Morpho-Orthographic Processing in Children with Autism Spectrum Disorder: The Case of Hebrew Orthography

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Keywords

Autism spectrum disorder · Reading · Graphemic-phonemic decoding · Morpho-orthographic identification · Pseudowords

Abstract

Objective: Most studies on word reading in children with autism spectrum disorder (ASD) focus on graphemic-phonemic decoding and the direct orthographic route. To extend the scope, we investigated morpho-orthographic identification beyond graphemic-phonemic abilities. **Patients and Methods:** The original study included 31 sixth-grade children with ASD and comparison groups of typically developing (TD) children: 23 age-matched children, 15 third-graders, and 17 second-graders. The groups were compared regarding reading of morphologically based Hebrew *pointed* pseudowords to examine graphemic-phonemic decoding, and *unpointed* pseudowords to test morpho-orthographic identification. To better focus on morpho-orthographic identification processes, we eventually included only children with a minimum threshold of $\geq 65\%$ correct in reading *pointed* pseudowords, thereby excluding 11 children with ASD, 1 TD age-matched child, and 1 TD third-grader. **Results:** About

half of the children with ASD eventually included were as accurate as the TD second-graders in reading *unpointed* pseudowords, and slow in reading both *pointed* and *unpointed* pseudowords. The other half were as accurate as their typical peers in reading *unpointed* pseudowords, but slightly slower. **Conclusion:** The results highlight the difficulties many Hebrew-reading children with ASD experience in using morpho-orthographic processes beyond their difficulties in using graphemic-phonemic processes, demonstrating effortful (slow) reading. While this study can be considered a pilot investigation, further studies are needed.

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Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental condition characterized by deficits in social communication; restricted, repetitive patterns of behavior, in-

This work was conducted at The Center for Academic Studies, Or Yehuda, and at the Department of Communication Disorders, School of Health Sciences, Sackler Faculty of Medicine, Tel Aviv University, Tel Aviv, Israel.

terests, or activities; and the fact that the presentation of the symptoms is not better explained by intellectual disability alone [1]. It is a spectrum disorder ranging from very mild to severe impairments. ASD may affect many aspects of thinking, learning, and behavior, and many children with ASD display unique patterns of development, both as a group and as individuals [2]. Although some areas of intellectual development such as fluid reasoning and visual spatial processing are relatively strong [3], other areas such as knowledge and particularly daily living skills are significantly delayed [4]. Individuals with ASD may demonstrate repetitious behavior, focus on details, and have difficulty integrating information, extracting meaning, and distinguishing relevant details [5]. There is a large group of children with ASD who have poor language skills, and some of them manifest a language profile similar to that of children with developmental language delay (or specific language impairment) [6, 7].

These cognitive and language deficits can exert a tremendous influence on reading skills in this population [8]. Although not all children with ASD learn to read [5], there is evidence indicating an early and spontaneous onset of word decoding ability in some children with ASD [9–11], and good reading accuracy skills in both children [9, 12–16] and adults [17] with ASD. In some studies, reading accuracy was higher than the given participants' IQ [18, 19].

The most commonly reported reading profile for children with high-functioning ASD is one of intact or even precocious word decoding (exceptional reading skill levels) combined with reduced reading comprehension [5, 12, 14, 20–24]. This profile of reading behavior has been called hyperlexia, which is the opposite of that of dyslexic individuals, who often demonstrate stronger comprehension despite weaker decoding [14, 25].

The often unexpected findings of precocious word reading ability in children with ASD are not yet fully understood. There is some evidence that rather than using graphemic-phonemic decoding, children with ASD may rely mostly on direct visual access pathways, using rote memorization of visual pattern recognition, namely, the orthographic lexicon [5, 26]. Some researchers have suggested that orthographic processing is stronger than phonological processing in these children. For example, Sparks [10, 27] studied 3 hyperlexic children over an 8-year period and concluded that their phonemic awareness was low as compared to their word reading level. Therefore, their main reading pathway could be the direct orthographic route, as opposed to graphemic-phonemic

decoding in typically developing (TD) readers [11, 24, 28, 29]. Conversely, the finding that hyperlexic children with ASD were weaker than nonhyperlexic children with ASD at visual processing tasks [22] does not lend support to the view that holistic visual rote learning of word forms can explain the precocious word reading ability in this population.

Alternative explanations relate the precocious word reading to exceptionally good graphemic-phonemic decoding skills. Many researchers have noted that hyperlexic children manifest a strong interest in reading to the exclusion of everything else; this might result in extensive reading experience and practice, thereby contributing to exceptional word decoding abilities [30]. Cardoso-Martins and Da Silva [13] suggested that hyperlexics' indifference to language as a meaningful, communicative device may be the key to the exceptionally good and precocious development of their ability to compute letter-sound relations implicitly, on the basis of statistical learning. Nation [31] proposed that cognitive strengths in ASD, including a preoccupation with circumscribed interests and a close attention to details, can account for their exceptionally good word decoding processing.

Graphemic-phonemic decoding is typically measured by the pseudoword reading task, which is widely considered to be one of the most critical predictors of successful reading acquisition [25, 32]. Since reading nonwords aloud cannot rely on the orthographic lexicon, readers are obliged to connect novel letter strings to sequences of phonemes. If children with ASD read by relying heavily on graphemic-phonemic decoding, nonword reading should be intact.

