) = 1.76, p = .09 \).

**Analysis of all spelling attempts**

Spelling attempts were analysed for evidence of underlying linguistic knowledge, including phonological, orthographic and morphological awareness, using the CSSS. Children in the ASD group achieved a mean SSS-W score of 1.45 \( (SD = .56) \) and a mean SSS-E score of 2.22 \( (SD = .50) \). The mean SSS-W and SSS-E scores awarded to the TD group were 1.62 \( (SD = .26) \) and 2.45 \( (SD = .15) \), respectively. Independent samples \( t \)-tests showed that group mean SSS-W scores were not significantly different, \( t(26.85) = 1.28, p = .21 \), while the difference in group mean SSS-E scores approached statistical significance, \( t(22.24) = 1.98, p = .06 \).

Output from the CSSS analysis showed that children in the ASD group attempted to spell a total of 1372 elements. Of these attempts, 113 elements were omitted (e.g. *an* for ‘and’), 249 were spelled illegally (e.g. *musd* for ‘must’), 123 were spelled legally (e.g. *reech* for ‘reach’) and 887 were correct. Of the 1475 elements attempted by children in the TD group, 94 were omitted, 233 were illegal, 179 were legal and 969 were correct. Figure 1 shows the distribution of elements types produced by children in the ASD and TD groups.

The types of elements produced by children in the ASD and TD groups were similarly distributed, with correct elements being the most prevalent followed by illegal elements, legal elements and omitted elements. Independent samples \( t \)-tests with Bonferroni adjusted alpha level of .0125 (.05/4) showed that there were no significant group differences in the production of omitted elements \( (t(34.43) = .87, p = .39) \), illegal elements \( (t(38) = .57, p = .57) \), legal elements \( (t(38) = 2.15, p = .04) \) or correct elements \( (t(29.85) = .57, p = .57) \).

**Discussion**

The current study examined the subskills associated with spelling accuracy in 20 English-speaking children with ASD aged 5–12 years. A group of 20 typically developing children matched for age and word spelling accuracy provided comparative data. We hypothesised that phonological awareness would be a significant predictor of word spelling accuracy for children with ASD. We also anticipated that children with ASD would produce spelling errors which contain evidence of underlying phonological awareness. Finally, we expected that an analysis of all spelling attempts, including correct and incorrect responses, would reveal similarities in the types of linguistic knowledge encoded by children with ASD and their typically developing peers.
Phonological awareness as a predictor of word spelling accuracy

Results showed that phonological awareness was a significant predictor of spelling accuracy for children with ASD. Indeed, performance on the Elision subtest was the single strongest predictor of word spelling accuracy for children in the ASD group as well as children in the TD group. Interestingly, scores on the other phonological awareness assessment, the Blending Words subtest, were not related to word spelling accuracy for either participant group. This highlights that phonological awareness is not a unitary skill and that specific phonological tasks carry different cognitive demands (Treiman, 1991). It may be that the Elision subtest which involved identification and removal of a specified phoneme from a target word was more challenging and better able to differentiate the phonological awareness skills of children in the current study as compared to the Blending Words subtest which required participants to blend phonemes together to create whole words. However, further research is required to test this possibility.

Letter knowledge was the only other significant predictor of word spelling accuracy for children in the ASD group. This is consistent with previous longitudinal research which has shown that letter knowledge is a significant predictor of spelling development for typically developing children across languages, including English, Finnish and Greek (Georgiou, Torppa, Manolitsis, Lyytinen, & Parrila, 2012). The finding that letter knowledge was not related to word spelling accuracy for typically developing children in the current study is likely due to the fact that most of these children performed at ceiling level on the letter knowledge assessment (i.e. scores ranged from 12 to 13 out of a possible 13 points).

While there were some differences in the final regression models for the ASD and TD groups, phonological awareness was closely linked to word spelling accuracy for children with ASD as well as their typically developing peers. This provides support for our first hypothesis that phonological awareness would be related to word spelling accuracy for children with ASD.

Analysis of spelling errors

Our findings suggest that children with ASD, like their typically developing peers, are better able to encode phonemes occupying the phonologically salient word-initial and word-final positions as compared to phonemes in the less salient word-medial positions. Parametric analyses showed that children in the ASD group produced significantly more word-initial and word-final letters that were phonologically unrelated to their targets relative to children in the TD group. However, data for these measures were not normally distributed and non-parametric analyses showed no significant group differences in the production of phonologically unrelated word-initial or word-final letters. This indicates that children in both the ASD and TD groups utilised phonological knowledge when encoding word-initial and word-final letters.

Further evidence linking phonological awareness and spelling was identified using an analysis of word-level CV adherence and phonological plausibility. The CV adherence analysis considered whether spelling errors produced by children with ASD, like those of typically developing children, reflect the phonemic CV structure of their respective target words. As anticipated, children with ASD produced some errors which adhered to the target CV structure (i.e. on average, 49% adhered to CV structure). The phonological plausibility analysis considered whether spelling errors encoded the phonemic composition of their targets, irrespective of violations of orthographic conventions (e.g. *ckook* for ‘cook’). This analysis showed that a considerable proportion (28%) of spelling errors produced by children with ASD accurately reflected the phonemic structure of their targets. Analyses also revealed no significant differences in the proportion of CV compliant and phonologically plausible errors produced by children in the ASD and TD groups.