Findings of nonword reading ability in individuals with ASD vary extensively. Some studies found that children [13, 20, 26] and adolescents [15] with ASD did not differ from TD controls in nonword reading tasks. Minshew et al. [15], for example, found that high-functioning adolescents with autism performed similarly to their age-matched counterparts in both word identification (sight word vocabulary reading) and word attack (decoding of nonwords). Moreover, their nonword reading was slightly better than their sight word identification, suggesting a heightened ability to apply phonetic analytic skills to decode nonwords. This finding is in line with that of O'Connor and Klein [16], who showed that children with ASD read phonetically regular words more easily than phonetically irregular words, indicating an intact phonetic decoding strategy.

However, it is notable that many studies that found high nonword reading abilities in children with ASD only included children who were reading at a reasonably ad-

vanced level [15, 20]. Nation et al. [5] stated that “caution is required when generalizing from homogeneous, high-functioning readers with ASD, especially given the wide variation in cognitive and linguistic skills seen in individuals with ASD” (p. 911).

Studies that included large heterogeneous populations of children with ASD clearly showed that not all such children exhibit exceptional nonword reading ability [5]. Many recent studies have found considerable variability across the ASD samples, with performance ranging from floor to ceiling levels [5, 12, 33] and subgroups displaying severe difficulties. For example, in the group of 41 participants in the study by Nation et al. [5], of the sample of 32 children who were able to read words at all, 42% were at least 1 SD below population norms for nonword reading, and 22% scored at least 2 SD below population norms. In the study by White et al. [33], approximately half of the ASD sample exhibited word decoding difficulties similar to those of a group of readers with dyslexia. A high rate of word reading impairment was also found by Åsberg et al. [34] in their study sample of high-functioning girls with ASD. Difficulties were also manifested in a letter-sound spelling task, where the performance of hyperlexic children with ASD was lower than that of typical readers [13], but superior to that of nonhyperlexic children with ASD [22]. Nation et al. [5] concluded that the low levels of decoding skills in many children with ASD constitute one of the factors in reading comprehension deficits in ASD. This notion is supported by studies that demonstrated relatively poor performance in phonological awareness tasks by children with ASD [13, 26], although hyperlexic ASD children demonstrated better phonological processing skills than nonhyperlexic ASD children [22].

Understanding the graphemic-phonemic correspondence is essential for learning to read. However, writing systems do not merely reflect phonological sequences; rather, they encode various aspects of the language system, including its morphology [35]. Thus, above and beyond phonology, which has preoccupied research on reading for many years [36], readers should also be able to identify morphological units in written words.

The Role of Morphology in Learning to Read

As decoding skills develop and children gain more experience with written words, they become capable of using larger units, such as syllables, morphemes, or whole words, to access meaning faster [37–39]. The repeated encounter with morphologically complex words that share the same stem (e.g., *price* in *priceless* and *pricey*) or the

same affix (e.g., *less* in *nameless* and *speechless*) highlights the consistencies between morphological form and meaning. This supports the establishment of orthographic patterns that represent morphemic units in young readers [40]. Equipped with these representations, children can identify complex words fast and accurately. Carlisle and Fleming [41] found, for example, that second- and third-grade English-speakers read derived words (e.g., *hilly*) faster and more correctly than they read matching monomorphemic words (e.g., *silly*).

Converging evidence suggests that as early as elementary school age, children make use of morphological information when they read morphologically complex words. This has been demonstrated in various languages including Italian [42], French [43], Arabic [44], and Hebrew [45, 46]. This view gained support from many studies showing a positive correlation between morphological awareness and reading development [47, 48] as well as reading disabilities [49]. Further support for using morphological knowledge in reading is emerging from studies demonstrating the contribution of morphological intervention to improved reading skills [50].

Languages differ in the extent to which they encode linguistic information within the word [51]. The role of morphology in word recognition is enhanced in languages with a rich word-internal structure [52, 53]. Hebrew is a Semitic language with a rich morphology that is widely reflected in its orthography [54, 55].

Hebrew Orthography

Hebrew is encoded in two orthographic versions: one is phonologically transparent, and the second is phonologically opaque but morphologically transparent [56]. The phonologically transparent version, namely, *pointed* script, is mainly used for beginning reading instruction, but also in poetry and most religious texts. It provides the reader with full phonological information by means of three graphemic components [45]: 18 letters denoting consonants, a set of 4 AHWY (אהוי) letters denoting both consonants and vowels, and a set of diacritical marks, called *nikud*, which mainly denote vowels and also stop/spirant alternation (e.g., k/x).

The second version, namely, *unpointed* script, is the default version for native speakers who are proficient readers. This script relies on letters alone to designate both consonants and vowels, with no *nikud* diacritics. Consonantal representation of *unpointed* words is exhaustive, except for stop/spirant alternations in 3 letters. In contrast, vowels are represented inconsistently and incompletely by the dual-function AHWY (אהוי) letters

alone. The 5 Hebrew vowels, *a*, *e*, *i*, *o*, and *u*, are almost always represented at the word-final position, where both the letters א (א) and ה (ה) denote both the vowels *a* and *e*, and the letter ו (ו) designates both the vowels *o* and *u*. In contrast to the full (yet ambiguous) representation of word-final vowels, internal *a* and *e* are almost never represented, and *i* representation is governed by complex conditions. As a result of the extreme underrepresentation of vowels, almost none of the *unpointed* words can be read by simply using phonological decoding. Recovering the vowels in reading *unpointed* words – at least words the reader encounters for the first time – requires the use of morphological cues provided by the root-and-pattern morpho-orthographic structure of the Hebrew words.

The bulk of Hebrew content vocabulary (nouns, verbs, and adjectives) is made up of two nonconcatenated interwoven morphemes: root and pattern. The spoken root, the core lexical meaning of the word, is an unpronounceable discontinuous morpheme and is inserted into patterns that specify a prosodic-vowel template. It often consists of additional peripheral consonantal or consonant-vowel affixes. For example, the words *šēkef* (slide), *šakuf* (transparent), and *miškèfet* (binoculars) are made up of the same root š-k-f and the patterns CèCeC, CaCuC, and miCCèCet, respectively.

The structure of the *unpointed* written words reflects the nonconcatenative, interwoven, bimorphemic nature of the spoken word [55]: root radicals are fully represented in the written word, while patterns, being composed mostly of vowels, have lesser orthographic representation. Cues for pattern identification in reading are the peripheral 6 function letters standing for pattern prefixes or suffixes, as well as 2 vowel letters, י (י) and ו (ו), denoting the internal vowels *i*, *o*, and *u* [45]. For example, the written forms of the three examples above are ŠQP (שקף), ŠQWP (שקוף), and MŠQPT (משקפת), respectively. Pattern is not represented at all in the first word; it is represented by only the internal vowel letter ו (ו) in the second, and by the peripheral letters מ (מ) and ת (ת) in the third. Note that none of the word vowels is represented in the first and third words, and only one vowel (u) is represented in the second word. Despite its spare representation, pattern cues constitute the main device that assists in the recovery of the vowels of the *unpointed* word. Thus, in learning to read Hebrew, children have to acquire the morpho-orthographic mapping strategy.

Learning to Read Hebrew

Share and Bar-On [56] propose a triplex model of learning to read Hebrew that consists of three developmental

phases. The first phase is related mainly to the first grade, when children learn to read *pointed* script. With a phonological decoding relying heavily on diacritics, Hebrew-speaking children achieve a high level of accuracy (about 80%) in reading the (relatively) easily decipherable *pointed* script at the end of the first grade [57]. Second-graders, still using diacritics, become more and more skilled in decoding *pointed* words. As their experience with written words increases, they rely less on low-level sublexical phonology and gradually move on to the next, second phase of faster and more fluent reading, based on developing lexico-morpho-orthographic identification strategies.

Relying on morphology is critical in reading Hebrew, particularly in the first years of learning to read, when readers encounter many *unpointed* words for the first time. Filling in the missing vowel information is viable only by using morphological information. The ability to apply the morpho-orthographic identification strategy is typically measured by reading morphologically based Hebrew pseudowords [45, 58]. Shany et al. [58] showed that second-graders read *pointed* morphologically based pseudowords significantly more accurately (76% success) than they read non-morphologically based pseudowords (60% success). Bar-On and Ravid [45] tested seven groups of novice and skilled readers in reading *unpointed* morphologically based pseudowords – a condition that necessitated the use of morphological information. A significant increase in reading accuracy (from 30 to 57%) occurred between the beginning and the end of the second grade, with a gradual development in reading accuracy between the end of the second grade and the third and fourth grades.

The acquisition of lexico-morpho-orthographic identification skills permits the transition (which occurs mostly in the fourth grade) to the third phase, namely, reading *unpointed* script. Interestingly, children who are at the stage of transitioning from *pointed* to *unpointed* texts are less accurate than younger readers in reading *pointed* pseudowords. This phenomenon is explained by a tendency to ignore the phonological bottom-up information in favor of using higher-level strategies of morpho-orthographic identification [58].

Due to their ambiguous nature, orthographic and morpho-orthographic identification are essential but not sufficient for successful reading of *unpointed* text. About a quarter of the words of every *unpointed* text are heterophonic-homographic, i.e., a letter string that can be read in two or more ways. For example, the above example – MŠQPT (משקפת) – represents not only *miškèfet* (binocular) but also *mešakèfet* (she reflects). The high level of lexical ambiguity of *unpointed* Hebrew text requires heavy

reliance on the sentential context [59]. However, the role of context in reading Hebrew is beyond the scope of the current study, which aims to explore the use of phonological and morphological information in single-word reading.

The Present Study

Findings regarding word reading abilities in individuals with ASD vary extensively, ranging between atypically superior [18, 19], typical [5, 12, 14, 15, 26], and very delayed [5, 12] word reading skills. It is still unclear what underlies the various reading abilities in ASD children. Recent evidence indicates that word identification requires a complex multidimensional coding, including not only graphemic-phonemic (phonological mediation) and direct orthographic (rote holistic visual learning of word forms) processes, but also morpho-orthographic identification processing [60, 61]. Interestingly, despite the considerable evidence supporting the notion of the critical role morphology plays in reading, most studies that tested reading in children with ASD focused on graphemic-phonemic decoding and the direct orthographic route. As far as we know, no research has hitherto attempted to provide any fine-grained empirical evidence concerning the use of morphological processing in reading among children with ASD.