Results from the CV adherence and phonological plausibility analyses support our second hypothesis, that children with ASD would produce spelling errors which contain evidence of underlying phonological awareness. Analyses relating to word-initial and word-final letters provided partial support for this hypothesis. It is interesting to note that children in the ASD and TD groups exhibited similar challenges when attempting to spell words containing less discernible phonemic sequences. Previous research has shown that typically developing spellers tend to omit letters encoding the /s/ phoneme in unstressed syllables (e.g. *bou* for ‘about’; Treiman, 1993). A similar error pattern was identified in the current study (e.g. bleve for ‘believe’). Children with ASD in the current study also tended to omit letters encoding interior consonant phonemes in word-final consonant clusters (e.g. *ad* for ‘and’; Treiman, Zukowski, & Richmond-Welty, 1995). These observations suggest that children with ASD and typically developing children encounter similar phonologically-based challenges when spelling.

Analysis of all spelling attempts

All spelling attempts, including correct and incorrect responses, were analysed using the CSSS. In addition to analysing all spelling attempts, the CSSS differs from the spelling error analyses outlined above in its
approach to identifying evidence of phonological awareness. Unlike the abovementioned error analyses which view phonologically plausible errors as entailing phonological awareness (e.g. *scy* for ‘sky’), the CSSS considers spelling errors which encode the same number of phonemes as their targets, irrespective of pronunciation, as providing evidence of phonological awareness (e.g. *sby* for ‘sky’). Thus, analysis using the CSSS provides an alternate perspective on the linguistic abilities underlying children’s spelling attempts.

Our third hypothesis was that analyses using the CSSS would reveal similarities in the types of linguistic knowledge encoded in the word spelling attempts of children in the ASD and TD groups. Element- and word-level metrics obtained using the CSSS provided support for this hypothesis. As a group, children with ASD achieved an average SSS-W score of 1.45 and an average SSS-E score of 2.22. Children in the TD group achieved an average SSS-W score of 1.62 and a mean SSS-E score of 2.45. Achievement on the SSS metrics was not significantly different for the ASD and TD groups, suggesting that children with ASD and typically developing children matched on word spelling accuracy are not dissimilar in terms of their ability to encode phonological, orthographic, and morphological information.

An examination of the types of elements identified in the current study showed that children in the ASD and TD groups produced similar proportions of omitted, illegal, legal and correct elements. Here, omitted elements are thought to reflect underlying deficits in phonological awareness while illegal elements entail intact phonological awareness skills and incomplete orthographic knowledge. Legal elements, on the other hand, provide evidence of adequate phonological and orthographic awareness but insufficient knowledge of word-specific spelling conventions. Results showing no significant differences in the production of omitted, illegal, legal, and correct elements for children in the ASD and TD groups therefore provide strong support for our third hypothesis.

**Limitations**

While informative, the results of this study are subject to limitations. The Spelling subtest from the WRAT-4 was not designed to explore the full range of spelling abilities (i.e. phonological, orthographic and morphological awareness) in great detail. Thus, we were limited in our capacity to examine specific aspects of spelling, particularly morphological awareness. Another limitation was that the sample in this study, although comparable to previous investigations (e.g. Cardoso-Martins et al., 2015: *N* = 19; Smith-Gabig, 2010: *N* = 14; Wiggins et al., 2010: *N* = 29), was small given the types of analyses undertaken. These analyses could be usefully replicated in future studies with larger samples of children with ASD and groups of typically developing children matched on a wider range of variables, including gender. A final limitation was that five children were excluded from participation on account of having very low spelling accuracy. For this reason, our results cannot be considered representative of all children on the autism spectrum. Rather, these results reflect a sample drawn from a subset of the ASD population (i.e. children with Kindergarten-level spelling accuracy and above).

**Directions for future research**

Given the contrast between results reported here and in Smith-Gabig (2010), it would be valuable to conduct further research on the associations between literacy and phonological awareness for children with ASD. Future studies could use a wider range of phonological awareness measures to delineate the links between specific types of phonological awareness and literacy skills. Studies on spelling could also use shorter, less complex targets to better accommodate children with lower spelling accuracy. Instead of concurrent predictive value which was the focus in the current study, it would be interesting to examine which types of spelling analyses and linguistic skills are predictive of spelling development over time for children with ASD (see Treiman, Kessler, & Caravolas, 2018, for a longitudinal study on predictors of spelling development for typically developing children). Such a study could help clarify which skills support literacy development for children with ASD and the characteristics of children in this population who are likely to achieve gains with appropriate literacy instruction.

**Conclusion**

Results from this study revealed similarities in the subskills underlying spelling in children with ASD and typically developing children. The finding that phonological awareness supports spelling for children with ASD stands in contrast to some previous studies on reading (e.g. Smith-Gabig, 2010) but also adds to a growing body of research showing a link between phonological awareness and literacy development for children in this population (Asberg & Dahlgren-Sandberg, 2012; Jacobs & Richdale, 2013; Nash & Arciuli, 2016; Newman et al., 2007; White et al., 2006; Wiggins et al., 2010). As such, it seems appropriate to suggest that reading and spelling instruction for children with ASD should include a focus on phonological awareness and explicit teaching of phonological decoding and encoding strategies, as in typically developing children.
The combined use of spelling error analyses and analyses which consider all spelling attempts (via the CSSS) that we have used here could be utilised in such research to gain a more comprehensive view of children’s outcomes following literacy interventions.

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Notes
1. Most responses produced by these children were illegible or shared no obvious link to the target, such as uf for ‘cook’, vf for ‘reach’, a for ‘light’.
2. Data for some variables were not normally distributed. Certain parametric analyses, such as t-tests, are thought to be robust even when the assumption of normality is violated (Rasch & Guiard, 2004). For this reason and for ease of reading, we only report parametric analyses hereafter except where findings from parametric and non-parametric analyses were inconsistent as in word-initial and word-final letter spellings.
3. Residuals in the TD model were not normally distributed. However, regression analyses conducted using logarithmically transformed values which met the assumption of normality produced the same pattern of results. Thus, for ease of reading, only analyses based on untransformed values are reported.

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