The goal of the current study was to expand the scope by investigating not only graphemic-phonemic processing but also morpho-orthographic identification – a process that resides between the phonological sublexical level and the whole-word level in children with ASD. The main question was whether Hebrew-speaking children with ASD demonstrate typical or atypical profiles of reading as regards the ability to use morpho-orthographic above and beyond graphemic-phonemic processes in word reading. The existence of two versions of Hebrew orthography (the transparent *pointed* script and the opaque *unpointed* script) afforded a useful framework for addressing our goal. We compared accuracy and speed of reading two types of morphologically based pseudowords: (1) *pointed* pseudowords, the reading of which can rely on both phonological information, provided by diacritics, and morphological information, reflected in morpho-orthographic patterns, and (2) *unpointed* pseudowords, where vowel recovery in reading relies mostly on morpho-orthographic information. Using pseudowords rather than real words afforded a neutralization of the lexico-orthographic processes from the morphological and phonological processes and an evaluation of the involvement of the two latter processes in reading single

words. Finally, in order to try to cope with the issue of a delay versus deviation in reading among children with ASD, we compared children with ASD to typical peers as well as to TD younger readers.

Given that accuracy and speed are sensitive and accepted measures for reading abilities, our specific questions were as follows: (1) Do children with ASD exhibit a typical profile of accuracy in reading *pointed* and *unpointed* pseudowords? (2) Do they exhibit a typical profile of speed in reading *pointed* and *unpointed* pseudowords? (3) Do they exhibit a typical profile of correlations between accuracy and speed in reading both types of pseudowords? Our hypotheses posited that children with ASD will experience difficulties in reading *pointed* pseudowords, that is, in using graphemic-phonemic decoding, and since graphemic-phonemic decoding precedes morpho-orthographic knowledge, they will experience even more difficulties in reading *unpointed* pseudowords. The difficulties will be manifested in both accuracy and speed.

Method

Participants

Eighty-six Hebrew-speaking children with Hebrew-speaking parents were recruited for this study: (a) 31 children with ASD aged 10 years 3 months (10:03 years) to 13:03 years (mean = 12:01) and (b) three groups of TD children, (1) 23 age-matched children aged 11:02–12:03 years (mean = 11:06), (2) 15 third-graders aged 8:01–9:00 years (mean = 8:07), and (3) 17 second-graders aged 7:00–7:10 years (mean = 7:04). Here we also compared 11- to 12-year-old children with ASD to early TD readers (second- and third-graders), since, at this age, Hebrew readers are proficient in phonological decoding and are progressing to the second stage of using morphological strategies [45]. This could be a useful approach when coping with the question of a delay or deviation in the reading abilities of children with ASD.

All participants came from middle-class families and were enrolled in public schools in the center of Israel. Of the 31 children with ASD, 12 were recruited from a special education elementary school specializing in the education of children with ASD, and 19 were recruited from special classes for children with ASD in regular schools. Before starting school, all children with ASD were assessed by psychiatric specialists and were diagnosed according to the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) [1] criteria for autistic disorder, and according to the WISC (Wechsler Intelligence Scales for Children)-V. According to their test results, they were assigned to a special school for children with ASD (IQ >70) or to special classes in regular schools (IQ >85). We recruited only children with ASD who, based on their teachers' reports, had learned to read and were relatively fluent readers of short *pointed* paragraphs. The teachers of the children with ASD at the special school reported that the children were able to talk and communicate verbally, but were below age level with respect to all aspects of the language. Nevertheless, many of them were slow and inaccurate readers whose errors occurred particularly when they read vowels.

According to their teachers' reports, their reading reflected that of second- and third-graders, despite the fact that they were in the sixth grade. According to the teacher's report, all children who attended the special classes in the regular schools were able to talk, communicate, and read. Ten of them were integrated into a regular fifth-grade class for at least one course, 5 were very good students, 2 had reading comprehension difficulties, and 1 was language impaired. The TD children were recruited from regular classes in regular schools. According to their teachers, they behaved typically for their ages, and did not have any reported special educational needs, history of ASD, or language or reading delay.

Our main goal was to evaluate morpho-orthographic identification processing in reading of children with ASD. Considering that the ability of graphemic-phonemic decoding is the sine qua non to the development of the ability of morpho-orthographic identification, we tried to avoid investigating children with difficulties in graphemic-phonemic decoding. Therefore, we decided to include in this study only children who reached a minimum threshold of $\geq 65\%$ correct in reading *pointed* pseudowords. This minimum threshold was calculated as 1.75 SD (19.4%) below the mean of percent correct of all typical readers (84.4%) in reading *pointed* pseudowords. After applying this criterion, 11 children with ASD (5 from the special school and 6 from the special classes) who demonstrated 25–60% correct (mean = 42) in reading *pointed* pseudowords, and 2 TD children (1 age-matched child and 1 third-grader) who manifested 60% correct in reading *pointed* pseudowords, were excluded from the study. Eventually, 73 children were included in this study – 20 with ASD who had a mean of 82.75% correct (SD = 12.98, range = 65–100) and 53 TD children who had a mean of 85.75% correct (SD = 11.07, range = 65–100) in reading *pointed* pseudowords. A *t* test revealed that there was no difference between the mean of the children with ASD and the general mean of the three TD groups.

Materials

In order to evaluate the ability to use phonological and morphological information in reading single words, we employed two lists of morphologically based pseudowords: 20 *pointed* and 20 *unpointed*. Both lists were made up of pseudoroots interwoven with real morphological patterns. The *pointed* list was taken from the Hebrew Standardized Reading and Writing Achievement Test – Alef ad Taf [62]. The morphological patterns of the *pointed* pseudowords reflected both nouns (13) and verbs, and comprised 6 two-syllable words and 14 three-syllable words (2.7 syllables on average). Since the pseudowords were *pointed*, each one represented a single phonological form. The accurate reading of items that the readers have never seen before relies on the phonological decoding process, whereby the reader linearly decodes and connects a sublexical letter plus diacritic grapheme units. The reading can also be enhanced by morpho-orthographic identification, where the morpho-orthographic cues invoke the appropriate morphological pattern [45].

The *unpointed* list was taken from Bar-On [63]. Although each of the *unpointed* pseudowords can be potentially decoded in many phonological forms, only one or two of them are compatible with one or two genuine morphological patterns. An example of this is the pseudoword MBHST (מבחסת). The accurate morphological identification of this word is *mivxèset* (which corresponds to the noun pattern *miCCèCet*) or *mevaxèset* (which corresponds to the verb pattern *meCaCèCet*). However, there are at least another 26

possible phonological readings of this word, all of which are non-morphological, such as *mabaxasat*, *mivxaset*, *mebxesat*, and so on. Thus, the correct morphological identification of *unpointed* pseudowords mainly reflects the activation of larger units, i.e., morphemic units. Four of the 20 *unpointed* pseudowords are heterophon-ic-homographic, i.e., pseudowords that represent two morphological patterns (e.g., MBHST), while the remaining 16 are non-homographic. Half of the pseudowords represent noun patterns and half of them represent verbs. The number of syllables in a word ranges from two to four: two syllables (5 words), three syllables (11 words), and four syllables (4 words) (2.95 syllables on average).

Procedure and Measures

Children were seen individually for one meeting at school, in a quiet room far away from everyday distractions. The meeting lasted approximately 15 min. The pseudowords in each list were presented in a large (16-point) font and were organized in two columns on one page. The reading of the *pointed* pseudowords was assessed first, followed by the reading of the *unpointed* pseudowords. Each participant was instructed as follows: "The words on this sheet are words that you have never seen before – invented words. Please read each word aloud from top to bottom. Please note that I will time how long it takes you to read them, but try to read as accurately as possible and at your own pace." Incorrect responses to the reading trials were not corrected, nor did the child receive any feedback with regard to his/her responses. The participants' oral reading was recorded and transcribed. We measured accuracy as well as time in seconds (speed) of reading.

Results

Graphemic-Phonemic Decoding and Morpho-Orthographic Identification Abilities

The group average accuracy (% correct) and time (s) of reading each list (*pointed* and *unpointed* pseudowords) attained by the ASD group were compared to those attained by each of the TD groups, i.e., the age-matched children, third-graders, and second-graders. Where necessary, we conducted post hoc pairwise comparisons at the 0.05 level for simple effects and for interactions. The means and SD of reading accuracy and reading time of both lists in the four groups are shown in Table 1.

Reading Accuracy. A two-way ANOVA that examined the effect of group (four groups) and list (*pointed*, *unpointed*) on reading accuracy revealed a significant interaction between group and list ($F(3, 69) = 11.97, p < 0.0001$) (Fig. 1). There were also found main effects for group ($F(3, 69) = 7.65, p < 0.0001$) and for list ($F(1, 69) = 31.92, p < 0.0001$). We chose not to elaborate upon the two effects in light of the interaction. We applied the post hoc Ryan-Einot-Gabriel-Welsch multiple-range test in order to analyze the differences between groups for each list. In the accuracy of reading the *pointed* list, a significant dif-

Table 1. Reading accuracy and reading time of *pointed* and *unpointed* pseudowords in children with ASD and the three TD control groups

Group	N	Accuracy, % correct		Reading time, s	
		<i>pointed</i>	<i>unpointed</i>	<i>pointed</i>	<i>unpointed</i>
ASD	20				
Mean		82.75	59.00	88.05	113.50
Range		65–100	25–85	26–181	36–255
SD		12.29	21.25	35.50	57.09
TD age matched	22				
Mean		87.04	85.23	50.45	53.30
Range		70–100	50–100	24–76	23–100
SD		8.68	12.48	11.88	20.40
TD third-graders	14				
Mean		78.57	81.79	54.43	56.93
Range		65–100	60–100	36–80	29–78
SD		10.64	12.49	11.75	15.18
TD second-graders	17				
Mean		90.00	65.59	61.75	68.18
Range		65–100	60–100	36–80	29–74
SD		11.86	14.46	19.18	20.39
All TD children	53				
Mean		85.755	78.02	55.13	59.03
Range		65–100	25–100	24–181	23–255
SD		11.07	15.58	15.12	19.90

ASD, autism spectrum disorder; TD, typically developing.

Fig. 1. Comparisons of accuracy performance between the children with ASD and the three control groups (TD age matched, TD in the third grade, and TD in the second grade) in reading *pointed* versus *unpointed* pseudowords. Error bars indicate SD of the mean. ASD, autism spectrum disorder; TD, typically developing.

ference ($p < 0.05$) was only found between the two younger TD groups, i.e., the second- and third-graders, with the third-graders being less accurate. In the accuracy of reading the *unpointed* list, the ASD group did not differ significantly from the TD second-grader group, and both groups read significantly less accurate ($p < 0.05$) than the TD third-grader and the TD age-matched groups, who did not differ from each other.

Reading Time (Speed). A two-way ANOVA that examined the effect of group (four groups) and list (*pointed*, *unpointed*) on reading time revealed a pattern of findings that was similar to the one revealed for reading accuracy. There was an interaction of group $\times$ list in reading time ($F(3, 69) = 5.92, p < 0.001$) (Fig. 2) and main effects for both group ($F(3, 69) = 13.23, p < 0.0001$) and list ($F(1, 69) = 15.77, p < 0.0001$). Again, we chose not to elaborate upon the two effects in light of the interaction. The post hoc analysis of the differences between groups for each list (Ryan-Einot-Gabriel-Welsch multiple-range test) showed that the children with ASD read significantly more slowly ($p < 0.05$) than the three TD groups for both lists.

Fig. 2. Comparisons of time performance between the children with ASD and the three control groups (TD age matched, TD in the third grade, and TD in the second grade) in reading *pointed* versus *unpointed* pseudowords. Error bars indicate SD of the mean. ASD, autism spectrum disorder; TD, typically developing.

Fig. 3. Scatterplot showing the relationship between accuracy (% correct) and speed (s) in reading *unpointed* pseudowords by children with ASD ($n = 20$). The reference line indicates parity between the two measures.

Table 2. Pearson correlations between accuracy (% correct) and speed (s) in reading the *pointed* and *unpointed* pseudoword lists in each of the four groups

Group	<i>Pointed</i>	<i>Unpointed</i>
ASD	−0.546*	−0.848***
TD age matched	0.002	−0.583**
TD third-graders	−0.127	−0.111
TD second-graders	−0.360	−0.360

ASD, autism spectrum disorder; TD, typically developing.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Correlation between Accuracy and Speed in Reading the Pointed and Unpointed Lists

To better characterize the graphemic-phonemic decoding and morpho-orthographic identification skills among the children with ASD and the three TD age groups, we also calculated the correlations between accuracy and speed for each list and for each group (Table 2).

A Pearson correlation analysis revealed that among the children with ASD, there was a strong correlation between accuracy and speed for the *unpointed* list, with some of them demonstrating low accuracy and speed scores and others demonstrating high accuracy and speed scores, as well as a weak correlation between accuracy and

speed for the *pointed* list. A correlation between accuracy and speed in reading the *unpointed* list was also found among the TD age-matched group, with most of them demonstrating high accuracy and speed scores. Nevertheless, no correlation between accuracy and speed was found among the two younger TD groups. The significant correlation between accuracy and speed in reading *unpointed* pseudowords among children with ASD is presented in Figure 3.

Discussion

The study sought to characterize the abilities of Hebrew-speaking children with ASD in the intermediate school years to use morpho-orthographic identification strategies for graphemic-phonemic decoding in reading pseudowords. In typical reading development, well-established phonological decoding skills precede morpho-orthographic identification. This enables the reader to allocate resources to the larger units, i.e., the morpho-orthographic structures of the written word [37–39, 45, 64]. Therefore, to address our goal, we included only children who demonstrated “good enough” graphemic-phonemic decoding abilities ($\geq 65\%$ accuracy in reading *pointed* pseudowords).

According to this criterion, while only 3% (2 out of 55) of the TD children were excluded from our final study,

35% (11 out of 31) of the children with ASD were excluded. Moreover, whereas the 2 TD children who were excluded manifested a borderline accuracy score (60%), the children with ASD who were excluded manifested lower scores (mean = 45%, SD = 11.37, range = 25–60) in reading Hebrew *pointed* pseudowords. Our rate of poor graphemic-phonemic decoding is somewhat higher than that reported by Nation et al. [5] for their ASD sample when reading English pseudowords (22% of their ASD sample scored <2 SD below population norms) but lower than that reported by White et al. [33] (about half of the ASD sample exhibited word decoding difficulties similar to those of a group of readers with dyslexia).

We expected most of the children with ASD who would be excluded from the study because of poor reading accuracy of *pointed* pseudowords to come from the special school, demonstrating lower graphemic-phonemic achievements than the children who were recruited from special classes in regular schools. However, the picture was slightly different; the children with ASD who were excluded ($n = 11$) came from both educational settings: 42% (5 out of 12) from the special school and 30% (6 out of 19) from the special classes in regular schools. Moreover, the children from these different educational settings had almost identical scores in reading *pointed* pseudowords (mean = 45, SD = 10.9, range = 30–60, and mean = 45.8, SD = 11.7, range = 25–55, for the special school and special classes, respectively). This may suggest that not only a large group of children with ASD who attended special autism schools, but also a large group of children with ASD who studied in special classes in regular educational settings, were very poor at using graphemic-phonemic decoding.

The children with ASD from the special school who were excluded displayed lower accuracy scores in reading the *pointed* pseudowords (45%) than the TD second- and third-graders (90 and 79%, respectively). This finding is not in line with the teachers' reports describing them as readers at the level of second- to third-graders. It is possible that the teachers overestimated their students. Furthermore, it is highly probable that the teachers' reports were based on the children's ability to read *pointed* real words. In the current study, however, we tested ASD children's ability to read *pointed* pseudowords. Pseudoword reading poses a unique challenge to the reader, since he cannot monitor his reading by means of the orthographic lexicon. Recent studies have reported that there are at least subgroups of individuals with ASD who struggle with reading pseudowords even when their real-word reading is developmentally adequate for their age. This

pattern was not observed in the TD children, who exhibited a high correlation between real-word and pseudoword reading levels [5, 13, 26]. Based on these studies, we can speculate that some of the children with ASD could read *pointed* real words better than *pointed* pseudowords.

While many (35%) of the children with ASD displayed poor graphemic-phonemic decoding, the remaining 20 children with ASD displayed good graphemic-phonemic decoding – as accurate as that of the three TD control groups. This finding supports the notion of a large variability in graphemic-phonemic decoding skills among children with ASD [5, 2, 33].

Of primary importance was the observed finding that children with ASD as a group failed to make the same progress as their typical peers or as typical third-graders, and that they remained at the level of second-graders in their ability to use a morpho-orthographic identification strategy. Both the TD third-graders and the age-matched children displayed a similar accuracy level in reading *pointed* and *unpointed* pseudowords, indicating an almost mature ability to use morpho-orthographic identification. Second-graders, however, could read *pointed* pseudowords accurately, but they were less accurate in reading *unpointed* pseudowords, indicating that they were still establishing their morpho-orthographic strategy [45].

The present finding of a delay in the ability of children with ASD to use a morpho-orthographic identification strategy for reading *unpointed* pseudowords could be associated with oral language skills, including morphological and lexical knowledge, as well as with cognitive abilities. Unfortunately, these abilities were not tested in the current study. Nevertheless, several explanations that may be useful for future studies are offered here.

Reading *unpointed* pseudowords is a challenging task, since most of the information concerning the vowels is missing and the only way to complete it is by identifying the morpho-orthographic patterns embodied in the written word [45]. Studies in various languages have shown that children with typical reading development utilize morphological information in order to read morphologically complex words [42–44, 46]. In other words, learning to recognize and use morpho-orthographic patterns in reading morphologically based *unpointed* pseudowords may be at least partially dependent on stable and mature morphological knowledge. Therefore, a deficit in morphological knowledge that may occur in children with ASD [65, 66] can at least partially explain the delay they experience in using a morpho-orthographic identification strategy. It is noteworthy that

some studies associated poor language skills among individuals with ASD with poor phonological decoding [5] or poor reading comprehension [67, 68]. Here, however, we conjecture that poor language skills among individuals with ASD may be associated with limitations in the morpho-orthographic identification strategy involved in reading.

Cognitive deficits can also explain some of the difficulties experienced by children with ASD in morpho-orthographic identification. Cognitive impairments are the intermediary link between the neuroanatomical abnormalities found in individuals with ASD and the behavioral symptoms that characterize them [69]. It is highly likely that learning to identify the morpho-orthographic units of written words and using them for reading are implicit; no one teaches these components of written words, and readers are not aware of using these representations. It has been suggested that children with ASD are impaired in implicit learning [69]. Individuals with ASD have been found to experience difficulty in disengaging and shifting their attention [70], and it has been proposed that this difficulty would prevent them from noticing relationships between different parts of a stimulus [70].

Moreover, reading *pointed* pseudowords and reading *unpointed* real words can rely on “stable anchors”: the first is dependent on graphemic-phonemic decoding of the diacritics, and the second on meaning and/or orthographic representations. *Unpointed* pseudowords lack both of these anchors and therefore depend on the ability to switch to another reading process that focuses on morphological identification. Thus, it is a challenge that may require flexible thinking and switching. There is evidence that both of these executive functions may be impaired in individuals with ASD [71, 72].

Reading Speed (Time)

In this study, we found robust and consistent evidence that, as a group, children with ASD were very slow readers; they were slow in reading the *pointed* Hebrew pseudowords, and even more so the *unpointed* ones. They were slower than all three TD groups, which did not differ from one another. They were one and a half times slower than the TD children (88 vs. 55 s, children with ASD vs. the average of the three TD groups) in reading the *pointed* pseudowords, and twice as slow (113 vs. 59 s, children with ASD vs. the average of the three TD groups) in reading the *unpointed* pseudowords. The reading speed of the 11 children with ASD who were excluded from the study was even poorer (104 and 121 s, *pointed* and *unpointed* pseudowords, respectively).

Interestingly, 12-year-old children with ASD were as accurate as – but much slower than – the TD second-graders in reading the *pointed* pseudowords. In transparent orthographies like German, Spanish, and *pointed* Hebrew, the consistency of graphophonemic correspondence could imply that speed rather than accuracy is sensitive to the level of reading proficiency [73, 36]. Therefore, reading speed is considered to be a strong indicator of reading level, that is, the mastery of the reading skill. The accepted notion is that fast reading constitutes the substrate for fluent reading, and that the latter constitutes the substrate for reading comprehension [74, 75].

Furthermore, while the ASD group was significantly slower in reading the *unpointed* pseudowords than in reading the *pointed* pseudowords, the reading speed of the three TD groups was not affected by the type of pseudoword (Fig. 2). Given that slow performance may indicate effortful processing [76], our findings suggest that reading the *pointed* – let alone the *unpointed* – pseudowords was very effortful for the children with ASD but not for the TD children. These results support the notion that while the children with ASD struggled with graphemic-phonemic decoding, they struggled much more with the implementation of morpho-orthographic strategies.

Effortful reading may lead to an avoidance of reading. Similarly, poor reading comprehension that may occur in individuals with ASD may discourage reading. Therefore, children with ASD may be less motivated to read, resulting in less reading. In addition, there are reports that the curricula of students with ASD focus on life skills rather than on academic and literacy skills [77]. Thus, some children with ASD may be less experienced with tackling written texts at school than TD students, who have numerous opportunities to practice reading in the classroom. This may lead to the known Matthew effect [78] with respect to literacy. The accepted notion posits that orthographic and morpho-orthographic learning is based on practicing graphemic-phonemic decoding [64]. Thus, limited experience may hamper the development of the morpho-orthographic identification strategy.

An alternative explanation for the slowness of reading that characterized the children with ASD states that many individuals with ASD are relatively slow processors. Slow processing in individuals with ASD was demonstrated in different cognitive tasks, including the Symbol Search subtest (WISC-III and -IV) and Rapid Visual-Motion Integration [79–82]. These tasks are commonly associated with learning and reading.

An analysis of the correlation between accuracy and speed increases our understanding of the reading abilities of children with ASD. It is well established that in skillful reading, both accuracy and speed are high as well as highly correlated, indexing efficient reading [75]. Nevertheless, there may be a lower correlation between accuracy and speed in reading morphologically based *pointed* pseudowords. Accuracy in reading these words can be achieved by using the information derived from processing both the diacritics and the morphological patterns. On the one hand, paying attention to the diacritics increases accuracy; however, it is time-consuming. On the other hand, readers who ignore the diacritics can read fast but are liable to make mistakes. This speed-accuracy trade-off can effectively explain our findings of a lack of correlation between accuracy and speed in the three TD groups and of a weak correlation in the children with ASD.

In contrast to *pointed* pseudowords, the completion of the missing vowel information in reading *unpointed* pseudowords relies wholly on morpho-orthographic identification processes. Since this strategy encourages the reading of the *unpointed* pseudoword as one unit, it should speed up the reading [45]. Therefore, accuracy and speed are likely to be highly correlated in this type of reading. Unexpectedly, the second- and third-graders did not display a correlation between the two measures. The TD age-matched group, however, demonstrated a mild correlation. It is highly probable that the lack of correlation between accuracy and speed among the typical young readers indicates that they are in a phase wherein the knowledge is still unstable, and therefore accurate reading may come at the cost of slowing down, while fast reading may come at the cost of a decrease in accuracy (speed-accuracy trade-off). In contrast, the older readers, who probably already possess a skilled morpho-orthographic identification strategy, manifested more mature knowledge whereby readers were both accurate and fast.

Interestingly, a high correlation between accuracy and speed was found among the children with ASD, who, in this regard, were similar to their peers. A perusal of the distribution of the results for the children with ASD revealed a very wide range of achievements in both accuracy and speed in reading the *unpointed* pseudowords (Fig. 3). It appears that the children with ASD can be divided into two distinctive groups: a group of 9 children who were slow and inaccurate in reading the *unpointed* pseudowords, probably due to a delay in acquiring the morpho-orthographic identification strategy, and a sec-

ond group of 11 children who showed similar achievements to those of their TD peers but were slightly slower.

We can thus conclude that based on reading abilities, the 31 children with ASD who were recruited for our original study can be divided into three almost equal groups: (1) a group of children with ASD who exhibited very poor reading abilities and were excluded from the final study, (2) a group of children who acquired the alphabetic knowledge but did not manage to progress to the morpho-orthographic phase, and (3) a group of children who possessed similar reading abilities to those of their typical peers. This outcome is again in line with the view of large variability in reading skills among the population of ASD.

Conclusions

The unique contribution of the current study is the enlargement of the scope by examining morpho-orthographic identification above and beyond graphemic-phonemic processing in ASD children's reading. By using this multidimensional observation, we were able to show that many (but not all) of the 12-year-old children with ASD were delayed by about 5 years in activating a morpho-orthographic identification strategy for reading *unpointed* Hebrew pseudowords and were very slow readers – even slower than TD second-graders. The results show that the reading abilities of children with ASD are not the typical ones; however, they do not show that they are unique to children with ASD. These findings have important implications for intervention programs targeting this population. It appears that it is very important to instruct these children explicitly in basic word recognition and fluency so as to facilitate the learning of the morpho-orthographic system.

There are several reasons, however, to be careful not to overgeneralize the current findings. We recruited the ASD children according to a previous diagnosis that had been furnished by the education system in order to assign them to an appropriate educational setting. Moreover, the information related to the ASD children's reading, cognitive, and language abilities was provided only by their teachers. Additional detailed and formal test-based information related to real-word reading, as well as to the general and verbal IQ and particularly to phonological and morphological awareness, could better explain their limitations.

Thus, this study could be considered a pilot study, signifying that it is very likely that additional studies will

be needed. We hope that the present study will provide preliminary evidence to help lay the foundation for future research in this domain. Future studies may also benefit from a comparison/control group of non-ASD students with reading/learning disabilities in order to ascertain whether it is the ASD that is delaying their reading, or whether the sample represents ASD students with the added burden of a serious reading/learning disability.

Statement of Ethics

We state that the subjects gave their informed consent and that the study protocol was approved by the institute's committee on human research and thus meets the standards of the Declaration of Helsinki in its revised version of 1975 and its amendments of 1983, 1989, and 1996.

Disclosure Statement

The authors have no conflict of interest to declare.

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